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About this Series

The Kiel Computer Science Series (KCSS) covers dissertations, habilitation theses, lecture notes, textbooks, surveys, collections, handbooks, etc. written at the Department of Computer Science at Kiel University. It was initiated in 2011 to support authors in the dissemination of their work in electronic and printed form, without restricting their rights to their work. The series provides a unified appearance and aims at high-quality typography. The KCSS is an open access series; all series titles are electronically available free of charge at the department's website. In addition, authors are encouraged to make printed copies available at a reasonable price, typically with a print-on-demand service.

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Preface

Information Modeling and Knowledge Bases has become an important technology contributor for the 21st century's academic and industry research that addresses the complexities of modeling in digital transformation and digital innovation, reaching beyond the traditional borders of information systems and computer science academic research.

The amount and complexity of information itself, the number of abstraction levels of information, and the size of databases and knowledge bases are continuously growing. Conceptual modelling is one of the sub-areas of information modelling. The aim of this conference is to bring together experts from different areas of computer science and other disciplines, who have a common interest in understanding and solving problems on information modelling and knowledge bases, as well as applying the results of research to practice. We also aim to recognize and study new areas on modelling and knowledge bases to which more attention should be paid. Therefore, philosophy and logic, cognitive science, knowledge management, linguistics and management science as well as machine learning and AI are relevant areas, too.

In the conference, there will be three categories of presentations, i.e., full papers, short papers and position papers. The international conference on information modelling and knowledge bases originated from the cooperation between Japan and Finland in 1982 as the European Japanese conference (EJC). Then professor Ohsuga in Japan and Professors Hannu Kangassalo and Hannu Jaakkola from Finland (Nordic countries) did the pioneering work for this long tradition of academic collaboration. Over the years, the organization extended to include European countries as well as many other countries. In 2014, with this expanded geographical scope, the European Japanese part in the title was replaced by International. The conference characteristics include opening with a keynote session followed by presentation sessions with enough time for discussions. The limited number of participants is typical for this conference.

The 32nd International conference on Information Modeling and Knowledge Bases (EJC 2022) held at Hamburg, Germany constitutes a research forum exchanging of scientific results and experiences drawing academics and practitioners dealing with information and knowledge. The main

topics of EJC 2022 cover a wide range of themes extending the knowledge discovery through Conceptual Modelling, Knowledge and Information Modelling and Discovery, Linguistic Modelling, CrossCultural Communication and Social Computing, Environmental Modeling and Engineering, Multimedia Data Modelling and Systems, Visual Reasoning and aspects of Artificial Intelligence extending into complex scientific problem solving. The themes of the conference presentation sessions; Learning and Linguistics, Systems and Processes, Data and Knowledge Representation, Models and Interfaces, Formalizations and reasoning, Models and Modelling, Machine Learning, Models and Programming, Environment and Predictions, Emotion Modeling and Social Networks reflected the coverage of those main themes of the conference.

The contributions of this proceeding of the 32nd International Conference of Information Modeling and Knowledge Bases feature nineteen reviewed, selected, and upgraded contributions that are the result of presentations, comments, and discussions during the conference. Suggested topics of the call for papers include, but are not limited to:

Conceptual modelling: Modelling and specification languages; Domain-specific conceptual modelling; Concepts, concept theories and ontologies; Conceptual modelling of large and heterogeneous systems; Conceptual modelling of spatial, temporal and biological data; Methods for developing, validating and communicating conceptual models.

Knowledge and information modelling and discovery: Knowledge discovery, knowledge representation and knowledge management; Advanced data mining and analysis methods; Conceptions of knowledge and information; Modelling information requirements; Intelligent information systems; Information recognition and information modelling.

Linguistic modelling: Models of HCI; Information delivery to users; Intelligent informal querying; Linguistic foundation of information and knowledge; Fuzzy linguistic models; Philosophical and linguistic foundations of conceptual models.

Cross-cultural communication and social computing: Cross-cultural support systems; Integration, evolution and migration of systems; Collaborative societies; Multicultural web-based software systems; Intercultural collaboration and support systems; Social computing, behavioral modeling and prediction.

Environmental modelling and engineering: Environmental information systems (architecture); Spatial, temporal and observational information systems; Large-scale environmental systems; Collaborative knowledge base systems; Agent concepts and conceptualization; Hazard prediction, prevention and steering systems.

Multimedia data modelling and systems: Modelling multimedia information and knowledge; Contentbased multimedia data management; Content-based multimedia retrieval; Privacy and context enhancing technologies; Semantics and pragmatics of multimedia data; Metadata for multimedia information systems.

The EJC 2022 was held hybrid and hosted by the Department of Computer Science of the University of Applied Sciences Hamburg, Germany on May 30th – June 3rd. Presentations, prepared according to the instructions, were presented on-site and on-line via zoom. We thank all colleagues for their support in making this conference successful, especially the program committee, organization committee, and the program coordination team, especially Naofumi Yoshida who maintains the paper submission and reviewing systems and compiles the files for this book.

The Editors
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AI-Sensing Functions with SPA-based 5D World Map System for Ocean Plastic Garbage Detection and Reduction

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Abstract. The “SPA-based 5D World Map System” realizes Cyber-Physical-Space integration to detect environmental phenomena with real data resources in a physical-space (real space), map them to the cyber-space to make knowledge bases and analytical computing, and actuate the computed results to the real space with visualization for expressing environmental phenomena, causalities and influences. This paper presents an important application of 5D World Map System, adding “AI-Sensing” functions for “Global Environment-Analysis” to make appropriate and urgent solutions to global and local environmental phenomena in terms of short and long-term changes. In this paper, focusing on the ocean plastic garbage issue, the methodology of AI-Sensing, the preliminary models and experiments on the accuracy of AI-Sensing, and the substantive experiments on the feasibility and effectiveness of AI-Sensing with real local data are described. In addition, the example outputs of the integration of AI-Sensing algorithm and SPA-based 5D World Map System and the future direction of a collaborative project for ocean plastic-garbage reduction are introduced.

Keywords. CPS, Cyber-Physical-System, Sensing-Processing-Actuation, Machine Learning, Image, Visualization, Knowledge, SDGs, SDG14, Marine Pollution, Ocean Environment, City, River, Coastal waste, Global Environment

1. Introduction

“SPA-based 5D World Map System” [5]-[11] is a global and environmental knowledge-integrating and processing system for memorizing, searching, analyzing and visualizing “Global and Environmental Knowledge and Information Resources,” related to natural phenomena and disasters in global and local environments. This system analyzes environmental situations and phenomena with “environmental multimedia data sharing,” as a new global system architecture of collaborative and global environment analysis. This system realizes a remote, interactive and real-time environmental research exchange among different areas.

As an important global environmental system, we have proposed a multi-dimensional data mining and visualization system, 5D World Map System [5]-[11]. The main feature of this system is to realize semantic data mining, visualization and analysis

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in the “multi-dimensional semantic space” and “semantic-distance computing” with semantic functions. This space is created for dynamically computing semantic equivalence, similarity and difference as distance functions.

In this paper, we present an important application of 5D World Map System, adding AI-Sensing functions for “Global Environment-Analysis” to make appropriate and urgent solutions to global and local environmental phenomena in terms of short and long-term changes. The following “six functional-pillars” are essentially important with “environmental knowledge base creation” for sharing, analyzing and visualizing various environmental phenomena and changes in the real world.

- 1) Cyber & Physical Space Integration
- 2) SPA-function
- 3) Spatiotemporal computing
- 4) Semantic computing
- 5) World map-based visualization
- 6) Warning message propagation

The “SPA-based 5D World Map System” realizes Cyber-Physical-Space integration to detect environmental phenomena with real data resources in a physical-space (real space), map them to the cyber-space to make knowledge bases and analytical computing, and actuate the computed results to the real space with visualization for expressing environmental phenomena, causalities and influences. The 5D World Map System and its applications create new analytical circumstance with the SPA concept (Sensing, Processing and Analytical Actuation) for sharing, analyzing and visualizing natural and social environmental aspects. This system realizes “environmental analysis and situation-recognition,” which will be essential for finding out solutions for global environmental issues.

To enhance SPA functions, we have developed a sensing algorithm called “AI-Sensing” to analyze photos and images captured by mobile phones, cameras and other instruments on the ground and from aerial devices (such as drones) to detect specified objects such as plastic garbage on the water surface. AI-Sensing algorithms are based on intelligent sensing with machine learning and deep learning, including image-filtering process with “domain-boundary” analysis for color, shape, and location variables. The main feature of the methodology of AI-Sensing is the analyzing function for multiple patterns of plastic waste pollution scenarios based on heterogeneous data resources such as images, texts, statistics, sound, and video. When the users set up conditions and query, the algorithm will evaluate all the connected image data, by means of spatial, temporal and semantic computation functions, and integrate these results of dynamic multi-contextual computation onto a set of chronologically-ordered maps of 5D World Map System.

This paper consists of 7 sections. In Section 2, the overview of SPA-based 5D World Map System with AI-Sensing function for ESCAP Closing the Loop (CTL) project is introduced. In Section 3, the methodology of AI-Sensing is explained. In Section 4, the preliminary model and experiments on the accuracy of image sensing algorithms are described. In Section 5, the substantive experiments on the feasibility and effectiveness with real local data are described. In Section 6, the example outputs of the integration of AI-Sensing algorithm and 5D World Map System are introduced.

2. Overview of SPA-based 5D World Map System and UN-ESCAP Closing-the-Loop project

5D World Map System [5]-[11] is a knowledge representation system that enables semantic, temporal and spatial analysis of multimedia data and integrates the analyzed results as 5-dimensional dynamic historical atlas (5D World Map). The composition elements of 5D World Map are a spatial dimension (3D), a temporal dimension (4D) and a semantic dimension (5D).

A semantic associative search method [1][2][3] is applied to this system for realizing the concept that "semantics" of words, documents, multimedia, events and phenomena vary according to the "context". The semantics of each target multimedia data regarding to any events, phenomena or topics are calculated on a multidimensional vector space and represented as one dimensional ranking on a time-series world map space. The main feature of this system is to create various context-dependent patterns of social stories according to user's viewpoints and the diversity of context in phenomena dynamically.

As an important global environmental system, we have proposed 5D World Map System [5]-[11] as a multi-dimensional data mining and visualization system. In the design of this global environment-analysis system, we focus on methodology for searching and analyzing environmental media data related to environmental situations and phenomena. This system realizes semantic computing and search for media data and it is applied to compute semantic correlations between keywords, images, sensing data, sound data, documents and sensing data dynamically, according to user's contexts and analysis-points in a context-dependent way. The main feature of this system is to realize semantic computing in the multi-dimensional semantic space with semantic distance functions. This space is created for dynamically computing semantic equivalence, similarity and difference as distance functions.

5D World Map System [5]-[11] has been providing various functionalities to share and visualize various types of multimedia data [6][7][8]. A combination of the analysis and visualization functions for multimedia and real-time sensing-data of 5D World Map System has been proposed to make environmental analysis much richer and deeper, which contributes to activities of collaborative environmental knowledge creation. Also, a multi-dimensional and multi-layered visualization and Monitoring-Analysis-Warning functions of 5D World Map System for building sustainable ocean and disaster resilience has been proposed for monitoring Sustainable Development Goals (SDG14, SDG9, SDG11) in United Nations ESCAP [9][10][11].

Currently, the 5D World Map System is globally utilized as a Global Environmental Semantic Computing System, in SDG14, United-Nations-ESCAP's Closing-The-Loop project [12] for observing ocean-environment situations with local and global multimedia data resources [9][10]. In this project of plastic garbage detection and reduction, we include a new function of AI-Sensing to 5D World Map System, and apply the analytical visualization functions in the SPA (Sensing-Processing-Actuation) process as shown in **Figure 1**.

SPA functions of 5D World Map System

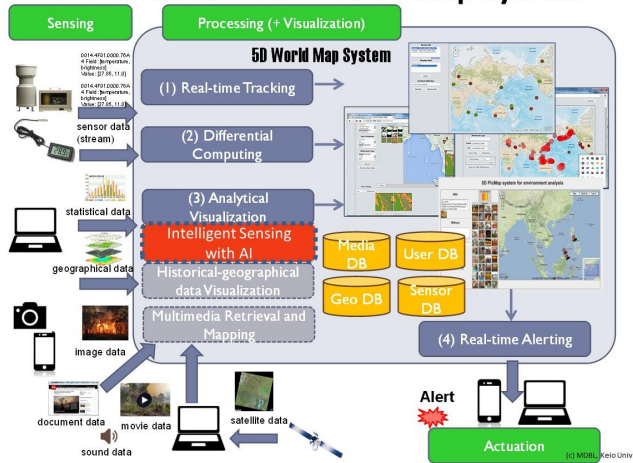


Figure 1. System Structure of 5D World Map System with AI-Sensing

Figure 2 and Figure 3 shows the output images of 5D World Map System with AI-Sensing module using plastic garbage photos, demographical data and water-quality sensing data in Surabaya, Indonesia. If a user takes some photos of plastic garbage in the city, canals, rivers and coastal areas and upload to the 5D World Map System, then the AI-Sensing module judges whether the photos include plastic garbage or not, how match the garbage is included, where and when the photos are taken, and the photos are mapped to the chronologically-ordered maps automatically. Also, if another user uploads the demographical data such as the number of houses in the city with geolocation or the sensing data such as water quality of canals and river, the system also visualize the statistical and numerical data together with the uploaded image data.

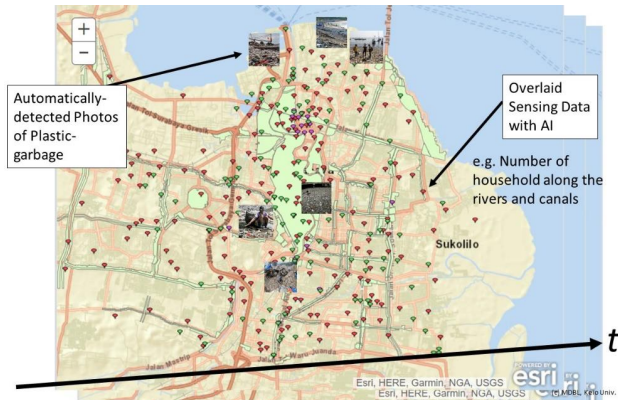


Figure 2. Output Image of SPA-based 5D World Map System with AI-Sensing module: Surabaya Case (photos + Demographic data)

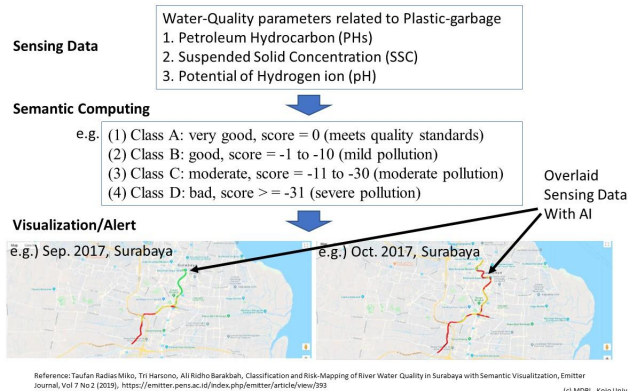


Figure 3. Output Image of 5D World Map System with AI-Sensing module: Surabaya Case (water-quality data)

3. AI-Sensing

3.1. 3-Phase Algorithm for "AI-Sensing"

A 3-Phase Algorithm has been designed as an Intelligent Sensing AI process for plastic garbage detection as shown in **Figure 4** and **Figure 5**. In Phase-1, two sets of images for learning data are collected with "Domain-boundary" such as river/canal/sea image "with plastic-garbage" and "without plastic garbage". In Phase-2, the target image taken by mobile phone, action camera, drone or 360-degree camera with Exif is input to the Machine Learning/Deep Learning process as a query to judge if it includes plastic garbage or not. In Phase-3, the judged image with plastic/non-plastic tag is automatically posted and mapped to 5D World Map System.

By this algorithm, it is possible to judge the amount and flow of plastic garbage detected at several spots of monitoring if we set various data sets for learning such as "with plastic", "without plastic", "small amount of plastic", "mid amount of plastic", "big amount of plastic", and so on.

Phase-1: Image-filtering process with "Domain-boundary" applicable to Deep Learning and Semantic Computing
Phase-2: ML / DL learning for automatic detection of plastic garbage-photos
Phase-3: Automatic posting/mapping of plastic garbage-photos to 5D WMS

Figure 4. 3-Phase Algorithm of AI-Sensing

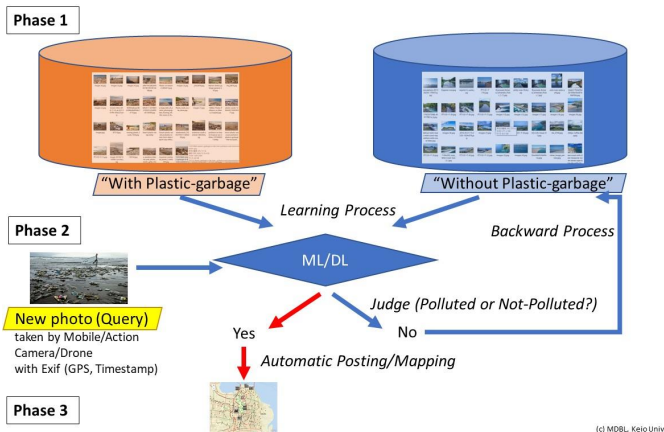


Figure 5. AI-Sensing based on the 3-Phase Algorithm

(c) MOBL, Keio Univ.

3.2. Implementation of “AI-Sensing” and the integration design with external systems

The implementation method is described in **Figure 6**. The Phase-1 and Phase-2 are realized by Java and PostgreSQL and the Phase-3 is realized by PHP interface.

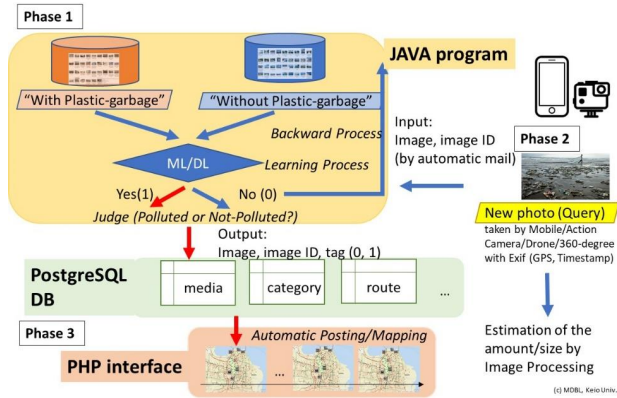


Figure 6. System Implementation of AI-Sensing based on the 3-Phase Algorithm

In the Closing-the-Loop project lead by UN-ESCAP, 5D World Map System is expected to connect with other external systems such as GIS Data Sharing System (GDSS) developed by Japan Space Systems (JSS) [13] to collect and analyze actual local data as much as possible for the collaborative knowledge base creation and sharing. For the purpose, we have designed an integration method between 5D World Map System and other systems as shown in **Figure 7**. Using the integrated two systems, we jointly conducted a series of substantive experiments for the case of Nakhon Si Thammarat (NST), Thailand with the learning and test data sets collected by JSS, which is introduced in Section 5 and Section 6.

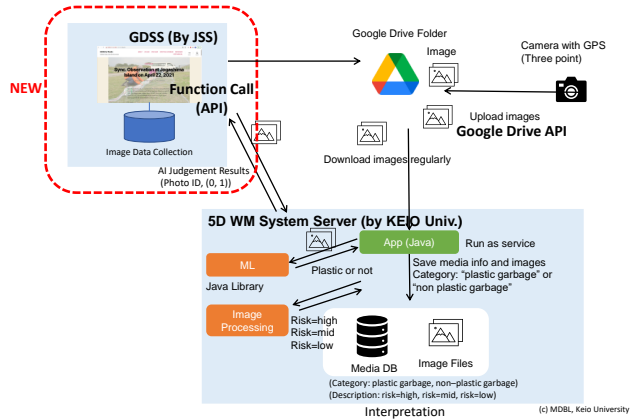


Figure 7. Integration method between 5D World Map System and other external systems

4. AI-Sensing (Model I) and the preliminary experiments for validation

A preliminary model (Model I) for machine learning was designed and a series of validation and accuracy tests of image sensing algorithms was conducted according to the number of target images for learning process. The general scale of datasets of leaning process is defined as follows: a.) less than 100 data, b.) $100 < \text{data} < 1,000$, c.) $1,000 < \text{data} < 10,000$, d.) over 10,000 data. In our experiments, we performed accuracy tests of a.), b.) for the first trial and c.) $1,000 < \text{data} < 10,000$ using online images on the Web.

4.1. Machine Learning Algorithm: Multi perceptron Neural Networks with ALI (Analytical Libraries for Intelligent computing)

To apply Machine Learning (ML) to the automatic judgement of whether an image include plastic garbage or not and the classification of images with plastic garbage or without plastic garbage, we apply a color feature extraction method with ALI (Analytical Libraries for Intelligent-computing) [4] (Figure 6) to our image sensing algorithm and multi perceptron Neural Network (NN) (Figure 7) for relatively-small data sets ($100 < \text{data} < 10,000$). RGB color information of each image is quantized and converted to $5 \times 5 \times 5$ histogram bins of color vectors and the similarity between the images are calculated in the $5 \times 5 \times 5$ color vector space.

After color feature extraction, we build the classification model to identify images whether an image inside the river containing plastic garbage, or not. Here we use Multi Perceptron Neural Network consisting of 2-hidden layers with 125 input units (comes from $5 \times 5 \times 5$ histogram bins) and 2 output units (comes from 2 classes of plastic garbage and non-plastic garbage). For the activation function, Tanh function is applied to 1st and 2nd hidden layers and Sigmoid function is applied to the last layer.

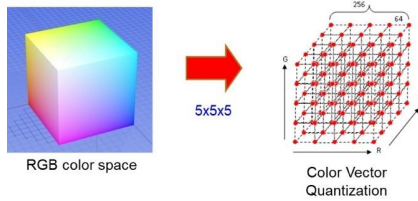


Figure 6. Color Feature Extraction Method with ALI [4]

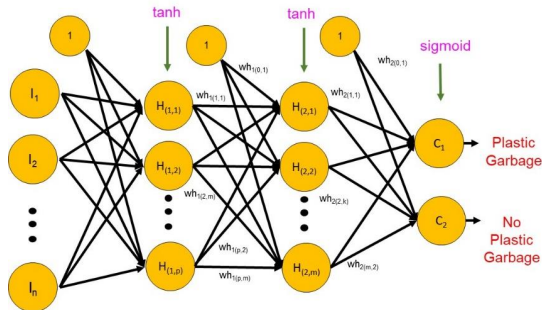


Figure 7. Model I of AI-Sensing: Multi perceptron Neural networks (with 2 Hidden Layers, 2 outputs) with ALI [4]

4.2. Evaluation Methods

In the evaluation experiments, we listed up three major evaluation methods: 1) Leave-one-out, 2) Cross Validation, and 3) Hold-out described in Figure 8. For a.) less than 100 data, we applied 1) Leave-one-out, and for b.) for the first trial and c.) 1,000 < data < 10,000, we applied 1) Leave-one-out and 3) Hold-out.

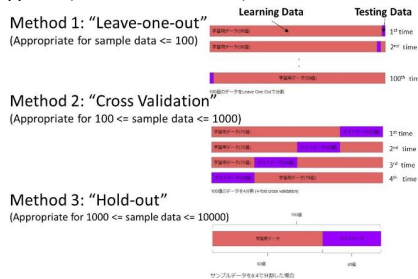


Figure 8. Typical Evaluation Methods for Machine Learning

4.2.1. Experiments with small datasets a.) less than 100 data

We set up the experimental environment and the learning and target images for Evaluation Test 1 with small data sets a.) less than 100 data as below:

Plastic Garbage Images

1.50 images for learning process: river/sea with plastic garbage

2.50 images for learning process: river/sea without plastic garbage

3.100 images for testing: the same data of 1 and 2

The images are resized to 250 pixel height. We use 50 units of the 1st hidden layer and 30 units of the 2nd hidden layers, with learning rate (μ) = 0.05 and 5000 epoch.

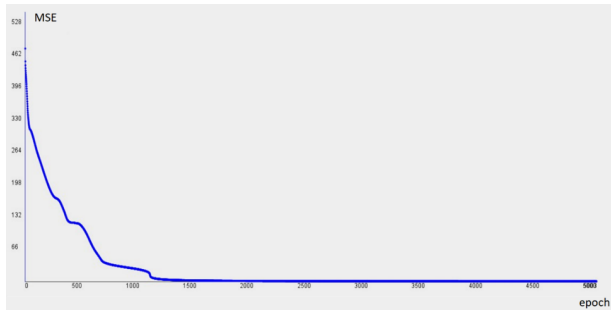


Figure 9. Calculation Results of Model I with small data set a): Mean Squared Error (MSE) using Gradient Descent (One of the Gradient Method Algorithms for Optimization problem)

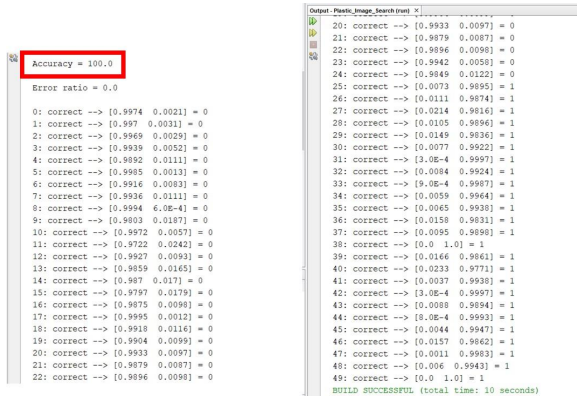


Figure 10. Calculation Results of Mean Squared Error (MSE) using Gradient Descent (One of the Gradient Method Algorithms for Optimization problem)

We applied the evaluation method 1) Leave-one-out and calculated the error ratio and the accuracy rate. The testing results are shown in **Figure 9** and **Figure 10**. Mean Squared Error (MSE) is calculated using Gradient Descent (one of the Gradient Method Algorithms for optimization problem). The epoch (run time) was 5000 and the accuracy was 100% within 10 seconds. This result means that every target image is categorized to either “image with plastic garbage” to “image without plastic garbage” correctly.

4.2.2. Experiments with relatively big datasets b.) $100 < \text{data} < 1,000$ and c.) $1,000 < \text{data} < 10,000$

We set up the experimental environment and the learning and target images for Evaluation Test 2 with a relatively large data sets b.) $100 < \text{data} < 1,000$ and c.) $1,000 < \text{data} < 10,000$ as below:

Collected Plastic Garbage Images

- 1st collection: garbage (48 images), normal (56 images)
- 2nd collection: garbage (654 images), normal (517 images)
- 3rd collection: garbage (160 images), normal (167 images)
- Total: garbage (862 images), without garbage (740 images)

The images are resized to 250 pixel height.

Dataset for testing

- Garbage: 861 images (img no. 0-860)
 - Learning: 500 images (img no. 0-499) - (virtually id 0-499 for train)
 - Testing: 361 images (img no. 500-860) - (virtually id 0-360 for testing)
- Not-Garbage: 739 images (img no. 861-1599)
 - Learning: 500 images (img no. 861-1360) - (virtually id 500-999 for train)
 - Testing: 239 images (img no. 1361-1599) - (virtually id 361-599 for testing)

Due to the higher variety of the colors in the image dataset, we use 80 units of the 1st hidden layer and 50 units of the 2nd hidden layers to give better separation in the vector space between the classes, with learning rate (μ) = 0.05 and 5000 epoch. We applied the evaluation method 1) Leave-one-out and 3) Hold-Out and calculated the error ratio and the accuracy rate. The test results are shown in **Figure 11** and **Figure 12**. Mean Square Error (MSE) is calculated using Gradient Descent (one of the Gradient Method Algorithms for optimization problem). The error ratio for 1) Leave-one-out was 0.7%, which means the accuracy rate was 99.3%. The error ratio for 3) Hold-Out was 22.17%, which means the accuracy rate was 78.83%. These results mean that every target image is categorized to either “image with plastic garbage” to “image without plastic garbage” correctly.

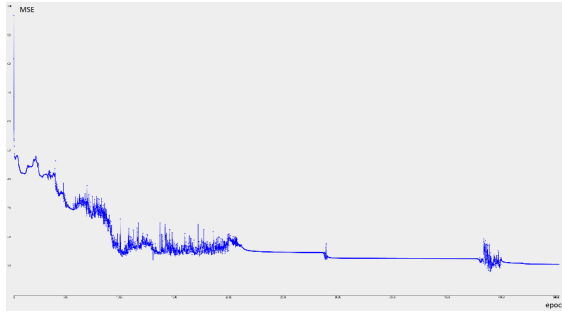


Figure 11. Calculation Results of Model I and dataset b): Mean Square Error (MSE) using Gradient Descent (One of the Gradient Method Algorithms for Optimization problem)

```

Output - Plastic_Image_Search (run)
EUN:
Learning parameters loaded successfully from new_plastic4.nn
Error ratio with Leave-one-out=0.7% (Accuracy=99.3%)
Error ratio with Hold-out method=22.17% (Accuracy=77.83%)

```

Figure 12. Calculation Results of Mean Squared Error (MSE) using Gradient Descent (One of the Gradient Method Algorithms for Optimization problem)

4.3. Analysis on the results

By the evaluation method 1) Leave-One-Out, we acquired the good results (**99%-100%**) both with small data-set (100 training-data set) and relatively-big-data-set (1000 training-data set). By the evaluation method 3) Hold-Out, we acquired **appx. 80%** accuracy with relatively big data set (1000 training-data set). If we increase more learning data and perform “try-and-error” experiments with different parameter setting (eg. the learning rate ($\hat{\epsilon}$) and the momentum coefficient (μ), it is possible to get more accuracy. Also by checking the error-cases (images) to make a *regulation* for training data collection, we are able to identify the cause of errors and the way to cope with.

5. AI-Sensing (Model II) and the substantiative experiments with actual local data

In this experiment, a model for substantiative experiments (Model II) was created and a series of monitoring tests was conducted to examine the feasibility and effectiveness with real local data. The detailed monitoring regulation and evaluation process with AI-Sensing are indicated and provided as “Manual for Capturing Photos” and “Manual for Uploading Photos” at UN-ESCAP CTL project [12]. By using these manuals, the actual monitoring experiments were conducted at Kalimas River and TMD River in Surabaya, Indonesia from Sep. 2020 to Sep. 2021 by a research partner group in Politeknik Elektronika Negeri Surabaya (PENS), Surabaya, Indonesia. In addition, to check the applicability of the model, other substantiative experiments were conducted at

Ta Pi river and the watershed in Nakohn Si Tammarat, Thailand from May, 2021 to November, 2021 by a research partner group in Japan Space System (JSS), Japan.

5.1. Case I: Plastic Garbage on the city-river, Surabaya, Indonesia

Several fieldworks, experiments and evaluation of AI-Sensing were conducted with the local target images taken at TMD river in Surabaya. First, Kalimas river running through the city from the South to the North was a candidate for the analysis as an initial plan suggested by ESCAP. After the fieldwork and photo taking, the research group noticed that plastic garbage was not found so much in this river because of the Surabaya City's campaign of cleaning-up from 5 years ago. Then, we changed the target river from Kalimas to TMD river running through the city from the West to the East (**Figure 13**). The evaluation model is shown in **Figure 14** and the experimental results are shown in **Figure 15, 16, 17, 18** and **Figure 19**.

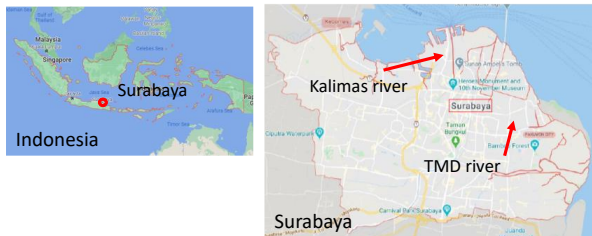


Figure 13. Target rivers for monitoring (Kalimas river and TMD river) in Surabaya, Indonesia

We made experiment with use real images from the river of TMD in Surabaya city. In this experiment, we set these images consisting of 3 categories: (1) clean river (with 8 images, as shown in **Figure 15**), (2) the river containing non-plastic garbage (with 22 images, as shown in **Figure 16**), and (3) the river containing plastic garbage (with 28 images, as shown in **Figure 17**). Therefore, there are 3 output units of the Neural Network, which are clear, Non-Plastic Garbage and Plastic Garbage. For the input units, we set 125 inputs from 5x5x5 histogram bins of color scape. We still use 2 hidden layers consisting of 80 units in the 1st hidden layer and 50 units in the 2nd hidden layer. For the activation function, we use Tanh function for all hidden layers and Sigmoid for the output layer. **Figure 14** shows the model of Neural Network that we use. For the learning process, we set 0.05 for the learning rate with 5000 epoch. The gradient descent from the learning process can be shown in **Figure 19**. These results shows that our AI-Sensing performance is reasonably high.

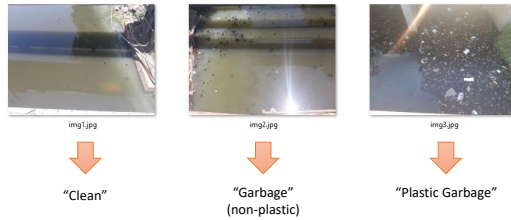


Figure 18. Example monitoring results of AI-Sensing for a case of Surabaya, Indonesia

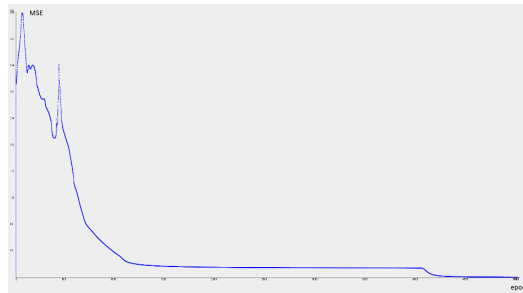


Figure 19. Evaluation (Precision) of AI-Sensing (Model 2) for a case of Surabaya, Indonesia

5.2. Case II: Plastic Garbage on the river with waterweed, Nakhon Si Thammarat, Thailand

In the Closing-the-Loop project lead by UN-ESCAP, 5D World Map System is expected to connect with other external systems such as GIS Data Sharing System (GDSS) developed by Japan Space Systems (JSS) [13] to collect and analyze actual local data as much as possible for the collaborative knowledge base creation and sharing. For the purpose, we have designed an integration method between 5D World Map System and other systems as shown in **Figure 7** at Section 3. Using the integrated two systems, we jointly conducted a series of substantive experiments for the case of Nakhon Si Thammarat (NST), Thailand with the learning and test data sets collected by JSS. The fieldwork and data collection was conducted at Ta Pi river and the watershed in Nakhon Si Thammarat, Thailand during the period between September to November, 2021.

Compared with Surabaya's case, the local image of plastic garbage in NST include a lot of green (aquatic plants) on the water. Thus, we jointly collected a set of images with green as a learning dataset (**Figure 21**, **Figure 22**), and created a specified model with NST's images to fit the local condition (**Figure 23**). The examples of experimental results are shown in **Figure 24**.

The accuracy of detection of plastic garbage was increased because of a specified model with NST's images to fit the local condition (green on the water or aquatic plants).



Figure 20. Target river and the watershed for monitoring, Nakohn Si Thammarat, Thailand

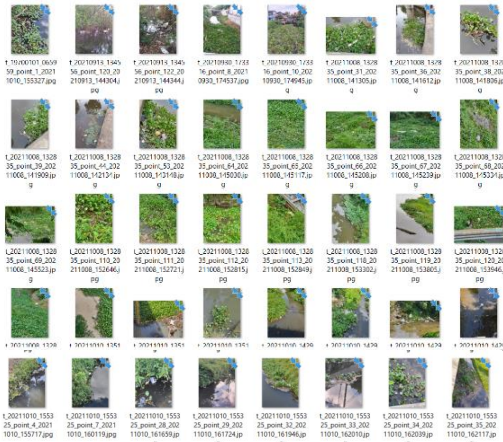


Figure 21. Learning Data of "Plastic Garbage" with green (aqua plants and bush) on the water

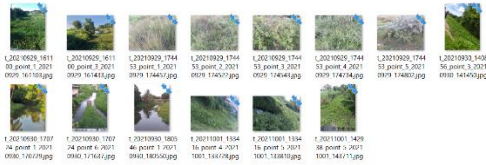


Figure 22. Learning Data of "Clean" with green (aqua plants and bush) on the water

5.3. Risk Categorization of Plastic Garbage

After identification of the plastic garbage inside the river, we also present an approach to categorize the plastic garbage into 4 categories, which are very low risk (the river tends to clear), low risk, middle risk, and high risk. This approach consists of 3 computational steps: (1) Color Filtering, (2) Neighborhood Windowing, and (3) Risk Determination. For the color filtering, we filter the color of an image by 64 closer color to white inside the RGB color space, as shown in Figure 25(a). Figure 25(b) shows the result of color filtering.



Figure 25. Color filtering: (a) closer the white inside the RGB color space, and (b) result of color filtering

The next step is Neighborhood Windowing, which intends to reduce the sun light reflection from the filtered image after Color Filtering (**Figure 26**). The typical visual of sun light reflection, boundary of white neighborhoods is commonly wide. It needs to see the number of neighbors inside the window (size of the neighborhood). Here, we use the window 5x5, as shown in Figure 26. If number of white neighbors inside the window has adequacy, pixel x remains white. Otherwise, it will be converted into black. **Figure 27** shows the results of sun light reduction by using neighborhood windowing.

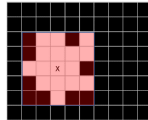


Figure 26. Neighborhood windowing with 5x5 windows

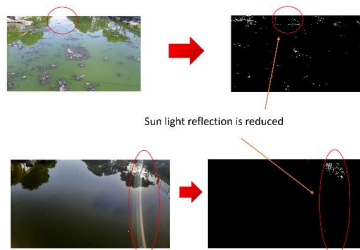


Figure 27. Results of sun light reduction by using neighborhood windowing

The next step is determination for the risk of the plastic garbage. First, we calculate the ratio of white color inside the image. Then, after making a series of empirical experiments, we set the threshold of the risk determination into 4 categories:

- (1) White ratio < 0.003 , the risk is very low (means that the river is clear from garbage)
- (2) $0.003 \leq \text{Ratio} < 0.005$, the risk is low
- (3) $0.005 \leq \text{Ratio} < 0.01$, the risk is middle
- (4) $\text{Ratio} \geq 0.01$, the risk is high

Figure 28 shows the effectiveness of our proposed approach of risk categorization.



Figure 28. Results of our approach for risk categorization

6. Output of 5D World Map System and the scenario for plastic reduction actuation

The examples of automatic mapping outputs of 5D World Map System with AI-Sensing module with actually-collected plastic-garbage images in Surabaya (Indonesia), Bangkok (Thailand) and Kuala Lumpur (Malaysia) are shown in **Figure 29, 30, 31** and **Figure 32**. They show the mapping results of AI-Sensing onto SPA-based 5D World Map System using geolocation and time stamp of images for the case of Nakhon Si Thammarat, Thailand with JSS's collected images.

As an evaluation plan, the following scenario (use case) has been designed and proposed for a local situation analysis in the target four cities in the Closing-the-Loop project [12].

- Step 1. A local user takes photos of river by smartphone or action cameras. In this step, it is recommended for users to follow the photo capturing regulation indicated in "Manual for Capturing Photos" [12] to increase the accuracy of detection of plastic garbage by AI-Sensing and adequately acquire geolocation and timestamp.
- Step 2. Upload photos of the river onto the specific URL of Google Drive via GDSS by JSS [13] or onto 5D World Map System directly by following "Manual for Uploading Photos" [12].
- Step 3. SPA-based 5D World Map System with AI-Sensing judges whether each photo includes plastic garbage or not by AI-Sensing function and returns the results to GDSS by a function call.
- Step 4. 5D World Map System extracts the geolocation and time stamp information from the uploaded images from Exif, and automatically maps the images on the timeseries maps on 5D World Map System Web interface.

Step 5. The local user selects “plastic garbage”, “non plastic garbage” or “clean river” from the category list of 5D World Map System to find out where is the place with plastic garbage, non-plastic garbage or clean river.

Step 6. The local user zooms in to the specific areas by map interface of 5D World Map System to focus on the details.

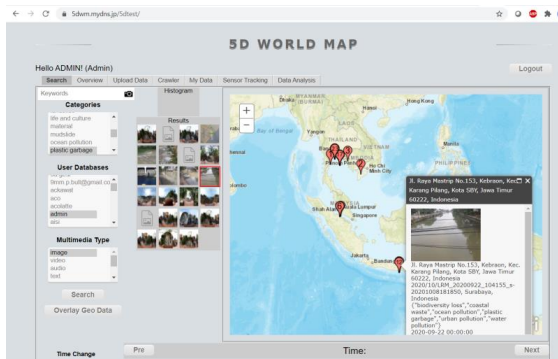


Figure 29. Actual Output of 5D World Map System with Image Search and AI-Sensing module with Collected Plastic-Garbage Images in Surabaya (Indonesia), Bangkok (Thailand) and Kuala Lumpur (Malaysia)

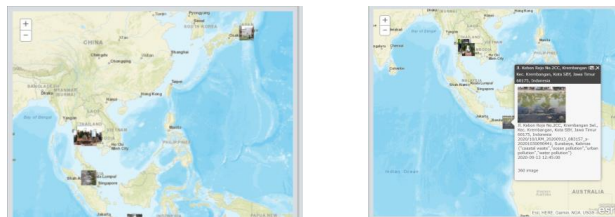


Figure 30. Actual Output of 5D World Map System with Time-series Analysis and AI-Sensing module with Collected Plastic-Garbage Images in Surabaya (Indonesia), Bangkok (Thailand) and Kuala Lumpur (Malaysia)



Figure 31. Automatic-mapping results of AI-Sensing onto AI & 5D World Map System for the case of “clean river” in Nakhn Si Thammarat, Thailand with JSS’s collected images

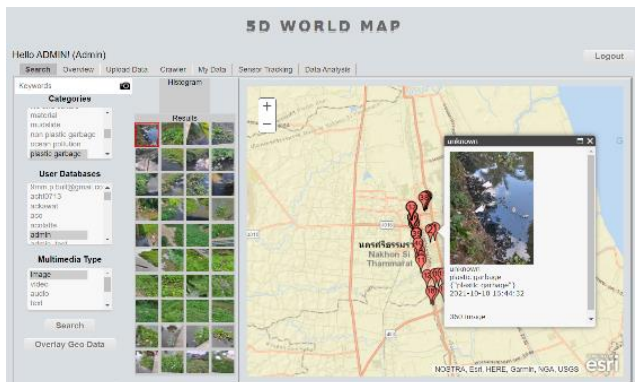


Figure 32. Automatic-mapping results of AI-Sensing onto AI & 5D World Map System for the case of “plastic garbage” in Nakhn Si Thammarat, Thailand with JSS’s collected images

7. Conclusion and Future Direction

In this paper, we have presented an important application of 5D World Map System, adding “AI-Sensing” functions for “Global Environment-Analysis” to make appropriate and urgent solutions to global and local environmental phenomena in terms of short and long-term changes. In this paper, focusing on the ocean plastic garbage issue, the methodology of AI-Sensing, the preliminary models and experiments on the accuracy of AI-Sensing, and the substantiative experiments on the feasibility and effectiveness of AI-

Sensing with real local data are described. In addition, the example outputs of the integration of AI-Sensing algorithm and SPA-based 5D World Map System and an evaluation scenario for actual local users in target four cities in Closing-the-Loop project are introduced.

As a future direction of a collaborative project for ocean plastic-garbage reduction, we have expanded our research activities of SPA-based 5D World Map System with AI-Sensing functions to actual plastic garbage reduction projects and constructed a new partnership with Asia AI Institute (AII) [14] in Musashino University, Japan and Thammasat University, Thailand. We have co-designed a function setting of "Plastic Garbage Detection and Reduction" with advanced technologies in the field of AI, Big-Data Analysis, Machine Learning, VR/AR, IoT and Robotics.

Acknowledgement

We would like to appreciate the members of ICT & Disaster Risk Reduction Division (IDD), UN ESCAP and Asia AI Institute (AII), Musashino University and Thammasat University for their significant discussions and experimental studies.

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Sign Language Recognition by Similarity Measure with Emotional Expression Specific to Signers

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Abstract. Through technology, it is essential to seamlessly bridge the divide between diverse speaking communities (including the signer (the sign language speaker) community). In order to realize communication that successfully conveys emotions, it is necessary to recognize not only verbal information but also non-verbal information. In the case of signers, there are two main types of behavior: verbal behavior and emotional behavior. This paper presents a sign language recognition method by similarity measure with emotional expression specific to signers. We focus on recognizing the sign language conveying verbal information itself and on recognizing emotional expression. Our method recognizes sign language by time-series similarity measure on a small amount of model data, and at the same time, recognizes emotion expression specific to signers. Our method extracts time-series features of the body, arms, and hands from sign language videos and recognizes them by measuring the similarity of the time-series features. In addition, it recognizes the emotional expressions specific to signers from the time-series features of their faces.

Keywords. Sign Language Recognition, Similarity Measure, Emotional Behavior, Diverse Speaking Communities

1. Introduction

It has become increasingly important to understand how diverse people can work together to contribute to society in recent years. Smooth communication is the most necessary for diverse people to work together. In order to achieve smooth communication, we are focusing on the implementation of new global communication methods. In particular, we expect information technology to realize smooth communication across heterogeneous languages and sign languages.

Through technology, it is essential to seamlessly bridge the divide between diverse speaking communities (including the signer (the sign language speaker) community). In order to realize communication that successfully conveys emotions, it is necessary to recognize not only verbal information but also non-verbal information. In the case of sign language speakers, there are two main types of behavior: verbal behavior and

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emotional behavior. Verbal behavior requires technology to recognize the sign language itself, and emotional behavior requires technology for recognizing emotions. By realizing both behavior recognition, we realize semantic mutual understanding and emotional mutual understanding, which can utilize as a new global communication method. Therefore, it is essential to extract the features of verbal and emotional behavior and to realize a sign language recognition method that combines them.

Some signers say that sign language is less burdensome for emotional communication than written communication. Written communication is one of the ways of communication by sign language speakers with speakers of other languages. Written communication is a very effective way of conveying meaning. However, it is difficult to convey emotions to the other person through written communication alone. In order to solve these problems, it is essential to realize a sign language recognition and composition system that can reflect not only verbal behavior but also emotional behavior features. The realization of a place where diverse people can communicate smoothly requires a platform with a system that recognizes, composes, and expresses meanings and emotions. This platform can seamlessly bridge the divide between diverse speaking communities (including the signer (the sign language speaker) community). Our new method of global communication can be the core technology to realize this platform.

This paper presents a sign language recognition method by similarity measure with emotional expression specific to signers. We focus on recognizing the sign language conveying verbal information itself and on recognizing emotional expression. Our method recognizes sign language by time-series similarity measure on a small amount of model data, and at the same time, recognizes emotion expression specific to signers. Our method extracts time-series features of hands from sign language videos and recognizes them by measuring the similarity of the time-series features. In addition, it recognizes the emotional expressions specific to signers from the time-series features of their faces.

Our method consists of a hand gesture recognition function, a facial expression recognition function, and a recognition result integration function. The hand gesture recognition function enables recognizing sign language by time-series similarity measure. It is the ability to realize the semantic recognition that sign language represents. The facial expression recognition function recognizes facial expressions evolve to communicate intentions. The recognition result integration function integrates hand gesture recognition results and facial expression recognition function results.

The main features of this paper are as follows:

- We propose a new sign language recognition method by similarity measure from extracted features of the hands from sign language videos.
- We also propose a recognition method for emotional expression specific to signers from extracted features of the face from sign language videos.
- We position our proposed method as a new global communication method and develop our method to bridge over diverse communities.

This paper is organized as follows. In section 2, we present some related works of our method. Section 3 presents our proposed method, a sign language recognition method by similarity measure with emotional expression specific to signers. In section 4, we represent the result of similarity measures for recognizing sign language. In addition, in the section, we also present the extraction of emotional expression specific to signers. Finally, in section 5, we summarize this paper.

2. Related Works

The reference [1] provides a research survey on recognizing emotions from body gestures. This paper [1] assumes that body gesture-based emotion recognition generally consists of human detection, body pose detection, representation learning, and emotion recognition. This paper shows some research in each function.

We focus on verbal and emotional behavior to recognize sign language with emotion. Our method not only recognizes signs that convey actual meaning but also recognizes signer-specific expressions that express emotion. According to reference [2], sign language recognition alone can only recognize 35% of the content to convey, and non-verbal signals are essential for smooth communication. The reference [2] presents that the final message of an utterance is affected 35% by the actual words and 65% by non-verbal signals.

The reference [3] present a survey of machine learning methods applied in sign language recognition systems. This reference [3] says that sign language involves the usage of the upper part of the body, such as hand gestures [4], facial expression [5], lip-reading [6], head nodding and body postures to disseminate information [7] [8] [9]. We classify hand gestures and lip reading as verbal behavior. We classify head nodding, and body postures to disseminate information as emotional behavior. We classify facial expression as both verbal and emotional behavior. In this paper, we present a new hand gesture and facial expression recognition method.

Our previous works [10][11] present finger character recognition in sign language using a finger feature knowledge base for similarity measures. Especially, our previous work [10] presents finger character feature extraction by combining a camera and a deep learning model for extracting finger joint coordinates. In this paper, we apply our previous works [10][11] and Mediapipe [12] to time-series feature extraction for sign language recognition. Existing methods for time-series feature extraction for sign language recognition are broadly classified into direct feature extraction using a glove with multiple sensors [13][14], indirect feature extraction using a depth sensor [15], and indirect feature extraction using a monocular camera [16][17][18]. In the case of methods that use gloves equipped with multiple sensors, while the method extracts accurate features, it can be inconvenient to communicate with gloves in daily life. In the case of methods that use depth sensors, it is also necessary to prepare depth sensors. In the case of methods using a monocular camera, the accuracy is lower than the first two methods, but we can smoothly introduce it in daily life. Recently, monocular camera-based methods such as Mediapipe [12] make extracted features high accuracy and ease.

The reference [19] creates two datasets: a synthetic motion dataset for model training and a dataset containing human annotations of real-world video clip pairs for motion similarity evaluation for human motion similarity measures. The reference [19] points out that measuring motion similarity has attracted less attention due to the lack of large datasets. In the case of realization of sign language recognition, it is difficult to apply the standard machine learning method due to the lack of large datasets like the above case.

Our method enables sign language recognition by similarity measure between the input sign language features and a miniature model data set. The sign language features represent some time series data. DTW [20][21][22] is a method to measure the similarity of time series data. DTW can robustly determine the distance between two sets of time-series data with different lengths, such as waveforms with different frequencies. Our previous work [23] proposes a similarity measure for time series semantic data based on

DTW [20][21][22]. It enables the calculation of the similarity of media content based on time-series changes.

3. Sign Language Recognition Method by Similarity Measure with Emotional Expression Specific to Signers

3.1. Overview of our proposed method

This paper presents a sign language recognition method by similarity measure with emotional expression specific to signers. We focus not only on recognizing the sign language itself but also on expressing emotions. Our method recognizes sign language by time-series similarity measure on a small amount of model data, and at the same time, recognizes emotion specific to signers.

Figure 1 shows an overview of our proposed method. Our method consists of a hand gesture recognition function, facial expression recognition function, and a recognition result integration function. The hand gesture recognition function enables recognizing sign language by time-series similarity measure. It is the ability to realize the semantic recognition that sign language represents. It recognizes sign language by time-series similarity measure on a small amount of model data. It extracts time-series features of the body, arms, and hands from sign language videos and recognizes them by measuring the similarity of the time-series features. The facial expression recognition function recognizes emotional behaviors other than sign language. This paper focuses on recognizing emotional behaviors as expressions of emotion-specific to signers. Especially, we realize facial expression recognition specific to signers in this paper. The recognition result integration function integrates hand gesture recognition results and facial expression recognition function results.

Our method extracts time-series features of the hands from sign language videos and recognizes them by measuring the similarity of the time-series features. In addition, it recognizes the emotional expressions specific to signers from the time-series features of their faces.

In section 3.2, we describe the realization method of the hand gesture recognition function. In section 3.3, we show the one of the solutions of facial expression recognition function focusing on the facial expression specific to signer. In section 3.4, we represent the recognition result integration function.

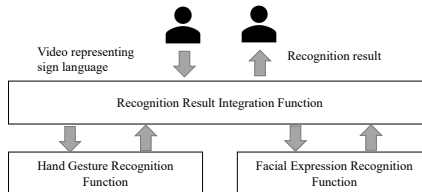


Figure 1. Overview of our proposed method.

Our method consists of a hand gesture recognition function, facial expression recognition function, and a recognition result integration function.

3.2. Hand gesture recognition function

3.2.1. Overview of hand gesture recognition function

Figure 2 shows a structure chart of the hand gesture recognition function. The hand gesture recognition function consists of metadata creation and recognition phases. The metadata creation phase takes as input a video of a sign language model and a label representing the semantic of the sign language, extracts time-series waveform features from the videos, and stores them in the sign language glossary. The recognition phase inputs a video of sign language, extracts time-series waveform features from the videos and measures waveform similarity between time-series features from the input video and stored waveform features in the sign language glossary. This function recognizes sign language by time-series similarity measure on a small amount of model data. It extracts time-series features of the body, arms, and hands from sign language videos. This function determines the semantic of a sign language by selecting the one with the highest similarity between the time-series waveform features extracted from the sign language example video, and the time-series waveform features extracted from the input sign language video.

There are two modules in the hand gesture recognition function: a time-series feature extraction module appearing in both the metadata creation phase and recognition phase and a waveform similarity measure module appearing in the recognition phase. The time-series feature extraction module extracts each normalized position (x,y,z) of 42 landmarks from both hands in each time as the time-series waveform features. The waveform similarity measure module calculates the similarity between each time-series waveform feature extracted from the time-series feature extraction module. We realize the waveform similarity by applying our previous method [23] based on DTW [20][21][22]. It enables the calculation of the similarity of media content based on time-series changes. Implementing two modules makes it possible to perform a similar search for sign languages as waveforms. In addition, it is possible to visualize time-series variance by time-series change of sign languages. Measuring the similarity of time-series waveform features extracted from each time-series feature extraction makes it possible to derive a similarity corresponding to the dynamism of the sign languages. The similar search determines semantic of the input sign language.

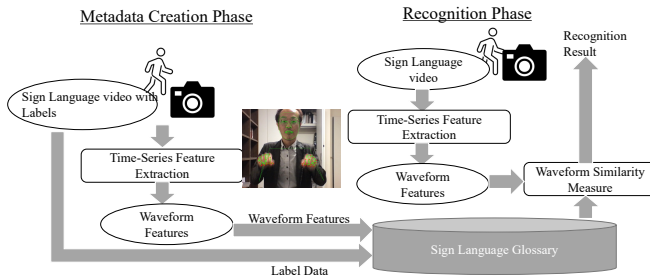


Figure 2. Structure chart of hand gesture recognition function.

3.2.2. Time-series feature extraction module in hand gesture recognition function

The time-series feature extraction module extracts waveform features representing both hands' positions each time from sign language video data.

Figure 3 shows the detail of the time-series feature extraction modules.

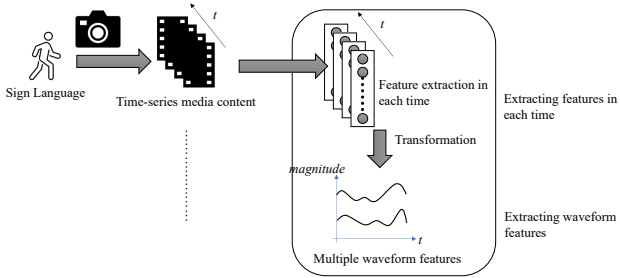


Figure 3. Time-series feature extraction module.

First, it converts the input sign language video data into a set of images in each time as the time-series media content set.

Next, it extracts features representing both hands' positions in each image. By this process, we can obtain time-series multiple features at each time. In this paper, we apply Mediapipe [12] to feature extraction. The Mediapipe can extract hands, faces, arms, and body parts landmarks. This paper uses landmarks of both hands' parts as features. The Mediapipe extracts each normalized position (x,y,z) data of 42 landmarks from each image. We can obtain 126 features each time as time-series features. Therefore, it generates a $126 \times t$ time-series feature matrix shown in Figure 4. This matrix shows the 126 features of the motion extracted from the sign language represented in the input video and their temporal variation. This matrix represents motion transitions for sign language.

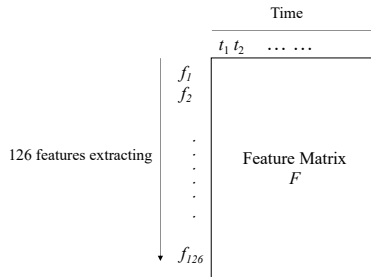


Figure 4. Time-series feature matrix.

The Mediapipe extracts each normalized position (x,y,z) data of 42 landmarks from each time. This matrix shows the 126 features extracted from the sign language represented in the input video and their temporal variation.

Finally, it creates multiple waveform features. It performs a moving average over each time-series feature extracted from Mediapipe, resulting in 126 waveform features. These waveform features represent time-series changes for recognition of sign language. Figure.5 shows the detail of this process.

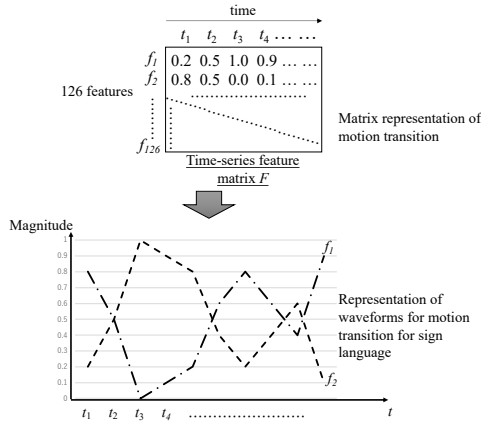


Figure 5. Waveform features creation. This module generates 126 waveform features from the $126 \times t$ time-series feature matrix shown in Figure 4.

We can obtain 126 waveforms features that present sign language motion transitions by these processes.

In the case of the metadata creation phase in Figure 2, we prepare some sets of sign language videos with each label as a model data set. The time-series feature extraction module generates 126 waveforms features in each model data set and stores them in the sign language glossary. In the case of the recognition phase in Figure 2, we input a sign language video. the time-series feature extraction module generates 126 waveforms features from the input video. In this method, all sign language videos are converted to 126 waveforms features by the time-series feature extraction module.

The time-series feature extraction module consists of the following three steps:

- (1) Dividing video data according to a specified window size
It divides the input video data at regular intervals according to a specific window size to obtain time-series characteristics from the video data. By this step, we can obtain image data set.
- (2) Creating feature matrix
It extracts 126 features representing both hands' positions in each image using Mediapipe. Therefore, it generates a time-series feature matrix shown in Figure 4. This matrix shows the 126 features extracted from the sign language represented in the input video and their temporal variation. This matrix represents motion transitions for sign language.
- (3) Representing waveforms as motion transition

It represents multiple waveforms as motion transition. It performs a moving average over each time-series feature extracted from Mediapipe, resulting in 126 waveform features. These waveform features represent time-series changes for the recognition of sign language. When these values are plotted on the time axis, waveforms are visualized for each feature. We define the multiple waveforms as motion transition.

3.2.3. Waveform similarity measure module

The waveform similarity measure module is possible to show the relationship between each sign language based on time-series development by calculating the similarity between the motion transitions represented as waveforms. It realizes new time-series similarity by comparison with motion transitions represented by waveforms applying a signal processing technique—the DTW distance [20][21][22].

DTW is a pattern-matching technique used for one of the signal processing techniques, such as voice recognition, and so on. DTW can robustly determine the distance between two sets of time-series data with different lengths, such as waveforms with different frequencies. DTW finds the path where the two sets of time-series data are the shortest after calculating the distance between each point of the two sets of time-series data by brute force. Figure 6 shows the difference between Euclidean matching and dynamic time warping matching. DTW matching minimizes cumulative distance measurement consisting of local distances between aligned samples.

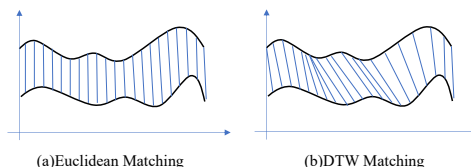


Figure 6. Different matching of two similar time series. (a) is Euclidean matching. (b) is dynamic time warping matching. The DTW matching minimizes cumulative distance measurement consisting of local distances between aligned samples.

Using the waveform similarity measurement makes it possible to realize sign language retrieval corresponding to the time-series motion transition of sign language. Using the waveform similarity measurement makes it possible to realize sign language retrieval corresponding to the time-series motion transition of sign language. Using a search mechanism based on waveform similarity measure, the sign language recognition method enables sign language recognition even from a small amount of sign language model data. It is tough to create a large amount of sign language model data. We would like to provide a platform for heterogeneous signers to communicate. In order to realize this platform, it is necessary to create various sign language model datasets. Therefore, sign language recognition methods must be feasible with small sign language model data sets.

Figure 7 shows the realization methods for the waveform similarity measurement module. This module consists of two steps.

- (1) Computing DTW distance in each waveform feature

The time-series feature extraction module outputs waveforms as motion transition from time-series media content. It computes the DTW distance in each waveform feature. This means computing the similarity of each single waveform.

- (2) Composition of each DTW distance
 It composes each DTW distance derived in (1). The composition value is a multiple waveform similarity value for motion transition.

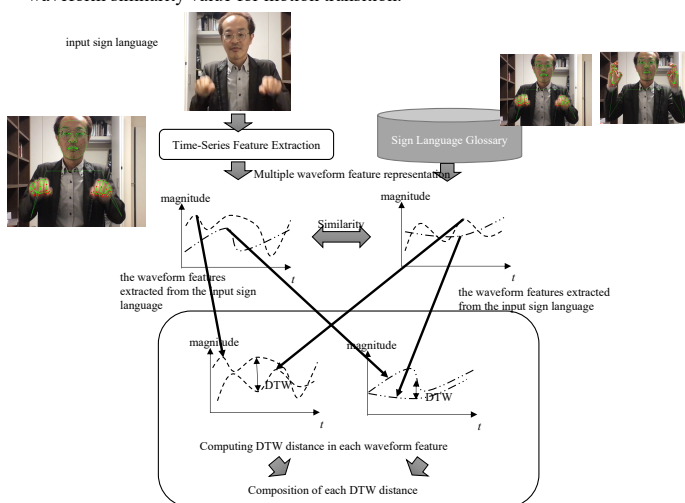


Figure 7. An overview of the waveform similarity measure module. The time-series feature extraction module outputs waveforms as motion transition from time-series media content. In order to compute similarity of motion transition, the module computes DTW distance in each waveform feature. Finally, the module composes each DTW distance. The composition value is a waveform similarity measurement for each motion transition.

3.3. Facial expression recognition function

3.3.1. Overview of facial expression recognition function

Figure 8 shows a structure chart of the facial expression recognition function. It consists of an event definition phase and recognition phase. The event definition phase defines the emotion to be recognized as an emotional event. Each event is stored in the emotion event meta database. The recognition phase inputs a video extracts time-series waveform features from the videos, and detects emotion events by the emotion event meta database.

There are two ways in the event definition phase: a rule based definition and a machine learning based definition. The rule based definition is used when a change in the features reliably defines the expression of the emotion. The machine learning based definition is used when the expression of emotion cannot be described by rules but can

be derived by learning from a large amount of model data. For emotional expressions such as standard facial expressions, we can use previous research such as facial expression recognition (e.g., Reference [24]). Our interviews with have confirmed the existence of several signer-specific emotional expressions. For example, a squinting expression indicates that the signer emphasizes the expression. By defining the emotional events of the signer's specific emotional expression, it is possible to convey the content of the sign language more accurately.

The recognition phase consists of a time-series feature extraction module and an emotion event detection module. The time-series feature extraction module extracts each normalized position (x,y,z) of landmarks from face, body, both feet, both arms and both hands in each time as the time-series waveform features. The emotion event detection module uses the emotion event meta database to detect emotion events.

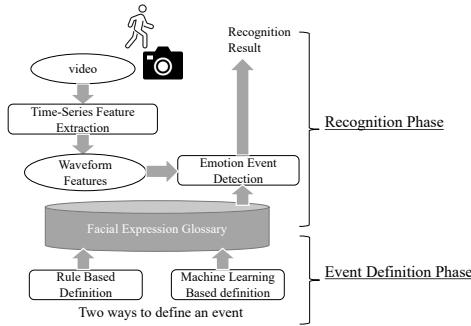


Figure 8. Structure chart of emotion recognition function.

3.3.2. Event definition phase

There are two ways in the event definition phase: a rule based definition and a machine learning based definition.

The rule based definition labels changes in time-series features. It is often possible to link changes in facial expressions and motion feature points to their semantic. When defining an event to detect that squinting implies emphasis, it should be possible to detect when a certain amount reduces the area occupied by the eyes.

The machine learning based definition consists of a training dataset consisting of time-series features and their labels. Unlike rule-based definitions, where changes in facial features and their meanings cannot be clearly labeled, definitions are made using large amounts of training data.

Here, in the case of event definitions for detecting signer-specific expressions, it is considered that the rule based definitions can be used in most cases. The signer-specific expressions of emotion are derived from interviews with signers and the research results by sign language experts. In other words, we need to realize a common understanding of emotional expression for signers on an ad hoc basis. We define a common understanding of each signer's specific emotional expression as each emotion event. In order to define as many signer-specific emotional expressions as possible as emotion events, it may be

necessary to implement a collaborative editing environment for emotion event definitions.

3.3.3. Time-series feature extraction module in facial expression recognition function

The time-series feature extraction module extracts each normalized position (x,y,z) of landmarks from face, body, both feet, both arms and both hands in each time as the time-series waveform features. In this paper, we apply Mediapipe [12] to feature extraction as same as the hand gesture recognition function. It uses all the hands, faces, arms, feet and body parts landmarks extracted by Mediapipe.

3.3.4. Emotion event detection

The emotion event detection module uses the emotion event meta database to detect emotion events. Emotion event outputs a recognition result only when an event is detected. For example, in the case of an emotional event indicating emphasis by squinting, the label “emphasis” is output as a recognition result only when the eyes are squinted. The waveform features extracted from the time-series feature extraction module described in section 3.3.3 are used as input for event detection.

3.4. Recognition result integration function

The recognition result integration function integrates hand gesture recognition results and facial expression recognition function results. For example, if an emotional event indicating emphasis by squinting is detected and a sign meaning “long time no see” is detected, the result “very long time no see” is output. However, there are cases where it is better to separate the detected verbal behaviors from the emotion event. For example, in the case of clear emotional events such as “happy” or “sad,” the semantic may be inaccurate if mixed with the results of sign language detection.

Visualizing and presenting these recognition results to the user is future works.

4. Experiment

In this section, we implement the hand gesture recognition function shown in section 3.2 and a part of the facial expression recognition function shown in 3.3 and verify the recognition result.

4.1. Experiment 1 (Experiment on sign language glossary lookup using sign language video query)

4.1.1. Experiment environment

We prepared each two sign language videos, each for “good morning,” “good afternoon,” “good evening,” and “long time no see,” in Japanese sign language as model data are shown in Figure 9. The sign language videos shown in Figure 9 stored in the sign language glossary. We verified whether the waveform similarity metric correctly recognized the videos of “good morning,” “good afternoon,” “good evening,” and “long time no see” taken from different angles from the prepared model data as query sign language videos. Figure 10 shows query sign language videos and their IDs.

Video ID	Video(parts of frames)
Good morning1	
Good morning2	
Good afternoon1	
Good afternoon2	
Good evening1	
Good evening2	
Long time no see1	
Long time no see 2	

Figure 9. Each two sign language videos, each for “good morning,” “good afternoon,” “good evening,” and “long time no see,” as model data

Video ID	Video(parts of frames)
Good morning query	
Good afternoon query	
Good evening query	
Long time no see query	

Figure 10. Query sign language videos and their IDs.

4.2. Experimental results

We show waveform similarity measure results shown in Table 1 (in the case of “Good morning query”), Table 2 (in the case of “Good afternoon query”), Table 3 (in the case of “Good evening query”), and Table 4 (in the case of “Long time no see query”). The Waveform similarity measure shown in section 3.2.3 determines that the smaller the value, the higher the similarity.

In the case of “Good morning query” shown in Table1, the system shows that the similarity between the input and “Good morning2” and “Good morning1” is high. Therefore, the sign language indicated by “Good morning query” is correctly recognized as “Good morning”.

In the case of “Good afternoon query” shown in Table2, the system shows that the similarity between the input and “Good afternoon1” and “Good afternoon2” is high. Therefore, the sign language indicated by “Good afternoon query” is correctly recognized as “Good afternoon”.

In the case of “Good afternoon query” shown in Table2, the system shows that the similarity between the input and “Good afternoon1” and “Good afternoon2” is high. Therefore, the sign language indicated by “Good afternoon query” is correctly recognized as “Good afternoon”.

In the case of “Good evening query” shown in Table3, the system shows that the similarity between the input and “Good evening2” and “Good evening1” is high. Therefore, the sign language indicated by “Good evening query” is correctly recognized as “Good evening”.

In the case of “Long time no see query” shown in Table4, the system shows that the similarity between the input and “Long time no see1” is high. Therefore, the sign language indicated by “Long time no see query” is correctly recognized as “Long time no see”. However, the system indicates that the similarity of “Good evening1” is also

high. The sign language for “Good evening” and “long time no see” has an arm-opening motion; therefore, the system measures high similarity.

The introduction of methods such as dimension deduction is one of the future works. This method tends to be computationally expensive. Moreover, it is necessary to create more sign language example data and verify the effectiveness of using them.

Table 1. Waveform similarity measure results in the case of “Good morning query”

	Data name	Waveform similarity measure
1	Good morning2	166.224711110
2	Good morning1	185.8336289461081
3	Good afternoon1	216.42646559481693
4	Good afternoon2	242.99949708402085
5	Good evening1	536.7560547591917
6	Good evening2	559.1061592315774
7	Long time no see1	586.2445960920552
8	Long time no see2	814.9661315709342

Table 2. Waveform similarity measure results in the case of “Good afternoon query”

	Data name	Waveform similarity measure
1	Good afternoon1	179.90706160093168
2	Good afternoon2	197.8562313570992
3	Good morning2	206.342194446534
4	Good morning1	223.68309196158623
5	Long time no see1	486.0481500020227
6	Good evening1	548.4300859502855
7	Good evening2	564.911794575454
8	Long time no see2	823.1264081739348

Table 3. Waveform similarity measure results in the case of “Good evening query”

	Data name	Waveform similarity measure
1	Good evening2	232.74890747326342
2	Good evening1	236.62293856350536
3	Long time no see1	491.2600778100607
4	Good morning1	492.3505294598326
5	Good morning2	504.9853604666803
6	Long time no see2	558.4608788777249
7	Good afternoon2	599.5930115504634
8	Good afternoon1	599.7239569006395

Table 4. Waveform similarity measure results in the case of “Long time no see query”

	Data name	Waveform similarity measure
1	Long time no see1	316.3062876378202
2	Good evening1	335.19070713716405
3	Long time no see2	336.5217383472059
4	Good evening2	391.3205649517722
5	Good afternoon1	427.5670674213245
6	Good afternoon2	428.2101874432208
7	Good morning1	438.1667977241975
8	Good afternoon1	599.7239569006395

4.3. Experiment 2 (Implementation of the facial expression recognition function)

4.3.1. Experimental environment

We implement the system detecting the expression “squinting”. As an expression of emotion unique to signers, an interview with two signers revealed that the expression “squinting” can mean emphasis. Figure 11 shows test data for the squinting expression detection. The image on the left side of Figure 11 shows the facial expression of a normal eye. The image on the right side of Figure 11 shows a squinted eye expression. The person in this image has narrow eyes even under normal facial expression, so it is not easy to distinguish between them.



Figure 11. Test data for the squinting expression detection.
The image on the left side shows the normal eye expression.
The image on the right side shows the squinted eye expression

4.3.2. Experimental results

We have implemented a system that detects eye regions and extracts squinting expressions by comparing the area of these regions. The Table 5 shows the values of the area of the detected eye region for the left and right images of Figure 11. The area of these regions in the case that the eyes are squinting is smaller. The system can recognize expressions that mean emphasis by squinting by detecting that the eye area is small for a certain amount of time in a row.

Table 5. the values of the area of the detected eye region for the left image (normal eyes) and right image (squinting eyes) of Figure 11

	Normal eyes	Squinting eyes
Left eye	0.00658263	0.00580797
Right eye	0.00667033	0.00585308

The results showed that it was possible to detect one of the emotional expressions unique to signers. We need to realize these signer-specific expressions on an ad hoc basis.

5. Conclusion

This paper presented a sign language recognition method by similarity measure with emotional expression specific to signers. We focus not only on recognizing the sign language itself but also on expressing emotions. Our method recognizes sign language by time-series similarity measure on a small amount of model data, and at the same time, recognizes emotion specific to signers.

We position our proposed method as a new global communication method and develop our method to bridge over diverse communities. It is essential to seamlessly bridge the divide between diverse speaking communities (including the signer (the sign language speaker) community). In order to realize communication that successfully conveys emotions, it is necessary to recognize not only verbal information but also non-verbal information. Our proposed method realizes the platform bridging over diverse communities.

We have implemented a basic sign language recognition and emotion expression recognition system using our method and verified its effectiveness.

We will realize a new function that recognizes words and sentences in sign language as our future work. We will realize the sign language of various countries. We need to establish a sign language segmentation method for this to work. Moreover, It is necessary to develop a sign language corpus to realize this method, verify its effectiveness using large-scale data, and conduct experiments on subjects with native signers.

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Virtual Art Exhibition System: An Implementation Method for Creating an Experiential Museum System in a Virtual space

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Abstract. In order to provide art exhibitions in a virtual space, which integrates various data of an art museum and gives an emotional experience, the Virtual Art Exhibition System is proposed. This research uses a multi-database called Artizon Cloud to display museum data, combine with technologies called Data Sensorium and Torus Treadmill to project images and enable visitors to walk around the virtual museum. Moreover, the virtual museum will exploit the user's intentions and be personalized, automatically generating further art exhibitions.

Keywords. museum systems, virtual reality, virtual museum

1. Introduction

The social transformation with information technologies is rapidly widening in the world even for public facilities. It is also the same for the museums. Museums in the world have started importing the transformation, such as digitizing the art information archives [1], and photographs of artworks beginning to be digitally archived [2,3,4]. As an example, Google's "Google Art Project" is an archive of extremely high-resolution digital images, with about 600 museums and galleries participating worldwide [5]. For another example, archiving the museum layouts through the analysis of visitor behavior [6], archiving the traditional culture and the staging of new experiences through digital technology [7] are the examples of the current entries of digitization in museums. As shown here, there are numerous things that digital implementation can do to museums.

The virtual (VR) museums are also getting lots of attention. Although there are various definitions of the term "virtual museum" [9], in this paper, a virtual museum is defined as making digitized objects available online or using high-tech equipment such as VR glasses to make the visitors feel as if they are actually in a museum [8].

With the increasing popularity and acceptance of virtual reality technology, especially in the field of museums, virtual museums have once again become the focus of attention [9]. Until today, there have been art museums reproduced on websites such as the online museum services named HASARD [10], which is a service that displays archives and details of artworks on the website and VIRTUAL MUSEUMS [11], which

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museums around the world are displayed on a map, and the user can watch tour videos and 360-degree images of each museum. In this way, the benefits of digitization have taken us to a stage where visitors can enjoy artworks regardless of the artwork's location and the user's location. Not just an advantage for users, while many museums around the world have been forced to close temporarily due to the spread of COVID19, a "virtual museum" that allows visitors to experience the artworks displayed in the museum via internet can be said to be a lifeline for serving museum services under the current pandemic circumstance. Although, while there are many virtual museums as the examples above, there is still no museum that actually projects in a form of real size. In general, real-world museums display multiple artworks in the room and provide the space and the experiences to the visitors. The concept of a VR museum with the advantage of being able to view artworks on the internet is very positive, yet we believe that including more sense of reality to this concept would create an even better experience for users. According to [12], the author advocates how important a sense of reality is to the museum experience. The author claims: On a video screen, a painting has no texture, and when three dimensions become two, something is always lost. Therefore, realism could be a major keyword in the construction of a virtual museum. Thus, have chosen to create a VR museum that provides newly designed art experiences and to also pursue a sense of reality.

In this paper, we will propose a virtual museum which will be called a Virtual Art Exhibition System.

2. An Experiential Museum System

2.1. Art Sensorium Project

To enhance the art experiences of art museums, the Art Sensorium Project was launched at Musashino University in 2020(Fig.1). Current research goals of the project are as follows: 1) system design and implementation of a multidatabase system that integrates multiple digital archives of art collections, and 2) system design and implementation of a virtual exhibition environment that provides more experiential and emotional impact to an individual. In this paper, we propose an experimental system design and implementation of a Data Sensorium application for Artizon Cloud [1] that 1) automatically displays artworks, 2) extracts users' interests, and 3) automatically re-displays artworks based on the extracted interests.

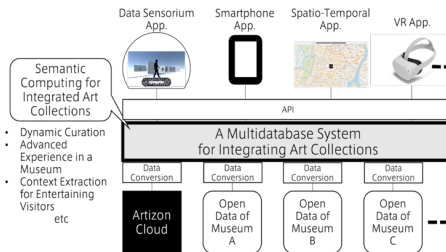


Figure 1. An overview of Art Sensorium Project

2.2. Virtual Art Exhibition System

The goal of the Virtual Art Exhibition System is to provide art experiences to each user according to their interests and intentions. Toward the goal, we aim to pursue reality and provide a dynamic virtual museum experience in cyberspace based on the idea “Emotional Excitements” which we defined as something that visitors can truly enjoy and be moved by.

By using the multidatabase system, where many artworks are converted into image data, it is possible to display a number of artworks in a virtual space which would not be possible in a physical museum. Furthermore, the Virtual Art Exhibition System will exhibit dynamic and automatic curation according to each visitor’s intention and interests. No matter the user’s and artwork location, this could provide an “Emotional Excitement” that goes beyond the world. Below shows the features of the proposed system:

1) Personalized Exhibition generated based on the user’s physical characteristics

Each user will be asked to input the height information before viewing. Then the system will be displaying artworks adjusted to each user’s height and the height of the eyes so the users could easily view the artworks in the best position.

2) Personalized Exhibition generated from the user’s mind

The concept of personalization is extracted from the user’s interests and intentions. The definition of “interest” and “intention” is complex, and there are various ways to extract user interest. Such as letting the user input, recording the user’s walking trajectory, the time the user stopped in front of the artwork, user eye tracking, etc. In this system, we defined “user interest” as the time the user spent in front of the artwork.

By combining these factors, visitors will be able to experience an even more immersive experience in the virtual museum, and an unique “Emotional Experience” that could only be achieved in cyberspace.

2.3. Exploiting users’ intentions and generating art exhibitions

As a premise, we define that the more the user spends time in front of the artworks, the more the user prefers the artwork. In other words, it can be said that the user’s behavior shows the user’s preferences. In this system, we succeeded **2) Personalized Exhibition** in which generating and exhibiting the artworks related to the user’s intention by calculating the user’s staying time in front of the artworks. Firstly, a set of artworks will be randomly exhibited in the exhibition room. While the user is walking around, an artwork that the user has mostly viewed will be extracted. Secondly, the new set of artworks will be searched in the database from the interested artwork which was in the previous set (**Figure 2**). Related artworks are defined as: artwork that is from the same period, author, and its region to the chosen artwork. Finally, the new set of (related) artworks will be exhibited. This curation function is designed as a database user interface in a virtual space, so the intension is converted to a query in SQL form. When a user spends more time in the virtual space for viewing many sets of artworks, more precise interest for artworks could be extracted for searching in detail. There are many possible approaches to re-design the curation function such as semantic computation or spatio-temporal computation, although these more advanced methods will be discussed in the future.

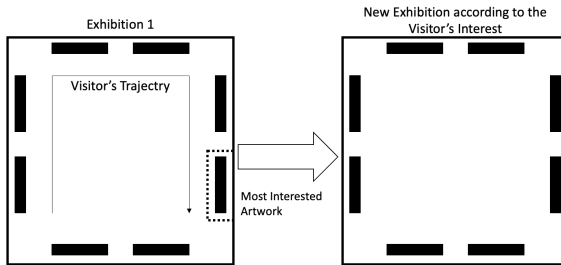


Figure 2. An implementation of the art exhibition system.

3. Implementation Environment

To implement the actual size exhibition for the proposed system, the proposed system uses a dynamic full-scale projection system called Data Sensorium which can provide realistic virtual exhibitions of artworks. The next section will explain what Data Sensorium is, and how it will be used in the Virtual Art Exhibition system.

3.1. Data Sensorium

Data Sensorium [13] is a Full-scaled and omnidirectional screened technology designed by Iwata, H. of Tsukuba University in 2020 which can project 3D images on the wall and floor using a total of 12 projectors. The proposed system also uses a VR locomotive device called a Torus Treadmill [14] to let the visitors actually walk around the virtual museum with the user's own body. By using these systems, projecting the museum space, and allowing users to walk around using these technologies, it will be possible to view artworks in their actual size surrounding the users and provide the dynamical virtual art experience.

3.2. Artizon Cloud

For the database, we use an art multidatabase system called Artizon cloud as target art data. The system combines multiple databases and provides information about an art museum and artworks which is collected from various archives of artworks and past exhibitions. Currently, the Artizon cloud only handles data of Artizon Museum [15]. By using this multidatabase system, it will be able to display heterogeneous content at the Virtual Art Exhibition system.

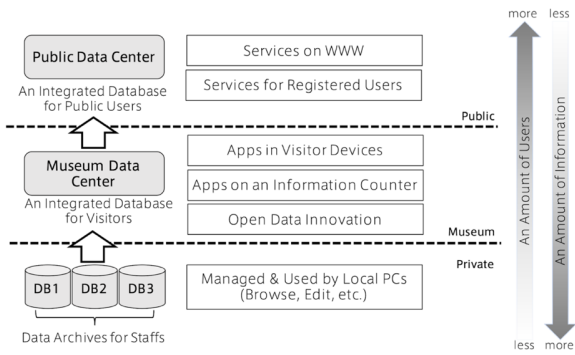


Figure 3. An implementation of Artizon cloud

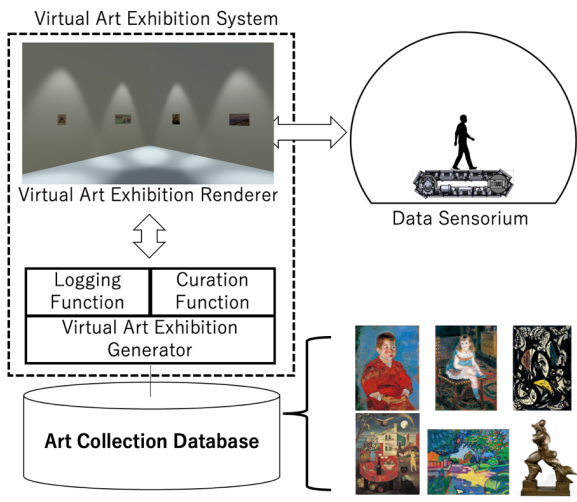


Figure 4. System Structure of the Virtual Exhibition System

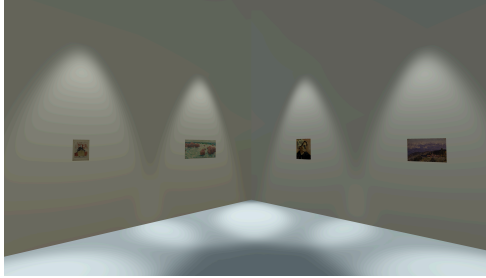


Figure 5. A Screenshot of an exhibition in Virtual Art Exhibition Renderer

4. System structure & Implementation Method

4.1. System Structure

Virtual Art Exhibition System extracts art data from the Art Collection Database, accepts user interaction data obtained from the Data Sensorium, and sends graphics to Data Sensorium (Fig.4). To achieve this, the system consists of the 4 following elements.

4.2. Implementation Method

a) Virtual Art Exhibition Renderer

The first step to set up a virtual museum is to create a room in virtual space (Figure 5). After creating the room, two pictures are placed on each side, in a total of eight artworks in the room (Figure 7). Outside the room (Figure 6), there are two bars which the user can go through. The right one will be re-searching the related artwork based on the most viewed artwork by the user, so if the user enters the right bar, the user will be shown a new set of artworks related to the user's intention. The left bar will reset the user's viewed data so the user will be shown random exhibits again as the first time. The exhibiting artwork's size will be based on the real size of each artwork when loaded. When the user starts the program, each user is assigned an ID. Based on the ID, the program will calculate and display which picture the user most liked (which most stayed longer). Figure.8 shows a sphere embedded underneath each artwork as a component to record the user's viewing time, and the sphere is set to $2m$ radius and invisible by default so that it will not disturb the exhibition. If the user gets close enough to the artwork, the sphere will count as "IN", and when the user gets away, it will count as "OUT". Timestamps of IN/OUT as well as an artwork identifier are sent to the logging function. The virtual art exhibition renderer is implemented by using a cross-platform game engine, unity [16]. There are many possible approaches to extract users' intention such as monitoring gaze, EEG detection and so on, however we decided to apply the simple metric using sphere to study feasibility of the Virtual Art Exhibition system. More intelligent metrics should be discussed in the future.

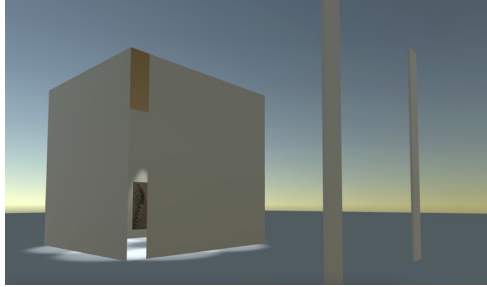


Figure.6 Outside Appearance of Virtual Exhibition Hall

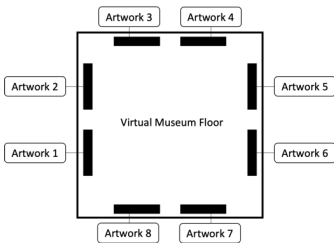


Figure 7. The implementation of *personalized exhibition (1)*

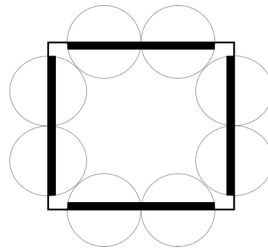


Figure 8. The implementation of *personalized exhibition (2)*

b) Virtual Art Exhibition Generator

Virtual Art Exhibition Generator receives data of user behavior with the Logging Function and generates a set of artworks according to users' interest by the Curation Function. The collection data of the Artizon Museum are used as the target data. Since the museum collection is managed by using the Artizon Cloud, a proprietary multi-database system, this system uses the Artizon Cloud API to use the collection data.

c) Logging Function

Logging Function receives IN/OUT timestamps as well as the artwork identifiers and registers this data in the database in the Virtual Art Exhibition Generator.

d) Curation Function

The method to calculate the total viewing time per each artwork will be calculated the time the user entered the sphere (OUT) -(minus) the time the user left the sphere (IN). The result time will be the user's staying time in front of the artwork, which means the user has the most "intention" towards. After getting the staying time result, the system will list it in order of the most-stayed and most-less-stayed. After the most-stayed artwork gets extracted, the system will search the next set of related artworks and send the set to the Virtual Art Exhibition Renderer. Related artworks are defined as: artwork that is from the same period, created by the same author and region to the chosen artwork.

5. Feasibility Study

As a feasible study, details how the changes of the exhibits in the exhibition room experienced by a user using the actual system are presented. Table 1 shows an initial set of artworks that is randomly extracted. In this example, the user stayed in front of Paul Klee's "garden in POT" for the longest time among others. After the user finishes viewing and goes out of the room and re-search the related art works, the next set of artworks is extracted (Table 2). In this case, it shows that the set of related artworks had been extracted by the same period and same author. For the second exhibition, the user viewed the artwork named "Sunrise" as the longest. Based on this result, the system exhibited the third set of artworks related to this author and also the place.

Overall, through this experiment, it was proven that the Virtual Art Exhibition System had worked successfully and could automatically generate exhibits based on the user's interests and intentions.

Table 1. The searched result of database (1)

Marino MARINI	Rider on an Ochre Ground	1957	Pistoia	00:00:04.054004
Marino MARINI	Waiting	1965	Pistoia	00:00:03.500778
KAWABATA Minoru	Untitled	1993	Tokyo	00:00:08.23219
MASANOBU Masatoshi	Work	1967	Susaki, Kochi	00:00:03.451733
FUKUSHIMA Hideko TAKIGUCHI Shuzo	Displacement Diagram	1974	Tokyo Toyama	00:00:04.386278
Henri MATISSE	Woman with Checked Collar	1937	Le Cateau-Cambresis {now Le Cateau}	00:00:07.014538
Paul KLEE	Garden in POT	1926	Munchenbuchsee, nr Berne	00:00:13.242213
Lee KRASNER	Moon tide	1961	New York	00:00:02.550423

Table 2. The searched result of database (2)

Henri MATISSE	Odalisque	1926	Le Cateau-Cambresis {now Le Cateau}	00:00:04.319401
KOIDE Narashige	Nude	1926	Osaka	00:00:02.767603
Georges ROUAULT	VIII. Satin III (from Flowers of Evil)	1926	Paris	00:00:02.566769
Georges ROUAULT	XIII. "Debauchery and death..." (from Flowers of Evil)	1926	Paris	00:00:02.552296
YOSHIDA Hiroshi	Sunrise (from Views of Mt. Fuji)	1926	Kurume, Fukuoka	00:00:19.112251
Paul KLEE	House in the Water	1930	Munchenbuchsee, nr Berne	00:00:03.921128
Paul KLEE	Garden of the Level-Crossing Attendant	1934	Munchenbuchsee, nr Berne	00:00:03.653234
Paul KLEE	Jointed Doll Walking	1937	Munchenbuchsee, nr Berne	00:00:06.153174

Table 3. The searched result of database (3)

AOKI Shigeru	Bathers	1904	Kurume, Fukuoka	00:00:03.785742
AOKI Shigeru	Landscape	1910	Kurume, Fukuoka	00:00:02.802216
TAKATA Rikizo	Fountain at the Villa Medici	1972	Kurume, Fukuoka	00:00:15.76204
KOGA Harue	Copy from Hans Prinzhorn's Artistry of the Mentally Ill	c. 1930	Kurume, Fukuoka	00:00:03.76265
TAKATA Rikizo	Erechtheum in Athens	1938	Kurume, Fukuoka	00:00:01.786504
YOSHIDA Hiroshi	Matterhorn, Evening	1925	Kurume, Fukuoka	00:00:02.053703
SAKAMOTO Hanjirō	Enokidera Shrine (from Five Views of Tsukushi)	1918	Kurume, Fukuoka	00:00:04.18662
SAKAMOTO Hanjirō	Hatsuse Namiko playing Akiyama Sizuko (from Sketch of Players on Stage)	1971	Kurume, Fukuoka	00:00:09.803794

6. Conclusion

The virtualization of museums has a lot of advantages. This benefit is not just for the virtual museum, but also for physical museums as well, which means physical and virtual museums can ultimately reinforce each other. In addition, digitization of artwork has the advantage that artworks can be permanently preserved and passed on to the next generation. In this paper, a virtual art museum system is proposed. As mentioned in the beginning, The goal of the system is to create a realistic, full-scaled virtual museum. Therefore, the proposed virtual museum used the multidatabase system called art collection database (Artizon Cloud) [1] and a walking device Torus Treadmill and Data Sensorium. In this case, we succeeded in generating a museum based on the user's interests and intentions. Through the feasibility study, based on the key word of "Emotional Excitements", the virtual art museum system provided users an art experience that can only be achieved through virtual technology such as personalized exhibitions. As for the future works, more intelligent and dynamic sensing metrics to extract precise user's intention, semantic computation functions for the dynamic curation, and storing and sharing functions of user experiences for art communication.

Acknowledgement

This research is strongly supported by Asia AI Institute of Musashino University, especially Prof. Hiroo Iwata for introducing Data Sensorium and Prof. Yasushi Kiyoki for coordinating the Art Sensorium Project. The art data are provided by Artizon Museum and Ishibashi Foundation, and a collaborative research relationship with the museum have strengthened this research. We would like to show gratitude to everyone in these organizations.

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An Exploratory Survey of Recreational Activities Using Twitter Data with Logic-Based Location Categorization

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Abstract. Social media analysis has become a major instrument for data-driven tourism. It allows surveying visitor behavior on multiple scales. Considering the geographical characteristics of users' posts from social media platforms, we were able to address more specific questions related to the place type selection patterns of the visitors. In this paper, we present OPENLOSTCAT, our first-order-logic-based location categorizer applicable for modeling location types depending on OpenStreetMap data. We report our findings revealed by this tool on more than one year's collection of global-scale Twitter data, focused on potential trail-related hiking and trekking activities. We categorized visited locations in our experiments based on place accessibility – transport and trail infrastructure –, and analyzed these categories according to the travel distance taken by visitors in general to reach these areas. Our comparisons reveal seasonal characteristics, continental differences (between Europe and North America), as well as specifics related to selected recreational areas. Besides these preliminary findings available for further verification, we show both the perspectives and limitations of our approach for future improvements and experiments.

Keywords. outdoor recreation, visitor monitoring, social media, volunteer-based mapping, location types, logic-based modeling

1. Introduction and Related Work

1.1. Outdoor Recreation, Trails and Visitor Management

Outdoor tourism and recreation, especially visiting natural sites and protected areas while exercising physical activities such as walking or biking, has been getting increased popularity in recent years. While it is desirable for a number of reasons, including mental and physical health, as well as education and experience about our environment, the impact of human presence, especially in fragile habitats, may cause deterioration if not managed well. The advantage of visitor monitoring and management is manifested not only in mitigating such impacts but in general, gaining better knowledge about visitation patterns related to outdoor activities ensures improved decision-making about potential infrastructural developments, policymaking, maintenance efforts, or business and marketing analyses and endeavors in local or regional settings, or even on a global scale.

A crucial infrastructure of such outdoor activities is the network of marked or designated touristic and recreational *trails*, whose visitation patterns are mostly studied on a local or regional level, such as specific parks and sites for specific management and marketing purposes. Studying trail-related activities and visitation patterns on a global scale with the most probable geographical accuracy seems to be an interesting and not yet well-studied topic. Such an approach would not only provide common references for regional or park-based surveys but would also extend the scope of such studies into areas not directly or differently managed, or fall outside of the usual scopes of research and monitoring projects for any reason. For example, hiking and pilgrimage trail routes, especially in Europe, form an interconnected and broad network across all different countries, types of landscape or terrain, administrative and land management units with a wide variety of stakeholders.

Traditionally, on-site surveys are primarily utilized for visitor monitoring (such as in e.g. [25], [8]), in order to gain knowledge about the actual number, behavior, preferences and satisfaction of visitors in an area or at specific sites. With the development of technology, this has been extended with different methods such as trail counters and secondary data sources [23]. More large-scale aspects are revealed by secondary surveys and studies like [9]. A relatively early work on social media and tourism in general is [19], which is more into business and marketing aspects. Tracking movement trajectories of users by mobile devices has emerged as a possible approach, but it needs appropriate tools, willingness and explicit consent by the visitors.

1.2. Social Media Analysis in Visitor Monitoring

In recent years, social media analysis has become a hot topic even for visitor management and monitoring. A recent paper [28] shows that the majority of related research is focused on the area of the USA. It mentions some studies on Twitter, and reveals that geolocation-based analysis is dominant over terms and tags looked for in textual contents, but very few consider associating volunteer-generated public map data (such as OpenStreetMap). The study identifies the following types of analyses: spatial analysis, temporal, cultural ecosystem services, economic values and sentiment analysis. Amongst the studied platforms, Flickr, Panoramio, Instagram, OpenStreetMap and Twitter are shown to have been the most popular. None of the mentioned works consider combining micro-level location characterization based on OpenStreetMap data with geotagged social media posts.

Another remarkable work is [32], a systematic review on social media and visitor use management in parks and protected areas, which also discusses limitations. In their study, Twitter follows directly after Facebook as the second most widely used platform, and Asia is coming right after Europe and North America in continental comparison. The popularity of different social media platforms has been changing over the years, and in many cases, and in many cases, data needs manual processing so that proper automated tools and methods provide high value. They also report that only a few studies have utilized fine-grained social media resolution in space and time, and it should be investigated more on how spatial and temporal visitation patterns can be estimated based on geolocated user posts. At the same time, they give warnings about limitations, inaccuracies and biases of such approaches, mainly regarding social media posts not being representative for the population of all the visitors or the visited sites. They give best practices, some of which can be utilized to verify or improve our study results in the future as well.

Multi-source analyses and correlation studies with other data sources include [29], comparing different social media platforms and official statistics in South Africa and Finland and identifying potential sources of mismatch such as geography (cell signal coverage), sudden events, park profiles, visitor profiles. [22] works with thematically categorized photos and compares them with user profiles revealed in online surveys, without fine-tuned location categorization or geotags, but based solely on photo content. An Instagram-based study with photo classification for user interests and activities, as well as home location detection and temporal patterns is [16], comparing social media findings with visitor survey. A fine-tuned but somewhat similar research approach is followed by [11] using geotagged photos along particular trails, comparing the results with official forest service surveys for validation and generalizability. The latter uses Flickr images, trip reports and on-site monitoring tools, and suggests social media analysis as a complementary, 'gap-filling' means in addition to regular on-site surveys and monitoring actions. Flickr is also used for quantifying nature-based tourism and recreation (visitation rates, origins, changes over time) by [33], concluding that Europe and the USA are the most popular areas, followed by Japan and New Zealand, almost a decade ago. Geotagged photos are used by [13] to identify hotspots in a smaller area using statistical methods and an overlay of particular on-site facilities.

Further works include [27] about national parks in Germany (using Flickr and a grid-based geographical splitting method and residence resolution of users), [12] about the Jeju Island in Korea analysed using Twitter data overlaid with other data sources such as land cover and OpenStreetMap, but also used grid cells for dealing with locations, and [14] using photo data with fine-grained land-cover to tackle hotspots for cultural and heritage tourism in a coastal region of Mexico.

Amongst other approaches, it is worth mentioning that [30] uses Foursquare venue check-ins by twitter collection related to travel diaries and activity preferences, [15] applies machine learning and natural language processing for classifying users and visitation areas based also on photos, [26] uses Twitter for studying seasonality of activities in urban parks, and [24] applies sentiment analysis for georeferenced visitor posts created in a single theme park.

1.3. Location Modeling using Volunteer-Generated Geographical Data

One of the main questions related to analyzing social media or other user-generated data is to determine and categorize the actual location of the posting user. As we saw above, some studies analyze photos taken by visitors, and the type of location may be determined based on image content analysis and classification without even knowing the exact photo location in terms of geographic coordinates. Other approaches use explicit place type information, such as Foursquare check-ins. In our paper, we explore a different approach: considering only geotagged content with (supposedly) exact locations, determine the type of place based on the geographical features found at the location.

Our approach is similar to the *Recreational Opportunity Spectrum (ROS)* [10], which categorizes locations based on the environment and the proximity of specific types of assets and facilities. ROS has a normative status in the USA and has been adapted in slightly different variations to some other areas as well. Its rule-based nature makes it straightforward to apply to different areas if the appropriate data is available. For instance, [18] applies a rule-based approach for defining ROS categories in New Zealand,

applies a rule-based approach for defining ROS categories in New Zealand, but their classification is more complex than ours. Instead, we aim for a simple and possibly uniform definition of global-scale location categories to explore rough visitation patterns. Another, more recent publication [21] uses a complex approach based on ecosystem services and ROS, including accessibility categorization, and among other data sources, uses the volunteer-generated public mapping database OpenStreetMap.

OpenStreetMap [3] has become a widely used data source and platform for a multitude of purposes, including tourism and humanitarian applications. It is free to use and based on volunteer contributions. Its power not only lies in its flexibility and the many tools and applications already built atop, but also in the way it organizes geographical data and enforces contributors to organically extend the existing content with their additions and modifications instead of uploading independent content in parallel about the same area or place. This way, a single global unified mapping database is being built and improved step-by-step, although there can be slight differences in the exact way of representing similar items across regions or countries.

Details on the data model of OpenStreetMap can be found in its community-based documentation [4], which contains a specific part for representing walking- and hiking-related facilities [5]. OpenStreetMap uses a free-form *tagging* approach instead of predefined table schemata for storing data assigned to geometric shapes: a geographic element (node or way) may have an arbitrary number of *tags* associated with it, with arbitrary names and values, and the rules are defined as community conventions [4]. Tags describe the type as well as any properties or measures of the geographic object. An additional data element type is the *relation*, which acts as a container for nodes and ways. A relation can hold its own tags and defines a higher-level object composed of its parts, such as a (usually longer) route, containing its parts and pieces as ways already existing in the database as street segments. OpenStreetMap uses the relation approach to represent marked and designated trail routes for hiking, biking, and other activities. As the database contains semantic and not presentation information such as styling, it has a multitude of map visualizations, and potentially any rule-based map symbology can be defined, depending on the purpose. As an example, a relevant interface for our topic is the WaymarkedTrails website, having customized maps of different types of routes [17]. Figures 1 & 2 show the national and international trails as an example, mapped on OpenStreetMap and presented by WaymarkedTrails.

In our exploratory study of this paper, we will define a simple yet flexible and powerful way of location type modeling by filter-based categorization, formulated as a subset of first-order logic. Since we do not need joins or complex, correlated subqueries for location type definitions, but only to determine the existence or nonexistence of geographic objects with specific tag values or value combinations in the proximity of each queried location, we do not need the full expressive power of relational calculi. A similar approach based on filtering and key-value equality testing is common practice in map visualization as well, to determine which geographical objects should be displayed on a particular map visualization and how (styling). We consider sets of all geographic objects in proximity of a point instead of single features. It is similar to the ROS approach but simpler and more universal.

Our rule language for location categorization will be a subset of JSON [1], i.e. all well-formed formulae in our language will also be a well-formed JSON expression. The main advantage of JSON is the direct human readability while at the same time it is ma-



Figure 1. Marked national and international hiking trails in North America mapped on OpenStreetMap [17]. Regional and local trails are not included here.

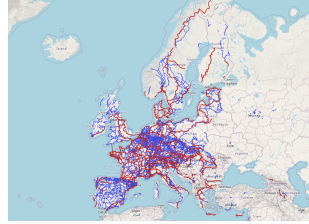


Figure 2. Marked national and international hiking trails in Europe mapped on OpenStreetMap [17]. Regional and local trails are not included here.

chine processible. A similar language has been developed as JsonLogic [31], but we do not need that complexity. One of the keys to keeping our expressions simple and intuitive is the natural correspondence between JSON constructs and logical operations, as we will see later in the paper. Another key is the implicit quantification we utilize through wrapping subformulae with default logical quantifiers based on their operands and context, similarly to how it was proposed in the system by [34], but with an opportunity for explicit variable quantification wherever convenient. Implicit quantification is a common practice in more complex languages and settings as well, such as, for example, in [7].

1.4. Goal and Outline of this Paper

Our current study aims to explore whether any relevant potential visitation patterns can be discovered for outdoor recreation activities (especially for hiking, trekking, or other means related to trails) using geotagged Twitter data combined with OpenStreetMap location data on a global scale. For that purpose, we had selected a set of keywords characteristic to such activities and locations and collected matching Twitter data for more than a year. We applied our simple logic-based location categorization method on nearby geographic objects to infer the type of each geotagged location, mainly according to its accessibility by transportation and/or by marked trails. If they seem to be relevant, any preliminary findings should be verified and investigated in more detail in future studies, as we assume the data cannot be representative but can give hints for patterns and phenomena to look for more specifically. Our exploratory study aims to show the advantages, perspectives, and limitations of our approach and discuss possible future improvements, experiments, and applications.

The outline of the rest of our paper is as follows: Section 2 presents our tool used for location categorization with characteristics and examples of its rule language. Section 3 describes our Twitter data collection and the related data preprocessing steps, including user residence assignment. Here we also present geographical aspects of the specific locations in the highlight of our analysis (Section 3.3). Our results are exhibited and discussed in Section 4 in detail, while Section 5 concludes with some general remarks on the advantages and limitations of our approach, as well as possible future directions and applications.

2. Location Categorization with OPENLOSTCAT

2.1. Introducing OPENLOSTCAT, the Logic-Based Location Categorizer

OPENLOSTCAT (*Open Logic-based Simple Tag-bundle Categorizer*) is a free open-source utility designed and implemented by the authors in Python for data analysts, engineers and scientists who want to determine the characteristics of geolocated points in their datasets [20]. OPENLOSTCAT does the job by assigning category labels to each point based on logical rules defined in JSON for tags of nearby OpenStreetMap objects.

The tool can query OpenStreetMap objects at exact locations given by WGS 84 coordinates via the Overpass API (with a customizable proximity distance) [6]. User-defined location category labels are then generated for the given locations, based on logical formulae defined for available categories and evaluated for the set of queried OpenStreetMap objects in the proximity of each location. The set of database tags of each OpenStreetMap object (attribute instances, i.e. the actual data associated with the object is similar to a data tuple with no fixed schema) is called a *tag bundle*. Therefore, a logical rule is evaluated over a *tag bundle set*, giving a true or a false result for each defined location category.

A simple and comprehensive JSON format is used to describe a category rule collection, called a *category catalog*. Each category is defined by a rule expression, in which references to other, previously defined (sub)expressions can be reused. Reusable subexpressions are called *references* inside a location category catalog. For the assignment of location categories, the category catalog may prescribe its evaluation strategy as *single-category* (applying the first matching rule) or *multi-category* (applying all matching rules).

2.2. Location Category Definition Language Characteristics and Examples

The formal language of *OpenLostCat* consists of location category definition rules is a univariate first-order logic. Allowing only a single, implicit variable in predicates keeps the language and its evaluation overly simple. It can also be viewed as a simplified tuple calculus (without cross-product or join operations) for tuples without a fixed schema because OpenStreetMap allows arbitrary (finite number of) data tags assigned to a geographic object in its tag bundle. The order of tags is irrelevant as they are identified by their names. The language is implemented in JSON format, which allows utilizing a natural correspondence between arrays and disjunction, as well as object (record) notation and conjunction. For some cases, special keywords in the form of JSON field name prefixes are introduced, as it will be shown in the example formulae.

During the evaluation process, a condition formulated as a predicate formula is evaluated for each queried geographical object (actually represented as a tag bundle) in the proximity of a specific location being categorized, thus producing a true/false value for every single geographical object. Eventually, these values are aggregated into a single true/false value for a given location to be decided whether the location belongs to a particular category. Therefore, each rule defining a category must be quantified, either explicitly or implicitly. Variable quantification is added implicitly according to the ac-

tual operations of the formula, when not specified explicitly. The language can easily be extended in the future with more complex operations as needed.¹

Because only a single variable is used in each (sub)formula, but already quantified (sub)formulas can also be connected via logical operators, this results in our language having two explicit levels of (sub)expressions:

- *Item-level (a.k.a. geographic-object-level or filter-level)* subexpressions are non-quantified expressions composed of atomic formulae and logical connectives actually correspond to set operators as being evaluated one-by-one on elements of the input set of queried map objects in the proximity of a given location, thus resulting in a subset of their input set containing the matching geographical objects (actually, the tag bundles of them) for further processing.
- *Category-level (a.k.a. bool-level)* (sub)expressions are (explicitly or implicitly) quantified expressions, resulting in a single boolean value. Such an expression can be a directly quantified item-level subexpression with its result set aggregated into a single aggregated boolean value, or composed of such formulae using logical connectives whose operators work on the category level with boolean inputs and produce boolean results.

References as named subexpressions can also be defined and can be used and referenced from multiple category definitions, like building blocks, referring to distinct (sub)concepts. This way, repeated parts of rules do not have to be explicitly duplicated, and whenever a change is necessary, it can be done in one place. The language distinguishes item-level and category-level references, prefixed with a single and a double hashmark, respectively. A single-hashmark reference refers to a concept defined over a single geographic object under evaluation for filtering, while a double-hashmark reference refers to a location under question having already a set of geographic objects being evaluated in its proximity.

Some representative examples are shown in Table 1 with their JSON syntax and corresponding first-order formulae.

The smallest building block of this language – besides the boolean constants *true* and *false* – is the *atomic filter*, which checks whether a key is present in a tag bundle and the value of the tag equals the desired value, or values listed in an array (actually a compact disjunction). A *NULL* value is used to indicate non-existence of the named tag in the tag bundle. Atomic filters can be combined into a *conjunctive* formula by adding more than one tag filter to a single *JSON object* in curly brackets – or using the special name prefix *_AND_* as needed. Alternatively, a *disjunctive* formula can be created by the *JSON array* notation (values or objects listed in square brackets) – or by the prefix *_OR_*, whichever is appropriate. The rest of first-order operations are expressed by the prefixes *_NOT_* (negation), *_IMPL_* (for implication), *_ANY_* (existential quantifier) and *_ALL_* (universal quantifier), and the prefix *_REF_* is used to indicate a reference wherever needed, but the hashmark notation already identifies references where no additional JSON attribute name is necessary as in a key-value notation setting. The reason for using prefixes is that each attribute name must be unique in a JSON object and adding an

¹Implicit quantification is achieved by default quantifier wrapping: if a (sub)formula occurs in a context where no free variable should be present anymore, the system 'wraps around' the subformula with a \exists or \forall quantifier, depending on the actual content of the (sub)formula. For simple cases, a positive statement gets a \exists while a negative (negated) statement becomes quantified with \forall . More details follow.

Reference Name	OPENLOSTCAT JSON Rule	First-Order Logical Formula
a) Defining geographic item-level location concepts as references in form of predicate formulae with a free variable:		
#residential_area	{ "landuse": "residential" }	$x[\text{landuse}] = \text{"residential"}$
#marked_trail	{ "route": ["bicycle", "canoe", "foot", "hiking", "horse", "inline_skates", "mtb", "piste", "running", "ski"] }	$x[\text{route}] \in \{ \text{"bicycle"}, \text{"canoe"}, \text{"foot"}, \text{"hiking"}, \text{"horse"}, \text{"inline_skates"}, \text{"mtb"}, \text{"piste"}, \text{"running"}, \text{"ski"} \}$
#public_motor_accessible	{ "...NOT.1": [{ "access": [false, "private"] }, { "motor_vehicle": false }] }	$\neg \vee \begin{cases} x[\text{access}] \in \{ \text{"no"}, \text{"private"} \} \\ x[\text{motor_vehicle}] = \text{"no"} \end{cases}$
#common_public_road	{ "highway": ["motorway", "trunk", "primary", "secondary", "tertiary", "unclassified", "residential", "motorway_link", "trunk_link", "primary_link", "secondary_link", "tertiary_link", "living_street", "service", "pedestrian", "bus_guideway", "escape", "raceway", "surface": [null, "paved", "asphalt", "concrete", "concrete:lanes", "concrete:plates", "paving_stones", "sett", "unhewn_cobblestone", "cobblestone", "metal", "wood"], "...REF.not": "#public_motor_access" }	$\wedge \begin{cases} x[\text{highway}] \in \{ \text{"motorway"}, \text{"trunk"}, \text{"primary"}, \text{"secondary"}, \text{"tertiary"}, \text{"unclassified"}, \text{"residential"}, \text{"motorway_link"}, \text{"trunk_link"}, \text{"primary_link"}, \text{"secondary_link"}, \text{"tertiary_link"}, \text{"living_street"}, \text{"service"}, \text{"pedestrian"}, \text{"bus_guideway"}, \text{"escape"}, \text{"raceway"} \} \\ x[\text{surface}] \in \{ \text{NULL}, \text{"paved"}, \text{"asphalt"}, \text{"concrete"}, \text{"concrete : lanes"}, \text{"concrete : plates"}, \text{"paving_stones"}, \text{"sett"}, \text{"unhewn_cobblestone"}, \text{"cobblestone"}, \text{"metal"}, \text{"wood"} \} \end{cases}$ #public_motor_accessible
#transport_accessibility	{ "amenity": ["ferry_terminal", "parking"], { "public_transport": "platform" }, { "aerialway": "station" }, { "railway": "station" }, { "highway": ["services", "trailhead", "rest_area", "emergency_bay", "elevator", "bus_stop", "...REF.1": "#public_motor_accessible"], }, { "...REF.2": "#common_public_road" } }	$\vee \begin{cases} x[\text{amenity}] \in \{ \text{"ferry_terminal"}, \text{"parking"} \} \\ x[\text{public_transport}] = \text{"platform"} \\ x[\text{aerialway}] \in \{ \text{"station"} \} \\ x[\text{railway}] \in \{ \text{"station"} \} \end{cases}$ $\wedge \begin{cases} x[\text{highway}] \in \{ \text{"services"}, \text{"trailhead"}, \text{"rest_area"}, \text{"emergency_bay"}, \text{"elevator"}, \text{"bus_stop"} \} \\ \text{#public_motor_accessible} \end{cases}$ #common_public_road
b) Defining category-level location concepts as references in form of quantified (closed) logical formulae:		
##Easy_access	["#residential_area", "#transport_accessibility"]	$\exists x \vee \begin{cases} \text{#residential_area} \\ \text{#transport_accessibility} \end{cases}$
##Trail_close	["#marked_trail"]	$\exists x \text{#marked_trail}$
##Trail_close_2	{ "...ANY.1": "#marked_trail" }	$\exists x \text{#marked_trail}$
##Calm_streets_only	{ "...NOT.1": { "...ANY.1": { "highway": ["primary", "secondary"] } } }	$\neg \exists x \begin{cases} x[\text{highway}] \in \\ \{ \text{"primary"}, \text{"secondary"} \} \end{cases}$
##No_public_transport_access	{ "...ALL.1": { "...NOT.1.1": { "public_transport": ["stop_position", "platform"] }, "...NOT.2": { "amenity": "ferry_terminal" }, "...NOT.3": { "aerialway": "station" }, "...NOT.4": { "railway": "station" }, "...NOT.5": { "highway": "bus_stop" } } }	$\forall x \begin{cases} \neg x[\text{public_transport}] \in \{ \text{"stop_position"}, \text{"platform"} \} \\ \neg x[\text{amenity}] = \text{"ferry_terminal"} \\ \neg x[\text{aerialway}] = \text{"station"} \\ \neg x[\text{railway}] = \text{"station"} \\ \neg x[\text{highway}] = \text{"bus_stop"} \end{cases}$
##Fully_wheelchair_accessible_station	{ "...IMPL.1": [{ "public_transport": ["stop_position", "platform"] }, { "wheelchair": [true, "designated"] }], "...ANY.1": { "public_transport": ["stop_position", "platform"] } }	$\wedge \begin{cases} \forall x \begin{cases} x[\text{public_transport}] \in \{ \text{"stop_position"}, \text{"platform"} \} \rightarrow x[\text{wheelchair}] \in \{ \text{"yes"}, \text{"designated"} \} \end{cases} \\ \exists x \begin{cases} x[\text{public_transport}] \in \{ \text{"stop_position"}, \text{"platform"} \} \end{cases} \end{cases}$

Table 1. Example logical rules defined as (sub)expression references used by OPENLOSTCAT for location categorization. The JSON syntax is explained by corresponding first-order logic formulae. Note the implicit logical variable x , the connectives generated from arrays and objects, and cases of implicit quantification.

arbitrary suffix to any of the operator prefixes allow adding further subexpressions with the same operator on the same level into a conjunctive formula expressed by a JSON object.

Implicit quantification for a formula is defined generally as *existential*, except when *each* of the disjunctive subformulas in its *conjunctive normal form* has *at least one negated* atomic operand (or an operand being the *false* boolean constant). In that case, the implicit quantifier applied will be *universal*. This principle is exactly that of [34] and has the advantage of the assigned implicit quantifiers being invariant of the actual way of expressing equivalent logical (sub)formulae. It naturally corresponds to the common-sense interpretation of a negation of a single atomic filter (or their conjunction) as being universal, and for the implication, which is implicitly wrapped into a universal quantifier, reflects the assumed intention by the implication being declared as a universal rule. Logical connectives inherit the default quantifier type from their subexpression(s) and resolve them according to the rule of each connective.² If a quantified subformula is directly connected to a free-variable subformula via a logical connective, then implicit quantification will be enforced on the latter, or for the whole formula if a free-variable formula is used for defining a category or a category-level reference.

A detailed description of language rules and definitions for all the syntax and semantics are given in the documentation files of [20].

2.3. Location Categorization for Our Study

Location categories used for the exploratory analysis of this paper reflect the assumed accessibility for each location. Places located in residential areas, or in the proximity of conventional roads, public or motorized transport services are defined as *frontcountry* locations. Generally, visitors do not need much hiking or other physical activity to reach these areas. On the contrary, backcountry points are further away from such infrastructure in our terms and generally assumed to be reached by active physical movement only, at least based on the locally found OpenStreetMap objects (items) around them. Note that these concepts are used here somewhat differently from the standard ROS categories or their usual interpretation in recreation geography or ecology, but these terms are appropriate for our current purpose. Furthermore, each location may or may not have marked or designated *trails* in their proximity, thus forming four different categories together with the two above.

More precisely, the four location categories are based on some of the concepts defined as subexpressions in Table 1. We set the OpenStreetMap query radius as 100m, so the location of each geotagged tweet is categorized by evaluating its logical formula on the geographical objects found in its proximity of 100 meters. The definitions are given below as a *category catalog*, with the logical subformula references defined in Table 1. Its evaluation strategy assigns the first matching category to each location being categorized:

²Negation switches the default quantifier type of its operand between \exists and \forall , conjunction defaults to existential \exists if any of its operands default to \exists (otherwise \forall), and disjunction inherits the universal default quantifier \forall if any of its operands have it as default (otherwise defaults to \exists). Therefore, note that e.g. in Table 1 at `##No_public_transport_access` the quantifier `_ALL_` could have been omitted as it would produce the same, universally quantified formula due to being a conjunction composed only of negated atomic filters.

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Frontcountry_with_trail: `##Easy_access ^ ##Trail_close` (being at most 100m distant from a marked trail and a residential area or a place accessible by conventional motorized or public transportation), or else:

Frontcountry: `##Easy_access` (being at most 100m distant from a residential area or a place accessible by conventional motorized or public transportation), or else:

Backcountry_with_trail: `##Trail_close` (being at most 100m distant from a marked trail but further away from any residential area or transportation access point), or else:

Backcountry: `⊔` (everything else: being more than 100m distant from a marked trail and from any residential area or transportation access point).

Note that we do not utilize the full power of OPENLOSTCAT’s logical language for our current location categorization setting.

3. Recreational Data Collection from Twitter

3.1. Twitter Data Collection

In this work, we collected geotagged tweets from August 2020 to November 2021 to uncover recreational user activity patterns for different countries and geographic locations. Table 2 presents the rich keyword set that we specified for the public Twitter search API during the data collection. It contains general phrases related to nature, wilderness parks, and various recreational activities (mainly hiking, trekking or pilgrimage), but popular keywords and hashtags referring to distinct relevant and popular geographic locations and landmarks are also included.

Initially, we were also experimenting with the geolocation-based Twitter search API, which returns tweets within a pre-defined radius of a given reference point. Unfortunately, the volume of trekking-related data in this setup was susceptible to the choice of the radius parameter. For example, close to populated areas, most of the tweets returned by geolocation search was not related to recreational activities. Due to this behavior, we decided to use the keyword-based search approach without any *a priori* geolocation restrictions.

During data collection, we found that Twitter users have a very low tendency to geotag their tweets. Thus, we excluded the majority of collected tweets from our experiments, as we consider geotagged tweets only. Next, we excluded spam Twitter accounts related to bots, weather, earthquake, fire, and traffic reports based on their activity patterns in the collected data. In total, we managed to collect 437098 geotagged tweets from 116916 different users.

3.2. User Residence Locations

In this work, we rigorously assess the travel distance Twitter users are willing to take to reach their desired recreational areas (e.g., marked trail, wilderness park, nearby lake, or park). For this reason, we needed to assign a residence location to users in our data set. Twitter users may opt to publish their residence (home location) on their profile in the form of textual information. We first extracted the underlying city or district names from these text snippets along with the corresponding latitude and longitude coordinates

Group	English	Keywords
General	Yes	nature, walking, lake, view, views, landscape, trail, hike, hiking, trekking, climbing, mountains, mountain, mount, mountainlife, mountainlovers, rockclimbing, trailrunning, backpacking, naturebeauty, naturelovers, naturephotography, hikingadventures
	No	wandern, randonnee, randonnées, excursionismo, escursione, escursioni, montaña, montagna, montagne, senderismo, naturaleza, peja
Natural parks	Yes	stateparks, nationalpark, national/state/regional + park/forest/grassland/seashore/reserve, protection/wilderness/recreation/conservation area, mountain park
	No	parque/parco/parc/réserve + national/nacional/natural/regional/régional/faunique, parco nazionale, reserva da biosfera, naturpark, naturschutzgebiet
Pilgrimage	Mixed	pilgrimage, peregrinacion, peregrino, pilgrim, pelerin, camino, caminho, caminopeople, elcaminopeople, caminodesantiago, caminofrances, buencamino
Location hashtags	Mixed	prisojnik, julijскеalpe, adirondacks, dolomiti, dolomites, austrianalps, pyrenees, zermatt, matterhorn, montblanc, snowdonia, mountmonadnock, mountwhitney, whitemountains, runyoncanyon, lagodicarezza, valldenuria, valdifassa, valledaosta, valfiorentina, altoadige, hautesavoie, peakdistrict, lakedistrict, vignemale, laketahoe, tahoe, bardonecchia, appalachia, trentino, südtirol, southtyrol, yosemite, mittamalpais, appalachiantrail, glaciernationalpark, valdisole, karersee, banffnationalpark, himalayay, everest, cantwellcliffs, chiefloganstatepark, hudsonvalley, hockinghillstatepark

Table 2. Set of key phrases used during the Twitter data collection.

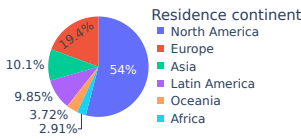


Figure 3. Distribution of user residence by continents.

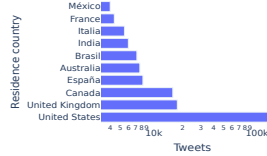


Figure 4. Number of tweets posted by users who live in the top 10 most popular countries by user residence.

using the *wikipedia* Python package. Then, by querying the *Nominatim* geocoding API [2], each user was additionally assigned a country based on its approximate residence coordinates. This way, we assigned a valid residence location to 83779 users. In Figure 3, we show their distribution by continents, while Figure 4 presents the tweet volume posted by users with residence in the most popular countries occurring in the data set. Unfortunately, many users publish invalid or inconclusive locations in their Twitter profiles (e.g., 'Around the world', 'Mars', 'London&NYC'). We excluded tweets posted by these users from further experiments.

3.3. Selected Countries and Areas

Our data contains both local and global recreational user patterns as we did not restrict data collection to specific countries. However, as Figures 3 & 4 showed, Twitter users are more active in the Western Hemisphere (e.g., USA, Canada, Western Europe). Fur-

Area	Tweets	Users	Circle centers (lat, long)	Radius (km)
Western Alpes	1543	589	(44.141754, 6.9726151)	50
			(45.0437458, 6.3892906)	50
			(45.9666772, 7.6373506)	50
			(45.8323849, 6.8637096)	50
Dolomites	865	323	(46.4118581, 11.8216688)	50
Pyrénées	856	357	(42.6997233, -0.4364245)	50
			(42.6551014, 0.6589325)	60
			(42.3923069, 1.9831357)	50
Snowdonia	552	307	(53.070095, -3.969984)	20
Peak District	276	134	(53.419918, -1.771878)	10
Lake District	1058	443	(54.464247, -3.035512)	25
Scotland	697	377	(57.4834038, -5.0739052)	150
Rockies	2471	1209	(39.6933868, -105.8914474)	50
			(39.1723719, -106.8358464)	50
			(40.5709711, -105.8804096)	50
White Mountains	1051	410	(44.0908472, -71.5055852)	50
Smokies	1122	529	(35.139817, -83.750694)	60

Table 3. The number of tweets and users related to the selected recreational areas in our data set. We also present the covering circles with radius for each location.

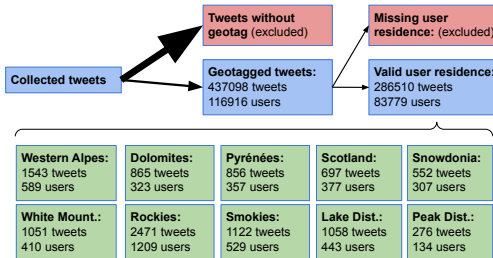


Figure 5. Data cleaning and filtering steps

thermore, we selected ten specific locations to compare and analyze recreational areas during Covid-19 within the USA and Europe. Each area is defined by one or more circles presented in Table 3, along with the number of tweets posted within these areas. For most of the circles, we set a radius of 50 kilometers, but some further adjustments were made to adapt to the dimensions of the given recreational area. For example, the radius is decremented in the case of nearby populated areas. Figure 5 includes a flow chart explaining the major data preprocessing steps we applied before filtering the data for the selected recreational areas.

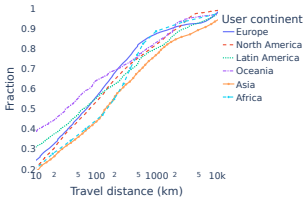


Figure 6. Cumulative distribution function for travel distance with respect to different residence continents.

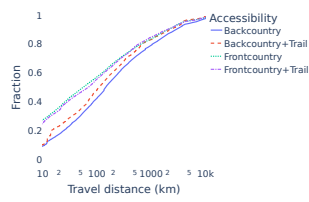


Figure 7. Cumulative distribution function for travel distance that visitors took to reach places that belong to different accessibility categories.

4. Results and Discussion

4.1. Users and Travel Distances

In order to understand recreational user patterns shown by the Twitter posts we have collected, we calculate the Haversine distance between the location of each post and the residence of the corresponding user. This way, we get the approximate distance the user took to visit a given place. In the knowledge of these distances, we can extract traveling trends for users that belong to the same residence. For example, the travel distance distribution of users living on different continents is shown in Figure 6. Our results reveal that Twitter users located in Oceania and Latin America tend to go less further on average, which reflects the geographical properties of these regions. Namely, both continents consist of various islands, plus only a small fraction of Australian land is suitable for recreational activities, being usually close to populated areas.

Similarly, for a selected place, we can analyze the travel distance of the visitors. Figure 7 assesses the travel distance distribution for the accessibility categories described in Section 2.3. Our results indicate that users in general travel much further to reach backcountry locations compared to recreational areas in the frontcountry.

4.2. Accessibility Comparison

This section further analyzes the travel distance with respect to different accessibility categories (e.g., frontcountry, backcountry). Almost two-thirds of the collected tweets were posted from frontcountry locations (see Figure 8). It means that users in our data rarely leave areas that are easily accessible through a motorized road or public transport network. Unfortunately, we do not have data from the pre-Covid period. Thus, we cannot properly quantify the effect of different Covid-19 waves or other travel restrictions on recreational patterns of Twitter users, but these events might have also encouraged people to visit frontcountry places more frequently.

In our next experiment, we compare travel distance patterns over time for users who live in Europe or North America. By choosing these regions, we cover almost 75 percent of all users (see Figure 3). By collecting data for more than a year, we had the chance to observe seasonal changes in travel distance for each accessibility category. Figure 9

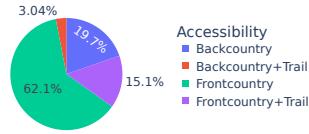


Figure 8. Distribution of accessibility categories in the collected data

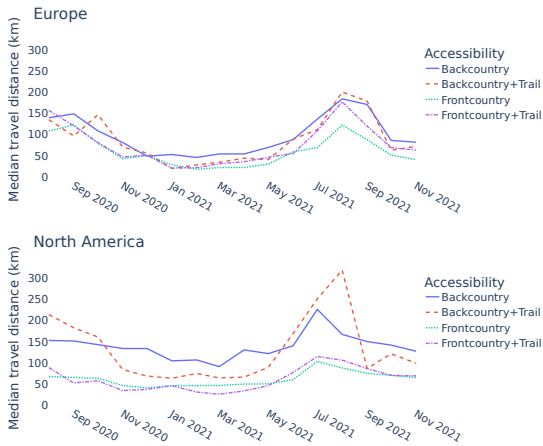


Figure 9. Median travel distance of visitors by location categories restricted to Europe and North America.

reveals that North American users are willing to travel further to reach backcountry locations even during the winter. On the other hand, half of all European tweets were posted no more than 50 kilometers from the corresponding user residence location during Q1 of 2021. This behavior might also be the effect of various Covid-related traveling restrictions that took place in several European countries during this period.

4.3. Comparison of Selected Recreational Areas

Our previous results were related to large geographic regions like continents or every backcountry location on Earth that our data covers. Here, we assess recreational user patterns on a more fine-grained level. We compare and analyze the travel distance taken by visitors of multiple recreational areas introduced in Section 3.3. It is important to note that users can post multiple tweets from the same area (e.g. photographers). In order to

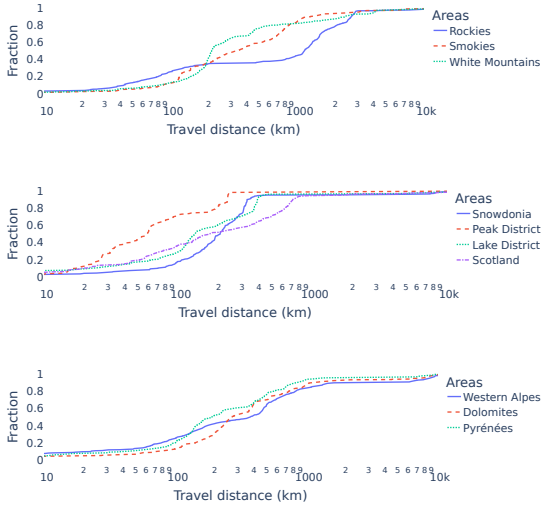


Figure 10. Cumulative distribution function for travel distance that visitors took to reach selected recreational areas in the USA (**top**), UK (**middle**), and continental Europe (**bottom**).

avoid the possible user bias during our analysis, for each recreational area, we keep only a single post per user, the one with the largest travel distance.

In Figure 10, the cumulative distribution functions on travel distance clearly signal whether a given area is a popular tourist hotspot or is only visited by regional users. For example, almost half of the Rocky Mountains visitors come from its 200-kilometer radius, while most of its remaining tourists live further than 1000 kilometers. Thus, it is a real paradise for interstate hikers in contrast to the White Mountains, which addresses relatively more regional hikers. Figure 11 also expresses this behavior where the residence distribution of visitors is shown for each recreational area. Similar case studies are presented for the United Kingdom and continental Europe. The Peak District national park in the UK and the Dolomites in Italy are good examples of sites visited mostly by regional users. On the contrary, Lake District and Snowdonia national parks are more popular in the UK nationwide, while the area of the Western Alps indeed attracts international travelers from further distances. It is also interesting to observe that the selected recreational areas in the US and UK are more diverse in terms of their cumulative travel distance distribution function than the three continental European locations (Western Alps, Dolomites, Pyrénées), see Figure 10.

By deploying our logic-based location categorization tool, OPENLOSTCAT, we can further analyze travel distance patterns for different accessibility groups within these areas. Our results exhibit a significant separation of user interests for popular tourist

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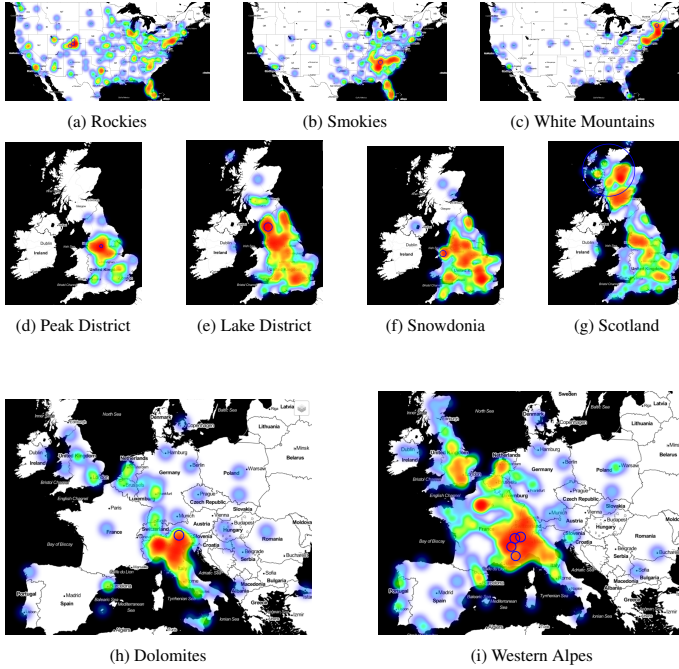


Figure 11. Visitor residence distribution for the selected recreational areas in the US (**first row**), UK (**second row**), and continental Europe (**third row**). The covering circles for each selected area are marked by blue.

hotspots (e.g. Rockies, Western Alps); see Figure 12. For example, frontcountry locations are visited by users living much further than those interested in the backcountry. These are probably international or interstate travelers who only visit the most popular landmarks within these recreational areas or simply not familiar with backcountry trails or areas. On the other hand, for areas most visited by regional hikers (e.g. Dolomites, Pyrénées, Peak District), the median travel distance for the backcountry and frontcountry are more balanced. Interestingly, visitors of the UK national parks and similar areas are traveling the most for marked trails in the backcountry. This behavior was specific for these regions from the 10 selected recreational areas.

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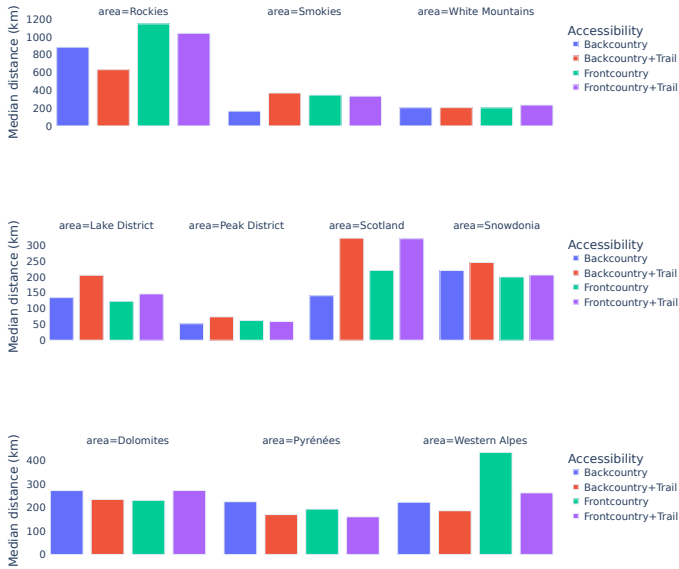


Figure 12. Median travel distance by accessibility category for the selected recreational areas in the USA (top), UK (middle), and continental Europe (bottom).

5. Conclusion and Future Work

In this paper, we presented an initial exploratory study on analyzing geotagged social media posts on a global scale with micro-level location categorization. Location types are modeled based on geographical features and their descriptive properties found in the proximity of each visited data point. The goal was to find out whether this approach is useful for identifying any potentially verifiable differences in large-scale visitation patterns of different location type settings, depending on geographical areas at multiple levels, seasonality, and traveling distance of visitors.

For such purposes, we designed and implemented OPENLOSTCAT, a free, open-source, logic-based location categorization tool by which the modeler can define location categories over OpenStreetMap data found around a point on Earth. To achieve this, a JSON-based rule language can be used as a customized form of univariate first-order logic with convenience features such as implicit variable quantification.

We collected Twitter data of visitors by keyword-based filtering from August 2020 until November 2021, applied location categorization according to transportation and

trail accessibility characteristics to each of the geotagged posts, determined the user home location of users where appropriate, then aggregated and visualized these data according to different aspects relevant for seeking potential large-scale visitation patterns for each location category.

Results of our experimental analysis are presented by the visited place types, their seasonal characteristics, and distribution of visitor travel distances. Geographical comparisons between North America and Europe, as well as for specific selected recreational areas show significantly different visitation patterns by users of geotagged tweets posted in those areas. Based on our collected data, heatmaps reveal the catchment areas of selected recreational areas, i.e., from where their identified Twitter visitors arrive. Observations can be refined according to the visited location categories, showing the median of distances traveled by each accessibility category. These findings may be subjects for further verification according to evidence from alternative sources or surveys in further studies since we have seen the low ratio of geotagged tweets, the inherent bias caused by keyword selection, as well as the variety in the popularity of Twitter amongst users in different areas.

Our main contribution on the methodological level is showing the feasibility and potential of enhancing social media content analysis with logic-based location modeling on a global scale by potentially characterizing any point on earth based on its local geographical features and looking at large scale visitation patterns by location categories such as home locations of users visited trailless natural areas compared to users at places accessible by motorized transportation. In contrast to most related studies, our major advantage is the global-scale approach, with no *a priori* particular focus area, that is achieved by the power of potentially global coverage of OpenStreetMap.

The main technical contribution of the study is the reusable open-source tool called OPENLOSTCAT, which does the actual location categorization with its simplified and convenient first-order-logic-based rule language for modeling location types, where the single-variable approach, the JSON formalism, and the implicit quantification mechanism provides simplicity in formulating many common rules or subexpression types and is capable of effective evaluation with large-scale datasets.

Although these initial results seem to be promising, interpretation of the actual survey outcomes needs caution due to data coverage and quality limitations, as potential biases are also reported in the related literature. Our study has shown the potential in our approach to discover relevant patterns and to be a viable source of information for complex surveys, in which such findings can be verified by other means. We highlight that our results are restricted to users posting geotagged tweets on Twitter with specific keywords related to hiking and nature-based recreation activities and whose location of residence can be resolved. Thus, our findings should not be interpreted as representative visitation patterns in general.

There are obvious differences in the popularity of Twitter usage in different countries, as shown by or data in Figures 3–4, which may highly affect the outcomes if we wanted our results to reflect actual visitor frequencies on a global scale. Our selected keywords are also far from complete and keyword-based filtering is somewhat biased by nature. It is a future issue whether a more fine-tuned filtering of social media posts data can be achieved. As location categorization is currently based solely on local features in close proximity, one must consider casual patterns while interpreting these categories. For instance, some city park locations will be categorized as backcountry in our terms (if

not covered directly by a residential area polygon), which is completely acceptable by our category definition based on transportation and marked-trail-accessibility. However, it may be surprising from a common-sense viewpoint. OpenStreetMap data quality and coverage also affect the results in general, as some areas may have incomplete data, and the different trail designation and signage systems in different regions and countries, the phenomenon or concept of a marked trail will be very different. Unfortunately, we do not have data from the pre-covid era, so it is not possible at the moment to make comparisons with the time of the pandemic as we face limitations of the Twitter API with querying historical data. Finally, only a fraction of the collected data proved appropriate for our analysis as Twitter users generally do not tend to share geotagged tweets. Thus, it would be essential to characterize visitors who post geotagged tweets during their hiking, trekking, or other outdoor tours compared to others who do not, and so for which segment(s) of users are our results typical, compared to the whole population of visitors at specific areas. Nevertheless, our results revealed some relevant and interesting patterns, especially by the continental and area-based comparisons and the timeline charts, which can be validated by other types of surveys outside of the scope of this paper.

As a future prospect, this approach or its tools may be adapted to surveys of other fields with similar needs and characteristics. The rule definition language or even the location categorization method may also be extended to capture more sophisticated modeling of location settings. The flexibility and extensibility of the JSON format allows a potentially complex and heterogeneous modeling language to be developed, where special keywords and prefixes may identify even the type or (sub)language of the rule being defined at some point. On the other hand, the fine-tuning of our results can be achieved by refining our keyword set in combination with more sophisticated methods for relevant post selection. For example, sentiment analysis, user, and location profiling can reveal additional details on the collected users and content.

Analyzing similar content posted to other social media platforms can make our analysis more robust and complementary to the coverage of Twitter data. Comparisons with field surveys such as questionnaire-based user studies may validate our results and orient their interpretation by discovering additional user-profile characteristics.

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Heuristics for Spatial Data Descriptions in a Multi-agent System

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Abstract. Navigation and an agent's map representation in a multi-agent system become problematic when agents are situated in complex environments such as the real world. Challenging modifiability of maps, long updating period, resource-demanding data collection makes it difficult for agents to keep pace with rather quickly expanding cities. This study presents the first steps to a possible solution by exploiting natural language processing and symbolic methods of supervised machine learning. An adjusted algorithm processes formalized descriptions of one's journey to produce a description of the journey. The explication is represented employing Transparent Intensional Logic. A combination of several expliciations might be used as a representation of spatial data, which may help the agents to navigate. Results of the study showed that it is possible to obtain a topological representation of a map using natural language descriptions. Collecting spatial data from spoken language may accelerate updating and creation of maps, which would result in up-to-date information for the agents obtained at a rather low cost.

Keywords. Machine learning, Refinement, Generalization, Specialization, Hypothesis, Heuristics

1. Introduction

Multi-agent systems are commonly embedded in the space. In order to operate, they need to explore the structure of this space and learn to navigate within it. They need to build up a knowledge base representing the locations in the space, the possibilities of moving between them, and possibly other accompanying information. For this purpose, it is possible to use the means of supervised machine learning, specifically natural language processing, which is an interdisciplinary discipline involving linguistics, logic and computer science [1]. This paper aims to describe the application of machine learning methods in agents' learning paths in the city. The system uses the formal knowledge representation by means of Transparent Intensional Logic (TIL) constructions. We deal with learning based on the representation of agents' journey.

A similar algorithm was exploited in several papers that obtained expliciations used for several applications. The seeking relevant information source from many textual sources

was introduced in [2]. Using Formal Conceptual Analysis (FCA) and Association rules analysis, seeking additional appropriate textual sources was introduced in [3], [4]. Improvement of recommendation method using Iceberg concept lattices was introduced in [5]. Explications obtained with a combination of FCA were used in [6] for seeking the most appropriate concept. In [7] and [1], authors processed natural language sentences containing information about a particular concept.

Agents' journey through the city can be described as an ordered set of sentences. Each sentence describes one whole part of the journey, usually containing information about who, how, from where, towards where, along with what and for how long the agent moved. For simplicity, we will assume that the consecutive individual parts of the path, described by particular sentences, are mutually connected. Therefore, some of the missing information from the following sentence can be taken from the previous sentence. Once a path representation is created based on the available description (path introduction), it can be further updated based on new information obtained from other agents' reports (path update).

The paper is structured as follows. Chapter 2 summarises supervised machine learning and Chapter 3 describes inductive heuristics. Chapter 4 demonstrates inductive heuristics functionality on some examples. Chapter 5 contains conclusions and future work descriptions.

2. Supervised Machine Learning

Supervised machine learning is a task of learning functional dependency based on observing classified positive or negative examples. Supervisor to an agent provides those examples. Examples are described by a set of input and output attributes. There is an unknown functional dependency f between values of those two sets. Observing the values of input and output attributes of examples, the agent builds his functional dependency h called the hypothesis. The hypothesis should approximate the original unknown function dependency f . Using this hypothesis, the agent should be able to predict the value of output attributes based on values of input attributes on unseen examples.

For example, conditions for receiving a loan by a bank can be described by input attributes *employment*, *salary*, *age*, *indebtedness*, and *health condition* of an applicant. The risk of providing a loan to the applicant is the output attribute.

The hypothesis can be verified by a set of test examples where only values of input attributes are known to the agent. If the hypothesis predicts the values of output attributes as the original dependency f on test examples, the hypothesis is correct. More about supervised machine learning can be found in [8], [9], [10].

In the following sections, we briefly summarise the supervised machine learning algorithm and its adjustments to our previous works leading to the current stage of development.

2.1. Building a Concept

In [7], we exploited Patrick Winston's symbolic algorithm [11] to obtain a hypothesis of a concept classifying unknown examples described by the language of TIL-script construction. TIL-script is a computation variant of Transparent Intensional Logic (TIL). TIL is a partial, typed hyperintensional lambda calculus with procedural as instead of set-theoretical denotational semantics.¹

The algorithm's goal was to find a general concept specifying the property of being an *arch*.² *Arches* are built from blocks of different colors, positions, and shapes. The resulting molecular concept should be general enough that the agent should be able to identify those individuals that belong to the class of arches and at the same time specific enough to exclude those individuals that do not belong to this class.

The algorithm built a general concept using two heuristic methods, namely *Generalization* and *Specialization*. Both methods contain heuristic functions that manipulate the symbolic representation of the hypothesis.

Positive examples are processed by the Generalization that adjusts the hypothesis, i.e. molecular construction, therefore more objects can be correctly identified as the concept described by the hypothesis.

Negative examples are processed by Specialization that serves to distinguish the output concept from similar ones. For instance, a wooden horse can serve as a negative example to the concept of the horse, because a wooden horse is not a horse; instead, it is a toy horse though it may look like a genuine living horse.

2.2. Refinement of a Concept

In [1] we adjusted the [7] algorithm for natural language processing. The goal was to create explications of atomic concepts using natural language sentences. Carnapian explication is a refinement process of an inaccurate or vague expression into an adequately accurate one. For example, the atomic concept of a *Dog* might have an explication that *A dog is a domesticated carnivore*. Therefore, the goal of an agent is to discover the best refinement of the learned simple concept of an object *O*, i.e. a molecular closed construction that produces the same object. Moreover, this molecular concept should specify the requisites of the object *O* as much as possible so that it excludes other similar concepts.

Original Winston's algorithm uses examples with complete information about the concept. The agent's hypothesis differs from the presented example in one significant difference, and the hypothesis is adjusted by the machine learning algorithm based on that one significant difference.

However, in [1] examples are in the form of natural language sentences formalized into the language of TIL-script constructions. Unlike Winston's examples, natural language sentences do not carry complete information instead, they contain new (partial) infor-

¹TIL has been introduced in numerous papers and two books, see, for instance [12], [13], [14], [15], [16], [17].

²A concept is a closed construction in its normal form in the notion of TIL.

mation about the explicated object. Hence, examples differ in more than one significant difference compared to the hypothesis.³ It was necessary to modify the algorithm.

We have introduced a new heuristic method called *Refinement*. This method contains one heuristic function called *Concept introduction*, and this function inserts new information about the object to be explicated into the molecular construction as its new constituent.

2.3. Network Building

In this paper, we are dealing with a new challenge. In [7] and [1] we processed natural language sentences mentioning a particular concept, and those sentences contained partial information about a particular concept. We also deal with natural language sentences formalized into TIL-script constructions but as different examples. Examples now contain pieces of information about an agent's journey, and a new method of processing them must be implemented. At this time, we are not refining a simple concept; instead we build an agent's journey from its description in the form of TIL-script constructions, i.e. we build molecular construction describing the agent's journey.

To connect pieces of information contained in examples, we exploit the class of motion verbs, for example, *to go to walk, to cross, to turn, to come*, etc., and valency frames. Valency might be seen as the capacity a verb has for combining with particular patterns of other sentence constituents.⁴ Valency frames provide information on which kind of complement is a valency bound with a particular verb in a particular sentence. For example, a verb *to come* might by valency bond in a sentence with complements such as an *actor* (who is walking), *directions* (from, where to, which way), *manner* (speed of the walk, the direction of the walk), *extent* (how far).

For one's journey analysis we are using the following *functors* that indicate the types of syntactic-semantic relationship between a verb and its complement that might occur in valency frames:

- Actor (ACT): *Paul is riding a bike.*
- Direction - from (DIR1) : *He came **from woods** soaked wet.*
- Direction - which way (DIR2): *He went to the neighboring village **through the forest**.*
- Direction - where (DIR3): *He went **to the neighboring village** through the forest.*
- Manner (MANN): *He treated her **kindly**.*
- Extent (EXT): *Dad measured **2 meters**.*

The sentence "*Tom walks quickly from home to school.*" might be analyzed by exploiting the valency frame of the verb *to walk* as follows:

- ACT: Tom
- DIR1: home

³For details, see [11].

⁴For details, see [18].

- DIR3: school
- MANN: quickly

Using valency frames and information that follows from them, we might obtain a formal description of one’s journey by description in natural language formalized in the expressive language of TIL.⁵

$$\lambda w \lambda t \left[[ACT_{wt} 'Tom' walk] \wedge [DIR1_{wt} 'home' walk] \wedge [DIR3_{wt} 'school' walk] \wedge [MANN_{wt} 'quickly' walk] \right]$$

Types:

DIR1, *DIR3*/($\alpha\pi v$) $_{\tau\omega}$; *ACT*/ (αv) $_{\tau\omega}$; *MANN*/ ($\alpha\alpha v$) $_{\tau\omega}$; *Tom*/ ι ; *home*, *school* / π ; *walk*/ v , where π is type of places; v is type of the activity denoted by a verb.

As algorithms introduced in [7] and [1], we can also describe adjusted algorithms using a general framework for symbolic methods of supervised machine learning. This general framework consists objectives, training data, data representation, and a module for manipulation with the symbolic representation.

- **Objectives:** Our algorithm produces hypotheses in the form of molecular TIL-Script construction.
- **Training data:** Training data are natural language sentences that describe one’s journey. Hence, they contain information about traveller’s names, directions, attributes of the traveling such as speed, distances, changes in directions, etc.
- **Data representation:** Same as previously mentioned algorithms, this algorithm also exploits the TIL. For computational purpose, training data are formalized in TIL-script language.
- **Module for manipulation with the symbolic representation:** This module contains three heuristic methods that manipulate the hypothesis of one’s journey based on training data examples. The methods are *Generalization*, *Specialization*, and *Refinement*. This paper is dedicated to the *Refinement* method in which we define two new heuristic functions: *Path Introduction* and *Path Update*.

Path Introduction inserts new pieces path pieces into the molecular description, thus extending the path description. Using *Path Update*, the path description is altered with a possibly more precise description. For example, one might describe his journey briefly, and the brief description serves us as a hypothesis of the journey. Another one might describe the same journey more in detail. *Path Update* will alter the hypothesis so the description of the journey might be as detailed and accurate as possible.

⁵For the sake of readability we will use just TIL language to display examples. Our computations are executed over TIL-Script constructions.

3. Inductive Heuristics

A journey description is obtained by exploiting the valency structure of motion class verbs. We divide the journey description into two kinds of information; the core information about directions, distance, and places we call the *network* and the description of surroundings on the journey. The description of surroundings is not a topic of this paper and it will be a subject of our future work. In this paper, we have focused on the first part; the creation of the *network*.

The journey is a sequence of places that one might visit, complemented with additional information such as an actor who took the journey, the distance it took the actor to move from one place to the other, etc. Valency frames of motion class verbs identify that information. Places of the journey are identified by *direction's* functors (DIR1, DIR2, DIR3). Change in the movement direction change of speed is identified by the *manner* functor (MANN). The one who took the journey is identified by the *actor* functor (ACT). The *extent* functor (EXT) identifies the distance between two places.

Places are the essential information in the *network*; therefore, we call *nodes* constituents of *direction's* functors. Places might be connected via valency to the motion verb. Direction functors (DIR1 - from, DIR3 where) determine the direction. Motion verb together with other functors (such as ACT, MANN, EXT) we call *edge*.

Definition 1 (*node, edge*). Let V be a *motion verb*, let $S = \{B \mid ('DIR1$ or $'DIR3)$ and V are constituents of $B\}$ and let $D^V = \{C \mid V \text{ is a constituent of } C\} \setminus S$ then D^V is a set of *edges* and S is a set of *nodes*.

Definition 2 (*place, functor, value*). Let $[\alpha \ x \ v]$ be a *node* and let $[\beta \ y \ v_1]$ be an *edge*. Then x is a *place*, α, β are *functors*, and y, v, v_1 are *values*.

A simple sentence might connect two places via verb valency with additional information. For example, let us have a sentence "John went from X to Y.", formalized as:

$$\lambda w \lambda t \ [[ACT_{wt} 'John 'went] \wedge [DIR1_{wt} 'X 'went] \wedge [DIR3_{wt} 'Y 'went]] \quad (1)$$

By definition 1, $[DIR1_{wt} 'X 'went]$ and $[DIR3_{wt} 'Y 'went]$ are *nodes*. The rest, $[ACT_{wt} 'John 'went]$, is an *edge*. By definition 2, X and Y are *places*; they are constituents of *nodes*. We can define a *connection* using nodes and edges, thus forming a *network*.

Definition 3 (*connection*). Inductive definition:

1. Let α be an *edge* then α is a *connection (atomic)*.
2. Let α, γ be *connections*, let β be *node* then $\alpha \rightarrow \beta \rightarrow \gamma$ is a *connection*.
3. Only structures in 1 and 2 are *connections*.

Remark: Connection is a transition between nodes.

Definition 4 (*path*). Let α and γ be *nodes* and let β be a *connection* then $\alpha \rightarrow \beta \rightarrow \gamma$ be a *path*.

Definition 5 (*same path*). Let $\alpha \rightarrow \beta \rightarrow \gamma$ and $\alpha \rightarrow \delta \rightarrow \gamma$ be *paths* in model and positive example respectively, let $\delta = \varepsilon \rightarrow \dots \rightarrow \omega$ then if $\lambda x [DIR2_{wt} \ x \ y]$ in β (model) = $\lambda y [DIR2_{wt} \ y \ z]$ in δ (positive example) then both paths represent the *same path*.

Definition 6 (network). A network is a set of all paths.

3.1. Path Preprocessing

This section describes the essential part of our algorithm. *Path Introduction* and *Path Update* can operate only over the paths. Therefore, input constructions representing a route description must be converted to constructions representing a path by definition 4.

Following Figure 1 represents path preprocessing. The algorithm consists of decision parts, namely *Path*, *Sen1*, *DIR1*, *DIR3*, and procedures.

The decision represented by *Path* tests whether the input description represents a path; *Sen1* check if the construction represents the first sentence; *DIR1* and *DIR3* check whether there are constituents 'DIR1 and 'DIR3 in the input construction or not respectively.

Procedures $D1^S \Leftarrow D3^{S-1}$ and $D3 \Leftarrow Dummy$ inserts nodes to produce path by the definition.⁶

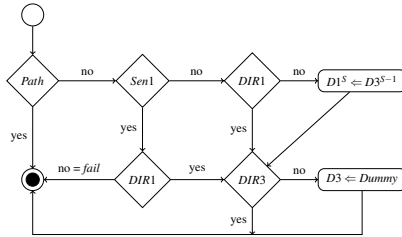


Figure 1. Path Preprocessing flow diagram

For a better reader's understanding, we will describe the functionality of the particular parts of the preprocessing in more detail here.

Decisions

We have three basic types of decision-making. The first one checks whether the input is a path-describing construction (*Path*). The second one checks whether the input represents the first sentence (*Sen1*). The third one (*DIR1*, *DIR3*) verifies that the input description contains constituents representing the beginning and the end of the path.

Path

If an input is of the form $\alpha \rightarrow \beta \rightarrow \gamma$ where α and γ are nodes and β is a connection then input description is a path. If not so then proceed to decision *Sen1*.

Sen1 + DIR1

At this point, it is necessary to check whether the input represents the first sentence. If so, it is crucial to know where the path will begin. Therefore, if there is no information about *D1*, we cannot start the process and it is necessary to ask the user to add this crucial information.⁷ If *D1* is included then we can proceed to *DIR3*.

⁶ $D3^{S-1}$ represents node containing constituent 'DIR3 from previous sentence.

⁷ Di represents node [$DIR_{int} x y$]

DIR3

This decision part checks whether our input contains the information about the end or heading of a specified direction. If there is no such information we trigger the $D3 \Leftarrow Dummy$ procedure which introduces the given description node with *dummy* $D3$.

DIR1

This condition verifies that the description includes the direction's origin. If it does, it is proceeding to $DIR3$. If $D1$ is not included in the description and not the first sentence, then $D1$ is added to the description. The new $D1$ is obtained from node $D3$ of the previous sentence.

Algorithm represented by figure 2:

Let's have a sequence of constructions as the input: $(S_1, S_2, \dots, S_n), I = \{1, \dots, n\}$.

start: For each $i \in I$ do⁸

- (a) IF $i = 1$ then *dirs1*
- (b) IF ' $DIR1$ in S_i then *dir3*
- (c) introduce [$DIR1_{wt}$ *x verb*] into S_i where *x, the verb* is taken from $D3^{S_i-1}$
- (d) *dir3*

dir3: IF ' $DIR3$ in S_i then end

- (a) introduce [$DIR3_{wt}$ *Dummy verb*] into S_i , where the *verb* is taken from S_i
- (b) end

dirs1: IF not('DIR1 in S_1) then fail

- (a) *dir3*

end: return S_i

3.2. Path Introduction / Path Update

Several heuristics must be applied to create the path network. Since we process spatial data, a new heuristic had to be introduced to update the path. The heuristic for introducing a new path remains unchanged.⁹ Deciding which heuristic to run is based on path comparison. If the paths are the same, the *Update Path* heuristic is triggered.

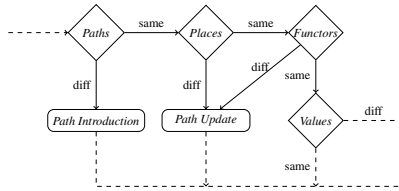


Figure 2. Refinement heuristics

⁸ start/(c) represents procedure $D1^S \Leftarrow D3^{S-1}$

⁹ Path introduction correspond to the heuristic *Concept introduction* in [1]

4. Inductive Heuristics' Functionality Examples

Assume the following situation: We have two different journey's descriptions. One is from Tom's point of view and the other is from John's point of view. The following sentence describes Tom's perspective:

- "Tom is walking down A street from B to C."

TIL *explication* mapping the sentence is:

$$\begin{aligned} \lambda w \lambda t [[ACT_{wt} 'Tom 'walking] \wedge [DIR1_{wt} 'B 'walking] \\ \wedge [DIR2_{wt} 'A 'walking] \wedge [DIR3_{wt} 'C 'walking]] \end{aligned} \quad (TR)$$

These sentences describe John's perspective:

- "John came to E from B on street A."
- "After 100m John came to F on A street"
- "And after another 100m John came to C on street A."

TIL descriptions:

$$\begin{aligned} \lambda w \lambda t [[ACT_{wt} 'John 'came] \wedge [DIR1_{wt} 'B 'came] \\ \wedge [DIR2_{wt} 'A 'came] \wedge [DIR3_{wt} 'E 'came]] \end{aligned} \quad (J_1)$$

$$\begin{aligned} \lambda w \lambda t [[ACT_{wt} 'John 'came] \wedge [EXT_{wt} '100 'came] \\ \wedge [DIR2_{wt} 'A 'came] \wedge [DIR3_{wt} 'F 'came]] \end{aligned} \quad (J_2)$$

$$\begin{aligned} \lambda w \lambda t [[ACT_{wt} 'John 'came] \wedge [EXT_{wt} '100 'came] \\ \wedge [DIR2_{wt} 'A 'came] \wedge [DIR3_{wt} 'C 'came]] \end{aligned} \quad (J_3)$$

The description from John's sentences will be as follows:

$$\begin{aligned} \lambda w \lambda t [[[ACT_{wt} 'John 'came] \wedge [DIR1_{wt} 'B 'came] \wedge [DIR2_{wt} 'A 'came] \\ \wedge [DIR3_{wt} 'E 'came]] \wedge [[ACT_{wt} 'John 'came] \wedge [DIR1_{wt} 'E 'came] \\ \wedge [EXT_{wt} '100 'came] \wedge [DIR2_{wt} 'A 'came] \wedge [DIR3_{wt} 'F 'came]] \\ \wedge [[ACT_{wt} 'John 'came] \wedge [DIR1_{wt} 'F 'came] \wedge [EXT_{wt} '100 'came] \\ \wedge [DIR2_{wt} 'A 'came] \wedge [DIR3_{wt} 'C 'came]]] \end{aligned} \quad (JR)$$

To obtain the final *journey explication* which is in our case (JR) we need to go through several steps which follow:

4.1. Path Preprocessing

In order to start the actual explication process, it is required to prepare the input structures first. All TIL constructions, namely TR, J_1 , J_2 , J_3 , need to meet the *path* conditions.

- TR \rightarrow passed
- $J_1 \rightarrow$ passed
- $J_2 \rightarrow$ missing node $D1 \rightarrow$ run $(D1^{J_2} \Leftarrow D3^{J_1})$

$$\lambda w \lambda t \left[[ACT_{wt} 'John 'came] \wedge [DIR1_{wt} 'E 'came] \wedge [EXT_{wt} '100 'came] \right. \\ \left. \wedge [DIR2_{wt} 'A 'came] \wedge [DIR3_{wt} 'F 'came] \right] \quad (J_2^*)$$

- $J_3 \rightarrow$ missing node $D1 \rightarrow$ run $(D1^{J_3} \Leftarrow D3^{J_2})$

$$\lambda w \lambda t \left[[ACT_{wt} 'John 'came] \wedge [DIR1_{wt} 'F 'came] \wedge [EXT_{wt} '100 'came] \right. \\ \left. \wedge [DIR2_{wt} 'A 'came] \wedge [DIR3_{wt} 'C 'came] \right] \quad (J_3^*)$$

We have prepared all the necessary inputs to run the heuristics at the end of this process. The following heuristics in sections 4.2 and 4.3 are called separately.

4.2. Path Introduction

Because the descriptions TR and J_1 meet the *path* conditions we do not need to preprocess them. The given construction TR is already an *explication* of a given journey. The construction J_1 represents just a part of a journey; therefore it needs to be used as an input for *heuristics*. Constructions J_2 and J_3 had to be modified into single path descriptions by the *path preprocessing* where we obtained constructions J_2^* and J_3^* . All these constructions (J_1 , J_2^* , J_3^*) are merged, represented as John's journey *explication* JR. For these reasons, we apply the *Path Introduction* heuristic.

The *Path introduction* proceeds as follows:

1. The first construction, J_1 , becomes a *model*.
 - (a) The second construction, J_2^* , is a positive example.
 - (b) Introduce J_2^* into a *model* J_1 .

$$\lambda w \lambda t \left[[ACT_{wt} 'John 'came] \wedge [DIR1_{wt} 'B 'came] \wedge [DIR2_{wt} 'A 'came] \right. \\ \left. \wedge [DIR3_{wt} 'E 'came] \wedge [ACT_{wt} 'John 'came] \wedge [DIR1_{wt} 'E 'came] \right. \\ \left. \wedge [EXT_{wt} '100 'came] \wedge [DIR2_{wt} 'A 'came] \wedge [DIR3_{wt} 'F 'came] \right]$$

2. J_{12} is a new *model*.
 - (a) The construction J_3^* is a positive example.
 - (b) Introduce J_3^* into a *model* J_{12} .

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$$\begin{aligned} & \lambda w \lambda t [[['ACT_{wt} 'John 'came] \wedge ['DIR1_{wt} 'B 'came] \wedge ['DIR2_{wt} 'A 'came] \\ & \wedge ['DIR3_{wt} 'E 'came]] \wedge [['ACT_{wt} 'John 'came] \wedge ['DIR1_{wt} 'E 'came] \\ & \wedge ['EXT_{wt} '100 'came] \wedge ['DIR2_{wt} 'A 'came] \wedge ['DIR3_{wt} 'F 'came]] \quad (JR) \\ & \wedge [['ACT_{wt} 'John 'came] \wedge ['DIR1_{wt} 'F 'came] \wedge ['EXT_{wt} '100 'came] \\ & \wedge ['DIR2_{wt} 'A 'came] \wedge ['DIR3_{wt} 'C 'came]]] \end{aligned}$$

After obtaining all the journeys' explications TR and JR, we follow a process that compares the explications. They describe the *same path*, triggering the (*Path Update*) heuristic.

4.3. Path Update

1. The first explication TR is becoming a *model*. This *model* contains all parts necessary for defining a *path*:

Nodes:

$$\begin{aligned} & a \quad ['DIR1_{wt} 'B 'walking] \\ & b \quad ['DIR3_{wt} 'C 'walking] \end{aligned}$$

Edges:

$$\alpha \quad \{['ACT_{wt} 'Tom 'walking], ['DIR2_{wt} 'A 'walking]\}$$

2. Second explication JR is a positive example. This example represents *path* as well.

Nodes:

$$\begin{aligned} & c \quad ['DIR1_{wt} 'B 'came] \\ & d \quad ['DIR3_{wt} 'E 'came] \\ & e \quad ['DIR1_{wt} 'E 'came] \\ & f \quad ['DIR3_{wt} 'F 'came] \\ & g \quad ['DIR1_{wt} 'F 'came] \\ & h \quad ['DIR3_{wt} 'C 'came] \end{aligned}$$

Edges:

$$\begin{aligned} & \beta \quad \{['ACT_{wt} 'John 'came], ['DIR2_{wt} 'A 'came]\} \\ & \gamma \quad \{['ACT_{wt} 'John 'came], ['EXT_{wt} '100 'came], ['DIR2_{wt} 'A 'came]\} \\ & \delta \quad \{['ACT_{wt} 'John 'came], ['EXT_{wt} '100 'came], ['DIR2_{wt} 'A 'came]\} \end{aligned}$$

3. We are checking the possibility that they are the *same path*.

(a) Structures:

$$\text{Model: } \{a\} \rightarrow \alpha \rightarrow \{b\}$$

$$\text{Example: } \{c\} \rightarrow \beta \rightarrow \{d, e\} \rightarrow \gamma \rightarrow \{f, g\} \rightarrow \delta \rightarrow \{h\}$$

- (b) Checking first and last places in paths
 - First-model $\{a\}$: $\lambda x[DIR1_{wt} x 'walking] = \{B\}$
 - First-example $\{c\}$: $\lambda x[DIR1_{wt} x 'came] = \{B\}$
 - Last-model $\{b\}$: $\lambda x[DIR3_{wt} x 'walking] = \{C\}$
 - Last-example $\{h\}$: $\lambda x[DIR3_{wt} x 'came] = \{C\}$
- (c) Checking DIR2 equality:
 - Model: $\lambda x[DIR2_{wt} x 'walking] = \{A\}$
 - Example: $\lambda x[DIR2_{wt} x 'came] = \{A\}$
 - \Rightarrow same path

- 4. Replacing connections
 - Replace *model's* connection by *example's* connection:
 $\alpha \Rightarrow (\beta \rightarrow \{d, e\} \rightarrow \gamma \rightarrow \{f, g\} \rightarrow \delta)$
- 5. The final updated *Path*:
 $\{a\} \rightarrow \beta \rightarrow \{d, e\} \rightarrow \gamma \rightarrow \{f, g\} \rightarrow \delta \rightarrow \{b\}$

Since we have already processed all the explications, triggering the heuristics is complete. The resulting explication covers both journeys, resulting in the desired *network*.

5. Conclusion

This paper deals with building representation of space using descriptions of journeys. Descriptions are obtained from formalized natural language sentences processed by a supervised machine learning algorithm. They might be combined into a network describing space. Such a network can be used as a navigation tool in complex environments of multi-agent systems, e.g., cities. Creating and modifying explications are realized by applying heuristic functions of the adjusted algorithm, which we introduced in this paper. The paper's novelty is the processing of the journey's description exploiting specific motion verbs' valency frames in the descriptions.

The developed procedure of converting the textual description of possible journeys around the city into a formalized form, enriched with much accompanying information, makes it possible to create a more detailed representation of a given space gradually. It might be possible to develop a city orientation plan from this representation in the future. The next step will be to link this orientation plan with the existing map in GIS and enrich it with information obtained from agents.

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Scalp The Foreign Exchange Market with Deep Reinforcement Learning

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Abstract. This paper presents a reinforcement learning approach for foreign exchange trading. Inspired by technical analysis methods, this approach makes use of technical indicators by encoding them into Gramian Angular Fields and searches for patterns that indicate price movements using convolutional neural networks (CNN). In addition to the policy that determines the action to take, an extra regression head is utilized to determine the size of market orders. This paper also experimentally shows that maximizing the return of individual trade or cumulative reward in a finite time window results to better performance.

Keywords: Foreign Exchange Trading · Gramian Angular Field · Deep Reinforcement Learning.

1 Introduction

The development of reinforcement learning is accelerating, Deep Reinforcement Learning (DRL) algorithms have been widely used in diverse fields such as robotics, autonomous driving, healthcare and finance. Various DRL approaches for algorithmic trading have been proposed over the last two decades; the problem, however, still can not be considered as solved. Movements in financial markets are the result of human decisions and interactions; thus, they are affected by political, natural events and a variety of unknown factors. This high grade of uncertainty has made the markets extremely challenging to predict. Because understanding human decisions and interactions is essential for trading in financial markets, not only Time-Series Prediction but also Natural Language Processing and Sentiment Analysis are strongly involved in this field, which require a lot of effort and resources.

Apart from the Stock Exchange Market, there is the Foreign Exchange (or Forex) Market, which is the largest financial market in the world and is open 24-hours a day, 5 days a week. The high level of liquidity in the Forex market makes it easier to buy or sell currencies, orders are executed nearly immediately without large price difference. This characteristics is also advantageous for RL agents since delayed execution suffers from market fluctuations, and thus, the actual market trend at execution time could be different from the trend at order placement time. Although the market dynamics is in general unpredictable, the

human behavior is considered invariant, or in other words predictable. Psychological and emotional patterns can be found in the price movements, especially when no rare event is occurring.

RL studies for algorithmic trading mainly learn to trade in the daily time frame and aim to gain large profit in each order. This work, inspired by technical analysis and scalping strategies, proposes an RL approach that uses candlestick charts and technical indicators to learn price movement patterns, aims to make profits from minor changes in price by trading in a short-term manner.

2 Related work

A Double DQN [12] with feed-forward fully-connected layers was used in [9]. Gradient clipping is utilized to prevent the gradient exploding problem. Another study proposed a policy gradient based method [5] that uses a single recurrent neural network (RNN) and the tanh activation function to approximate the policy; [7] also uses RNN but with Deep Q-Learning approach.

In order to enrich the data and to prevent the model from overfitting, extra minute-candle data were used to train the agent that trades on daily-candle data in [6]. Although the data have the same structure, movement patterns in minute-candle data are different from patterns in daily-candle data. Therefore, only few instruments can be traded using this method; they must be selected by a mechanism based on skewness and kurtosis.

One can consider the classification/regression head of the deep neural network as the policy and the rest as an encoder that learns the representation of the market state. A stack of denoising autoencoders were used in [8], followed by an LSTM layer. In [11], wavelet transforms were added as an extra pre-processing step. Instead of using RNN to process time series data, the present work uses CNN to process time series data, since recurrent operations are much more computational expensive in comparison to convolutional operations.

The reward function in the most studies is mainly the raw profit/loss, i.e. the change in equity after each time step:

$$R_t = v_{t+1} - v_t$$

Another popular reward function is the percentage return:

$$R_t = (v_{t+1} - v_t)/v_t$$

The most popular objective is to maximize the infinite horizon discounted return. Because the infinite horizon discounted return is extremely difficult to approximate in algorithmic trading due to the high grade of uncertainty. In addition, infinite horizon discounted return also takes long temporal dependency in account, which is not desired under the perspective of scalping strategies. This work hypothesizes that aiming to approximate and to maximize short-term return can achieve better result.

Using continuous action space to choose action and trading amount simultaneously is practical; however, the money management strategy will be built-in in

the learned policy and extremely difficult to replace. Thus, this work attempts to construct a separate money management module.

3 Method

Each minute can have thousands of ticks; hence, training an agent with historical tick data consumes a vast amount of time. This work aims to construct an RL agent that uses Open-High-Low-Close (OHLC) data and makes a decision every 15 minutes in order to reduce training time and the required computational capacity. However, this approach should also work with tick data (or in real-time), since tick data can be resampled into OHLC format. An update in tick data will change the last candle in the candlestick chart, and the agent can make a new decision after each tick. The RL agent can have only one open position at a time; i.e. the current position must be closed first in order to open a new one.

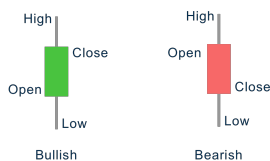


Fig. 1. An illustration of candlesticks

3.1 Time series input

OHLC data in 15-minute and 1-hour time frames were used to generate inputs. Each time frame has 32 latest candlesticks. The 15-minute candles capture short-term price actions, while the 1-hour ones help to identify the market trend.

The price movement patterns do not depend the actual price; they rather depend on the relative positions of the past prices. Thus, instead of using raw prices, the log return function is used to transform them into relative movements.

$$\text{LogReturn}_t = \log(p_{t+1}/p_t)$$

Apart from the price movements, the following technical indicators were utilized in order to predict market trends better:

- Relative Strength Index (RSI).
- Bollinger Bands and %B.
- Money Flow Index (MFI).
- Moving Average Convergence Divergence (MACD).

Technical traders often use MACD by looking at its relative position to the signal line, which is a fast exponential moving average of the MACD line. Therefore, the difference of the two lines is taken instead of both lines.

3.2 Gramian Angular Field (GAF)

The time series input data need to be transformed into a kind of image, so that the 2D convolutional layers of the CNN can process them. Gramian Angular Field is a Gram Matrix; hence, it can preserve temporal dependency since time increase from left to right and from top to bottom. The main idea of GAF is to convert the values into polar coordinates, then uses the sine and cosine functions to compute the final values. Therefore, the input data X need to be scaled to the interval $[-1, 1]$ using the following equation:

$$\tilde{x}_i = \text{clip} \left(\frac{2x_i - \max(X_{train}) - \min(X_{train})}{\max(X_{train}) - \min(X_{train})}, -1, 1 \right)$$

Due to the fact that the scaled test data can still lie outside the interval $[-1, 1]$, the clip function is applied on the scaled data. This work assumes that the training data must contain enough diverse movement patterns, ranging from slow, small to sudden and large movements.

The variant Gramian Angular Difference Field (GADF) was used in this work, which is defined as follows:

$$\phi_i = \arccos(\tilde{x}_i)$$

$$GADF = \begin{bmatrix} \sin(\phi_1 - \phi_1) & \dots & \sin(\phi_1 - \phi_n) \\ \vdots & \ddots & \vdots \\ \sin(\phi_n - \phi_1) & \dots & \sin(\phi_n - \phi_n) \end{bmatrix}$$

Each time series of length n is transformed into a GADF of size $n \times n$. Each technical indicator produces a time series; therefore, m indicators result to an output of shape $m \times n \times n$, which the CNN can treat as an image of size $n \times n$ with m channels.

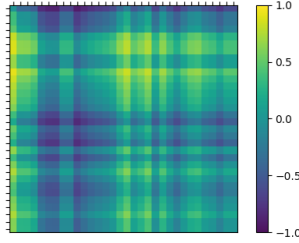


Fig. 2. An GADF representation of 32 RSI values

Piecewise Aggregation Approximation (PAA) [13] is often used in combination with GAF in order to smooth the data and to identify trends easier. This

work, however, discards PAA because it may remove information that is relevant to match price movement patterns. The trends can still be recognized in a larger time frame (1-hour) without having to apply PAA on the data.

3.3 Proximal Policy Optimization (PPO)

A small batch can contains only one or a few patterns, which may lead to poor policy or model collapse after updating the weights if the step size is large enough. Proximal Policy Optimization (PPO) [2], based on the idea of Trust Region Policy Optimization (TRPO) [3], makes sure the policy is not stepping to far away from the starting point in each update. Instead of using an extra Kullback-Leibler divergence term in the loss function, the Clipped Surrogated Objective function [2] is used:

$$r_t = \frac{\pi_\theta(a_t|s_t)}{\pi_{\theta_{old}}(a_t|s_t)}$$

$$L^{CLIP}(\theta) = \hat{\mathbb{E}}_t \left[\min(r_t(\theta)\hat{A}_t, clip(r_t(\theta), 1 - \epsilon, 1 + \epsilon)\hat{A}_t) \right]$$

Generalized Advantage Estimation (GAE) [4] is used to approximate the advantage function, which is the exponentially-decayed sum of TD residuals:

$$\delta_t^V = R_t + \gamma V(s_{t+1}) - V(s_t)$$

$$\hat{A}_t^{GAE(\gamma, \lambda)} = \sum_{l=0}^{\infty} (\gamma \lambda)^l \delta_{t+l}^V$$

Apart from GAE, this work hypothesizes that maximizing the cumulative reward in short term can result to better performance. In particular, the ultimate objective is maximizing the return of individual trades, which will act as a guidance for the model to find the optimal policy; namely, profit from a trade does not compensate any loss from previous trades. Hence, the model should always learn to cut loss and take profit at the right time. In order to implement this idea, an additional flag that indicates the end of a trade is stored in the experience memory. The returns are computed as usual but with discount factor $\gamma = 1$ and the return will be reset to zero after seeing the flag.

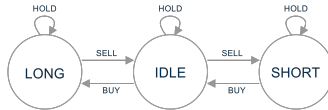


Fig. 3. Illustration of the state transitions

Actions There are 3 discrete actions: *BUY*, *SELL* and *HOLD*. For instance, a long position can be opened by taking the action *BUY* if there is currently no open position; a long position can be closed by taking the action *SELL* (see Figure 3). Because there can be only one open position at a time, there are some invalid actions; e.g. the agent cannot take the action *BUY* if a long position is currently open. Invalid actions are handled by using a valid action mask $m_t \in \{0, 1\}^3$ that is provided by the environment. A possible method is applying the mask to the probabilities directly by using element-wise multiplication, followed by redistributing the probabilities for the remaining actions. Another method is applying the mask to the activation of the actions by setting the activation to a large negative number, e.g. $-1e + 8$, where the value in the mask is 0. The softmax function will return zero probability for the masked out actions.

Reward To support the idea mentioned above, the reward function is the change in profit/loss of the opening position (hence, also the change in equity) plus the change in balance, which only changes after closing the position. This can be formulated as the following equation, where E_t is the equity and B_t is the balance at time step t :

$$R_t = (E_t - E_{t-1}) + (B_t - B_{t-1})$$

Loss function The loss function combines the following components: the Clipped Surrogated Objective L^{CLIP} , the squared-error term of the value function L^{VF} (weighted by c_1) and a small entropy term H (weighted by c_2) to encourage exploration:

$$H(\pi(\cdot|s_t)) = - \sum_{a \in A} \pi(a|s_t) \log \pi(a|s_t)$$

$$L(\theta) = -L^{CLIP}(\theta) + c_1 L^{VF}(\theta) - c_2 H(\pi_\theta(\cdot|s_t))$$

3.4 Model architecture

Architecture overview The CNN extracts features from the GAFs and flattens them into a vector, which is then concatenated with 4 additional information: the current position state (-1 for buying, 1 for selling and 0 otherwise), profit/loss of the opening position, the current hour and the elapsed hours since the position opened divided by 24. The result of the concatenation forms a state of the environment. The actor and the critic are just shallow networks that consist of a hidden layer and an output layer. Figure 4 illustrates the overview of the architecture.

CNN architecture A CNN with residual connections [14] is used to construct the feature extractor (see Figure 5). Unlike image classification tasks where only layer-wide activation is important since spatial translation is irrelevant, the cell position in this approach contains temporal meaning and has significant

during back-propagation. However, because the policy is constantly changing during the training phase, training both the actors simultaneously can easily make the model suffer from model collapse, or even worse, hit NaN loss during training. It is better to train this actor separately in a self-supervised manner, where the labels are generated on-the-fly by the actual returns of the agent. The binary cross entropy loss function is used in this work, which can be formulated as follows:

$$L^{MM} = -\frac{1}{N} \sum_{i=1}^N (\mathbb{1}_{G_i > 0} \log(\hat{y}_i) + \mathbb{1}_{G_i \leq 0} (1 - \hat{y}_i))$$

4 Experiments & Results

Two years data of the currency pair EUR/USD¹ were used to train and test the agents:

Training data: Jan. 2017 → Dec. 2017

Test data: Jan. 2018 → Dec. 2018

All the experiments have the following hyper-parameters:

- Learning rate: 0.0003
- Batch size: 128
- Replay memory size: 1024
- Clipping range ϵ : 0.2
- Value function coefficient $c1$: 0.5
- Entropy coefficient $c2$: 0.001

The discount factor γ is 0.99 and GAE- λ is 0.95 when using GAE, whereas γ is 1.0 when maximizing finite horizon undiscounted return.

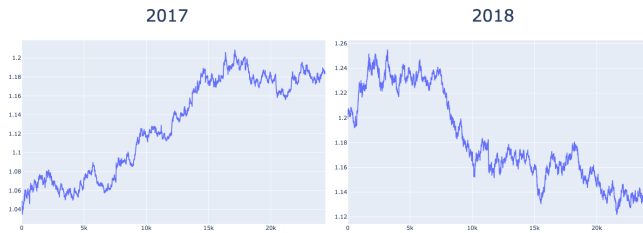


Fig. 6. Training data and test data

¹ Provided by FXCM. Online available at <https://github.com/fxcm/MarketData>

The optimizer used in the experiments is Adam [15]. The weights were initialized by the Xavier Uniform method [16], which inits the weights from a uniform distribution $\mathcal{U}(-a, a)$:

$$a = gain \times \sqrt{\frac{6}{fan_in + fan_out}}$$

Because the models in this work use only ReLU as activation function, $gain$ is always $\sqrt{2}$. In addition, a dropout layer is added after each convolutional block, the dropout rate is 0.2. L2 regularization term is also added to the loss function in order to keep the weights small; $\lambda = 0.0001$ is used in the experiments. This can be formulated as follows, where L_0 denotes the unregularized loss.

$$L = L_0 + \frac{\lambda}{2n} \sum_w w^2$$

This papers assumes that the agent trades in micro-lots, i.e. 1 lot is equal to 1,000 units of the base currency instead of 100,000 units when trading in standard-lots. Every agent starts to trade with a capital of €100.

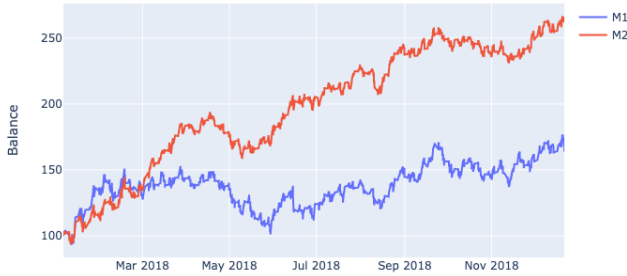


Fig. 7. Comparison between M1 and M2

The first experiment compared the two approaches: maximizing infinite horizon discounted return (denoted as M1) and maximizing undiscounted return of individual trades (denoted as M2). Both agents were trained with the same initialization, hyper-parameters. The size of orders is constant in this experiment: 1 lot. The results in Figure 7 shows that maximizing undiscounted return of individual trades indeed helped to achieve better performance. Although the market trends in 2018 are very different from the trends in 2017 (see Figure 6), both agents managed to achieve positive return at the end of the year. However, the performance of M2 is significantly better than that of M1. Moreover, max drawdown of M1 is 33.5%, while M2 has only **18.1%**.

In the second experiment, the same agent was evaluated 3 times with different settings: fixed order sizes (1 and 2 lots; denoted as F1 and F2, respectively), and dynamic order size with the money management module (denoted as MM), $S_{min} = 1$ and $S_{max} = 2$.



Fig. 8. Comparison between fixed order sizes and dynamic order size

The results of the second experiment is shown in Figure 8. The agent MM achieved slightly better performance than F2. The max drawdown of F2 is 26.68%, whereas the max-drawdown of MM is **23.29%**. The results confirmed that the money management module can indeed estimate the chance of winning with and therefore, helps to reduce loss and maximize profit.

5 Conclusion

This work experimentally showed that reinforcement learning can be applied for Automated Forex Trading with scalping strategies, which only use technical indicators to predict short-term market trends. Although scalping strategies only catch small price movements, they can still manage to earn a large amount of profit since the agent trades in relatively high frequency.

Gramian Angular Fields help to process time series data with convolutional neural networks, which reduce computation time since RNN is slower than CNN by design. The model architecture for CNNs that handle GAF input, however, is different from that for CNN in computer vision tasks, since the cell position can contain relevant temporal meaning. Downsampling techniques can be used but with caution.

The first experiment confirmed the hypothesis that maximizing cumulative reward of individual trades can help to achieve better performance. The main

reason could be the elimination of the chance to compensate losses from previous trades, which relies heavily on upcoming price movements at that time. This behavior reduces the generalization capability of the model. Thus, the elimination acts as a guidance for the model to know where to focus on.

An additional money management module can help to reduce loss and maximize profit, since it can estimate the chance of winning in the current state. This, however, needs to be trained separately in a self-supervised manner because the chance of winning strongly depends on the current policy. Training this module with the main model simultaneously is extremely unstable. Further methods for money management strategy could be an interesting topic for future work.

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Data Analytics and Aggregation Platform for Comprehensive City-Scale AI Modeling

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Abstract. This research proposes an AI platform for data sharing across multiple domains To go beyond the digital transformation efforts in smart city development, the AI city is created on the architecture of cross domain data connectivity and transform learning in the machine learning paradigm. The basic emotion expression study is conducted to interpret the emotional states and the mental health of people in the urbanized city. The validation in healthcare and human behavioral detection has been conducted. The results of information augmentation draw attention in the immersive visualization of Thammasat model.

Keywords. healthcare, elderly care, image recognition, speech emotion recognition, AI city, smart city

1. Introduction

Since the term of smart city is unveiled there are many efforts have been made by the escalation of the advancement of information and communication technology (ICT) and big data. Until now, it is still hard to find a formal definition of the smart city. However, there seems to have a sharing ultimate goal of improving the inhabitant's quality of life (QoL) by means of the efficiency and sustainability of urban operations with respect to economic, social and environmental aspects [1]. A broad view of smart city is elaborate

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in the combination of smart infrastructure, smart building, smart transportation, smart energy, smart healthcare, smart technology, smart governance, and smart citizen. The advancement in digital technology is another factor that enables the smartness of devices interfacing to the applied domains. On another research track, the artificial intelligence (AI) technology significantly gains its potential in the real-life applications in the recent years. There are many good examples such as a machine can interact with people by speaking the same language, diagnose disease by learning the patient symptoms or x-ray images, recognize object or face from images, sense the emotion in the composed music, etc. The next challenge of the smart city which realizes the efficiency in city operation becomes insight by the achievement of artificial intelligence technology. Data connectivity for modeling and prediction are the key challenge for making a city-scale AI system. Some good examples can be seen in AI City challenge organized by Smart World and NVIDIA². Multiple cameras for vehicle tracking and anomaly detection are one of the interests in intelligent traffic systems (ITS) challenge. AI City gets into view when Oliver Wyman Forum gets started extensive global research on 105 cities to better understand the potential disruption brought by AI³. The goal of the survey is to move beyond admiring things like “smart cities” and start a data-informed conversation about how to address the very real opportunities and challenges of AI disruption. It is reported that most cities do not address major societal changes driven by AI and other technologies. They mainly focus on smart city operation efficiency and sustainability developments.

Thammasat AI City initiative has an aim to establish a resilient AI platform for the inhabitants to find out the opportunities and challenges of AI disruption. Rangsit campus is in where Thammasat University is located, surrounded by research and higher education facilities, industrial, business and agricultural areas. To confront with the AI disruption, Rangsit campus is geared to be a role model of AI City for the fully activation of the use of data and physical availability. The Thammasat AI City focuses on the four domains of elderly and healthcare, mobility, agriculture, and environment under the awareness of societal change after the COVID-19 pandemic technology trends namely distributed city, human traceability, new reality, home-office integration, contactless technology, digital lending, and frugal innovation⁴.

2. Issues in Urbanization

Concentration of urban development both in terms of infrastructure transportation system and employment thus causes immigration from rural areas to urban areas in order to find opportunities to improve their quality of life. Many problems occur in the city density of daily activity and traveling if there is no well urban planning. The majority of the population are unable to bear the cost of living in the city area. This is one of the reasons why urban sprawl has occurred, which can be observed in the country center city like Bangkok and its vicinities with a population growth rate of 0.5 percent. The urban areas deteriorated during the period of 1980s before reviving due to the development of mass transit systems in the 1990s under the higher efficiency of connecting the urban areas.

² AI City Challenge, <https://www.aicitychallenge.org>, <http://smart-city-sjsu.net/AICityChallenge/>

³ Global Cities AI Readiness Index by Oliver Wyman Forum, <https://www.oliverwymanforum.com/city-readiness/global-cities-ai-readiness-index-2019/index-summary.html>

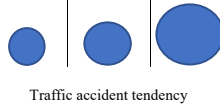
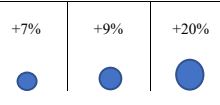
⁴ After Corona, Nikkei BP, Xtech, July 2020

The better transportation system allows the people to get access to more places in the city. The urban area is thus revitalized again while the urban area is continuously expanding to cover the area outside the city. The Bangkok urban area grew from 1,900 square kilometers to 2,100 between 2000 and 2010, making it the fifth-largest urban area in East Asia in 2010, larger than megacities such as Jakarta, Manila, and Seoul [2].

Thammasat University, Rangsit Campus, is located in Pathum Thani Province, a Bangkok vicinity city in the north. It covers an area of 1,526 square kilometer with 985,643 in population, in 2020 report by National Statistical Office of Thailand⁵. It is renowned for an area of research and education, economy, and agriculture. It serves an infrastructure for ten renowned universities, Thailand Science Park, seven mega economic areas of shopping malls and agricultural markets, where its agricultural areas⁶ are 35.11 percent of the city.

No exception, Pathum Thani Province is facing its high-rising population situation. It comes along with urbanization problems i.e. insufficient elderly care facilities, environmental deterioration, traffic congestion that deteriorates the total inhabitants' quality of life. The problems and challenges to bring about new opportunities are tabulated in Table 1 [3].

Table 1. Problems and challenges of Pathum Thani Province urbanization⁷

Problems	Trends of Situation			Challenges
	2021	2026	2036	
1. Traffic congestion and road safety problems <ul style="list-style-type: none"> - Traffic jams - Traffic accident problems - Transportation management of industrial estates and Talat Thai commercial districts - Travel alternatives 	+46%	+93%	+186%	<ul style="list-style-type: none"> - Never solved traffic problems - Increasing of accidents - Creation of multiple alternative traveling systems
 <p>Traffic accident tendency</p>				
2. Environmental problems <ul style="list-style-type: none"> - Garbage problems (Pathum Thani province is 25th dirtiest province in the country) - Air and noise pollution - Water quality problems 	+7%	+9%	+20%	<ul style="list-style-type: none"> - Construction of a wastewater treatment system of the province - Campaigning to maintain water quality and industrial wastewater treatment - Creating an efficient solid waste management system
 <p>Trends in the amount of waste in the future</p> <p>(The trend of water quality problems is unpredictable, with wastewater from Industrial, community and agriculture sectors, some are not treated before discharged into water reservoirs.)</p>				
3. Economic and tourism problems <ul style="list-style-type: none"> - Upgrading of local wisdom to the national market - Growth of a subsidiary company 	<ul style="list-style-type: none"> - The trend of the increase of small companies in Pathum Thani Province has an average increase of 0.14% per year (2007-2016), with an increase of more than 1,000 companies every year. 			<ul style="list-style-type: none"> - Adding value and productivity of the agricultural sector - Developing the capabilities of the target industries - Service sector development

⁵ Pathum Thani population report, <http://service.nso.go.th/nso/nsopublish/districtList/S010107/th/5.htm>

⁶ Pathum Thani area information, <https://www.opsmoac.go.th/pathumthani-dwl-files-421691791843>

⁷ Source : Pathum Thani Plan 2018 - 2022, The Pathum Thani Provincial Office, 2018

	- The most registered businesses are wholesale, retail, automotive repair and motorcycles, followed by industrial production.	- Raising the standards and potential of local entrepreneurs
4. Lifestyle problems <ul style="list-style-type: none"> - The population is increasing. - The number of latent populations from work has increased. - The security from crime. - The sufficiency of the infrastructure in the future due to the increasing population. 	<div style="display: flex; justify-content: space-around;"> <div style="text-align: center;"> <p>+7%</p> </div> <div style="text-align: center;"> <p>+11%</p> </div> <div style="text-align: center;"> <p>+17%</p> </div> </div> <p style="text-align: center;">Population trends from the civil registration in the future</p> <div style="display: flex; justify-content: space-around;"> <div style="text-align: center;"> <p>+17%</p> </div> <div style="text-align: center;"> <p>+38%</p> </div> <div style="text-align: center;"> <p>+78%</p> </div> </div> <p style="text-align: center;">The latent population trend from the past latent population.</p> <ul style="list-style-type: none"> - Crime cases in the past year (2016) have an increasing trend. 	<ul style="list-style-type: none"> - The development of specialized medicine - Surveillance of the epidemic and research studies on emerging disease prevention methods - Increasing medical resources to meet local needs - Social Immunity - Social development and basic security of the people

3. AI Ready City Initiatives

Thammasat University has launched its initiative in enabling a city-scale AI in the project of AI Ready City Networking in RUN. The project is to transform the area of 2.8112 square kilometers of Thammasat University in Rangsit campus for modeling the AI capacity in a city scale since the current research in AI is heavily suffered from the insufficiency and diversity of data. Reliability and connectivity of the data will be collected and made available to fully demonstrate the capability of AI in the real-life campus. It is designed to function as a based platform [4] for the four most highly impact domains in the Rangsit city, i.e. healthcare, environment, mobility, and agriculture by being equipped with AI enabled healthcare monitoring devices [5], noninvasive bed sensors [6], environmental sensors, video analytics cameras, street lights, indoor tracking devices [7], and drones for aerial photography. Figure 1 depicts the project architecture with its domain specific connectivity.

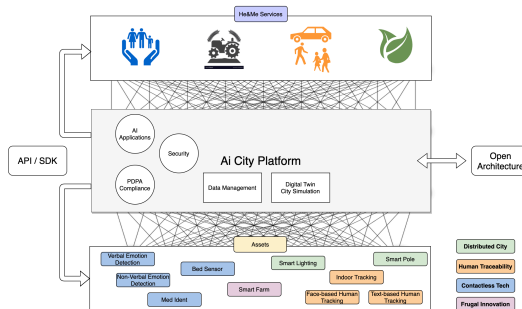


Figure 1. AI Ready City architecture and domain specific connectivity

To make the data from various sources available for modeling, the data are stored and forwarded via low energy mesh network (6LoWPAN protocol in case of smart lighting, Bluetooth low energy (BLE) in case of indoor positioning and bed sensor, etc.) to the cloud services. To reduce the high bandwidth consumption devices such as video streaming of surveillance cameras, LAN connectivity and several techniques⁸ (steady state at rest, motion detection, etc.) are adopted. In bed sensor for elderly care system, the detection of types of on-bed position is localized for not only to realize the real-time warning but also to conserve the bandwidth by sending the compressed results to the cloud.

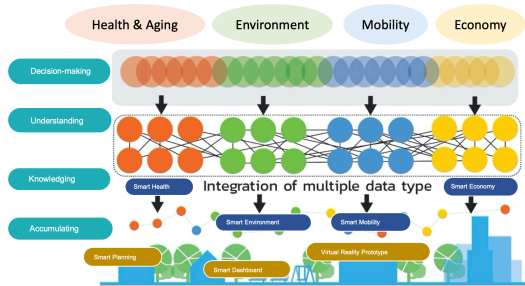


Figure 2. Deep intelligent IoT in fully connected network

The AI City Project is realized by establishing the four main layers composed of accumulating, knowledgeing, understanding and decision-making layers as illustrated in Figure 2. Accumulated data from any kinds of Internet of Things (IoT) devices is analyzed and connected to yield the models and prediction results in four targeted domains. The lowest layer is the layer of accumulating physical raw data through sensor network devices to provide sufficient labeled data in knowledgeing layer. Model training for specific tasks is conducted in the understanding layer. The appropriate machine learning paradigms are introduced and evaluated to produce the results in decision-making layer. The connectivity and selection of the data from various sources are crucial to implement in the city-scale AI platform development.

4. Health Monitoring and Elderly Care

The Internet of Things and wearable technology have made life easier. With these small electronic sensors, placed on human body, the body temperature, blood pressure, blood oxygen, respiratory rate, etc. can be continuously measured. However, there are many issues in designing the real-time health data monitoring devices to be comfortable for wearing and harmonious with daily activities. Complexity in maintaining the wearing, especially for the elderly, hinders the continuous use of the devices. The contactless technology is primarily considered to reduce the barrier of use.

⁸ <https://info.verkada.com/surveillance-features/bandwidth/>

To connect health data from basic medical devices, the Smart Health Platform is introduced as overviewed in Figure 3. Fast Healthcare Interoperability Resources (FHIR) standard is adopted to describe the data formats and elements (resources) and the API for exchanging electronic health records (HER) [8]. The standard was created by the Health Level Seven International (HL7) health-care standards organization.

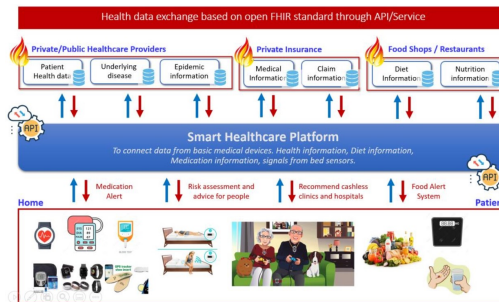


Figure 3. Smart Health Platform architecture

Emphasizing on the contactless technology, the project related healthcare applications have been implemented to conduct on the Smart Health Platform such as bed sensor for elderly care (BedSense) and medicine blister package identification (MedIdent).

4.1. Bed Sensor for Elderly Care (BedSense)

BedSense is created for monitoring the on-bed position of elderly for bed fall prevention.. The system includes an on-bed position prediction system, real-time monitoring system, and notification system via LINE application (a widely used mobile messenger application especially in Thailand).

Falling from a bed frequently occurs when an elderly attempts to get out of the bed or comes close to the edge of the bed. The mishaps have a high possibility of serious injuries, such as bruises, soreness, and bone fractures. Moreover, lacking of repositioning the body of a bedridden elderly may cause a serious bedsore. To avoid such a risk, a continuous activity monitoring system is needed for taking care of the elderly.

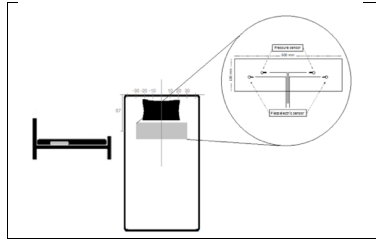


Figure 4. Sensor panel positioned under the mattress in the thoracic area

BedSense performs the bed position classification based on the sensor signals collected from only four sensors embedded in a panel. The set of sensors is composed of two piezoelectric sensors and two pressure sensors. The panel is installed under the mattress on the bed, as depicted in Figure 4.

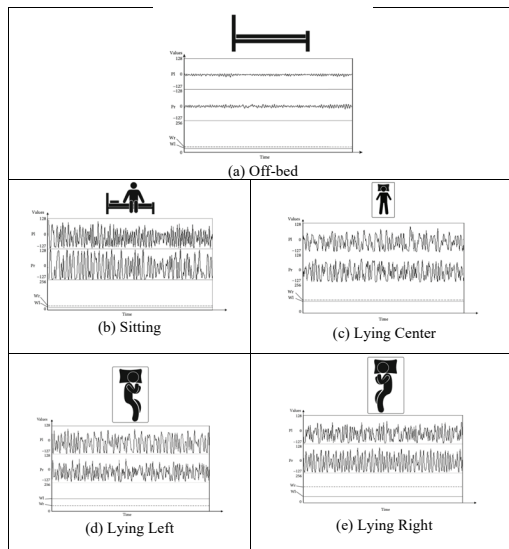


Figure 5. Correlation between signals and positions

The bed positions are classified into five different classes, i.e., off-bed, sitting, lying center, lying left, and lying right, as shown in Figure 5. To collect the training dataset, three elderly samples are asked for consent to participate in the experiment. In our approach, a neural network combined with a Bayesian network is adopted to classify the bed positions and put a constraint on the possible sequences of the bed positions. The results from both the neural network and Bayesian network are combined by the

weighted arithmetic mean. The experimental results have a maximum accuracy of position classification of 97.06% when the proportion of coefficients for the neural network and the Bayesian network is 0.3 and 0.7, respectively [6, 9].

4.2. Medicine Blister Package Identification (MedIdent)

Drug dispensing statistics from Rajavithi Hospital reveal that the drug dispensing process contains errors at 3.8 percent [10]. To sustain the health condition, elderly also needs a medicine reminder when the number of prescription drugs to take per day has a trend of getting higher. Almost 90% of older adults regularly take at least 1 prescription drug, almost 80% regularly take at least 2 prescription drugs, and 36% regularly take at least 5 different prescription drugs [11]. Medicine Blister Package Identification (MedIdent) application is created to ensure the drug dispensing process in the hospital and assist elderly in medicine reminding. The accuracy of image classification model is improved by using a double-side transformed image dataset with download from Highlighted Deep Learning (HDL) work [12]. The dataset which is composed of two-hundred seventy-two images for types of medicine blister packs, including 72 images of front side and back side merged with a horizontal cropped background, are used for training the model. The blister package image dataset uses a deep learning model with a ResNet-101 pre-trained model from the TensorFlow framework. The experimental results indicated that the TensorFlow framework achieved higher precision, recall, and F1-score than the Caffe framework. A ResNet-101 model with histogram equalization in the front and back sides has yielded the highest accuracy of 100 percent [13], as shown in Figure 6.

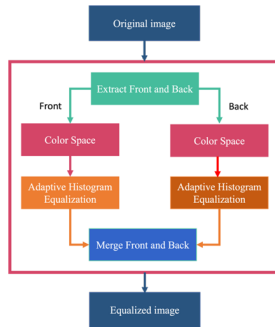


Figure 6. Pre-process blister package image

5. Human Behavioral Detection

To ensure the safety of urban residents and still maintaining their privacy, in the AI Ready City project, we therefore introduce the concept of human traceability using the principles of digital image processing and natural language processing to find suspicious persons and objects. Some necessary works are conducted on emotional expression detection to trace their intention, and multiple vehicle tracking to capture the time-to-

time traffic situation. Transfer learning approach is essentially attempted for domain adaptation to avoid the vast computation and time resources consumption.

5.1. Weapon Detection Using Faster R-CNN Inception V2

Among the most common illegal behaviors, including robbery, quarrels and the carrying of weapons in public, carrying a weapon in public is the most dangerous crime. The situations frequently draw to the case of losses according to the criminal public records. We develop a model to detect the common weapons such as firearms and knives which are commonly found in the criminal cases bringing about big losses.

To train a model for the weapon detection, the datasets used in this research are collected from two public datasets: ARMAS Weapon detection dataset and IMFDB Weapon detection system. TensorFlow Object Detection API is used to detect the target objects by using 1) SSD MobileNet-V1, 2) EfficientDet-D0, and 3) Faster R-CNN Inception Resnet-V2. The experimental results show that the object detection model trained by the Faster R-CNN Inception V2 using ARMAS Weapon detection dataset yields the highest mAP of 0.540 with the Average Precision of 0.5 IoU and 0.75 IoU at 0.793 and 0.627, respectively [14].

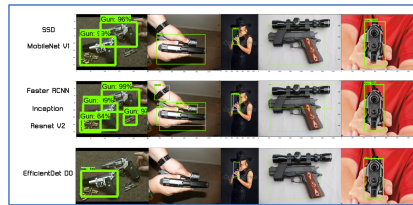


Figure 7. Weapon detection model on example images

However, the MobileNet-V1 provided higher detection precision than in EfficientDet-D0 and Faster R-CNN Inception Resnet-V2 for detecting gun images. Figure 7 exhibits that the EfficientDet D0 is unable to detect the labels on gun images, while Faster R-CNN Inception Resnet-V2 shows false positive detection on non-pistol objects.

5.2. End-to-End Speech Emotion Recognition for Low Resource Languages

Emotion balance of the residents is critical when the city is urbanized in a high pace along with the rapid availability of the social activity invasion technology. Individual activities are easily tracked by the public devices not only by the visibly aware cameras but also the interactive communication via various types of social media applications. Regularly detection of the resident emotion to measure their QoL is used to assist in the evaluation of the current state of urbanization.

Via the general conversation, the end-to-end speech emotion recognition is proposed to capture the speaker emotion from their responding speech. To realize speech emotion recognition for the low resource languages such as Thai, we adopt Wav2Vec2.0 [15] and XLSR [16] released by Facebook in 2020 as the pre-trained models in the transform learning process as depicted in Figure 8. XLSR outperforms Wav2Vec2.0 in low

resource language preliminary experiment by using shared quantization and shared context representation between languages. VTLP (vocal tract length perturbation) is augmented to simulate the new vocal tract information in speech which increases the informative number of speakers by perturbing the vocal tract length.

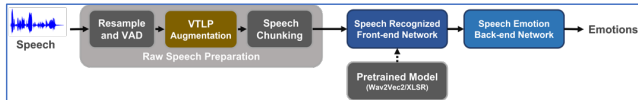


Figure 8. End-to-end speech emotion recognition in pipeline for low resource languages

5.3. Verbal and Non-verbal Corpus Construction

One of the problems affecting on the people QoL in the digital age is the mental health. No exception on the societies in Thailand, it has a chain affect on the individual, family and social level. One of the most common mental health problems is depression. It is reported in [17] that adolescent depression patients (15-19 years) have a 6.24% higher risk of suicide, and 6.70% are more common in the central and eastern regions, where females have a higher risk than males. There is a trend of the increase in number of adolescent depression patients.

Jantima Angkapanichkit et al. [18] indicates that language is a clue to spot the signs of depression in a person as well as to distinguish between people with depression and non-depression. However, expressions of emotion in the Thai language have not been grouped and classified systematically with clear criteria due to the difficulties in text analysis and interpretation. In addition, the expression of emotion in non-verbal or paralanguage, as a context of communication, has not been yet conducted in the Thai language.

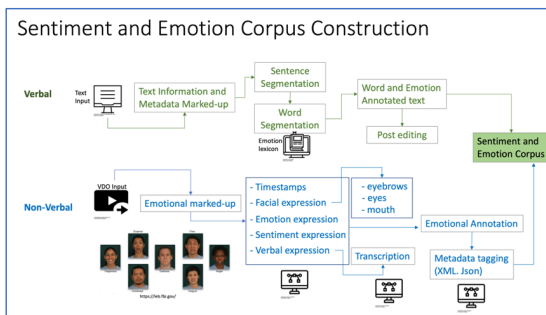


Figure 9. Process of sentiment and emotion corpus construction

The objective of the study is to create a repository of verbal emotions and sensory languages in Thai and non-verbal languages in order to interpret the emotional states and the mental health of people in the urbanized city. The verbal aspect is included in the linguistic information in word, phrase, sentence and dialog levels, which is relating to emotion and depressive disorder information. The overview of the process of sentiment

and emotion corpus construction is shown in Figure 9. Verbal information are labeled in text and non-verbal information are labeled in video which are aligned by the video timestamps to produce the final cut of the corpus.

Ekman coined the word emotion as “a process, a particular kind of automatic appraisal influenced by our evolutionary and personal past, in which we sense that something important to our welfare is occurring, and a set of psychological changes and emotional behaviors begins to deal with the situation” [19]. Based on the studies in [20-23], we aggregate the concern of cultural distinction and classify the expression into six basic emotions, i.e., happy, angry, sad, relax, stress, and neutral (fear and disgust are specified as a negative-activate feature in stress; surprise is specified as a positive-activate in happy), as shown in Figure 10.



Figure 10. Collection of six basic emotions

5.4. Person Image Search by Natural Language Description

Closed Circuit Television or CCTV is the most widely used in security camera system. It has a main function of recording events for later viewing, and also being used to monitor the on-going happenings in order to strengthen the stability and security of the target area. In the current CCTV systems, however, it is time-consuming to search for any specific scenes i.e. perpetrators or suspicious occurrences. To facilitate human traceability in AI City, person image search by natural language description is proposed to work on the huge amount of recorded videos. The task is defined to solve the social problems such as finding missing person, child abduction, suspicious person by means of the description of person appearance. We create a human dataset of full-body images such as the images captured from the recorded closed circuit camera. The images are described by the person appearance in the Thai language, such as a girl wearing a grey T-shirt, short pants, shouldering a black bag and wearing sneakers, as shown in Figure 11.



Figure 11. Example of human data collection with Thai description

Based on GNA-RNN [24] and TIPCB [25], we trained the model by changing the encoder layer for TIPCB and the embedding layer for GNA-RNN to model of Thai text in order to analyze the Thai-translated CUHK-PEDES data set. The TIPCB model is then trained in the Thai text version. The encoder is also changed from the BERT model [26] to the WangchanBERTa model [27]. The configuration is shown in Figure 12.

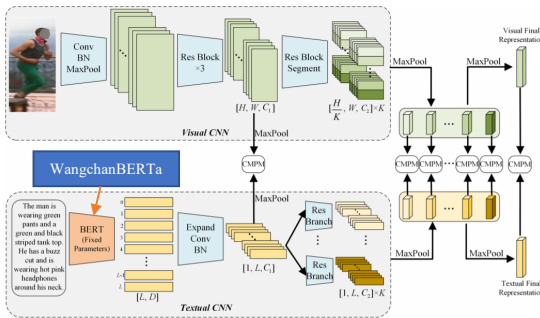


Figure 12. Configuration of text and image modeling to retrieve the target image by the image and the description of appearance

The result of trained model can reach the recall counted within the top five results is 0.74. The trained model is then used to calculate the similarity between the text input and the images. In the experimental results, it is found that the description text corresponding to the person appearance yield a higher score than the non-conforming description text. Therefore, this score can be used to retrieve the persons having the same appearance described in the text.

5.5. Transfer Learning-based Vehicle Classification

Traffic monitoring and management is a modern feat that allows authorities to achieve resilience in road safety, controlled commute and assessment of road conditions [28]. Vehicle detection on video sequence obtained from a network of surveillance cameras allows automation in the traffic management system. Computer vision and machine/deep learning have become the key technical advancement through the past years in the

domain of vehicle detection and multi-object tracking (MOT). The deep learning (DL) methods have achieved the state-of-the-art in detecting and classifying vehicles on video streams [29]. These methods when coupled with fast tracking algorithms can provide real-time multiple vehicle tracking, depending upon the accuracy and speed of detection. However, the DL models require to be trained on a large training dataset, and still can fail to produce an accurate multi-object detection and classification. In this section, we discuss real-time vehicle classification using a transfer learning-improved DL model.

Many of the studies that use DL models are pre-trained on a large training dataset such as COCO and KITTI [30], which include classes such as car, bike, truck and bus. In our study, we classify the vehicles into seven classes i.e. car, bus, taxi, bike, pickup, truck, and trailer. As some of the classes in the existing datasets include multiple of our desired classes (e.g. pickup and SUV are classified as trucks in COCO dataset), we are unable to use these dataset and pre-trained models in our method. The problem is often called a domain-shift problem. It occurs because the machine learning methods including DL assumes that the training and test dataset are produced in the same or similar environment. To address this problem, we use the method of transfer learning [31, 32] to improve the performance of the YOLO networks that we train on a custom large training dataset and further efficiently reduce the training time.

Classes	Average Precision (AP)				Classes	Average Precision (AP)			
	YOLOv3	YOLOv3t	YOLOv5l	YOLOv5s		YOLOv3	YOLOv3t	YOLOv5l	YOLOv5s
car	0.314	0.338	0.326	0.369	car	0.764	0.755	0.722	0.745
bus	0.22	0.172	0.158	0.16	bus	0.861	0.761	0.762	0.840
taxi	0.538	0.468	0.536	0.503	taxi	0.660	0.687	0.733	0.673
bike	0.338	0.258	0.358	0.304	bike	0.792	0.724	0.817	0.784
pickup	0.296	0.268	0.279	0.284	pickup	0.757	0.719	0.686	0.711
truck	0.255	0.178	0.199	0.071	truck	0.688	0.584	0.654	0.628
trailer	0.129	0.105	0.041	0.023	trailer	0.447	0.457	0.499	0.492

Figure 13. The result without transfer learning (left) and after transfer learning (right) with test dataset

Camera	No. of Frames	Vehicle Face	Class	GT	YOLOv3			YOLOv3t			YOLOv5l			YOLOv5s			OA
					P	R	OA	P	R	OA	P	R	OA	P	R	OA	
Cam 1	7500	Back	car	217	0.99	0.95	0.97	0.96	0.91	0.93	0.99	0.97	0.98	0.98	0.91	0.95	
			bus	5	0.56	1.00	0.78	0.80	0.80	0.80	1.00	0.80	0.90	0.80	0.80	0.80	
			taxi	6	0.86	1.00	0.93	0.86	1.00	0.93	0.75	1.00	0.88	0.86	1.00	0.93	
			bike	20	1.00	1.00	1.00	1.00	1.00	1.00	0.95	1.00	0.98	1.00	0.90	0.95	
			pickup	99	0.98	0.86	0.92	0.92	0.86	0.89	0.98	0.96	0.97	0.88	0.84	0.86	
			trailer	4	0.33	0.50	0.42	0.43	0.75	0.59	0.60	0.75	0.68	0.43	0.75	0.59	
Total				1	0.50	1.00	0.75	0.50	1.00	0.75	1.00	1.00	0.90	0.90	0.90		
Total				352	0.74	0.90	0.82	0.78	0.90	0.84	0.90	0.93	0.91	0.71	0.74	0.72	
Cam 2	9060	Side	car	16	1.00	0.88	0.94	1.00	0.94	0.97	1.00	0.94	0.97	0.93	0.88	0.90	
			bike	1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
			pickup	12	0.85	0.92	0.88	0.92	0.92	0.92	0.92	1.00	0.96	0.83	0.83	0.83	
			truck	3	0.75	1.00	0.88	0.75	1.00	0.88	1.00	1.00	1.00	0.43	1.00	0.71	
			trailer	4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.25	0.63	
			Total				36	0.92	0.96	0.94	0.93	0.97	0.95	0.98	0.99	0.84	0.79
Cam 3	8800	Side	car	87	0.96	0.93	0.95	0.99	0.86	0.92	0.98	0.84	0.86	0.99	0.83	0.91	
			taxi	6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
			bike	12	1.00	0.83	0.92	1.00	0.83	0.92	1.00	0.83	0.92	1.00	0.83	0.92	
			pickup	91	0.93	0.93	0.93	0.87	0.97	0.92	0.96	0.98	0.97	0.86	1.00	0.93	
			truck	12	1.00	0.58	0.79	0.86	0.50	0.68	0.92	1.00	0.96	0.82	0.75	0.78	
			trailer	3	0.43	1.00	0.71	0.43	1.00	0.71	1.00	0.67	0.83	0.67	0.33	0.50	
Total				211	0.89	0.88	0.88	0.86	0.86	0.98	0.90	0.94	0.89	0.79	0.84		
Cam 4	9575	Front	car	149	0.96	0.89	0.92	0.88	0.92	0.90	0.95	0.97	0.96	0.92	0.95	0.84	
			taxi	4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
			bike	25	1.00	0.96	0.98	1.00	0.96	0.98	1.00	1.00	1.00	0.96	1.00	0.98	
			pickup	73	0.81	0.92	0.86	0.82	0.75	0.79	0.84	0.90	0.92	0.91	0.84	0.87	
			truck	5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
			Total				256	0.95	0.95	0.95	0.94	0.93	0.93	0.98	0.98	0.96	0.96
Grand Total				855	0.88	0.92	0.90	0.88	0.92	0.90	0.96	0.95	0.95	0.85	0.82	0.83	

Figure 14. Model performance evaluated on validation video stream collected from test area using transfer learning-improved networks (P=Precision; R=Recall; OA=Overall accuracy)

To overcome the problem of domain-shift, we train new set of networks with new dataset by using the weights transferred from the previously trained models. These models are then used to detect and classify the vehicles in our multi-vehicle tracking algorithm, which is essentially a centroid tracking algorithm that tracks each class of

vehicles on each individual lane polygons provided to the system. Figure 13 shows the improvement of average precision by applying transfer learning models in all versions of YOLO evaluation. Figure 14 shows the accuracy of classification by applying transfer learning models to distinguish sides of vehicles.

6. Thammasat Immersive Model for Collective Data Visualization

AI City data are visualized on the Thammasat model generated from (1) direct inspection photography, (2) aerial photogrammetric survey by drone, and (3) laser scanner. The data are processed to determine the point cloud for generating 3D mesh for reference as shown in Figure 15.

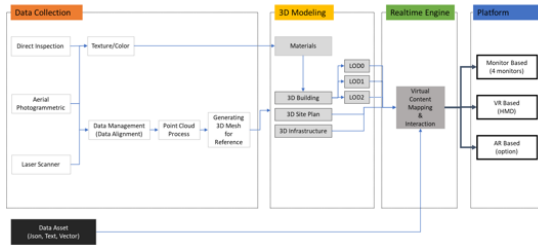


Figure 15. Modeling process of Thammasat Rangsit campus.

Figure 16 shows the visualization results on four surrounding screens to provide a room-like experience. It is node of Data Sensorium proposed by AAIL, Musashino University to exhibit the collective data visualization across the network. After the image stitching process, Figure 16 (a) shows the synchronized image controlled by the multiple points via the Internet. On each end, the users can control the view and point out the area of interest. The function allows the users to share their concerns in the same room-like experience. In addition, the models are smoothly augmented with the location sensitive information to realize the spatial experience to the users as shown in Figures 16 (b). The example information of social media density is expressed in a form of augmented graph in Figure 16 (c) to show the SNS population in a specific moment.

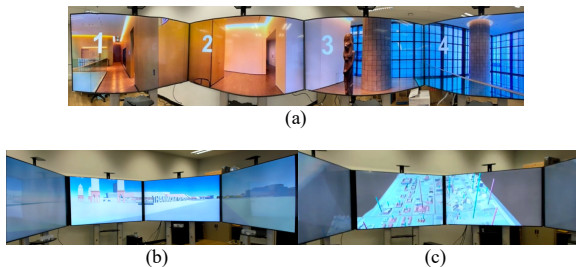


Figure 16. Modeling process of Thammasat Rangsit campus.

As a result, Data Sensorium shows its potential in realizing the spatial immersive environment to relieve the limitation of using HMD, especially in the case of urban planning that needs a city-scale environment sharing in the concept of AI City.

7. Conclusion

The limitation of digital transformation by ICT and big data analysis solely in facilitating the city operational excellence has been discussed. In many smart city implementation, the activities are upheld and visualized to grasp the city situation. Without the comprehensive analysis and data sharing across the domains it is not sufficient to predict the trend and prevent the undesired occurrence due to the growth of urbanization, especially in the vicinity of big cities. Thammasat AI city enabling initiatives in healthcare and behavioral detection by contactless and human traceability technology are explored across the domain sensory devices on the standardized AI city platform. The harmonization of health data and sleep monitoring BedSense provide a uninterrupted healthcare between home and hospital. Individual and public behavioral detection foster the inhabitant QoL measure to sustain the city evolution. Lastly, the pre-trained models using in transform learning approaches can be effectively utilized when the data are insufficient in some tasks.

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An Exploratory Research on the Expression of Knowledge and Its Generation Process based on the Concept of “Dark-matter”

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Abstract. Research work on machine learning techniques has been going on since the invention of computers. With the development of machine learning techniques, researches on how knowledge is expressed in computers and the learning process of knowledge have become more important. Unlike other machine learning models such as artificial neural networks, in the previous work of this paper, a machine learning model based on the concept of “dark-matter” is presented. In this model, matrixes are used to represent temporal and non-temporal data. The term “matter” is used to denote non-temporal data. The term “dark-matter”, on the other hand, is used to represent temporal data. In this paper, an exploratory research on the expression of knowledge and its generation process based on the concept “dark-matter” is presented. A case study is used to illustrate how knowledge is generated and expressed. The contribution of this paper is that new methods of knowledge generation and expression are proposed based on the concept of “dark-matter”. In the paper, first, the concept of “dark-matter” is briefly reviewed. After that, the methods of knowledge generation and knowledge expression are illustrated with examples. The process of knowledge generation is also illustrated with examples. Finally, the relationship between knowledge and “dark-matter” is revealed.

Keywords. Knowledge, knowledge presentation, knowledge generation, machine learning, semantic space, spatiotemporal space

1. Introduction

The expression of knowledge on a computer is an essential requirement for implementing knowledge processing on the computer. Although many methods and models are proposed for expressing knowledge, it is still not enough to process knowledge on computers to achieve the level of the human brain. In addition, these methods are not sufficient to express knowledge generated based on machine learning. The machine learning indicates the calculation methods that allow people to achieve the desired function without programming code. That is, people can create processing models through the training process to achieve the desired function. Machine learning is divided into supervised learning, unsupervised learning, and reinforcement learning. For supervised learning, supervised data set is required, which is the expected output data set for a given input data set. Unsupervised learning does not require supervised

data. For reinforcement learning, an agent needs to be created and trained to get the maximum reward in order to get the output data for a given input data. In this paper, case studies on reinforcement learning are used to illustrate how knowledge is generated and expressed. It is an exploratory research on the expression of knowledge and its generation process based on the concept of “dark-matter” [1].

The concept of “dark-matter” is developed based on the research works of semantic computing models [2, 3, 4, 5]. In the semantic computing models, matrixes are used to present “meaning” of data. In the models, input data are mapped through mapping matrixes into semantic spaces and presented as points in semantic spaces. Another data which present different meanings, referred to as meaning data, are also mapped to the same space. Distances of the points among input data and meaning data are performed. In this way, the semantic calculation is transmitted to calculate Euclidean distances of those points. For example, in the case for implementing semantic query, query data presenting query keywords are mapped into a semantic space and summarized as a point in the space. Retrieval candidate data are also mapped into the semantic space as other points. Euclidean distance is calculated between the query point and each retrieval candidate point. When the distance of a retrieval candidate is shorter than a given threshold, its relative retrieval candidate is extracted as the query output.

Two methods, Mathematical Model of Meaning (MMM) [4, 5] and Semantic Feature Extracting Model (SFEM) [2, 3], are developed on semantic space creation. In MMM, a common data set, for example an English-English diction is used to create the semantic space. In SFEM, the semantic space is created based on special defined data sets according to the requirement of applications.

After the semantic space is created, input data will be mapped to the space and the Euclidean distance calculation between the mapped data points in the space will be performed. Mapping matrixes are required to map input data into the semantic space. In SFEM, mapping matrixes are defined according to the applications of the models [6-14]. Many methods are developed to create mapping matrixes for applying the model in the areas of semantic information retrieving [9, 10, 14], semantic information classifying [11], semantic information extracting [12], and semantic information analyzing on reason and results [13], etc. Furtherly a method is developed to create the mapping matrixes through deep-learning [15]. Elements of the matrixes presenting semantic spaces are previously defined, which are different from those other models, such as the artificial neural network model and deep-learning artificial neural network model [16-19].

A mechanism is furtherly developed based on the semantic space model to implement the basic logic computation to implement true and false judgement which is the foundational mechanism required by machine learning [20]. The mechanism is applied to simulate unmanned ground vehicle control [21]. Temporal data processing is required for the ground vehicle control. In paper [1], a new model is presented for the temporal data processing. In the model, the word “matter” is used to represent features of spaces which are related to the non-temporal data. The word “dark-matter” is used to represent of spaces which elements are temporally changed. The word “energy” is used to represent matrixes which are used to generate output data. “Dark-matter” is a matrix which elements are generated during training processing.

In this paper, an exploratory research is presented on knowledge representation and its generation process based on the concept of “dark-matter.” Case studies are used to illustrate how knowledge is generated and expressed. The contribution of this paper

is that new methods of knowledge expression and generation are proposed based on the concept of “dark-matter.” The concept of “dark-matter” is reviewed in Section 2 of this paper. In Section 3, the relationship between “knowledge” and “dark-matter” is described. The method of knowledge expression is also illustrated with examples in this section. Then, the knowledge generation method based on training processing is illustrated. Finally, the conclusions of this paper are presented.

2. The machine learning model created based on the concept “dark-matter”

In this section, the machine learning model created based on the concept “dark-matter” is briefly reviewed through an example as shown in Figure 1. This model is called “dark-matter learning model” in the following. In this model, matrix multiply is referred to as “space mapping” or simply “mapping.” For example, the following equation (1) is described as to mapping a matrix \mathbf{X} by a matrix \mathbf{E} to a new space \mathbf{Y} . That is, a space represented by \mathbf{X} is mapped to a new space represented by \mathbf{Y} .

$$\mathbf{Y} = \mathbf{X} * \mathbf{E} \quad (1)$$

The matrix \mathbf{X} is further divided into two parts as shown in Figure 1. The first part is the first column of the matrix \mathbf{X} , which is referred to as “matter”. The second part of \mathbf{X} is referred to as the “dark-matter”, which is constructed by the second to the last column of the matrix \mathbf{X} . In Figure 1, “matter” is an index matrix correlated with sensor data. As sensor data are “visible,” it is referred to as matter. Elements in the matrix of “dark-matter” are randomly filled. As the matrix of the dark-matter is created randomly filled, it is referred to as “chaotic space”.

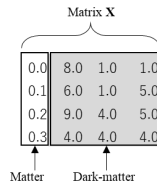


Figure 1. Creating a “chaotic space”

The learning process is to change the “chaotic space” to “ordered space.” The learning model is considered as a state machine. A state in the state machine will be changed from one to others, which is referred to as state transition. State transition diagrams are used to present the state transition. Figure 2 is an example of state transition diagram. In the figure, a circle and the number in the circle represents a state, an arrow represents a state transiting from one to another one. The numbers by the arrows represent the condition required for the state transition. For example, the state will be transited from state “0.0” to the state “0.1” if the input data is “0.0”.

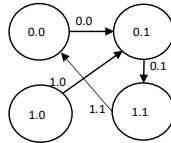


Figure 2. An example of state transition

Figure 3 presents how to create the “ordered space” from the “chaotic space” based on the state transition. The example of the state transition diagram shown in Figure 2 is used to illustrate it. In Figure 2, state “0.0” is the start state and the state transition from “0.0” to “0.1” is the first step of the state transition. Figure 3 (a) shows a chaotic space and Figure 3 (b) shows the first step state transition. In the second step, the state “0.1” transits to the state “0.3”, as shown in Figure 3 (c). When all the state transition diagram shown is represented as Figure 3 (d), we say that we created an “ordered space” from the “chaotic space.” In the figure, the “matter” is the first row of the matrix, and the “dark-matter” is the matrix constructed by the second, third and fourth row, painted in gray.

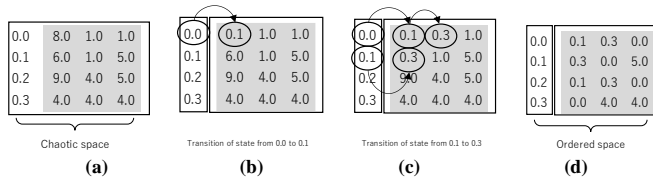


Figure 3. Creating an “ordered space” from a “chaotic space”

If X^{-1} is an inverse matrix of the matrix X , the matrix X^{-1} is referred to as an “*antimatter space*.” An example of the “antimatter space” is shown in Figure 4 (b), which is the inverse matrix of X shown in Figure 4 (a).

If Y is a matrix of the desired output result, by applying antimatter space to the matrix Y , a new matrix E is created, which is referred to as “*energy*” as shown in equation (2). The calculation presented by the equation (2) is referred to as “*learning*” or “*training*” calculation.

$$E = X^{-1} * Y \tag{2}$$

As the example shown in Figure 4 (c), matrix Y is the results of logical calculation “and,” “or” and “xor” represented as three vectors Y_{and} , Y_{or} and Y_{xor} . The “*energy*” E is presented as three vectors E_{and} , E_{or} and E_{xor} are represented as three vectors in Figure 4 (d).

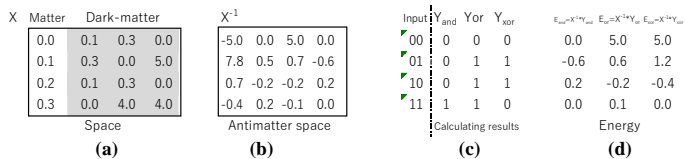


Figure 4. The concept of the “matter”, “dark-matter”, “anti-matter” and “energy”

When energy E is applied to the space X , the calculation result Y is obtained as shown in equation (3).

$$Y = X * E \quad (3)$$

For the example shown in Figure 4, a single regression analysis function is used to map input data on the matter-space. As shown in Figure 4, the input data presented as binary number “00”, “01”, “10” and “11” are mapped respectively to “0.0”, “0.1”, “0.2” and “0.3” on the matter-space. The mapped value on the matter-space is used as index to extract a row vector of matrix X . For example, if the input data is given as “10”, it is mapped to the value “0.2”. After that, the mapped value “0.2” is used as the index to extract the row vector V , [0.2, 0.1, 0.3, 0.0] from X . When the energy matrix E_{and} is applied to the extracted vector V as $V * E$, the calculation result “0” is obtained which is the logic value of “0 and 1”.

3. A knowledge representation method with “dark-matter”

In this paper, a new method is proposed to express knowledge by matrixes. Based on Oxford English dictionary [22], “knowledge” is defined as “facts, information, and skills acquired through experience or education”. In the following, an example is used to illustrate how an agent to acquire skills through experience.

In this example, there is a maze, represented by a 4 x 4 matrix, as shown in Figure 5 (a). An agent is created in this case study which should move from a start position to a goal position. The start position of the agent is at row 2 and column 1, which is marked with the character “S”. A position will be represented by row and column number as (row number, column number) in the following. Thus, the start position of the agent is represented as (2, 1) with the mark “S”. The goal position of the agent is (2, 4) with the mark “G”. The agent will go along the path shown by the arrow-mark “→”. From the start position to the goal position. That is, the agent goes through the points (2,1), (2, 2), (3, 2), (4, 2), (4, 3), (4, 4) and (3, 4) and reaches to (2, 4).

By defining states of the agent as its positions on the maze matrix, a space matrix can be defined. As there are 16 possible positions for the agent on the maze matrix, 16 values from 0.0 to 1.5 are used to represent the index as shown in Figure 5 (b).

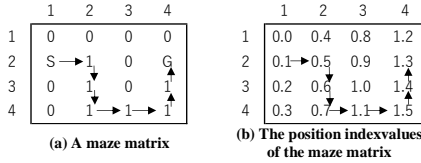


Figure 5. A maze matrix shown for an agent moving from “S” to “G”

Using the values of index as the matter, and a 16 x 15 matrix with the random values as the dark-matter, a 16 x 16 space matrix is defined as shown in Figure 6 (a). The path from the starting position to the goal position is indicated in Figure 5 (a). Using the path indicated in Figure 5 (a), the agent can get its next position of the current position. For example, at the start position, (2, 1), its next position is (2, 2). By using the index values, the current position index value is 0.1 and its next position index value is 0.5. Therefore, the index value 0.5 is recorded at the dark-matter matrix at row 2 and column 2 of the space matrix. Same as that, the next position index value 0.6 of is recorded at row 2 and column 3 and row 6 and column 2 as shown in Figure 6 (b), if the current position index value is 0.5.

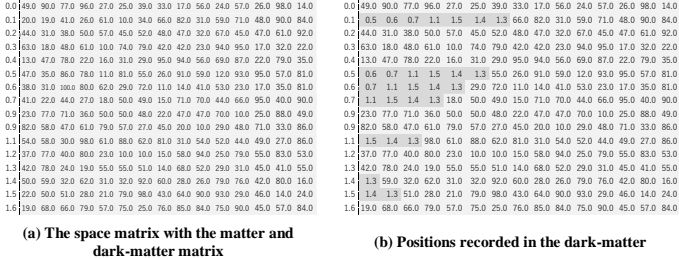
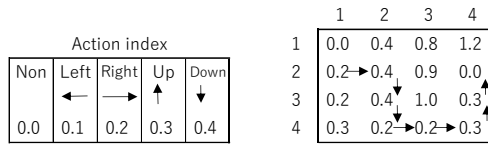


Figure 6. The 16 x 16 space matrix with the matter and the dark-matter

Actions at different positions are defined as shown in Figure 7 (a). There are five actions are defined. These are “Non”, “Left”, “Right”, “Up” and “Down”, representing “no-action is required”, “to move left”, “to move right”, “to move up” and “to move down”, respectively. Action index values are also defined as shown in Figure 7 (a). The values 0.0, 0.1, 0.2, 0.3 and 0.4 are defined as the action index values of “Non”, “Left”, “Right”, “Up” and “Down”, respectively. The action index value of the agent at each position on the path is shown in Figure 7 (b). For example, the required action at the start position (2, 1) is “moving right”, therefore, its index value 0.2 is written at (2, 1) as shown in Figure 7 (b).



(a) Actions and action index of the agent

(b) Actions of the agent at each position

Figure 7. Actions and action index of the agent

Defining the action vector as a vector \mathbf{Y} by using the action index value as shown in Figure 7 (b), an energy vector \mathbf{E} can be defined as the energy, which is defined in the same way as reviewed in Section 2 equation (2).

The action of the agent at each position can be calculated by using the space matrix \mathbf{X} and energy vector \mathbf{E} by using the equation (3). In order to calculate the action index value, a retrieval mechanism is required. In the retrieval mechanism, the index value of the agent position is used to retrieve the relative row from the space matrix \mathbf{X} . The retrieval result is a row vector of matrix \mathbf{X} corresponding to the position of the agent. Therefore, it is required that the agent must have a position sensor and the accuracy of the sensor output value is sufficient to meet the requirements of the retrieval mechanism.

If the retrieval mechanism is used, it can be used directly to retrieve the action index value based on the position index value. A correspondence table or a retrieval function can be used to implement the retrieval calculation. Table 1 is an example which can be used to implement the retrieval. It has two columns, one is the position index value column and the other is action index value column. Using the table, for given position, an action index value can be found directly from the table. That is, the action of the agent can be calculated without the dark-matter matrix.

Table 1. A table used to output the action index correlated to the position index

Position Index	Action Index
0.0	0.0
0.1	0.2
0.2	0.0
0.3	0.0
0.4	0.0
0.5	0.4
0.6	0.4
0.7	0.2
0.9	0.0
0.9	0.0
1.1	0.2
1.2	0.0
1.3	0.0
1.4	0.3
1.5	0.3
1.6	0.0

However, it is not always sufficient to calculate the action index value without the dark-matter. If the agent does not have the position sensor, but it has a laser sensor which output shows which direction that the agent can move. The output values of the sensor are defined as follows: As shown in Figure 8 (b), the agent can move in four

directions, moving to the “Down”, “Left” and “Right” direction, the outputs of the sensor are defined “0100”, “0010” and “0001”, respectively. The direction, in which the agent can move at each position, is shown in Figure 8 (a). The sensor’s output values when the agent is in different positions are shown in Figure 8 (c). For example, at the position (3, 2), the agent can move to “Up” direction, therefore, the output value of the sensor is “1000”. The agent can go back from the current position to its previous position. For example, if the agent is at the point (2, 2), as the agent can move back to the start position (2, 1). At the position (2, 2), the agent can move to two different positions. It can move “Left” back to the start position or move “Down”, to the next position (3, 2). The output value of the sensor at the position (2, 2) is “0110”, which is the summary of the two direction “0010”, “Left” and “0100”, “Down”.

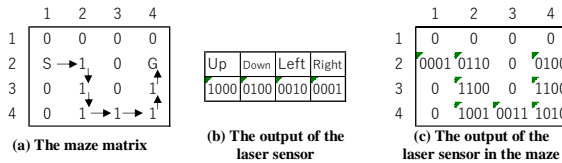


Figure 8. The output of the laser sensor of the agent

As shown in Figure 8 (c), when the agent is at the position (3, 2) and (3, 4), the output values of the sensor are the same “1100”. That is, the agent can move “Up” or move “Down”. If a table like Table 1 is used to retrieve the action of the agent, two different actions, “Moving Down” and “Moving Up” will be the output values. That is, if the retrieval values for a giving a sensor data correspond to different actions, without dark-matter, it is impossible to find a unique action for the agent. Therefore, it is necessary to use dark-matter in the calculation for deciding which action should be taken.

It is not always possible to know the path at the start position as that shown in Figure 6 (b). For example, when reinforcement learning is applied to find the path from the start position to the goal position, the path is unknown at the start position. The path will be found after many tries are performed. Sometimes, many paths are found. Rewards are assigned to found paths. If the length of a path is shorter than the others, higher reward than the others is assigned to the path. During the reinforcement learning, the agent is trained to obtain the maximum reward. In this way, the optimal path from the start position to the goal position can be found. At the same time, actions of the agent at the positions on the path are determined.

When the path is unknown at the start position, it is impossible to create the space matrix as that shown in Figure 8 (a). Here, *a new method is proposed for generating the space matrix*. At the same time, *a new method for knowledge expression is also proposed*. In the methods, passed positions are recorded instead of the next positions. For example, when the agent moves from the start position (2, 1) to the position (2, 2), the passed position (2, 1) is recorded. That is, dark-matter matrix can be created based on events that have occurred instead of the events which will occurred in the future. In the following, an example is used to illustrate the method in detail. In the example, the agent has a laser sensor.

In the example, a matrix is used to show a maze as shown in Figure 9 (a). The agent can be in any positions where the “1” is marked in the matrix. The agent cannot be in the positions where “0” is marked in the matrix. Figure 9 (b) shows the output of the sensor of the agent in each position, and Figure 9 (c) shows the index values of the sensor outputs at each position. For example, when the agent is at the position (2, 2), as the agent can move to “Up”, “Down” and “Left”, output of the sensor is “1110”, which is the summary of the value “Up”, “1000”, “Down”, “0100” and “Left”, “0010”. As the agent can not be in the position (3, 1), (4, 1), (2, 3), (3, 3) and (1, 4), the output of the sensor at those positions is marked with an “X”.

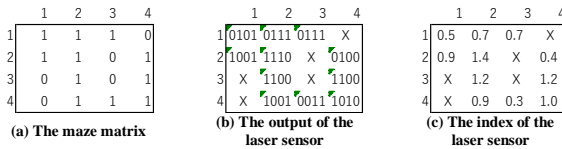


Figure 9. The output of the laser sensor of the agent

The reinforcement learning is performed as the follows. At the position (2, 1), the agent can move to two different directions “Up” and “Right”. The probability value 0.5 is assigned to the two directions. That is, the agent has a 50% chance of moving “Up” and a 50% chance of moving to the “Right”. When the agent moves to the position (2, 2), it has three moving directions, “Up”, “Down” and “Left”. Therefore, 0.33 is assigned as the probability value to the three directions. The maze is set up as follows. The target position is set at position (2, 4), and the starting position can be any position marked “1”, as shown in Figure 9 (a). When the agent moves from a position to its neighbor position, it is said to have “moved a step”. The number of the steps, which the agent is used to move from the start position to the goal position, is used for reward calculation. The fewer steps the agent used, the higher the score the agent got. If the start position is at the point (2, 1), the minimum number of steps required is seven for the agent moving from the start position to the goal position. When the agent moves to a direction where higher reward were obtained than the other directions, higher probability value is assigned to the direction. For example, at the position (2, 1), as moving to the “Right” can obtain higher reward than moving “Up”, 0.01 is added to the probability value of moving to that “Right”. Experiments were performed to find the path from the start position to the goal position. Based on the experimental results, trying about 200 times, the best path from the start position (2, 1) to the goal position (2, 4) can be found by the agent. After 2000 times trying, the probability values to the high reward directions are increased to 0.99.

In order to record sensor values, *a working memory mechanism is proposed*. In the mechanism, a vector is created which initial value is randomly assigned. The length of the vector is as same as the number of the steps required by the agent from the start position to the goal position. For example, when the agent started at position (2, 1) which is set as the start position, and the agent moved through positions, (2, 2), (3, 2), (4, 2), (4, 3), (4, 4), (3, 4), and reached the goal position (2, 4), there are seven steps are required. Thus, the vector is defined with seven elements with random values. Then, the value of the current sensor value is combined with the vector, thus a vector with eight elements is created, as shown in Figure 10. In Figure 10, index values of the

sensor values are used. The background of the element recording the current sensor value is painted white, and the background of the elements recording the past sensor values are painted gray. For example, at the start position (2, 1), the current sensor value is 0.9, which was recorded at the first element of the vector, and the background of the first element was painted white, as shown in Figure 10 (a). The background of all the other elements were painted gray. The values of the elements from the second to the eighth were remained the random values because no sensor data were recorded. When the agent moved to position (2, 2), 1.4 which was the index value of the sensor at the position, was recorded to the first element and the previously recorded data 0.9 was moved to the second element as shown in Figure 10 (b). In the same way, when the agent moved to position (3, 2), 1.2, which was the index value of the sensor output, was recorded to the first element, and the previously recorded data were moved to the second and third elements, respectively, as shown in Figure 10 (c). After the agent moved to the goal position (2, 4), all index values of the sensor output were recorded as shown in Figure 10 (d). The index value of the sensor output at the goal position was recorded to the first element, and the index value of the sensor at the start position was recorded to the eighth element.

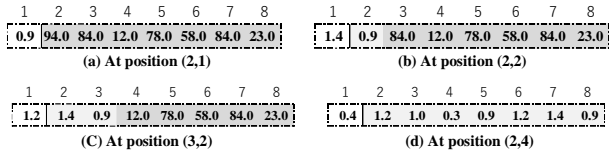


Figure 10. Working-memory and recorded index value of the sensor output

Actions of the agent are also recorded by action index value. For example, if the agent moved to the “Right” at the start position, the index value 0.1, which is the index value of moving to the “Right”, was recorded. A vector records all the action index values from the start position to the end position is used as the \mathbf{Y} vector, as shown in Figure 11 (c).

As shown in Figure 11 (a), the space \mathbf{X} is a collection of the working-memory of the agent moved from the start position to the goal position. Its inverse matrix \mathbf{X}^{-1} is shown in Figure 11 (b). By multiplying \mathbf{X}^{-1} by \mathbf{Y} , an energy vector \mathbf{E} is defined.

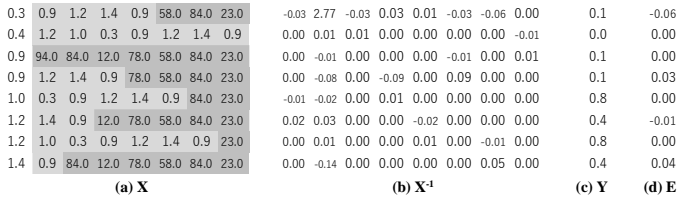


Figure 11. Working-memory and recorded index value of the sensor output

When the energy vector \mathbf{E} is defined, each action of the agent at each relative position can be calculated by multiply the vector of the working-memory by \mathbf{E} , as expressed by equation (3) introduced in Section2. The calculation result of the energy vector is shown in Figure 11 (d). When the dark matter matrix is utilized, a unique action index value can be calculated even if the output values of the sensor are the same. For example, at the position (3, 2) and (3, 4), the index values of the sensor output value are the same 1.2, as shown in Figure 12 (a) and (b), where the index values are recorded at the first elements of the two vectors. In the working-memory, the values of the dark-matter values in the second to the eight elements of the two vectors are different, as shown in Figure 12 (a) and (b).

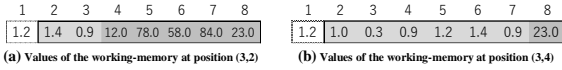


Figure 12. Working-memory and recorded index value of the sensor output

By multiplying the two vectors of the working-memory by the energy vector \mathbf{E} , two different action index values 0.4 and 0.8 are obtained, as shown in equation (4) and (5). The index value 0.4 means that the agent should take the action “Moving Down” at the position (3, 2), and the index value 0.8 means that the agent should take the action “Moving Up” at the position (3, 4).

$$[1.2, 1.4, 0.9, 12.0, 78.0, 58.0, 84.0, 23.0] \times \begin{bmatrix} -0.06 \\ 0.00 \\ 0.00 \\ 0.03 \\ 0.00 \\ -0.01 \\ 0.00 \\ 0.04 \end{bmatrix} = 0.4 \quad (4)$$

$$[1.2, 1.0, 0.3, 0.9, 1.2, 1.4, 0.9, 23.0] \times \begin{bmatrix} -0.06 \\ 0.00 \\ 0.00 \\ 0.03 \\ 0.00 \\ -0.01 \\ 0.00 \\ 0.04 \end{bmatrix} = 0.8 \quad (5)$$

During the above process, the agent obtained skills to take appropriate actions at different positions leading it to move from the start position to the goal positions. That is, skills are acquired through experience of the agent. Considering the definition of *knowledge*, which is defined as “facts, information, and skills acquired through experience or education”, it can be found that *knowledge is expressed in the dark-matter matrix* of the space matrix \mathbf{X} . *The energy vector \mathbf{E} is used to change knowledge into actions.*

In summary, the *learning process* of the agent can be divided into five steps:

1. Finding a path from the start position to the goal position,
2. Recording the sensor output value in the working memory during the movement of the agent from the starting position to the goal position,
3. Creating the space matrix \mathbf{X} based on the working-memory,
4. Calculating the inverse matrix of the matrix \mathbf{X} ,
5. Calculating the energy vector \mathbf{E} .

4. Conclusion and future work

In this paper, the concept of “*dark-matter*” is reviewed and further developed to express experience and knowledge. The concept of “*space*” is also reviewed and developed into a matrix that can be created based on experience. In addition, the characteristic of the concept of “*energy*” is revealed, indicating that it can be used to transform knowledge into the desired calculation. Based on the concept of dark-matter, examples of an agent moving in mazes are used for the exploratory research on knowledge expression and its learning process. In the paper, a working memory mechanism is proposed for recording the agent’s experience in the actions of the agent’s movement from the start position to the goal position in the maze. A new method is proposed for creating the space matrix \mathbf{X} by using the working-memory. During the exploratory research of the paper, the process of acquiring knowledge is revealed. The most important contribution of this paper is that new methods are proposed for acquiring and expressing knowledge based on the concept of dark-matter. In the paper, it is revealed that knowledge can be expressed in a matrix and energy vectors can be used to turn knowledge into actions of the agent. In the paper, the learning process is illustrated during the agent’s movements from a starting position to a goal position. Based on the illustration, the learning mechanism for the agent to acquire knowledge is revealed. As our future work, more features of the proposed methods and the mechanism will be further investigated, and application systems based on the proposed methods and the mechanism will be developed.

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BigRobot Mk.2

Emulation of Embodied Knowledge of a Walking Giant

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Abstract. BigRobot Mk.2, which creates the body motion of a giant, is described. The robot has 10 actuated joints so that it can emulate the body motion of human. A pilot rides on the top of the robot and it moves according with walking action of the pilot. This function provides the pilot to the body sensation that is extended to an 8-m giant. The basic design, implementation, and performance evaluation of BigRobot Mk.2 are presented.

Keywords. motion base, vestibular sensation, locomotion, embodied knowledge

1. Introduction

Embodied knowledge is a type of knowledge where the body knows how to act [1]. It can be explained as the representation of the body in the brain, the visual image of the body, or the mind's awareness of the body. Embodied knowledge has been discussed in the context of skills in sports or dance [2][3]. On the other hand, this paper focuses on innate action such as walking. In 2014, the authors launched "BigRobot" project aiming to develop large-scale humanoid robot on which a pilot can ride and walk [4]. The robot augment human sense of walking so that embodied knowledge of the pilot can be transformed.

The motion base, which presents vestibular sensation and is one of the basic technologies of virtual reality (VR), has been studied and put into practical use for flight simulators and driving simulators in such fields as airplanes and automobiles. VR that transforms physical sensations has already been performed. For example, CHILDFOOD [5] transforms one's body to emulate the body of a child by presenting an image for a camera head attached to the waist to the head-mounted display to experience the view from a child's eyes. The authors proposed, implemented, and exhibited BigRobot Mk.1, which transforms physical sensations as if the user were a giant using a motion base [4] [6] [7]. BigRobot Mk.1 changes the physical sensation by simulating the movement of a giant and presenting the acceleration and position of the viewpoint to give the user the feeling

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of being a giant. BigRobot Mk.1 has a rigid body that corresponds to the spine, and a fulcrum is placed on the pedestal to prevent falls. The degree of freedom of its walking motion is set to 2. Therefore, BigRobot Mk.1 has restrictions on the movement and size of the giant that can be simulated in consideration of fall prevention and portability to an exhibition. It was somewhat difficult to determine whether the movement looked like walking, but the user felt that it was certainly a giant walking. Fig. 1 is an overview of BigRobotMk.1.

Based on this finding, the aim of this research was to implement a self-sustaining movement with a degree of freedom configuration close to that of the human body, transform the body into a larger giant, and realize a more natural walking of the giant.



Figure 1. BigRobotMk.1.

2. Basic Design of BigRobot Mk.2

BigRobot Mk. 1 provided the feeling of becoming a giant and transformed the physical sensation of the user, but there was a problem. The state of walking when the movement was seen from a viewpoint other than that of the passenger looked somewhat unnatural when the legs moved back and forth. Furthermore, because the degree of freedom of the mechanism of BigRobot Mk.1 is low, there are few walking movement patterns, and the movements of giants that can be simulated are considerably limited. In addition, the height of BigRobot Mk.1 is approximately 5 m. Because it does not crouch, the height of the giant that can be simulated is limited to about 5 m.

To solve the above-mentioned problems, further development with the following elements was performed.

The control by the motor is increased to five degrees of freedom, two degrees of freedom for both ankles, two degrees of freedom for both knees, and one degree of freedom for the waist, so that the robot looks more natural when walking. At the same time, it was decided to increase the number of walking motion patterns that can be simulated (Fig. 2)

and to make crouching motion possible by controlling both knees so that giants of various heights can be simulated. By combining five degrees of freedom and the movement of the foot in the anteroposterior direction, not only pitch rotation but also yaw and roll rotation (Fig. 3) are possible.

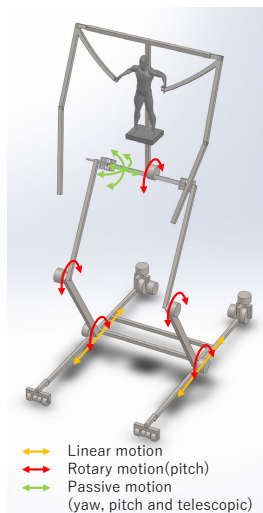


Figure 2. Basic structure of BigRobot Mk.2.

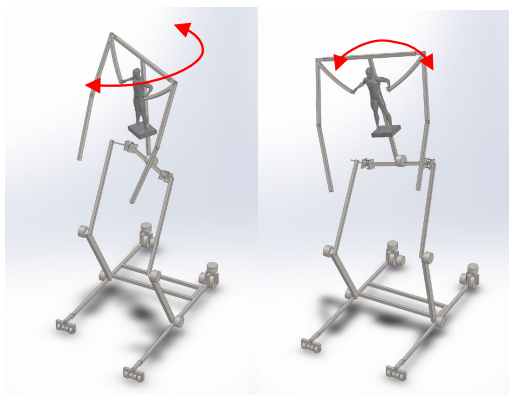


Figure 3. Yaw and Roll rotation.

3. Implementation

3.1. Structure

The basic concept was to lower the position of the center of gravity as much as possible, as with the BigRobot Mk.1. Therefore, the policy was to mount the actuators used for main attitude control and movement on the foot part and to make the part that is above the ankle and moves in the air as light as possible. Specifically, when the drive shafts of the ankle and knee are placed on the foot and the rotation angles are controlled, the positions of both ends of the pelvis are given, and the position of the pelvis and the posture of the yaw angle and roll angle are determined. The base of the thigh and the pelvis were connected by a universal joint, and a sliding shaft was provided so that the length of the pelvis could be changed. This sliding axis is required only in the plane where the ankle and knee joints of the leg move in a plane perpendicular to the ground. Therefore, a rotary axis actuator that determines the pitch angle of the spine is placed in the center of the pelvis depending on the posture. By controlling these actuators, the passenger is given a change in position and posture with six degrees of freedom, and the distance between the bases of the thighs changes.

In addition, to avoid the risk of falling, the foot part should be supported by five points or more by, for example, using many wheels, so that even one foot part does not fall. When the superstructure above the ankle is not attached, it can stand on its own and run on its own. In addition, omnidirectional wheels are used to allow movement in any direction.

Therefore, the legs have the appearance of a small omnidirectional moving vehicle. By attaching the superstructure above the ankle, it is possible to simulate the movement of a giant that moves with its feet in any direction as a whole.

The boarding part utilized a locomotion interface, such as a stepper mechanism, and the arm part was equipped with a pantograph link to improve the sense of unity with the giant.

In addition, the maximum height was set to 8 m because the ceiling height of the environment assumed for the operation of BigRobot Mk.2 is about 8m. This is approximately five times the enlargement rate, with 1.7 m as a normal human being, referring to the average height of Japanese men. In consideration of ease of storage, the length of the legs is 5 m, and the height of the upper body is 3 m, which is approximately 3 m when the legs and upper body are folded. The length of the foot in the anterior–posterior direction was set to 3.8 m to prevent the robot from tipping over both when standing upright and in the retracted state. Fig. 4 is an overview of the prototype.

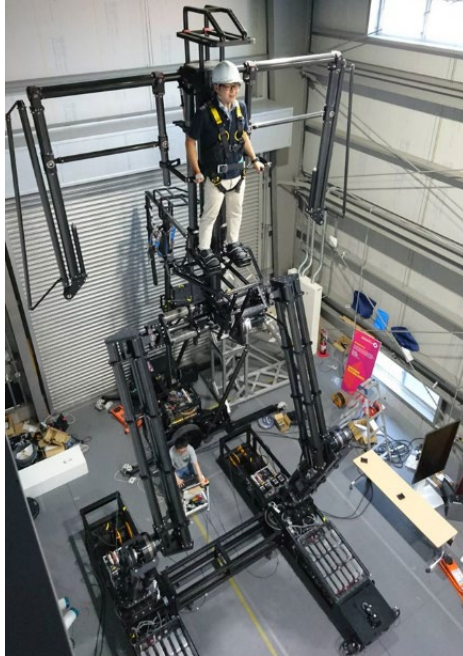


Figure 4. Overall view of BigRobot Mk.2.

3.2. Actuator

The most important factor in selecting a motor as an actuator and a reducer is whether the upper body is lifted. Based on the amount of carbon-fiber-reinforced polymer assumed to be used, the weight of the upper body was about 400 kg, the center of gravity in the retracted state was set to 1.5 m from the ankle, and estimation was performed at a speed of lifting 6° in 1 s around the ankle. Because the lifting motors are on the left and right, a load of approximately 200 kg is assumed for each, the required minimum torque is about 3000 N, and the required motor output is approximately 300 W. Because of the magnitude of the required torque, it is necessary to raise the reduction ratio considerably, and there is no ready-made reduction gear that supports it, so it is necessary to stack multiple reduction gears. The transmission efficiency is expected to decrease by that amount, and there is a margin so that it can be held with only one foot. The motor output of each part of the joint is 2-kW class, and one with the specification that the mechanical brake is applied when the power is lost was selected from AC servo motors (SV series,

KEYENCE) used for industrial use. This makes it possible to maintain posture and prevent falls, even when power is lost. Five motors were used for the ankles, knees, and hips.

It is possible to control the direction of the drive wheels with a motor so that the foot can move in all directions. The maximum walking speed of BigRobot Mk.2 was estimated to be 2 m/s, and 10 motors were selected and used, one for each foot and one for the 1.5-kW class motor. Thus, a total of 15 motors were used for the ankles, knees, and hips.

3.3. Control system

The selected AC servo motor has a built-in incremental encoder and is a control type that drives the motor by pulse train input. Therefore, four corresponding motor control boards (HUSB-CPD434, Hivertec) were used for motor data acquisition and control, and control was performed by communicating with these motor control boards from a PC (ThinkPad, Lenovo).

3.4. Locomotion interface

By constructing a spring damper system on a pendulum-type locomotion interface, it was decided to apply a load during walking to the passenger passively without using an actuator (Fig. 5). By adjusting the damping force of the damper, the load was set so that the walking cycle of the user would be approximately 3 s, which is five times the normal period. In addition, the user was fixed to the device with a harness and a safety belt to prevent the user from falling. A binding used for snowboarding was used to fix the foot. In addition, this binding can freely change the height of the foot lift and the angle of extension dorsiflexion by the bellows-shaped elevating mechanism composed of two hinges. The toes in the walking motion of the user are no longer restricted to the arc trajectory.

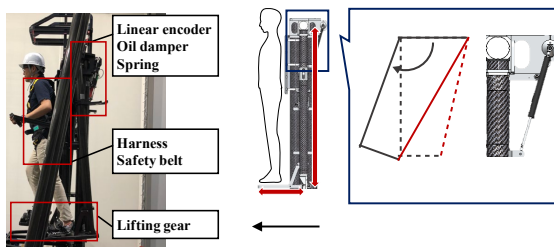


Figure 5. Locomotion interface and toes position calculation from linear encoder.

4. Model of Walking Motion of Giant

In reality, there is no equivalent to a giant. Therefore, in this section, the gait model of a giant is assumed with reference to a normal human being. First, the movement of the toes during human walking is considered using the law of conservation of mechanical energy. When the mass of the toes is m , the movement speed of the feet is v , the force to swing the feet is F , and the amount of movement of the feet is L , the relationship between human muscle strength, own weight, and walking speed can be described as Eq. (1).

$$FL = \frac{1}{2}mv^2, \dots\dots\dots (1)$$

Next, in the n -fold enlargement of the body, the amount of movement of the foot, force to swing the foot, and mass of the toe are nL , $n^2 F$, and $n^3 m$, respectively, from the square-cube law. Substituting this into Eq. (1) reveals that the foot movement speed of the giant is the same as that of a normal human. Meanwhile, although the foot movement speed does not change, the amount of foot movement is multiplied by n , so the walking time per step of the giant is multiplied by n . One also consider the vertical movement of the head that occurs during walking. Currently, the AIST walking database 2019 [8] is open to the public. Based on the position data of the heads of 10 people randomly selected from the AIST Gait Database 2015, which was published at the time of development and is not available at present, it was found that the average vertical movement distance of the head during human walking is approximately 0.04 m. Therefore, in the giant, it is assumed that the head moves up and down by an amount simply multiplied by n , and in BigRobot Mk.2, approximately 0.2 m is assumed to be the vertical movement distance of the head.

5. Performance Evaluation

Fig. 6 shows the target and measured trajectory of the toes and head of the BigRobot Mk.2. Those were actually operated by setting the target trajectory based on the above-mentioned giant walking model. Because it was difficult for this system to be sensed by an external sensor owing to the size of the device, the acquired data were derived from the attitude obtained from the encoder built into the device.

Fig. 6 shows that the delay time of this device is approximately 100 ms, which corresponds to the update cycle. This delay time was less than 300 ms, and it was confirmed that the passengers had the necessary response performance to create a sense of physical possession of the BigRobot Mk.2. The error between the target and the measured value was -0.04 m on average for the amount of walking swing and -0.01 m for the amplitude of the head. The error rates were 0.2% and 0.5% with respect to the target trajectory, respectively. Compared with the dispersion of the amount of foot swing per step of human beings of approximately 20% and the dispersion of head vertical movement of about 10%, the error amount is sufficiently negligible. The above results confirm that this device can sufficiently follow the expected walking motion of the giant.

Next, to evaluate whether the response speed was sufficient to generate a sense of exercise for the subject, three adult male subjects performed twice the procedure of walking continuously for approximately five steps. Table 1 shows the results where measurements were made with the start delay time defined as the time it took for the BigRobot Mk.2 to start moving from the time when the legs of the subject swung out and started to move forward. The end delay time was defined as the time from the end of the subject's walking motion to the stopping of the BigRobot Mk.2 motion. Fig. 7 shows the foot trajectory of BigRobot Mk.2 at that time. The "User" line shows the positions of the right and left feet of each subject. It can be seen from Fig. 7 that, when the subject puts his left foot forward, only the left foot of the BigRobot Mk.2 moves forward, the right foot remains stopped, and the subjects alternately put their feet forward, indicating that the feet of BigRobot Mk.2 are moving forward alternately. Fig. 7 shows the trajectory of the head swing presented to the passengers. Regarding the start delay time of less than 1 s, the subject commented, "I didn't feel any delay in the start." However, there was a comment from the subjects that the end delay time, in which a delay of more than 1 s occurred, was uncomfortable. From these comments, it can be concluded that the start delay time is a sufficient response speed and the end delay time is somewhat satisfactory. In other words, the movement-based feeling can be generated to some extent throughout the walking process, and the movement-based feeling is sufficiently generated, especially for the movement of taking a step with a giant. Because of problems in the operating environment, only walking movements of a few steps could be simulated. However, it was possible to simulate the walking movement according to the original aim. A feeling of movement for the subject in the walking of the giant could be generated; in particular, the feeling of the movement of the stepping of the foot could be generated sufficiently.

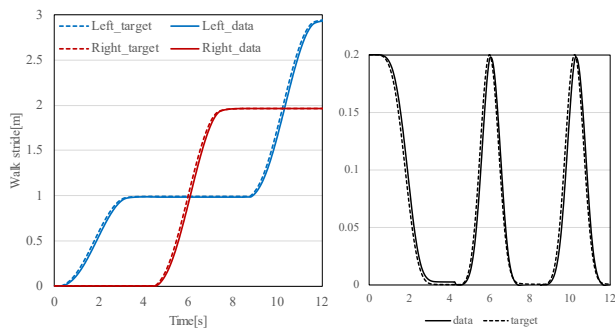


Figure 6. Trajectory of the toes and head of the BigRobot Mk.2

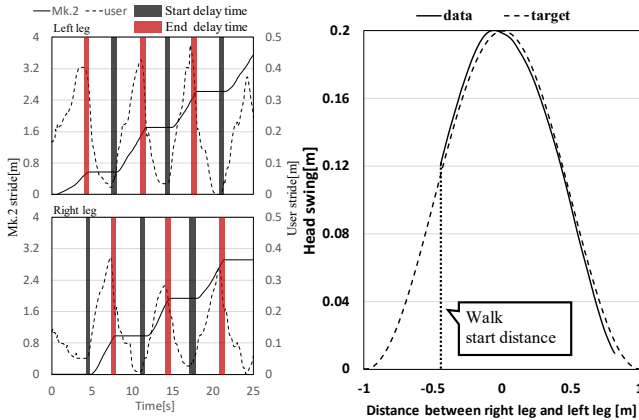


Figure 7. Trajectory of the toes and head of the BigRobot Mk.2.

Table 1 Delay time

	<i>Start (s)</i>	<i>End (s)</i>
Average	0.688	1.007
Standard deviation	0.278	0.399

6. Conclusion

A device was developed that realizes a high degree of freedom of movement, transforms the robot body into a larger giant, and realizes a more natural walking-like appearance of the giant.

As confirmed through operation, the developed BigRobot Mk.2, which is larger than BigRobot Mk.1, simulates walking movements with a sliding foot that looks more like the walking of a giant, and the feeling of the walking of a giant was also generated in the subject. In particular, the feeling of the subject of taking a step was sufficiently generated.

Future work will include cognitive research on embodied knowledge by using the BigRobot Mk.2. As J.J. Gibson pointed out in “The Ecological Approach to Visual Perception,” organisms recognize the outside world through the interaction between their bodies and the environment [9]. Therefore, by transforming BigRobot Mk.2 into various forms, the way the outside world is recognized should be diversified. In the future, simulating various walking patterns, including giant creatures, while improving the end delay time is planned, as well as verifying how physical sensations change.

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Rules for Converting Natural Language Text with Motion Verbs into TIL-Script

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Abstract. The paper deals with the rules for converting natural language text with *motion verbs* into TIL-Script, the computational variant of Transparent Intensional Logic (TIL). This function is part of the TILUS tool, which is now being worked on, and which will be used for the needs of appropriate textual information sources retrieval and natural language processing. Our work is currently starting on a module that allows the transformation of a particular subset of natural language texts describing journey description into logical constructions. Hence, in this paper, we focused on the transformation rules for sentences containing *motion verbs* describing the agent's movement on the infrastructure. These rules are based on the utilization of Stanford typed dependencies representation and verb valency frames of *motion verbs*.

Keywords. Motion verbs, Stanford typed dependencies, Verb valency frames, Transparent Intensional Logic, TIL-Script, Conversion rules

1. Introduction

In this paper we deal with the transformation rules for converting natural language text with *motion verbs* into TIL-Script. According to linguists, motion verbs, as implied by the term “motion”, are verbs that describe movement. They are intransitive (they usually have no object), so they cannot be used in the passive voice. Common examples of motion verbs include for instance “go”, “walk”, “run”, “swim” or “fly”, etc. The goal is to develop a module of the TILUS tool that allows the transformation of a natural language text describing journey into the TIL-Script logical constructions. From these constructions, the concrete representation of the journey can be later generated according to the heuristic. The future work is to convert this representation to a graph representing a topology. The paper is organised as follows.

In chapter 2, there is a brief introduction of TILUS modules and its main functions. TILUS presuppose that all the data are previously formalised in TIL-Script, the computational variant of Transparent Intensional Logic (TIL). We are currently working on the semiautomated conversion of natural language texts into TIL-Script. In the first phase of our work, we limited ourselves to the transformation of the sentence with motion verbs.

This is the main problem we are dealing in this paper with. In chapter 3, there is an outline of how we utilise the Stanford dependencies relations and the theory of verb valency frames for the purpose of transformation rules which are specified in the following chapter 4. Concluding remarks on further research can be found in the last chapter 5.

2. A brief introduction to the TILUS tool

We are developing the TILUS tool for the needs of natural language processing via TIL-Script constructions. Our system currently presupposes that all the inputs are transformed into TIL-Script. We chose the TIL-Script based on TIL, because its procedural semantics is close to natural language and have great expressive power. TIL was developed by Pavel Tichý who introduced its main principles in [1], the complete works from Tichý can be found in [2]. TIL has been further developed for example by M. Duží, P. Materna, B. Jespersen, J. Raclavský and a great deal of the TIL contemporary research can be found in [3]. The outcomes of this book are especially relevant to the inter alia conceptual modelling area. TIL-Script as well as TIL is hyperintensional, typed, a partial specification language with a ramified hierarchy of types.

TILUS has a number of modules. One of them is the module of logical deduction in order to be able to infer the conclusions of premises and verify the validity of arguments. The inferential mechanism is based on natural deduction. This module was introduced in [4], [5], [6]. The second module is based on machine learning and serves as a searching tool for relevant text sources. This module generates an *explication* in TIL-Script of an atomic concept. The term *explication* can be understood as a brief description of the sought term in a particular source text. We generate an *explication* from each source text and present it to the user of our application. The user then selects a particular explication based on their preferences and our system then recommends other possible relevant documents. This module was introduced in [7], [8], [9], [10], [11].

The theoretical framework for the recommendation module design is the method of association rules and the FCA theory, where the relevant documents are ordered according to their significance to the user, for more see [12]. First, we need to analyse textual natural language sources to obtain their logical formalisation in TIL-Script constructions. The conversion from natural language to the TIL-Script is a rather demanding process and requires logical-linguistic analysis. Hence, all our contributions, published up to now, presumed cooperation with the Department of Computational Linguistics to obtain the conversion of text to the TIL-Script constructions. The set of relevant propositional constructions is then selected from the formalised set; namely those where the concept to be explicated occurs.

Our work is currently starting on a module that allows the transformation of a natural language text describing journey into the TIL-Script logical constructions. The journey through the city can be described as an ordered set of sentences. Each sentence describes one whole part of the journey, usually containing information about who, how, from where, towards where, along with what and for how long the referee moved. For simplicity, we will assume that the particular sentences describing consecutive parts of the path are mutually connected. Therefore, some of the missing information in the following sentence (i.e. for instance the starting point, etc.) can be taken from the previous

sentence. From these constructions, the concrete representation of the whole journey is later generated according to the heuristic. This journey representation will serve after our future work as the input for the part based on geographic data which will generate the map topology from these constructions.

As mentioned earlier, all our contributions published up to now presumed cooperation with the Department of Computational Linguistics to obtain the conversion of text into TIL-Script constructions. Our main goal is to currently semiautomate the conversion of natural language text to TIL-Script constructions and build it within the TILUS. The general outline of the utilisation of Stanford type dependencies relations for these purposes was introduced in [13]. We follow the basic ideas also in this paper where we focus on the transformation of sentences containing motion verbs which are substantial for describing a given path. However, we have found out that the use of Stanford type dependencies relations is not sufficient to be able to provide the transformation rules. Hence, in this paper we additionally take into account the valency of *motion verbs*.

3. Stanford typed dependencies and the theory of verb valency frames as the basis of the conversion rules

The goal is to develop a module of the TILUS tool that allows for the transformation of natural language text describing journey into logical constructions. The movement of agents along the trajectory is described by special types of verbs, so-called motion verbs that describe motion. From the linguistic point of view, they are intransitive which means they usually have no object. Hence, they cannot be used in the passive voice. Common examples of motion verbs, for the description of agents' movement along the trajectory, are for instance "go", "walk", "run", etc. Typical examples of sentences expressing movement along a route are for instance the following ones: *'John is walking down Sapkowski street from the town hall to the secondary school building. After 100 metres, John came to the cinema building. After another 100 metres, he came to the crossroads.'* To design specific rules for converting these types of sentences into TIL-Script logical constructions, we used Universal Dependencies based on Stanford typed dependencies relations and the theory of verb valency frames.

The semantics of the respective verb is provided via its lexical valency frame. In general, verb valency is the ability of a verb to bind other formal units, i.e. words, which cooperate to provide its meaning completely. These units are so-called *functors* or *participants* or *thematic roles*. Thus the valency of a verb determines the number of arguments (participants) controlled by a verbal predicate. This ability of verbs results from their meaning rather than from formal aspects. More details on the theory of valency frames can be found, for instance, in [14] and [15]. Attention to lexical valency has to therefore be paid in order to build up an ontology independent of a used language. We shall proceed from the valency dictionaries and John Sowa's approach which provide the verb valency participants classification according to lexical valency. Consider the example of the sentence: *'John is going to Ostrava by train.'* The activity *is going* has the following participants: actor (*John*), instrument of transport (*train*) and the final destination (*Ostrava*).

In order to obtain basic participants, which can be used in the specification of the journey and which concerns the *motion verbs*, we are proceeding from two valency dictionaries, namely VALLEX (see in [16]) and Verbalex (see in [17]), and John Sowa's thematic roles (see in [18]). The following types of participants can be used for the specification of the agent movement across the infrastructure:

Actor: agent of movement,

DIR1: from where,

DIR2: which way,

DIR3: where to,

Manner: in the case of direction description – to the right, to the left,

Ext: the transport measure as a distance - *100 metres* in sentences like '*After 100 metres turn right.*'

DIR1 (from where), *DIR2* (which way) and *DIR3* (where to) are continuously updated in the journey description as the journey progresses. Hence, the translation into TIL-Script assumes a continuous sequence of path description due to DIR transformation into other sentences.

From the logical point of view, we deal with the verb phrases expresses an agents' *activities* as denoting a function that is applied to its arguments. The application of verb valency frame theory for the agents' activities specification was first introduced in [19] and further developed in [20], [21], [22]. The number of arguments is controlled by the verb valency content. Dynamic entities relating to activities can be characterised by the special relationships in intensions between activities and their participants modelled as functions of TIL-Script. In our background theory (TIL) we view α -intensions as functions mapping possible worlds (of type ω) to a type β . The type β is frequently the type of a chronology of the elements of type α . These α -chronologies are, in turn, functions mapping time (of type τ) to the type α . Thus, α -intensions are usually mappings of type $(\omega \rightarrow (\tau \rightarrow \alpha))$, or in TIL notation $((\alpha\tau)\omega)$, $\alpha_{\tau\omega}$ for short. Another frequent type of intensions is the property of individuals, an object of type $(ot)_{\tau\omega}$, in TIL-Script notation $((\text{Bool Indiv})\text{Time})\text{World}$). Consider for example the above mentioned sentence '*John is going to Ostrava by train.*' Below, there are examples of the results of conversion from natural language to TIL instead of TIL-Script for reasons of greater familiarity with TIL.

Sentence 1: *John is walking down Sapkowski street from the town hall to the secondary school building.*¹

$$\lambda w \lambda t [[ACT_{wt} 'John 'going] \wedge [DIR2_{wt} 'Sapkovski_street 'going] \wedge [DIR1_{wt} 'town_hall 'going] \wedge [DIR3_{wt} 'second_sch_bulding 'going]] \wedge] \quad (S_1)$$

Sentence 2: *After 100 metres, John came to the cinema.*

$$\lambda w \lambda t [[EXT_{wt} '100m 'came] \wedge [ACT_{wt} 'John 'came] \wedge [DIR3_{wt} 'cinema 'came]] \quad (S_2)$$

¹The construction in TIL-Script notation is the following: $\backslash w \backslash t [[DIR1@wt 'TownHall 'walking] \wedge [DIR2@wt 'Sapkovski_street 'walking] \wedge [DIR3@wt 'SecondarySchoolBuilding 'walking] \wedge [Act@wt 'John 'walking]]$. Note the specific notation character @wt. This character expresses an intensional descent to the respective possible world and time to obtain the final value of this intension in this possible world and time.

In order to generate these constructions automatically from natural language text, we decided to base our rules on Universal dependencies relations. Universal Dependencies (UD) is a framework for consistent annotation of parts of natural language texts across different human languages. It was designed to provide a straightforward description of grammatical relations for any user who could benefit from an automatic text understanding. UD is an open community effort with over 300 contributors producing nearly 200 treebanks in over 100 languages. It is a project which is developing cross-linguistically consistent treebank annotation for many languages, with the goal of facilitating multilingual parser development, cross-lingual learning, and parsing research from a language typology perspective. The annotation scheme is based on the evolution of (universal) Stanford dependencies see [23], Google universal part-of-speech tags, see [24], and the Intersect interlingua for morphosyntactic tagsets, see [25]. The theoretical framework for the types of syntactic relations are Stanford dependencies which map straightforwardly onto a directed graph representation, in which the words in the sentence are nodes in the graph and the grammatical relations are edge labels. This representation contains approximately 50 grammatical relations and in [26], you can find the list of all the types with their specifications and natural language examples. Below are the most common types of grammatical relations connected with motion verbs.

- *acomp*: adjectival complement. An adjectival complement of a verb is an adjectival phrase which functions as the complement (like an object of the verb). Example: *She looks very beautiful*: *acomp*(looks, beautiful).
- *advmod*: adverb modifier. An adverb modifier of a word is a (non-clausal) adverb or adverb-headed phrase that serves to modify the meaning of the word. Examples: Genetically modified food: *advmod*(modified, genetically), less often: *advmod*(often, less).
- *nsubj*: nominal subject. A nominal subject is a noun phrase which is the syntactic subject of a clause. The governor of this relation might not always be a verb: when the verb is a copular verb, the root of the clause is the complement of the copular verb, which can be an adjective or noun. Examples: *Clinton defeated Dole*: *nsubj*(defeated, Clinton), *The baby is cute*: *nsubj*(cute, baby).
- *pobj*: object of preposition. The object of a preposition is the head of a noun phrase following the preposition, or the adverbs “here” and “there”. (The preposition in turn may be modifying a noun, verb, etc.) Example: *I sat on the chair*: *pobj*(on, chair).
- *prep*: prepositional modifier. A prepositional modifier of a verb, adjective, or noun is any prepositional phrase that serves to modify the meaning of the verb, adjective, noun, or even another preposition. In the collapsed representation, this is used only for prepositions with NP complements. Examples: *I saw a cat in a hat*: *prep*(cat, in), *I saw a cat with telescope*: *prep*(saw, with), He is responsible for meals: *prep*(responsible, for).
- *prt*: phrasal verb particle. The phrasal verb particle relation identifies a phrasal verb, and holds between the verb and its particle. Example: *They shut down the station*: *prt*(shut, down).

- *num*: numeric modifier. A numeric modifier of a noun is any number phrase that serves to modify the meaning of the noun with a quantity. Examples: *Sam ate 3 sheep.*: num(sheep, 3), *Sam spent forty dollars.*: num(dollars, 40).

These relations provide a straightforward description of grammatical relations in the analysed text and in [13] we demonstrated how to extract some important semantic information from this Stanford typed dependencies representation. We can use the tools generating tag annotations based on Stanford typed dependencies, such as, for instance, Explosion (for details, see the website [27]). This is a software company specialising in developer tools for artificial intelligence and natural language processing (NLP). They are the makers of spaCy (the leading open-source library for advanced NLP) and Prodigy (an annotation tool for radically efficient machine teaching).

In [13], we introduced the first motivation and general outline as to how to utilize the Stanford typed dependencies relations. In many cases, we are also able to detect the activity and its participants in general on the basis of Stanford typed dependencies relations. Let us look at the above-mentioned example of the sentence ‘*John goes to Ostrava by train.*’ The verb valency participants of the activity *going* are the following: John is the agent of the activity, Ostrava is the final destination and train is the instrument of transport. For comparison, Figure 1 shows annotation scheme for this sentence based on Stanford dependencies.

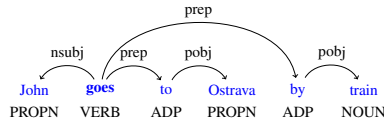


Figure 1. The Stanford dependencies annotation scheme.

We are able to recognize the activity determined by the verb and the agent of this activity which is determined by the proper name *John* and is in the relation *nsubj* with the verb. The terms *Ostrava* and *train* are detected as consecutive relations *prep* (preposition) and *pobj* (object of preposition). Hence, we can recognise in an automated way via analysis of dependencies that these terms are the verb valency participants in general, but not the respective categories of these participants (destination, instrument). For this purpose, we also have to include world types and the specific word shape of the prepositions specifying the direction within the rules. In the following paragraph, there is a specification of the rules based on Stanford dependencies and verb valency frames for the conversion of natural language sentences containing *motion verbs* into TIL-Script.

4. Transformation rules

As mentioned above, our transformation rules are based on the use of Stanford dependencies and the theory of verb valency frames. In this chapter, we provide the specification of the substantial rules for the conversion of sentences with *motion verbs* to TIL-Script constructions. For the formal form of the rule, we take into account the respective type of relation according to Stanford dependencies, the respective type of word (i.e. noun, verb,

preposition, etc.) and the specific word shape of the prepositions specifying the direction. We demonstrate these rules within the concrete examples. At first we give the example of the path description sentence, then we provide the output of this sentence tagged with Stanford dependencies. Finally, we provide the respective rules of conversion to TIL-Script and the final construction of converted sentence. We present the constructions in TIL instead of TIL-Script for reasons of greater familiarity with TIL.

4.1. Rules for: Actor, Dir1, Dir2, Dir3

J_1 : John went from home to school down Main Street.

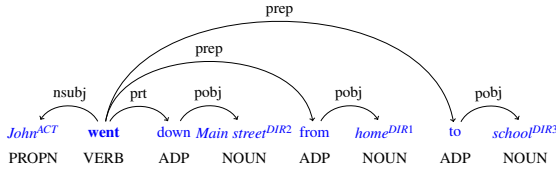


Figure 2. The Stanford dependencies annotation scheme.

J_2 : John came to a pub on Main street

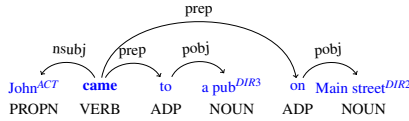


Figure 3. The Stanford dependencies annotation scheme.

- RA: $nsubj(verb(x), propn(y)) \rightarrow \lambda w \lambda t [ACT_{wt} y x]$
- RD1: $prep(verb(x), adp(from)) \wedge pobj(adp(from), noun(y)) \rightarrow \lambda w \lambda t [DIR1_{wt} y x]$
- RD2a: $prt(verb(x), adp(down)) \wedge pobj(adp(down), noun(y)) \rightarrow \lambda w \lambda t [DIR2_{wt} y x]$
- RD2b: $prep(verb(x), adp(on)) \wedge pobj(adp(on), noun(y)) \rightarrow \lambda w \lambda t [DIR2_{wt} y x]$
- RD3: $prep(verb(x), adp(to/onto)) \wedge pobj(adp(to/onto), noun(y)) \rightarrow \lambda w \lambda t [DIR3_{wt} y x]$

The conversion of the sentence J_1 , the rules applied: RA, RD1, RD2a, RD3:

$$\begin{aligned} & \lambda w \lambda t [[ACT_{wt} 'John' went] \wedge [DIR3_{wt} 'school' went] \\ & \wedge [DIR1_{wt} 'home' went] \wedge [DIR2_{wt} 'Main_street' went]] \end{aligned} \quad (CJ_1)$$

The conversion of the sentence J_2 , the rules applied: RA, RD1, RD2b, RD3:

$$\begin{aligned} & \lambda w \lambda t [[ACT_{wt} 'John' came] \wedge [DIR3_{wt} 'pub' came] \\ & \wedge [DIR2_{wt} 'Main_street' came]] \end{aligned} \quad (CJ_2)$$

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4.2. Rule for Extent

J_3 : After 100m John came to pub on Main street.

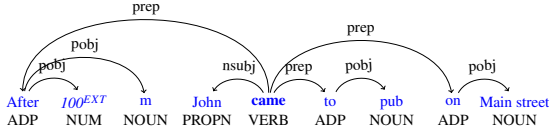


Figure 4. The Stanford dependencies annotation scheme.

The conversion of the sentence J_3 , the rules applied: RE, RA, RD3, RD2b:

- RE: $prep(verb(x),adp(after)) \wedge pobj(adp(after),num(y)) \rightarrow \lambda w\lambda t[EXT_{wt} y x]$

$$\lambda w\lambda t[[EXT_{wt} '100 'came] \wedge [ACT_{wt} 'John 'came] \wedge [DIR3_{wt} 'pub 'came] \wedge [DIR2_{wt} 'Main_street 'came]] \quad (JC_3)$$

4.3. Rule for Manner

J_4 : John turned right onto Havlicek street.

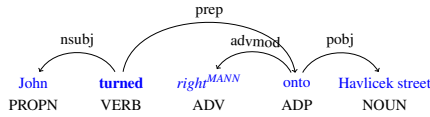


Figure 5. The Stanford dependencies annotation scheme.

- RM1: $prep(verb(x),adp(onto)) \wedge advmod(adp(onto),adv(y)) \rightarrow \lambda w\lambda t[MANN_{wt} y x]$

The conversion of the sentence J_4 , the rules applied: RE, RA, RD3, RM:

$$\lambda w\lambda t[[ACT_{wt} 'John 'turned] \wedge [MANN_{wt} 'right 'turned] \wedge [DIR3_{wt} 'Havlicek_street 'came]] \quad (JC_4)$$

The above presented rules are the substantial for the most commonly used motion verbs in journey description. We are currently working on taking into account other verbs and also the phrasal connections that may appear in path descriptions.

5. Conclusion and future work

In this paper, we have presented a proposal of rules for transforming natural language text with *motion verbs* into TIL-Script constructions. The rules are designed with respect to Stanford type dependencies and verb valency frames. From these constructions, the concrete representation of the whole journey is later generated according to the heuristic. In our future work, this journey representation will serve as the input for the part based on geographic data which will generate the map topology from these constructions.

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‘Knowing-that’ vs. ‘Knowing-wh’

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Abstract. Though there is a huge amount of the so-called propositional *epistemic logics* that deal with *propositional attitudes*, i.e., sentences of the form “*a* knows that *P*”, their ‘wh-cousins’ of the form “*a* knows who is a *P*”, “*a* knows what the *P* is”, “*a* knows which *Ps* are *Qs*”, etc., have been, to the best of my knowledge, almost neglected. A similar disproportion can be observed between the analysis of Yes-No questions, which has been under scrutiny of many erotetic logics, and Wh-questions which have been dealt with just by a few authors. To fill this gap, we have analysed Wh-questions in Transparent Intensional Logic (TIL) and adjusted Gentzen’s system of natural deduction to natural language processing in TIL; thus, our TIL question-answering system can answer not only Yes-No questions but also derive answers to Wh-questions. In this paper, I am going to apply these results to the analysis of sentences containing a ‘know-wh’ constituent. In addition, I will analyse the relation between ‘knowing-that’ and ‘knowing-wh’. For instance, if *a* knows that the Mayor of Ostrava is Mr Macura, can we logically derive that *a* knows who is the Mayor of Ostrava? Or, vice versa, if *a* knows who is the Mayor of Ostrava and the Mayor of Ostrava is Mr Macura, do these assumptions logically entail that *a* knows that the Mayor of Ostrava is Mr Macura? Though in case of rational *human* agents the answers seem to be a no-doubt YES, perhaps a rather surprising answer is in general negative. We have to specify rules for deriving the relation between knowing-that and knowing-wh, and if a software agent is rational but *resource bounded*, it does not have to have in its ontology the rules necessary to derive the answer. Hence, when applying these results into the design of a multi-agent system composed of software resource-bounded agents, we have to compute their *inferable knowledge*, which accounts not only for their explicit knowledge but also for their inferential abilities.

Keywords. Knowing-wh; Knowing-that; Transparent Intensional Logic; TIL; Natural Deduction; Inferential rules; Inferential abilities of agents; multi-agent system

1. Introduction

There is huge amount of epistemic logics which deal with the so-called *propositional attitudes*, i.e., sentences of the form “*a* knows that *P*” or “*a* believes that *P*”. These logics are mostly variants of intensional modal logics, whose language contains one or more knowledge operators and whose semantics is given in terms of Kripke models that contain epistemically possible worlds mutually related by accessibility relation. In these logics, ‘knowing that’ represented by the operator *K* corresponds to necessity (represented by box operator) and ‘believing that’ to possibility (represented by diamond). This modal approach to epistemic logic has been widely applied in philosophy, computer science and artificial intelligence. The sub-category ‘Doxastic Logic’ also includes formal work on belief revision.¹ These logics provide a handy notation, axioms and rules to deal with knowing/believing that, and a proof system syntactically characterized as a normal modal logic somewhere between K4 and K5 subjective to different opinions about the so-called introspection axioms. Yet, there are many shortcomings as well. First, there are many different kinds of these logics depending on the chosen axioms and rules. For instance, in the K4 system, positive introspection is presupposed (what is known is known to be known) and in K5 negative introspection (it is known what is not known). K5, in particular, is a subject of a lot of criticism. Indeed, how can one know what they don’t know? Hence, to apply some of these logics in a multi-agent system, one must decide which of them would be plausible depending on agents’ abilities, which is often hardly possible, or to design a system in which the agents would switch among particular logics, which is also hardly applicable. Second, all the intensional modal approaches suffer the problem of logical/mathematical omniscience. It means that once an agent *a* knows that *P* they should also know all the logical consequences of *P* (or, in a restricted Montague-Scott version, all the propositions equivalent to *P*). Third, intensional, modal epistemic logics do not deal with the limitations of resource-bounded agents accordingly, as they deal with two extreme kinds of knowledge, namely *implicit* and *explicit knowledge*. *Implicit knowledge* is closed under entailment or under equivalence; it is ascribed to an agent

¹ A first-class summary on epistemic logics can be found in Rendsvig & Symons (2021). In recent decades, a great deal of interdisciplinary attention has been paid to epistemic logics by economists and computer scientists who actively develop the field together with logicians and philosophers. The fertile interplay between computer science and epistemic logic has been introduced in Fagin et al. (1995) and Meyer & van den Herik (1995).

a from the outside so that *a* does not have to be aware of its knowledge. In particular, *a* does not have to actively behave according to it. *Explicit knowledge* is knowledge that *a* is aware of and is able to use.²

Logical omniscience is innocuous, as long as we are modelling only implicit knowledge, since the *K*-axiom of rationality simply traces all the logical consequences of a given stock of knowledge that obtain whether the agent is aware of them or not. The axiom does not entail that the agent should know *explicitly* what he implicitly knows. Yet, in order to model knowledge of active, rational but resource-bounded agents, we need the kind of knowledge the agents are aware of and are able to use in their behaviour. However, it would not be possible for resource-bounded agents to adhere to explicit-knowledge as the principle guiding their policy of drawing inferences because in such a case the agents are actually deprived of any inference abilities. They know only those pieces of knowledge that are explicitly stored in their knowledge base. Nor would it be possible and pragmatically rational for them to (attempt to) adhere to the other extreme of implicit knowledge, for they would have to infer each and every conclusion that would follow from their supply of explicit knowledge. They (we) would be inundated with irrelevant and useless knowledge taxing their (our) resources.

To deal with the omniscience problem, *hyperintensional* epistemic logics are being recently developed.³ In principle, there are two kinds of such systems. Either hyperintensions are primitive constructs and their behaviour is specified syntactically by axioms and rules, or hyperintensions are designed as structured entities, mostly of procedural character. If the latter, then particular rules controlling the operations with hyperintensions are dictated by their semantics. In our background theory of Transparent Intensional Logic (TIL), we vote for the latter approach. In sentences of the form “*a* knows that *P*” the complement *P* is conceived as the *procedure* producing a PWS-proposition rather than the proposition itself. To model knowledge compatible with resource-bounded agents, we apply the notion of *inferable knowledge*, which is the golden middle way in between the two extremes, namely implicit and explicit knowledge. The basic idea is to calculate the stock of *inferable* knowledge of a given agent, in the following manner. Given an agent *a*, a possible world *w* and an instant of time *t*, the inferable knowledge of *a* at *w*, *t* functionally depends on *a*'s stock of explicit knowledge at *w*, *t* together with a set of inference rules that *a* masters at *w*, *t*.⁴

While there is a lot of research done in *epistemic logics* into the analysis of *propositional attitudes*, i.e., sentences of the form “*a* knows that *P*”, their ‘wh-cousins’ of the form “*a* knows *who* is a *P*”, or “*a* knows *what* the *P* is”, “*a* knows *which P*s are *Q*s”, etc., have been, to the best of my knowledge, almost neglected. Says Resnsvig and Saymons (2021):

While epistemic logicians had traditionally focused on *knowing that*, one finds a range of other uses of knowledge in natural language. As Wang (2015) points out, the expressions *knowing how*, *knowing what*, *knowing why* are very common, appearing almost just as frequently (sometimes more frequently) in spoken and written language as *knowing that*. Recently non-standard epistemic logics of such expressions have been developed, though *knowing who* constructions are present in Hintikka's *Knowledge and Belief* (1962) [...]. (ibid., p. 5)

Recently, perhaps the only exception to this ignorance on *knowing-wh* is the work of Yanjing Wang (2015, 2018) who has developed a formal syntactic theory on this topic. The author does not aim at specifying the meaning of ‘knowing-wh’. Rather, he takes *knowing-wh* as a primitive atomic entity and introduces a new modal operator *K_v*. Hence, instead of breaking it down by allowing quantifiers, equalities and other logical constants to occur freely in the language, *K_v* is simply introduced as a new modality. For example, “knowing what a cat is” is rendered by “*K_v cat*” instead of $\exists xK(cat=x)$. Wang characterizes this move as being promising, since by restricting the language we may avoid some philosophical issues of first-order modal logic, retain the decidability of the logic, and focus on special logical properties of each particular knowing-wh construct at a high abstraction level.

Yet, much earlier, Hintikka addressed these issues; in the early days of epistemic logic, Hintikka (1962) elaborated theories of knowing-wh and its relation to questions in terms of the first-order modal logic. For example, “knowing who John is” is formalised as $\exists xK(John=x)$. However, partly because Quine's objections against philosophical issues in the foundations of first-order modal logic, the development of epistemic logics beyond *knowing that* was strangled. Perhaps, there are also other reasons for not pursuing the research on *knowing-wh*. First, while there is just one type of the complement of knowing that, possible types of the complements of knowing-wh are much more diverse. Second, it is not clear how to *define* knowing-wh. Sentences with this constituent become meaningless if the verb ‘know’ is replaced by ‘believe’, like for instance, “John believes how to play tennis”. This fact undermines philosophers' usual conception of knowledge as the ‘justified belief’. Linguistically, this phenomenon occurs frequently when dealing with factive verbs like knowing or regretting.

Linguists try to characterize such phenomena from a more general perspective in terms of classifications of verbs, and thus answer the question “which verbs can take an embedded wh-question?” For example, *forget*, *see*,

² See Rescher (2002, p. 478). Rescher dubs implicit knowledge ‘accessible knowledge’ while his term for explicit knowledge is ‘occurrent knowledge’.

³ For an introduction and a brief summary of hyperintensional approaches, see Jespersen & Duží (2015).

⁴ For details, see Duží, Menšík (2017).

remember are like *know* in this sense. However, it is a striking cross-linguistic fact that the verb *believe* cannot take any of those embedded questions, in contrast with philosophers' usual conception of knowledge in terms of strengthened justified true belief. Linguists have been trying to give explanations in terms of factivity and other properties of verbs with interesting exceptions. The semantic variability of the same knowing-wh-construct in different contexts also interest linguists a lot. Wang (2018) gives this example. "I know which card is the winning card" can mean I know Ace is the winning card for the game, or I know the card that my opponent holds is the winning card." For philosophers, especially epistemologists, it is crucial to ask whether those knowing-wh statements are also talking about different kinds of knowledge. For example, it has been a frequently debated topic whether knowledge-how can be reduced to knowledge-that. Moreover, knowing why is extremely important for philosophers of science. However, what amounts to knowing why? Many philosophers think knowing a *scientific explanation* is the key to answering why-questions, and there is a large body of research on it (cf. e.g., (van Fraassen, 1980)).

Wang (2015) characterizes knowing-wh as 'knowing an answer to the corresponding question'. Which brings forward to our attention logics of questions and answers, i.e., erotetic logics. Here a similar disproportion between the attention paid to Yes-No questions and Wh-questions can be observed. While there are many erotetic logics dealing with Yes-No questions,⁵ just a few works deal with Wh-questions.⁶

To fill this gap, we have developed a theory of Wh-questions and their analysis in TIL, together with the technique of their answering.⁷ Duží & Fait (2021) introduce Gentzen's system of natural deduction adjusted for TIL and natural-language processing. The system derives logical consequences of information recorded in the enormous amount of input text data. Thus, the system not only answers the questions by providing explicitly recorded knowledge sought by keywords. It also answers questions in an 'intelligent way' by computing inferable knowledge such that rational human agents would obtain if only it were not beyond their time and space capacities. The analysis of Wh-questions results into λ -terms with a free variable x ranging over entities of type α , which is the type of a possible direct answer. The system provides answers by suitable substitutions of the α -entities extracted from input sentences, the constituents of which match a given λ -term. The proposed more detailed classification of Wh-questions restricts the domain of a plausible answer to a subtype of the type α , which makes it easier for the agents to provide a rigorous answer. In addition, it also makes it possible to derive as an answer even more information by applying the semantic rules rooted in the rich semantics of a natural language. In particular, the agents can make use of the relations of requisites and pre-requisites between intensions, or the rules valid for factive verbs like 'knowing', 'regretting', and so like. Číhalová & Duží (2022) apply this theory to the analysis of dynamic activities of agents. Each activity liking 'going', 'building', etc., is connected with an agent who does the activity, and participants of different kinds. Hence, agents can ask Wh-questions like 'who' is doing this or that activity, 'when' and 'where' does it take place, for 'whom' is an agent building something, 'what' is being built, etc. The system also accounts for different tenses when this or that activity is being done and frequencies of the activity. If an agent obtains a direct answer to a Wh-question, we can conclude that the agent *knows-Wh* the answer. Thus, a natural step in further research is to go on to scrutinize *knowing-wh*, which I am going to do in this paper.

The rest of the paper is organized as follows. Section 2 is a brief summary of quantified epistemic logics. First, I introduce Hintikka's approach to *knowing-wh* by means of the existentially quantified *knowing-that*. Second, a brief summary of the new approach by Yanjing Wang is summarised. Section 3 introduces the fundamentals of Transparent Intensional Logic (TIL), which is my background theory. Section 4 presents the main novelty of the paper, which is the analysis of 'knowing-wh' as relating an agent to the α -value of the asked PWS-intension in a possible world w and time t of evaluation, or, in the case of mathematics, as relating the agent to the entity produced by the mathematical procedure. I also propose the rules for inferring consequences of such sentences, and the rules relating 'knowing-wh' to the corresponding 'knowing-that'. Concluding remarks can be found in Section 5.

2. Quantified Epistemic Logic and the Logics of Knowing-wh

2.1. Hintikka on Knowing-wh

Jaakko Hintikka can be truthfully characterized as the founder of epistemic logics due to his pioneering work (1962). Hintikka's notion of knowledge amounts to the elimination of uncertainty. In his 1962 book, he devoted most of the attention to propositional epistemic logic, though his logic is applicable also to doxastic attitudes such

⁵ See, for instance Benthem & Mincă (2012), Groenendijk (2003), Harrah (2002), Peliš & Majer (2011), Punčochář (2020), Wisniewski (2013). Comprehensive and extensive exposition on current intensional approaches to the semantics of questions can be found in Wisniewski (2015).

⁶ See Wiese (2002), Haida (2008) or Karttunen (1977). A typical representative of such studies is the work of Groenendijk (2003).

⁷ For details, see Duží, Číhalová (2015), Duží, Fait (2020), Duží, Fait (2021) and Číhalová, Duží (2022).

as belief. Hintikka's language is thus that of propositional logic enriched with the operator K_i that makes it possible to create formulas like $K_i\phi$ meaning "an agent i knows that ϕ ". The language is interpreted on Kripke's frames with the relation of accessibility $\rightarrow_i \subseteq S \times S$, where S is a non-empty set of possible worlds. The agent i knows that ϕ in a world s if and only if ϕ is true in all the worlds accessible for i from the world s .⁸

Depending on the properties of the accessibility relation, we obtain different systems of modal epistemic logic. Hintikka specifies this relation as being reflexive and transitive. If it is an equivalence relation, we obtain the strongest system $K5$, in which two rather problematic and much discussed axioms 4 and 5 hold. The axiom 4 is $K_i\phi \supset K_iK_i\phi$ (positive introspection) and 5 is $\neg K_i\phi \supset K_i\neg K_i\phi$ (negative introspection). These systems notoriously suffer the problematic issue of *logical omniscience* (which is due to the rule of necessitation and the axiom of rationality). Despite those problematic issues and a lot of philosophical dispute concerning the axioms 4 and 5, propositional epistemic logics have been successfully applied in many other fields such as artificial intelligence, program verification, distributed and multi-agent systems. In addition, combining Kripke's possible world semantics with other modalities such as temporal ones gave rise to other useful variants of epistemic logics, like *temporal epistemic logic* or *dynamic epistemic logic*, with many applications in theoretical computer science, game theory, or in modelling changes of knowledge and information in agents' knowledge bases.⁹

However, in ordinary vernacular, propositional epistemic '*knowing that*' is actually less frequent than objectual '*knowing which*', '*knowing who*', '*knowing what*', '*knowing how*', etc., for which I use in this paper the term '*knowing-wh*'. And though epistemic propositional logics of '*knowing that*' have been flourishing since Hintikka's time, despite the frequency and importance of their objectual '*knowing-wh*' cousins, research into this topic has been almost neglected. One of the exceptions is the work of Hintikka who devoted the last chapter of his (1962) book to the analysis of '*knowing who*' in terms of *quantified epistemic logic*.¹⁰ Currently, this topic has been open and studied by Yanjing Wang in his (2018), whose results I am going to summarise below.

According to Hintikka (1989b), a wh-question like "Who is b ?" amounts to the request for obtaining a piece of information so that the questioner a would know who b is. This wh-knowledge is the *desideratum* of the corresponding wh-question. Hence, the study of wh-questions and knowing-wh are closely related to each other, and this view led Hintikka to the opinion that *knowledge acquisition* is even more important than *knowledge justification* which has been the focus of the traditional epistemology. In (1962), Hintikka proposed to formalize " a knows who b is" by the existentially quantified formula $\exists xK_a(b=x)$ and called it *knowledge of objects*. In contrast, the formula $K_a\exists x(b=x)$ is the analysis of *propositional knowledge* (*knowing that*). Thus, the formalism of knowing-wh is based on knowing that, as one and the same operator K_a is used in both cases, which differ only by the scope of the quantifier. Introducing constants and quantifiers into the language calls for a richer structure of possible worlds, according to Hintikka. He conceives possible worlds as not sharing a universal domain of objects, the universe of discourse, for in Hintikka's theory there are non-existent individuals in some possible worlds while existing in others.

Similarly, "I know who murdered b " is here formalized as $\exists xK_I M(x,b)$, which is the desideratum of the question "Who murdered b ?". However, if one knows that a murdered b , i.e. $K_I M(a,b)$, it is not in general possible to meet the desideratum $\exists xK_I M(x,b)$, because $K_I M(a,b)$ does not have to yield knowing who, as Hintikka argues in (1989a); the questioner should also know who a actually is, which is called the *conclusiveness condition*. Indeed, as Wang (2018) shows, answering the question "Who gave the first speech?" by "The first speaker" may not be informative at all. From this point of view, the existential generalization rule does not hold: $K_I M(a,b)$ does not entail $\exists xK_I M(x,b)$.

Hintikka also considered more complicated wh-sentences like "I know whom every young mother should trust" (with the intentional meaning "her own mother"). The formalization should then be of the second-order by quantifying over functions; $\exists fK_I \forall x (M(x) \supset T(x,f(x)))$, where M is standing for young mother, f for the function mother-of somebody, T for trusting. But Hintikka wanted to avoid the problem of working in the second-order logic, which resulted into the introduction of the so-called *Independence Friendly Logic* (Hintikka and Sandu (1989)). The authors introduce the independence sign "!" into the language, which is interpreted as letting some quantifiers occurring within the scope of another quantifier be independent of the latter, as if to jump out of the scope. As a result, we obtain a branching structure of quantifiers linearly ordered in the formulas. This weird trick, as odd as it seems to be, has one affirmative effect. It makes it possible to stay in between first and second order logic. It can go beyond the first-order epistemic logic, although quantifying is still first order. The above young mother sentence would now be analysed by the formula $K \forall x (\exists y!K) (M(x) \supset T(x,y))$ in which only variables ranging over individuals are quantified.

Recent research in quantified epistemic logic is mostly application driven; we can find applications in cryptography with respect to modelling agents' decoding abilities, in the theory of games, verification of security

⁸ Hintikka himself prefers the term 'state' or 'situation' to the term 'possible world'. In the applications of epistemic modal logics to the field of program verification, it is also more natural to talk about possible states in which a program can be during its run time.

⁹ See Fagin et al. (1995).

¹⁰ In these paragraphs, I draw on a very nice summary of Hintikka's approach by Yanjing Wang in his (2018) paper.

properties, etc. These epistemic theories are fragments of first-order logic with knowledge and temporal operators. Applications in the theory of multi-agent systems are mostly propositional epistemic logics, where agent names are rigid designators. There must be a finite set of agents who know each other identity. In the second-order applications, it is possible to quantify over propositions and formalise sentence like “the agent a knows everything b knows.”¹¹

2.2. Wang’s logics of Knowing-wh

Wang in (2018) presents a new proposal of the logic of knowing-wh. He does not share Hintikka’s opinion that knowing-wh should be modelled by existential quantification of the sentences on knowing-that. Instead, Wang introduces a new modal operator K_V for knowing the value of some c . For instance, instead of formalizing “agent a knows what the value of c is” by $\exists x K_a(c = x)$, Wang introduces a simple formula $K_V a c$, where c belongs to a set C of constant symbols. Thus, K_V is a primitive modality, and the author aims at providing a complete axiomatic system for it. Says Wang: “Following Hintikka, we take a semantics-driven approach for there is usually not enough syntactic intuition on the possible axioms for such knowing-wh constructions. We can discover interesting axioms by axiomatizing the valid formulas w.r.t. semantics.”

The semantics for $K_V c$ is given by first-order Kripke models with a constant domain. Intuitively, an agent i knows what the value of c is iff c has the same value over all the i -accessible worlds. Having defined the language and semantics, the author aims at finding a complete axiomatization with meaningful axioms and prove some theorems. He deals with three cases of knowing-wh, namely knowing whether, knowing what and knowing how. Similarly, as in other modal logics, several classes of particular axiom schemata are examined depending on the properties of Kripke’s frame accessibility relation.

There is also a list of positive features and negative features of such a formal approach. According to the author, among the advantages there is a balance between expressivity and complexity, as the neat language with the simple modality K_V actually packages (using the author’s term) a quantifier, knowing that modality and equality together. Such a weaker language is computationally tractable, and some conceptual problems are avoided (or rather hidden). There are also limitations and difficulties of such a formal approach, as the author admits. First, in the language, one cannot formalise complicated sentences in a fully compositional way. Second, though the shared existential form is hidden, it can be sometimes necessary to quantify over higher-order entities like properties or propositions so that different modalities can ‘behave’ in a completely different way than specified by the allegedly plausible axioms. Finally, as the author himself admits, “in some cases it is highly non-trivial to give a reasonable semantics since we do not understand enough about the meaning of certain knowing-wh yet.”

So much for the current formal approach to dealing with the logics of knowing-wh. In my background theory TIL, I will try to go the other way around. I am going to first define the *meaning* of knowing-wh in full details in the form of a structured meaning procedure encoded by a given sentence, and only then to formalise semantically-driven rules for behaviour of agents in a multi-agent system.

3. Basic Notions of Transparent Intensional Logic

Pavel Tichý, the founder of Transparent Intensional Logic (TIL) was inspired by Frege’s semantic triangle.¹² Though Frege did not define the sense of an expression but only characterised it as the ‘mode of presentation’ of the denoted entity, Tichý defined the sense of an expression, i.e. its *meaning*, as an abstract, algorithmically structured *procedure* that produces the object denoted by the expression, or in rigorously defined cases fails to produce a denotation if there is none.¹³ Indeed, in natural language, there are non-denoting terms that have a perfect meaning, like ‘the greatest prime number’. Mathematicians had obviously to understand the sense of the term first and only then could they prove that there is no such number. Hence, in TIL, the meaning of an expression is understood as a context invariant *procedure* encoded by a given expression. By context invariant, we mean this. The procedure encoded by an unambiguous expression is one and the same independently of the context in which the expression is used. Yet, if the expression is ambiguous, logic cannot decide its intended meaning. In such a case, we furnish the ambiguous expression with more than one procedure corresponding to its different meanings.

Formally conceived, TIL is a hyperintensional, typed λ -calculus of partial functions. The λ -terms of the TIL language denote *procedures* (which could be approximated by Church’s *functions-in-intension*) that produce set-theoretical mappings (functions-in-extension) or lower-order procedures.¹⁴ Tichý coined these meaning

¹¹ For details, see Ditmarsch et al. (2012).

¹² See Tichý (1988).

¹³ A similar philosophy of meaning as a ‘generalized algorithm’ can be found in Moschovakis (2006); this conception has been further developed by Loukanova (2009).

¹⁴ Church (1941, pp. 2-3) discusses two different notions of a function, namely function-in-intension and in extension. Function-in-extension corresponds to the modern notion of function as a set-theoretical mapping, while function-in-intension is given by the meaning of

procedures *constructions* and I am going to stick to this term. Qua procedural objects, constructions can be *executed* so as to operate on input objects (of a lower-order type) and produce at most one object of the type they are designed to produce, while non-procedural objects (i.e. non-constructions like set-theoretical mappings) cannot be executed.

Tichý defined six kinds of *constructions*, and I will use five of them, as Single Execution is not needed for the purpose of this paper. There are two kinds of *atomic* constructions that present input objects to be operated on by molecular constructions. They are *Trivialisation* and *Variables*.

Variables produce objects dependently on valuations; they are said to *v-construct*. We follow the objective version of Tarski's conception of variables. To each type of the ramified hierarchy of types, countably many variables are assigned. Each type can be organised into countably many valuation arrays. Valuation v then selects a given array and the n^{th} -variable assigned to range over the type produces the n^{th} -entity of this array.

Trivialisation of an object X presents X without the mediation of any other procedures. Using the terminology of programming languages, the Trivialisation of X , denoted by 0X , is just a *pointer* or *reference* to X . Such a pointer is needed because no non-procedural object, be it an individual or a function-in-extension, can be a constituent of a procedure. The objects on which a construction operates are beyond the construction. Trivialization can present an object of any type, even another construction C . Hence, if C is a construction, 0C is said to *present* the construction C to be operated on as a whole within its super-construction. In such a case, C occurs hyperintensionally, i.e. in the *non-executed* mode. Then all the variables occurring in C occur hyperintensionally as well; they are bound by Trivialization and not amenable to logical operations.

The execution of a Trivialisation or a variable never fails to produce an object. However, since TIL is a logic of *partial* functions, the execution of some of the molecular constructions can fail to present an object of the type they are typed to produce. When this happens, we say that a given construction is *v-improper*. This concerns in particular one of the molecular constructions, namely *Composition*, $[X X_1 \dots X_n]$. It is the very *procedure of applying a function f* produced by X (if any) to the tuple argument (a_1, \dots, a_n) (if any) produced by the procedures X_1, \dots, X_n . A Composition is *v-improper* as soon as f is a *partial function* not defined at its tuple argument, or if one or more of its constituents X, X_1, \dots, X_n are *v-improper*.

Another molecular construction is *λ -Closure*, $[\lambda x_1 \dots x_n X]$. It is the very *procedure of producing a function* with the values v -produced by the procedure X , by abstracting over the values of the variables x_1, \dots, x_n to provide functional arguments. No Closure is *v-improper* for any valuation v , as a Closure always *v-constructs* a function, which may be, in an extreme case, a degenerate function undefined at all its arguments. For example, if x ranges over real numbers, the Closure $\lambda x [{}^0: x {}^0]$ produces such a degenerate function that has no value at any number.

TIL being a *hyperintensional* system, each construction C can occur not only in execution mode designed to produce an object (if any) but also as an object in its own right on which other (higher-order) constructions operate. The Trivialisation of C causes C to occur just presented as an argument, as mentioned above. Yet sometimes, we need to cancel the effect of Trivialisation and trade the mode of C for execution mode. *Double Execution*, 2C , does just that; it executes C twice over. If C *v-constructs* a construction D that in turn *v-constructs* an entity E , then 2C *v-constructs* E . Otherwise, 2C is *v-improper*. Hence, the following 20 -*Elimination* rule is valid for any construction C ; ${}^{20}C=C$.

With constructions of constructions, constructions of functions, functions, and functional values in TIL stratified ontology, we need to keep track of the traffic between multiple logical strata. The *ramified type hierarchy* does just this task. The type of *order 1* includes all objects that are not constructions. Therefore, it includes not only the standard first-order objects of individuals and truth values but also sets, mappings and also functions defined on possible worlds (i.e., the *intensions* germane to possible-world semantics). Definition is inductive, of course. We start with a base, i.e. a collection of non-empty mutually disjoint sets. For the purposes of natural-language analysis, we are usually assuming the following *base* of ground types:¹⁵

- o: the set of truth-values $\{\mathbf{T}, \mathbf{F}\}$;
- t: the set of individuals (the universe of discourse);¹⁶
- r: the set of real numbers (doubling as times);
- o ω : the set of logically possible worlds (the logical space).

From these basic types, an infinite hierarchy of collections of partial functions is defined by this inductive rule: where $\alpha, \beta_1, \dots, \beta_n$ are types, then $(\alpha \beta_1 \dots \beta_n)$ is a *functional type*, i.e. the collection of all partial mappings from the Cartesian product $\beta_1 \times \dots \times \beta_n$ into α .

the *rule* of correspondence between arguments and values of the function. Hence, while functions-in-extension are extensionally individuated, two or more functions-in-intension can share the same set-theoretical mapping.

¹⁵ TIL is an open system, and the choice of base depends on the discourse and subject matter under scrutiny. For instance, for the purpose of mathematics, we might vote for another base consisting of $\{o, \eta\}$, where η is the type of natural numbers, as in mathematics possible worlds and times play no role.

¹⁶ We assume that the universe of discourse t consists of at least two elements, though we leave aside the cardinality of this basic type.

The type of *order 2* includes the collection of constructions of order 1, i.e. the type $*_1$, which are constructions of first-order objects, and functions that have such constructions in their domain or range. Hence, $*_1$ and $(\alpha \beta_1 \dots \beta_n)$ where some of the types $\alpha, \beta_1, \dots, \beta_n$ is identical to $*_1$, are types of order 2.

The type of *order 3* includes the collection of constructions of order 2, i.e. the type $*_2$, which are constructions of first- or second-order objects, and functions that have such constructions in their domain or range. Hence, the atomic type $*_2$ and molecular types $(\alpha \beta_1 \dots \beta_n)$ where some of $\alpha, \beta_1, \dots, \beta_n$ is identical to $*_2$, are types of order 3.

The type of *order n* includes constructions of objects of order m , where $m < n$, and functions that have such constructions in their domain or range; and so on, ad infinitum.

Empirical expressions denote *empirical conditions*, which may or may not be satisfied at the world/time pair selected as points of evaluation. These empirical conditions are modelled as intensions. Intensions are entities of type $(\beta\omega)$: mappings from possible worlds to an arbitrary type β . The type β is frequently the type of the *chronology* of α -objects. These α -chronologies are, in turn, functions mapping time (of type τ) to the type α . Thus α -intensions are frequently functions of type $((\alpha\tau)\omega)$, abbreviated as ' $\alpha_{\tau\omega}$ '. Where w ranges over β and t over τ , the following logical form essentially characterises the logical syntax of empirical language: $\lambda w \lambda t [\dots w \dots t \dots]$. Dealing with the two modal parameters, namely possible worlds and times, separately, is connected with many assets, to name at least analysis of physical entities or nomic laws of necessity.

Analytical expressions denote *extensional entities*. They are of a type α where $\alpha \neq (\beta\omega)$ for any type β .

Examples of frequently used α -intensions are: *propositions* of type $o_{\tau\omega}$, *properties of individuals* of type $(ot)_{\tau\omega}$, *binary relations-in-intension between individuals* of type $(ot_1t_2)_{\tau\omega}$, and *offices or roles* of type $t_{\tau\omega}$, *propositional attitudes* of type $(ot_1o_{\tau\omega})_{\tau\omega}$ or $(ot_1*_{\tau\omega})_{\tau\omega}$ depending on whether we model implicit or explicit knowledge, respectively.

Logical objects like *truth-functions* and *quantifiers* are extensional: \wedge, \vee, \supset are of type (ooo) , and \neg of type (oo) . The *quantifiers* $\forall^\alpha, \exists^\alpha$ are type-theoretically polymorphic total functions of type $(o(\alpha\alpha))$, for an arbitrary type α , defined as follows. The *universal quantifier* \forall^α is a function that associates a class A of α -elements with **T** if A contains all elements of the type α , otherwise with **F**. The *existential quantifier* \exists^α is a function that associates a class A of α -elements with **T** if A is a non-empty class, otherwise with **F**.

Notational conventions. Below all type indications will be provided outside the formulae in order not to clutter the notation. Moreover, the outermost brackets of Closures will be omitted whenever no confusion can arise. Furthermore, ' X/α ' means that an object X is (a member) of type α . ' $X \rightarrow \alpha$ ' means that X is typed to ν -construct an object of type α . Throughout, it holds that the variables $w \rightarrow \omega$ and $t \rightarrow \tau$. If $C \rightarrow \alpha_{\tau\omega}$ then the frequently used Composition $[[C w] t]$, which is the *extensionalization* of the α -intension ν -constructed by C , will be encoded as ' C_w '. When no confusion arises, we use the standard infix notation without Trivialisation for the application of logical objects like truth-functions, equalities and quantifiers; thus, instead of ' ${}^0[\forall \lambda x B]$ ', ' ${}^0[\exists \lambda x B]$ ' we often write ' $\forall x B$ ', ' $\exists x B$ ' for any $B \rightarrow o$ to make quantified formulas easier to read. Arithmetic formulas can also be written in the infix way, without Trivializing relations like $\leq, =, >$, or functions like $+$ or \times ; for instance, instead of ' ${}^0 \leq x$ 50] we write ' $[x \leq 50]$ ', or instead of ' ${}^0 - [{}^0 \exists \lambda x [{}^0 = [{}^0 + x {}^0] x]]$ ' we can write ' $- \exists x [[x + {}^0] = x]$ '.

4. TIL Analysis of Knowing-wh

4.1. Answering Wh-questions

In Duži & Fait (2021) we introduced the method of deducing answers to Wh-questions by applying an adjusted version of Gentzen's natural deduction system. The adjustments concern in particular the integration of the special rules rooted in the rich semantics of natural language into the process of deriving consequences by means of the standard E/I-rules of natural deduction. These semantics rules are, inter alia, the rules for dealing with property modifiers, factive verbs, presuppositions, etc. Číhalová and Duži (2022) then applied these results to the analysis of dynamic activities of agents and answering questions on the participants of activities.

Empirical wh-questions denote α -intensions the value of which in a world w and time t of evaluation the inquirer would like to know. The type α of the value comes in many different variants, and it is determined by the type of a possible direct answer. For instance, a possible direct answer to the question "Who is the mayor of Ostrava?" is Mr. Macura, which is an individual of type t . Hence, the question denotes an individual office, and the inquirer wants to know who is the holder of the office in a given world and time. The analysis of the question comes down to this construction.

$$\lambda w \lambda t \lambda who [who = {}^0 Mayor\text{-of}_{\text{str}} {}^0 Ostrava]] \rightarrow t_{\tau\omega}$$

Types. $who \rightarrow t$; $Mayor\text{-of}(t)_{\tau\omega}$; $Ostrava/t$.

For another simple example, consider the question "Which Czech ladies are among the first 20 in WTA ranking singles?". Possible answer conveys the set of individuals, currently (written January 24th, 2022) they are

Krejčíková, Plíšková and Kvitová. Hence, the question denotes a property of individuals, and the encoded construction is this.

$$\lambda w \lambda t [\lambda x [[{}^0\text{Female}^0\text{Czech}]_{wt} x] \wedge [[{}^0\text{WTA-ranking } x] \leq {}^020]] \rightarrow (o1)_{\tau o}$$

Types: *Female*/ $((o1)_{\tau o}(o1)_{\tau o})$: the intersective property modifier that assigns to a property another modified property;¹⁷ *Czech*/ $(o1)_{\tau o}$; $x \rightarrow t$; *WTA-ranking*/ $(\tau 1)_{\tau o}$: the attribute that associates an individual with a number.

(Duží and Fait 2021) introduces a useful logical technique of answering Wh-questions. The answers are obtained by suitable substitutions, i.e. by the method of unification known from the general resolution method. For a simple example, assume that in an agent’s knowledge base, there are these formalised sentences.

- $\lambda w \lambda t [[{}^0\text{WTA-ranking}_{wt} {}^0\text{Barty}] = {}^01]$
- $\lambda w \lambda t [[{}^0\text{WTA-ranking}_{wt} {}^0\text{Sabalenka}] = {}^02]$
- $\lambda w \lambda t [[{}^0\text{WTA-ranking}_{wt} {}^0\text{Krejčíková}] = {}^03]$
- $\lambda w \lambda t [[{}^0\text{WTA-ranking}_{wt} {}^0\text{Plíšková}] = {}^04]$
- $\lambda w \lambda t [[{}^0\text{WTA-ranking}_{wt} {}^0\text{Muguruzza}] = {}^05]$
- ...
- $\lambda w \lambda t [[{}^0\text{WTA-ranking}_{wt} {}^0\text{Kvitová}] = {}^018]$
- ...
- $\lambda w \lambda t [{}^0\text{Australian}_{wt} {}^0\text{Barty}]$
- $\lambda w \lambda t [{}^0\text{Belarusian}_{wt} {}^0\text{Sabalenka}]$
- $\lambda w \lambda t [{}^0\text{Czech}_{wt} {}^0\text{Krejčíková}]$
- $\lambda w \lambda t [{}^0\text{Czech}_{wt} {}^0\text{Plíšková}]$
- $\lambda w \lambda t [{}^0\text{Spanish}_{wt} {}^0\text{Muguruzza}]$
- ...
- $\lambda w \lambda t [{}^0\text{Czech}_{wt} {}^0\text{Kvitová}]$
- ...

The answer to the above question “Which Czech ladies are among the first 20 in WTA ranking singles?” is derived like this.

- | | |
|---|---|
| (1) $[\lambda x [[{}^0\text{Female}^0\text{Czech}]_{wt} x] \wedge [[{}^0\text{WTA-ranking } x] \leq {}^020]]$ | Question (raised in a given w and t) ¹⁸ |
| (2) $[[[{}^0\text{Female}^0\text{Czech}]_{wt} x] \wedge [[{}^0\text{WTA-ranking } x] \leq {}^020]]$ | 1, \wedge -E |
| (3) $[[{}^0\text{Female}^0\text{Czech}]_{wt} x]$ | 2, \wedge -E |
| (4) $[[{}^0\text{WTA-ranking } x] \leq {}^020]$ | 2, \wedge -E |
| (5) $[[{}^0\text{Female}_{wt} x] \wedge [{}^0\text{Czech}_{wt} x]]$ | 3, left and right subsectivity |
| (6) $[{}^0\text{Female}_{wt} x]$ | 5, \wedge -E |
| (7) $[{}^0\text{Czech}_{wt} x]$ | 5, \wedge -E |
| (8) $\forall x \forall n [[{}^0\text{WTA-Ranking}_{wt} x] = n] \supset [{}^0\text{Female}_{wt} x]$ | <i>WTA ranking applicable only to ladies</i> |

For the sake of simplicity and due to the rule (8), in what follows we ignore the sub-goals checking whether a given candidate for the answer is female. Hence, to answer the question, the algorithm searches a given knowledge base for those sentences the constituents of which match with the atomic parts of the question, i.e., with (4) and (7). In addition, basic algebraic operations can be applied. Thus, the first candidate is $[[{}^0\text{WTA-Ranking}_{wt} {}^0\text{Barty}] = {}^01]$, as $1 \leq 20$. By substituting ${}^0\text{Barty}$ for the variable x , we obtain another sub-goal, namely $[{}^0\text{Czech}_{wt} {}^0\text{Barty}]$. Since this second goal cannot be met, the algorithm searches for another candidate. The first substitution meeting both (4) and (7) is the answer $x = {}^0\text{Krejčíková}$. Since the question concerns the set of individuals, the algorithm searches for another matching sentence, and which corresponds answering the question “Who else”? In the exactly the same way, the answers $x = {}^0\text{Plíšková}$ and $x = {}^0\text{Kvitová}$ are conveyed.

4.2. Knowing-wh as knowing the answer to a wh-question

I do not analyse knowing-wh and the corresponding wh-question in Hintikka’s way within quantified epistemic logic as an existentially quantified formula. Existence of the known object is the consequence, or rather the *presupposition*, of knowing-wh. Moreover, in TIL, once the base of the infinite hierarchy of types has been voted for, it is fixed within the theory. Hence, the universe of discourse is also fixed. We do not have any possibilia or

¹⁷ For details on property modifiers, see Jespersen, Carrara, Duží (2017) or Duží (2017). The authors introduce the rules of left and right subsectivity; the former is valid for all kinds of modifiers (for instance, a skillful surgeon is skillful, as a surgeon) while the latter is valid for intersective and subsective modifiers (e.g., the skillful surgeon is a surgeon).

¹⁸ When applying a proof or inferences in TIL, the first steps eliminate the left-most $\lambda w \lambda t$, which corresponds to two β -conversions. They apply the empirical propositions to the world w and time t of evaluation to obtain a truth-value. Similarly, Wh-question transforms a construction producing an object of type α . For details, see Duží, Fait (2021).

impossibilia as non-existent individuals. Individuals trivially all exist, and non-trivial existence is a property of *functions* that a given function has a value at a given argument. For instance, to claim that tangent of $\pi/2$ does not exist does not amount to talking about any non-existent number; (which one would it be?). Rather, non-existence is a property of the *function* tangent that it does not have a value at the number $\pi/2$. Similarly, the sentence “The King of France does not exist”, does not mention any non-existent individual that would exist in another possible world. Rather, it conveys information about the office of the French King that currently it goes vacant.

Hence, my analysis of Wh-questions deviates from Hintikka’s one. On the other hand, I agree with Wang (2018) that there is a constant domain of individuals in all the possible worlds, and that *knowing-wh* relates an agent to the *value* of an intension or in mathematical cases the value produced by a given construction. Yet, as mentioned above, I am not going to apply formal axiomatic approach without first specifying the meaning of ‘knowing-wh’.

Assume that the answer to a Wh-question has been derived and the questioner knows the answer. What else can be inferred in such a situation? First, we have to analyse what it amounts for an agent to know the answer. For instance, if *John* obtains the answer to the question “Who is the Mayor of Ostrava?”, then *John* knows who the Mayor of Ostrava is. How to analyse this knowledge? There are two possibilities, namely *intensional* (implicit) knowledge and *extensional* (explicit) knowledge. Let us first deal with the former.

By intensionally knowing-wh, John is related to the Mayor’s office itself. Hence, we have

$$\lambda w \lambda t [\text{Know-wh}_{wt} \text{John } \lambda w \lambda t [\text{Mayor-of}_{wt} \text{Ostrava}]]$$

Types. *Know-wh*/($\text{ot}_{1\tau_0}$) τ_0 ; *John*, *Ostrava*/t; *Mayor-of*/(t) τ_0 : an empirical attribute.

Yet, we would like to *specify* the relation of *Knowing-wh* in more detail, to refine this concept.

First, there is a presupposition that the Mayor of Ostrava exists. If it were not so, then the answer to the question “Who is the Mayor of Ostrava?” would be ‘nobody’, which actually is the negated presupposition.¹⁹ Moreover, John has identified that particular individual as the value of the Mayor’s office.

Second, we can explicate the relation *Know-wh* as *knowing the value* of the intension asked for, and define this relation as follows. Let $K^v \rightarrow (\text{ot}_{1\tau_0})\tau_0$ be the relation of knowing the value of an office $R \rightarrow t\tau_0$ in a world w and time t , $a \rightarrow \iota$ an agent who knows the value, $x \rightarrow \iota$, and *Ident(ified)*/($\text{ot}_{1\tau_0}$) τ_0 the relation between the agent, an individual and the office such that a has identified that individual as the value of the office R . Then in any world w and time t of evaluation

Def 1; *knowing the value of an office*

$$[K^v_{wt} a R] \text{ iff } \exists x [[x = R_{wt}] \wedge [\text{Ident}_{wt} a x R]]$$

Thus, we can specify the first rule for knowing the value.

$$(R1) \quad \frac{[K^v_{wt} a R]}{\exists x [x = R_{wt}]}$$

Using the definition of the property *Exist* (of an office of being occupied), i.e., $[\text{Exist}_{wt} R] = \exists x [x = R_{wt}]$, $x \rightarrow \iota$, this rule can be reformulated as follows:

$$(R2) \quad \frac{[K^v_{wt} a R]}{[\text{Exist}_{wt} R]}$$

Obviously, the second rule is this.

$$(R3) \quad \frac{[K^v_{wt} a R]}{\exists x [\text{Ident}_{wt} a x R]}$$

Generalizing a bit to properties, let $P \rightarrow (\text{o}\alpha)\tau_0$ be an α -intension, most frequently the property of individuals hence $\alpha = (\text{ot})$, $x \rightarrow \alpha$, $K^v/(\text{ot}(\text{o}\alpha)\tau_0)\tau_0$ be the relation of knowing the values of the property P in a world w and time t , *Ident(ified)*/($\text{ot}\alpha(\text{o}\alpha)\tau_0$) τ_0 the relation between an agent and an α -element of the set c of α -values of the extensionalised property P in the world w and time t of evaluation such that the agent identified all the elements of c as the values of P , the other types as above. Then

¹⁹ Duží and Číhalová in (2015) deal with propositions of questions. The main idea is this. If the presupposition of a question is not true, then there is no direct answer. Instead, a plausible answer is a complete one, to wit, negated presupposition.

Def 2; *knowing the value of a property*

$$[K^*_{wt} a P] \text{ iff } [\exists x [P_{wt} x] \wedge \forall x [[P_{wt} x] \supset [{}^0Ident_{wt} a x P]]]$$

The first conjunct is the existential presupposition that the set c of values of the intension P is non-empty; the second conjunct is the condition that the agent a has identified all the values of this set c . For instance, if a obtained only the answer Krejčíková to the question “Which Czech ladies are among the first 20 in WTA ranking singles?”, then the answer is not conclusive, as a has identified only one element of the set {Krejčíková, Plíšková, Kvitová}. The specification of the rules for this type of knowing the value is obvious.

So far so good. Yet, in which case has the agent identified particular individual as the value of the individual office? Imagine that John would obtain the answer ‘the previous boss of the social democrat party’ to the question “Who is the Mayor of Ostrava?”. Now we can hardly say that John identified the value of the office; all he knows is that the two terms, namely ‘the Mayor of Ostrava’ and ‘the previous boss of the social democrat party’ happen to be co-referring to the same individual in the $\langle w, t \rangle$ -pair of evaluation. Yet, John does not know to which one. Or, imagine that the answer conveyed to the question “Which Czech ladies are among the first 20 in WTA ranking singles?” would be ‘the Roland Garros 2021 women single winner’, ‘the player who lost in Wimbledon 2021 final with Ashleigh Barty’, ‘the Wimbledon 2014 and 2017 women winner’. Again, such an answer is inconclusive. Provided a is not a tennis expert, she does not know the value of the property of being the Czech among the first twenty in WTA ranking single.

Hence, there is a necessary condition for agent’s knowing-wh the answer, i.e. the value(s) of the intension asked for, that a has got the *conclusive answer* to his question in the form of a *definite description* that rigorously refers to the value(s). Most frequently, such a conclusive answer is provided by *proper name*(s).

Note that the definitions (Def1) and (Def2) comply with this demand. However, if we carelessly specified the second conjunct as $[{}^0Ident_{wt} a R_{wt} R]$ or $[{}^0Ident_{wt} a P_{wt} P]$, respectively, as $[x = R_{wt}]$ or $[P_{wt} x]$, the definitions would not be correct. The first occurrence of the construction of the office R is now in the supposition *de re*, unlike the second one. Hence the principle of the substitution of co-referring terms (or v -congruent constructions at the semantic level) is valid. As a result, we would obtain the conclusion that, for instance, if an agent a obtained an inconclusive answer in the form of another indefinite description, a knows who is R , which is not true, as we just explained above. For example, if John obtained the answer ‘the previous boss of the social democrat party’, we would obtain the undesirable result that John knows who is the Mayor of Ostrava because he identified ‘the previous boss of the social democrat party’ as the Mayor of Ostrava.

For completeness, we now specify these definitions and rules for a hyperintensional *Knowing*-wh*. Hyperintensional knowing*-wh relates the agent a to the construction of the intension the value of which a identified. Hence, the type of hyperintensionally knowing the value of the intension asked for is, $K^{*v}/(o1*_n)_{to}$. As the above definitions and rules relate the agent strictly to the given intension, be it an office R or a property P , the generalization to the hyperintensional case is obvious. We only have to care of the conceptualization of the respective intension whose values are known, as hyperintensional relation is the relation to the one specific construction C of the intension rather than to any other C' equivalent to C , i.e. such that $C = C'$ for any valuation v . Thus, though C and C' produce the same intension, we must keep the perspective of the agent a who sticks to C rather than C' . Here are the rules adjusted to hyperintensional level of knowing-wh.

Additional types. $K^{*v}/(o1*_n)_{to}$; $Ident^{*v}/(o1*_n)_{to}$: the relation-in-intension of an agent a who identified an entity x as the value of the office produced by R .

Def 1*; *knowing hyperintensionally the value of an office*

$$[K^{*v}_{wt} a {}^0R] \text{ iff } \exists x [[x = R_{wt}] \wedge [{}^0Ident^{*v}_{wt} a x {}^0R]]$$

$$(R1^*) \quad \frac{[K^*_{wt} a {}^0R]}{\exists x [x = R_{wt}]}$$

Obviously, the second rule is this.

$$(R3^*) \quad \frac{[K^*_{wt} a {}^0R]}{\exists x [{}^0Ident^{*v}_{wt} a x {}^0R]}$$

The generalised definition of knowing hyperintensionally the value of the property of α -objects is then this.

Def 2*; *knowing hyperintensionally the value of a property*

$$[K^{*v}_{wt} a {}^0P] \text{ iff } [\exists x [P_{wt} x] \wedge \forall x [[P_{wt} x] \supset [{}^0Ident^{*v}_{wt} a x {}^0P]]]$$

4.3. Knowing-wh and Knowing-that

4.3.1. Knowing whether

A special case of knowing-wh is *knowing whether*. Duží et al. (2010, §5.1.4) introduce the analysis of knowing whether in terms of knowing that. Let me briefly recapitulate this analysis. Knowing whether P concerns a proposition or a hyperproposition, i.e., construction of a proposition. The most important difference between *knowing that P* and *knowing whether P* is that the latter is *not* *factive*: *knowing whether P* is logically compatible with P being false or with P lacking a truth-value. Despite this difference, we can characterise knowing whether by means of knowing that. If one knows whether P it is because any one of the following three options obtains:

- *knowing that P is true*
- *knowing that P is false*
- *knowing that P is undefined (truth-value gap).*

To define knowing whether, we need the definition of the three properties of propositions, namely *True*, *False* and *Undef*, all of type $(\circ\circ\tau_0)\tau_0$. They are defined as follows ($P \rightarrow \circ\tau_0$):

$$\begin{aligned} [{}^0True_{wt} P] \text{ v-constructs } \mathbf{T} \text{ if } P_{wt} \text{ v-constructs } \mathbf{T}, \text{ otherwise } \mathbf{F}; \\ [{}^0False_{wt} P] \text{ v-constructs } \mathbf{T} \text{ if } P_{wt} \text{ v-constructs } \mathbf{F}, \text{ otherwise } \mathbf{F}; \\ [{}^0Undefined_{wt} P] = \neg[{}^0True_{wt} P] \wedge \neg[{}^0False_{wt} P]. \end{aligned}$$

Knowing whether requires two definitions, because in the empirical case *knowing* may be either a relation (-intension) to a proposition or a relation (-in-intension) to a propositional construction. We use this notation and typing:

$K/(\circ\circ\tau_0)\tau_0$ ('to know that a proposition is true')

$K^*/(\circ\tau^*_n)\tau_0$ ('to know that a construction constructs a true proposition').

Let $P, Q, \underline{Q}^*/_1 \rightarrow \circ\tau_0; p^*/_1 \rightarrow \circ\tau_0; c^*/_2 \rightarrow *_1; {}^2c \rightarrow \circ\tau_0; =_1/(\circ\circ\tau_0\circ\tau_0); =_2/(\circ*_1*_1); \iota/(\circ\tau_0(\circ\circ\tau_0)); \iota^*/(*_1(\circ*_1))$. Here ι, ι^* are singularizers, i.e., functions that return the only member of a singleton, otherwise undefined.

Def 3 (*knowing whether P*) Let P be a propositional construction. Then an agent a knows whether P iff

$$\lambda w \lambda t [{}^0K_{wt} a \text{ } p [p_{wt} \wedge [(p =_1 \lambda w \lambda t [{}^0True_{wt} P]) \vee [p =_1 \lambda w \lambda t [{}^0False_{wt} P]) \vee [p =_1 \lambda w \lambda t [{}^0Undefined_{wt} P]]]]]]$$

Def 3* (*knowing* whether P*) Let P be a propositional construction. Then an agent a knows* whether P iff

$$\lambda w \lambda t [{}^0K_{wt} a \text{ } \iota^*c [[{}^2c]_{wt} \wedge [(c =_2 {}^0[\lambda w \lambda t [{}^0True_{wt} P]]) \vee [c =_2 {}^0[\lambda w \lambda t [{}^0False_{wt} P]]) \vee [c =_2 {}^0[\lambda w \lambda t [{}^0Undefined_{wt} P]]]]]]]]$$

Mathematical attitudes invariably demand constructional treatment. Knowing* whether Fermat's Last Theorem is true (i.e., whether the Theorem is a theorem) is to know* which of two constructions constructs \mathbf{T} . The *analysandum* is the sentence (disregarding tense)

"Fermat knows whether there are positive integers a, b, c, n ($n > 2$) such that $a^n + b^n = c^n$."

Let v be the type of natural numbers. Let $a, b, c, n, x^*/_1 \rightarrow v$; *Pos(itive integers)* $/(\circ v)$; $2/v$; *Fermat* $/\iota$; $\forall, \exists/(\circ(\circ v))$; $d^*/_2 \rightarrow *_1$; ${}^2d \rightarrow \circ$. We write ' x^n ' for ' $[{}^0Exp \ n \ x]$ ', *Exp* $/(\forall v v)$ the power function taking x to its n^{th} power. Since, the value of the Fermat's last Theorem is either true or false, there is no need for the third option (truth-value gap), and the analysis is the Closure

$$\begin{aligned} \lambda w \lambda t [{}^0K_{wt}^* \text{ } \iota^*d \text{ } \text{Fermat } \iota^*d [{}^2d \wedge \\ [d =_2 {}^0[\exists abc n [[{}^0Pos \ a] \wedge [{}^0Pos \ b] \wedge [{}^0Pos \ c] \wedge [{}^0 > \ n \ ^02] \wedge [{}^0 = [{}^0 + \ a^n \ b^n] \ c^n]]]] \vee \\ d =_2 {}^0[\forall abc n [[{}^0Pos \ a] \wedge [{}^0Pos \ b] \wedge [{}^0Pos \ c] \wedge [{}^0 > \ n \ ^02] \supset \neg [{}^0 = [{}^0 + \ a^n \ b^n] \ c^n]]]]]]]. \end{aligned}$$

4.3.2. Knowing the value of an α -intension

The other cases of *knowing-wh* concern α -intensions where $\alpha \neq \circ$, and thus their definition in terms of knowing that is not applicable, as we have seen above, where we have defined knowing-wh as knowing the value of an α -intension.

Assume that John knows who is the Mayor of Ostrava, and the Mayor is Mr Macura. Does this situation entail that John knows that Macura is the Mayor of Ostrava? Though it seems undoubtable, it depends on John's deduction abilities. According to **Def 1**, John identified an individual x as the value of the Mayor's office in the world w and time t of evaluation:

$$\begin{aligned} & [K_{w'}^v \text{John } \lambda w \lambda t \text{ } [{}^0\text{Mayor-of}_{w'} \text{Ostrava}]] \text{ iff} \\ \exists x [[x = [{}^0\text{Mayor-of}_{w'} \text{Ostrava}]] \wedge [{}^0\text{Ident}_{w'} \text{John } x \lambda w \lambda t \text{ } [{}^0\text{Mayor-of}_{w'} \text{Ostrava}]]] \end{aligned}$$

Thus, we have:

- | | |
|--|----------------|
| 1) $\exists x [[x = [{}^0\text{Mayor-of}_{w'} \text{Ostrava}]] \wedge [{}^0\text{Ident}_{w'} \text{John } x \lambda w \lambda t \text{ } [{}^0\text{Mayor-of}_{w'} \text{Ostrava}]]]$ | \emptyset |
| 2) $x = {}^0\text{Macura}$ | \emptyset |
| 3) $[{}^0\text{Macura} = [{}^0\text{Mayor-of}_{w'} \text{Ostrava}]] \wedge [{}^0\text{Ident}_{w'} \text{John } {}^0\text{Macura } \lambda w \lambda t \text{ } [{}^0\text{Mayor-of}_{w'} \text{Ostrava}]]$ | $\exists E, 1$ |
| 4) $[{}^0\text{Macura} = [{}^0\text{Mayor-of}_{w'} \text{Ostrava}]]$ | $\wedge E, 3$ |
| 5) $[{}^0\text{Ident}_{w'} \text{John } {}^0\text{Macura } \lambda w \lambda t \text{ } [{}^0\text{Mayor-of}_{w'} \text{Ostrava}]]$ | $\wedge E, 3$ |

To derive $[{}^0\text{Know}_{w'} \text{John } \lambda w \lambda t \text{ } [{}^0\text{Macura} = \lambda w \lambda t \text{ } [{}^0\text{Mayor-of}_{w'} \text{Ostrava}]]]$, we have to *postulate* that identifying x as the value of an office amounts to knowing that the value of the office is x . Hence, we specify the **Meaning Postulates**:

$$\begin{aligned} [{}^0\text{Ident}_{w'} a \ x \ R] &= [{}^0\text{Know}_{w'} a \ \lambda w \lambda t \ [x = R_{w'}]] \\ [{}^0\text{Ident}_{w'}^* a \ x \ {}^0R] &= [{}^0\text{Know}_{w'}^* a \ {}^0[\lambda w \lambda t \ [x = R_{w'}]]] \end{aligned}$$

Without these postulates, it is not *logically* derivable that knowing the value of an office is identical to knowing that this or that individual is the holder of the office. For, assume that John obtained the answer to the wh-question formalised in TIL as

$$\lambda w \lambda t \ \lambda x \ [x = [{}^0\text{Mayor-of}_{w'} \text{Ostrava}]]$$

that in the world w' and time t' of evaluation $x = {}^0\text{Macura}$. Hence, John knows who is the Mayor of Ostrava. To derive that Macura is the Mayor, John has to apply the rule of β -reduction three times

$$[\lambda w \ [\lambda t \ [\lambda x \ [x = [{}^0\text{Mayor-of}_{w'} \text{Ostrava}]] \ w'] \ t'] \ {}^0\text{Macura}] =_{\beta} [{}^0\text{Macura} = [{}^0\text{Mayor-of}_{w',t'} \text{Ostrava}]],^{20}$$

and then again β -abstraction, as knowing-that is not the relation to a truth-value but to a proposition, in this case that Macura is the sought Mayor: $\lambda w \lambda t \ [{}^0\text{Macura} = [{}^0\text{Mayor-of}_{w,t} \text{Ostrava}]]$.

In order to ensure this desirable result even in case the agent does not have the capacity to derive the conclusion, we again specify the rules. Hence, let $K^v(\text{oi}\alpha_{\tau\text{oi}})_{\tau\text{oi}}$ and $K/(\text{oi}\alpha_{\tau\text{oi}})_{\tau\text{oi}}$ be the relation of knowing-wh and knowing-that, respectively, and let the agent $a \rightarrow \iota$ obtain the conclusive direct answer in the form of a rigorous definite description to the Wh-question concerning the value of an intension $\text{Int} \rightarrow \alpha_{\tau\text{oi}}$. Moreover, let this value in the world w and time t of evaluation be $c \rightarrow \alpha$. Then we have this rule.

$$\frac{[K_{w'}^v a \ \text{Int}] \wedge [c = \text{Int}_{w'}]}{[K_{w'} a \ \lambda w \lambda t \ [c = \text{Int}_{w'}]]}$$

Similarly, if the agent a knows that c is the value of Int in the world/time couple $\langle w, t \rangle$, then by applying the following rule, a should know-wh the value of Int in $\langle w, t \rangle$.

$$\frac{[K_{w'} a \ \lambda w \lambda t \ [c = \text{Int}_{w'}]]}{[K_{w'}^v a \ \text{Int}] \wedge [c = \text{Int}_{w'}]}$$

Generalization for the hyperintensional knowing* is obvious. As these rules capture basic patterns of reasoning with knowing-wh and knowing-that, they might contribute to a smooth communication of agents in a multi-agent system and to avoiding misunderstandings and inconsistencies among the agents.

5. Conclusion

In the paper, I investigated *knowing-wh* and its relation to *knowing-that*. Unlike formal syntactic theories that deal with knowing-wh as a primitive entity K^v , and specify axioms and rules how to deal with it, I first explicate the meaning of knowing-wh. My starting point is the close relation between knowing-wh and the corresponding wh-question. An agent a knows-wh the value of the intension asked for, iff a has obtained a conclusive answer that rigorously refers to the value, i.e., identifies it. Then I specify rules for dealing with such objectual knowledge; in

²⁰ Though β -reduction is in general not an equivalent conversion in the logic of partial functions such as TIL, these conversions are equivalent. The first two of them are the so-called *restricted* β -reductions which consist only in substituting variables for variables of the same type. The third conversion is equivalent because Trivialization ${}^0\text{Macura}$ is never v -improper. For details on β -conversions in TIL, see [157](#) and Kosteć (2017).

particular, I deal with the rules specifying the relation between objectual knowing-wh and propositional knowing-that.

These results, though valuable, are just the first step in the investigation of the objectual knowledge of a value in TIL. Further research will concentrate on the analysis of more complex sentences with the knowing-wh constituent, for instance like those examples adduced by Hintikka, where the quantification over functions and/or propositions is called for. Moreover, we will investigate knowing-how and knowing-why, which would bring our attention also to the ‘logic of because’.

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Shortest path method application in social networks

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Abstract. This paper analyses the shortest path problem (SPP) in social networks, based on the investigation and implementation of different methods on a simulated example. The objectives of the paper include identification of the most commonly used methods for finding the shortest path in a social network as a strategic attempt to speed the search of network nodes, focusing on the application of the two most used SPP methods: Dijkstra and Bellman-Ford algorithm. A comparative analysis is used as an investigation method for performance evaluation of different algorithms, based on their implementation and behaviour, tested on a social network example. The research results indicate that the Dijkstra algorithm is faster and therefore more suitable for searching the shortest connection in social networks.

Keywords. Social networks, Social network analysis, Shortest path problem, Dijkstra algorithm, Bellman-Ford algorithm, Optimization of search

1. Introduction

Social networks have become an indispensable concept in today's digital world, where devices and people connect online and the number of social network users is still rising. In 2010, there were roughly 1 billion users, rising to about three and half a billion in 2020. Although in some cases the users are virtual entities (users with multiple users accounts or generated user accounts managed by computers), it is estimated that one-third of the world's population is included into some kind of social networks [20], such as Facebook, Youtube, Instagram, Twitter and others. All social network users are in some way linked to a shared site, categorized by interest groups such as the same geographic area (for example, VKontakte, primarily intended for Russian-speaking users, or QZone for Chinese-speaking users), user groups from the same professional field (example LinkedIn), user groups with similar hobbies or beliefs [22] and other groups. The importance of social networks is also visible in business environments [14], which for example also differs whether the user is a male or a female [24]. The listed social networks types present a vast and diverse problem field of the new-age requirement to link smaller, medium-sized and large numbers of users with similar interests and the quick discovery of connections between them is our main research motivation. This paper addresses the social networks and their users, however focus on optimal (shortest) path selection, highlighting the shortest path problem (SPP) methods [32] [37].

Since SPP methods solve the problem of finding the shortest path from point A to point B, using graphs is the most common way to illustrate the problem. They are used

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in various fields, such as mapping (Google Maps), road connections, logistics processes, computer networks [3][7], in addition to the field of social media for social network analysis (SNA). SNA deals with the study of communication between people and groups of people in a business or a social network. Social networking is represented in mathematical theory as a graph, where graph nodes represent users and communication between them is represented by connections. Knowing the shortest path between users on the network enables identification of (unknown) indirect connections. SNA includes metrics that use SPP methods to calculate the shortest path between people, giving importance to the individuals within the network, often exploited by social media providers for the recommendation system (RS). The RS is a technology that is used in different environments, suggesting the users (customers, visitors, readers, application users) an item (product, movie, event, and article) that might be of interest to them, also collecting information about users and their past searches. With the help of different algorithms, user's interests are determined. A typical example of using an RS are advertisements on web pages that are displayed to a user, based on users past searches, increasing the possibility that the user will become a potential buyer of the product, a visitor to the show, an article reader, etc. In social networks, the RS works by suggesting users who might share similar interests, enabling connection of previously unconnected users [23] [31], an important feature in today's global markets, which focuses increasingly on customer needs. Based on the existing body of research, SPP methods give reliable results on listed networks. And a literature review is presented in the following sub-section.

1.1. Background/ Related literature

The larger body of research includes investigation of SPP in addition to social networks in various other areas, focusing also on travel time in the transportation network. Authors [36] proposed a data-driven distributional robust shortest path model for finding optimal paths to minimize the mean-excess travel time. The authors in [17] address the multi-criteria shortest path problem and present the interactive method of analyzing SPP by the reference point approach, pointing out the routing of hazardous materials as an example of SPP application. The authors in [13] address Bi-objective SPP finding (one-to-one) paths from a start node to an end node, while simultaneously minimizing two (conflicting) objective functions for large-scale road networks. There are also health-related areas of application, such as for predicting adolescent social networks to stop smoking in secondary schools with authors [16] researching the potential importance of adolescent friendships selection, affecting the health domain. SPP is applied also in other problem-solving efforts, presented in [34], where authors deal with a competitive Influence Maximization Problem, where two players make decisions sequentially; the first player (leader) wants to maximize the spread by activating an influential seed set, and the second player (follower) tries to minimize it by deactivating some of the activated nodes. Similar research, conducted by [27], analytically approaches to the problem of influence maximization in a social network where two players compete by utilizing dynamic targeting strategies. Large-scale group decision-making model based on social network analysis, for example, is analyzed in [26]. The importance of network structure in social and economic systems is presented in Evolution of social networks by [19] and literature review was used to examine the application of the SPP methods in social networks field, such as Facebook, Twitter, and YouTube, which are used daily by a large number of users, often mixing the terms social media and social network.

For clarification, in the context of the World Wide Web, social media is a website and mobile application that allow users to communicate with other users in a digital way, thus as a means of communication. Social media is a broader term and covers many different media such as images, videos, content, blogs and others. In contrast, the term social network denotes the social structure of users who are united by common interests. A social network can exist between organizations and can be set up on any social media, as well as in the real world with the main purpose to connect users. Social media, therefore, allows users to establish communication links, and social networks take care of strengthening those links, as a result, social networking is a sub-category of social media [9] [29]. The importance of the two concepts is visible in the number of users of social media as well as networks, which is, as stated before, still growing and according to [6] [28] reaching around 2 and a half billion users.

The massive number of social media users means that social media and related activities have become a lucrative business opportunity. Social media companies have become global corporations and are among the most valuable companies with the highest annual income. Due to online advertising, the companies make huge profits despite the users register and use social media for free, providing their data. The data collected through SNA is used further for recommendations, advertising and targeted display of relevant products to the right groups of people on social media. [18] [15]. Ads are tailored to the individual user based on the RS, often controversial in terms of personal data protection. For example, companies like Google, Facebook, Twitter and others store personal information about their users (profiling) and providing them with tailored ads, including personalized content and suggesting other potentially interesting users, transforming the user into a product itself. By addressing customers who have a proven record of interest in a particular product or service, significantly increases the percentage of advertising success. Indisputably, the companies benefit from social media, despite some potentially negative effects like rapid dissatisfaction information spread [21].

The listed benefits could also be beneficial in smaller business companies and organizations, gaining a strategic advantage if users (employees) would be better connected and their interests and needs would be better understood. Investigation of possible solutions, how to identify connected users and find the shortest path between them, is addressed in following sections. The remainder of the paper is organized as follows. Section 2 reviews methods and algorithms and presents a comparison of the two selected algorithms and a simulated example of chosen algorithms. Section 3 provides results, followed by discussion in section 4. Acknowledgements and bibliography follows.

2. Methods

The main paper's motivation is using SPP method in social networks and identifying which node is the most connected to other nodes and which path between them is the shortest. A searched for shortest pathfinding methods was conducted, used in the existing field of social network analysis. Most commonly used methods are DIJKSTRA ALGORITHM, BELLMAN FORD ALGORITHM, FLOYD-WARSHALL ALGORITHM, JOHNSON ALGORITHM, A* ALGORITHM and some others:

The Dijkstra algorithm uses the breadth search method to solve the shortest single-point path problem. It does not support negative weights at the nodes, but it performs fast. The Dijkstra algorithm (DA) has several variants and in some cases can also be used

to find the shortest path for all pairs. The Dijkstra algorithm works by creating a tree of shortest paths from the starting node to all other nodes [7] [4].

The Bellman-Ford algorithm (BFA) is used to find the shortest path from one starting node to all the other nodes in the directed and weighted graph, with the links having negative weights. If the graph is not oriented, it must be transformed into directed in such a way that two directed links are created from each non-directed link. It is based on the concept that the shortest path has at most $N - 1$ connections since the shortest path between two nodes never has a cycle [3] [8].

The Floyd-Warshall algorithm solves the problem of finding the shortest path for all pairs of nodes in the graph, using a dynamic programming technique. Node connections can have positive or negative weights. The Floyd-Warshall algorithm breaks down the problem into several smaller parts and combines the results of the smaller parts to solve the big problem. It operates according to the principle of the following statement: for each of the three nodes in the graph: if there is a shortest path A to C that is longer than the sum of the shortest path A to B and B to C, then the shortest path is A to C equal to this sum. The algorithm works well on graphs with many links and cycle graphs. [5] [8].

The Johnson algorithm is used to find the shortest path for all pairs of nodes in the graph where the connections can be negative or positive. It works by first executing the BFA and using the results to re-weight the graph by eliminating any negative weights. Then the DA for each graph node is executed to obtain the shortest path for all pairs of nodes. The implication is that for each node, the DA runs because the Johnson algorithm works well for graphs with few links, where it has a shorter execution time compared to the Floyd-Warshall algorithm. [7].

The A * algorithm is an extension of the DA with some features of the breadth method. The A * algorithm creates a tree of shortest paths from the starting node to all other nodes. It differs from the DA in that it uses for each node a function that gives an estimate of the total cost (cost is a weight) of the path through that node. The function, therefore, consists of the instantaneous cost of reaching the node and of predicting the cost from that node to the destination node. Because of this, the A * algorithm is a heuristic method, which means that it produces results that are the result of predictions and are not necessarily correct, but consequently, the A * algorithm is faster than the DA [4].

According to the literature review, the DA is the most famous and fastest method [33] and also most commonly used in the analysis of social networks. Since the two most common identified methods were the BFA and the DA, they will be explored in more detail within this paper. Both algorithms base on the principle of finding the shortest path from the starting node to all other nodes in the graph, with a significant difference: The DA does not allow negative weights on the links between nodes, unlike the BFA.

2.1. Algorithm comparison

Based on the literature review, the two most common identified shortest path methods are DA and BFA, therefore a closer comparison was made with the help of an experiment. Within the experiment, the speed of operation of the DA and BFA was tested in practice, on graphs. Both represent a method for finding the shortest path in weighted graphs and are both able to easily find the shortest path from the selected node to all other nodes in the graph. SPP in social networks is closely connected to the graph theory, where the problem of finding the shortest path is known as finding the shortest connection between two points on a graph. There are several types of graphs. The first

feature that determines the type of graph is the orientation of its links. Connections between nodes can be one-way or two-way. If the links are one-way, the graph is called a directed graph, however, if the links are bidirectional (in both directions), a graph is called a non-directional graph. If the graph's links are one-way and two-way at the same time, each two-way link is replaced by two one-way links (each in one direction), which is equivalent to a two-way link, and such a graph is then fully oriented [7]. The second feature of the graphs is related to link weights. A graph that has no weights on the links is called a non-weighted graph; otherwise, when there are weights on the links, it is called a weighted graph. The values of the weights can also be negative, which is not supported by all shortest path algorithms. The third feature of graphs that influences the choice of the shortest path search algorithm is cyclicity. A cycle is defined as any path through a graph that visits the same node more than once. So if there is any cycle path in the graph, the graph is cyclical, otherwise, it is acyclic. So there are the following 6 types of graphs, with two in a pair mutually exclusive: non-directional / directional graph, weighted/unweighted graph, cyclic/acyclic graph.

The DA works according to the principle of breadth search, which means that first all output connections of the current node are released, then we take the nearest neighboring node and release all its output connections and continue until all the nodes are processed. With the BFA, on the other hand, all output connections of all nodes are identified and released, repeated $|V - 1|$ times, where V is the number of nodes of the graph. In BFA, each connection is loosened several times (for a graph with 3 or more nodes), while it is always used only once by the DA, which is reflected in the greater time complexity of the BFA for graphs with many nodes. In contrast, increasing the number of connections at the same number of nodes reduces the running time of the BFA, which can be attributed primarily to the use of a data structure as a priority type for link implementation. Based on this, the implementation of the BFA, using the priority connection type, works most optimally on graphs with many connections. Alternatively, the implementation of the DA, using the "folder" data structure for links, has the effect of linearly increasing execution speed by increasing the number of links. The BFA, therefore, performs iterations over all nodes and connections, so its time complexity is measured as the number of nodes multiplied by the number of connections. Instead, the time complexity of the DA depends on the variant of the algorithm. There are some specialized variants of the algorithm that are optimized for specific graph shapes. A general variant of the DA, in which graph nodes are stored in the form of a list of adjacent nodes with a data structure folder or priority type, in the worst case, has a time complexity $O = |E| + |V| \log |V|$, where V is the number of nodes and E is the number of connections. Table 1 shows a comparative analysis of the DA and BFA based on several properties (Implementing nodes, Implementing connections, Type of algorithm, The use of heuristics, Search result, Speed, Weighted graph, Negative weights, Optimal performance, Time complexity, Implementation phases, Modus operandi), revealing several joint characteristics, however also several differences.

Although different, both algorithms are appropriate for finding the shortest path within a network. According to the comparison results (Table 1) the DA is faster than the BFA, the reason being the simpler implementation. The DA does not allow the entry of negative link weights, which means that there is no possibility of a negative cycle. As a result, the implementation of the DA can omit the phase of verifying the existence of a negative cycle in is therefore faster. Application of them on a simulated network is presented in the following sub-section

Table 1. Comparative analysis of Dijkstra and Bellman-Ford algorithm

Property	Dijkstra algorithm	Bellman-Ford algorithm
Implementing nodes	The set	The list
Implementing connections	Folder	Priority species
Type of algorithm	One starting point	One starting point
The use of heuristics	No	No
Search result	Precise	Precise
Speed	Quick	Less fast
Weighted graph	Enables	Enables
Negative weights	It does not	Enables
Optimal performance	Graph with few links	Graph with many links
Time complexity	$O = E + V \log V $	$O = V * E $
Implementation phases	2 fazes: <ul style="list-style-type: none"> • initialization, • evaluation. 	3 fazes: <ul style="list-style-type: none"> • initialization, • evaluation, • checking.
Modus operandi	Releasing the links into the width	Releasing all connections for $ V - 1 $ times

2.2. Social network metrics and test simulation

Social network analysis provides both mathematical and visual analysis of human relationships. In the field of social network analysis, centrality is a concept used to determine the relative importance of a node in a given network. Centrality, therefore, addresses the question of who is the most important or central person in the network. The following metrics are most commonly used to measure centrality [35] [1] [2] [12]:

- Degree Centrality - The simplest metric for centrality is the degree of centrality. This metric calculates the number of connections of each node in a given network. The more connections the node has, the greater the degree of centrality. This metric is crucial for identifying important nodes as it quickly identifies nodes that hold a lot of information. Nodes receive and transmit information, so the input (only for inbound connections) and output (only for outbound connections) node centrality can be calculated separately, which is useful in transaction analysis. [1] [2]
- Betweenness Centrality - Intermediate centrality is a metric that identifies nodes that often occur on the shortest path of communication between two nodes. This means that a node has a high value of intermediate centrality if it often acts as a facilitator in exchanging a large amount of information. It is measured by how many times the node lies on the shortest path among the other nodes. In social networks, nodes with high intermediate centrality are often on the outskirts of two densely populated groups. [1] [2] [12].
- Closeness Centrality - Proximity centrality is a metric for centrality that indicates the distance of a node to all other nodes. This value is obtained by calculating the reach of a node in the network. The node with the highest centrality proximity value reaches all nodes in the network faster than any other node. So it has the shortest path to all other nodes. Nodes with high proximity to centrality are well connected throughout the network and have a good overview of what's happening on the network. Removing such a node would cause communication problems. [35] [1].

Various tools for analyzing social networks online simplify retrieving data from social networks, creating social network graphs from given data, and calculating metrics. The purpose of all these tools is to simplify the processing of social network data since the user does not need to implement algorithms for finding the shortest path. Some of the tools used to analyze social networks are Gephi [25], Cuttlefish [11], Spider [11], Cytoscape [30], NodeXL [25], Social Network Visualizer [25] and NetMiner [25] [11]. Based on analysis of listed tools, NodeXL software tool was used, with which we obtained test data from social media and conducted an action survey/social network simulation. NodeXL is a template that can be used with Microsoft Excel to capture data from various files and web sources. The tool was chosen since it allows capturing data directly from social media (Twitter) (Figure 2). By capturing tweets from Twitter, we obtained test data to simulate social networking. As shown in Figure 1, we obtained tweets containing the desired keyword "Slovenia" and limited the number of tweets to 2000.

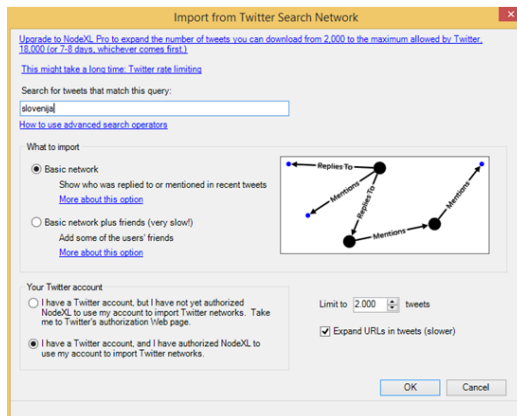


Figure 1. NodeXL for Twitter network import.

In Excel, a node table (Figure 2) and a link table (Figure 3) were created. Both tables have been transformed into the preferred format. Next, we performed a link analysis that showed that there were duplicates between the links. We combined the duplicate links with the tool by increasing the link weights by one for each duplicate link (the last column in Figure 3 shows the link weights). This resulted in a final number of nodes of 848 and a final number of connections of 2156. Metrics for social network analysis were calculated based on the data. The tool inserted a column showing metrics for social network analysis (light blue columns in Figure 2). The following metrics were calculated: entry-level of centrality, exit level of centrality, intermediate centrality, proximity to centrality, own centrality, page rank, clustering coefficient and reciprocated vertex pair ratio.

The table of nodes, therefore, contains a list of all Twitter social media user profiles that are in any way related to posts that contain the selected keyword. The node name in

the table is the same as the social media user profile name. On the other hand, the link table contains a column (the fourth column in Figure 3) that describes the type of link. For social media posts, the tool separates the following types of links: "Tweet", "Mentions", and "Replies to". A "Twit" link is created when a user posts a tweet to a social media profile, and the name of the user profile is entered as the start and end node of the link. These are, therefore, links that have a beginning and an end in the same node we call self-loops. A "Mention" type link occurs when a user mentions another user's profile or tweet, with the start node being the name of the user that mentions and the end node the name of the user whose profile or tweet is mentioned. A "Reply to" link occurs when a user replies to another user's tweet, with the start node being the name of the responding user and the end node the name of the user who posted the tweet. A connection to the same start and end node can occur several times, so the weight of the connection represents the number of occurrences of such connections.

Node ID	Name	URL	Start	End	Weight	Count	Score	Score	Score	Score	Score	Score	Score	Score	Score	Score	Score	Score	Score	Score
53	sluzba	http://sluzba.gov.si	0	0	1.000	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
54	dejanlojze	http://dejanlojze.si	0	1	0.000	0.143	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
55	veljavo747034	http://veljavo747034.si	0	1	0.000	0.133	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
56	lilijehard	http://lilijehard.si	2	0	2.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
57	emiljona	http://emiljona.si	0	1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
58	laskarbandball	http://laskarbandball.si	1	1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
59	stavjartanko	http://stavjartanko.si	0	1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
60	delo	http://delo.si	10	3	10.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
61	delendabuh	http://delendabuh.si	0	2	171.172	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
62	metronek	http://metronek.si	2	0	76.413	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
63	markobandball	http://markobandball.si	4	30	3306.414	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
64	slavostana	http://slavostana.si	0	3	7210.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
65	metron	http://metron.si	1	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
66	viedart	http://viedart.si	17	4	22775.594	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
67	rustempubu	http://rustempubu.si	1	1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
68	bandendabuh	http://bandendabuh.si	0	1	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
69	svetlancoder	http://svetlancoder.si	1	0	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
70	musaj_0209	http://musaj_0209.si	0	1	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
71	vevelo1023	http://vevelo1023.si	1	0	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
72	gigagost	http://gigagost.si	0	1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
73	gigabuh	http://gigabuh.si	0	1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
74	musajbuh	http://musajbuh.si	3	0	14136.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
75	slavostanemistry	http://slavostanemistry.si	0	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
76	slon	http://slon.si	1	0	0.000	0.111	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
77	vevelobuh	http://vevelobuh.si	1	0	0.000	0.111	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
78	svetlancoder	http://svetlancoder.si	1	0	0.000	0.111	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
79	rustempubu	http://rustempubu.si	0	0	0.000	0.111	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
80	slavostanegod	http://slavostanegod.si	1	0	0.000	0.111	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
81	svetlancoder	http://svetlancoder.si	1	1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
82	slavostan_0109	http://slavostan_0109.si	1	1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
83	slavostan	http://slavostan.si	0	2	336.404	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
84	slavostanegod	http://slavostanegod.si	0	1	1383.256	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
85	slavostanegod	http://slavostanegod.si	2	1	1679.859	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
86	slubuh	http://slubuh.si	1	1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
87	gigabandball	http://gigabandball.si	1	1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
88	slavostan	http://slavostan.si	1	1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Figure 2. Table of Nodes retrieved from tweets for keyword "Slovenia".

In the final phase of the study, the NodeXL tool was used to analyze and plot the entire graph (Figure 4). By analyzing the graph, we obtained information about the type of the graph, the number of connections and nodes, the number of loops, and the density of the graph. Also, the NodeXL tool does user and tweet analysis, providing a list of users with the most tweets, mentions and replies, and the top 10 results in each of the following categories: (1) the most frequently mentioned URL in tweets, (2) the most frequently mentioned domain in tweets, (3) the most frequently mentioned hashtag in your tweet, (4) the most frequently mentioned word in tweets, (5) the most frequently mentioned word pair in tweets.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	
1	Twitter ID	Twitter ID	Relationship	Link in	Domain	Twitter Page	Twitter Page	Twitter Page	Twitter Page	Twitter Page	Twitter Page	Twitter Page	Twitter Page	Twitter Page	Twitter Page	
2	Twitter ID	Twitter ID	Relationship	Link in	Domain	Twitter Page	Twitter Page	Twitter Page	Twitter Page	Twitter Page	Twitter Page	Twitter Page	Twitter Page	Twitter Page	Twitter Page	
2121	marj001	potepaski	No	Mentions	16.5.2018 13:28 RT @pofe: https://t.me/rt/reporter	16.5.2018 13:28	https://twitter.com/1605626896	16.5.2018 13:28	https://twitter.com/1605626896	16.5.2018 13:28	https://twitter.com/1605626896	16.5.2018 13:28	https://twitter.com/1605626896	16.5.2018 13:28	https://twitter.com/1605626896	1
2122	cevanj	demokracija1	No	Mentions	16.5.2018 10:29 RT @dove: https://t.me/demokracija	16.5.2018 10:29	https://twitter.com/1607889731012	16.5.2018 10:29	https://twitter.com/1607889731012	16.5.2018 10:29	https://twitter.com/1607889731012	16.5.2018 10:29	https://twitter.com/1607889731012	16.5.2018 10:29	https://twitter.com/1607889731012	2
2123	cevanj	cevanj	No	Tweet	16.5.2018 13:25: https://t.me/cevanj	16.5.2018 13:25	https://twitter.com/160791035575736	16.5.2018 13:25	https://twitter.com/160791035575736	16.5.2018 13:25	https://twitter.com/160791035575736	16.5.2018 13:25	https://twitter.com/160791035575736	16.5.2018 13:25	https://twitter.com/160791035575736	1
2124	marj001	cevanj	No	Mentions	16.5.2018 13:16 RT @ceva: https://t.me/nova24tv	16.5.2018 13:16	https://twitter.com/1607910452664800	16.5.2018 13:16	https://twitter.com/1607910452664800	16.5.2018 13:16	https://twitter.com/1607910452664800	16.5.2018 13:16	https://twitter.com/1607910452664800	16.5.2018 13:16	https://twitter.com/1607910452664800	1
2125	cevanj	nova24tv	No	Mentions	16.5.2018 13:17 RT @hnm: https://t.me/nova24tv	16.5.2018 13:17	https://twitter.com/1607910478134095	16.5.2018 13:17	https://twitter.com/1607910478134095	16.5.2018 13:17	https://twitter.com/1607910478134095	16.5.2018 13:17	https://twitter.com/1607910478134095	16.5.2018 13:17	https://twitter.com/1607910478134095	2
2126	cevanj	nenarambutov	No	Mentions	16.5.2018 13:17 RT @hnm: https://t.me/nova24tv	16.5.2018 13:17	https://twitter.com/1607910478134095	16.5.2018 13:17	https://twitter.com/1607910478134095	16.5.2018 13:17	https://twitter.com/1607910478134095	16.5.2018 13:17	https://twitter.com/1607910478134095	16.5.2018 13:17	https://twitter.com/1607910478134095	1
2127	cevanj	cevanj	No	Tweet	16.5.2018 13:25: Zavr je k: http://nov.nova24tv.si/twiter.com	16.5.2018 13:25	https://twitter.com/16079103061274018	16.5.2018 13:25	https://twitter.com/16079103061274018	16.5.2018 13:25	https://twitter.com/16079103061274018	16.5.2018 13:25	https://twitter.com/16079103061274018	16.5.2018 13:25	https://twitter.com/16079103061274018	1
2128	marj001	cevanj	No	Mentions	16.5.2018 13:16 RT @dove: https://t.me/nova24tv	16.5.2018 13:16	https://twitter.com/1607910478134095	16.5.2018 13:16	https://twitter.com/1607910478134095	16.5.2018 13:16	https://twitter.com/1607910478134095	16.5.2018 13:16	https://twitter.com/1607910478134095	16.5.2018 13:16	https://twitter.com/1607910478134095	1
2129	markosket	nova24tv	No	Mentions	15.5.2018 14:40 RT @Nova24TV: Goloblev temi zavaznik Bogdan B	15.5.2018 14:40	https://twitter.com/160283939042921918	15.5.2018 14:40	https://twitter.com/160283939042921918	15.5.2018 14:40	https://twitter.com/160283939042921918	15.5.2018 14:40	https://twitter.com/160283939042921918	15.5.2018 14:40	https://twitter.com/160283939042921918	6
2130	markosket	janasads	No	Mentions	15.5.2018 11:19 RT @Janasads05: Ned oti je upeglina Slovenija, ki tuj	15.5.2018 11:19	https://twitter.com/16025444210089461	15.5.2018 11:19	https://twitter.com/16025444210089461	15.5.2018 11:19	https://twitter.com/16025444210089461	15.5.2018 11:19	https://twitter.com/16025444210089461	15.5.2018 11:19	https://twitter.com/16025444210089461	1
2131	markosket	demokracija1	No	Mentions	15.5.2018 13:28 RT @Dcm: https://t.me/ceva	15.5.2018 13:28	https://twitter.com/16018103102820033	15.5.2018 13:28	https://twitter.com/16018103102820033	15.5.2018 13:28	https://twitter.com/16018103102820033	15.5.2018 13:28	https://twitter.com/16018103102820033	15.5.2018 13:28	https://twitter.com/16018103102820033	1
2132	markosket	markosket	No	Tweet	16.5.2018 13:19: Ispreno i https://t.me/ceva	16.5.2018 13:19	https://twitter.com/160624818817599172	16.5.2018 13:19	https://twitter.com/160624818817599172	16.5.2018 13:19	https://twitter.com/160624818817599172	16.5.2018 13:19	https://twitter.com/160624818817599172	16.5.2018 13:19	https://twitter.com/160624818817599172	4
2133	markosket	nenarambutov	No	Mentions	16.5.2018 13:16 RT @hnm: https://t.me/nova24tv	16.5.2018 13:16	https://twitter.com/1607910478134095	16.5.2018 13:16	https://twitter.com/1607910478134095	16.5.2018 13:16	https://twitter.com/1607910478134095	16.5.2018 13:16	https://twitter.com/1607910478134095	16.5.2018 13:16	https://twitter.com/1607910478134095	1
2134	marj001	markosket	No	Mentions	16.5.2018 14:10 RT @Markosket: "Ce vabak tretji svet, dobri tretji"	16.5.2018 14:10	https://twitter.com/1606428284244302	16.5.2018 14:10	https://twitter.com/1606428284244302	16.5.2018 14:10	https://twitter.com/1606428284244302	16.5.2018 14:10	https://twitter.com/1606428284244302	16.5.2018 14:10	https://twitter.com/1606428284244302	2
2135	benardibic	benardibic	No	Tweet	16.5.2018 14:05: Tona kiva https://t.me/ceva	16.5.2018 14:05	https://twitter.com/160717458871792	16.5.2018 14:05	https://twitter.com/160717458871792	16.5.2018 14:05	https://twitter.com/160717458871792	16.5.2018 14:05	https://twitter.com/160717458871792	16.5.2018 14:05	https://twitter.com/160717458871792	1
2136	marj001	benardibic	No	Mentions	16.5.2018 14:16 RT @Benardibic: Tona kiva? ima prav. Rida z	16.5.2018 14:16	https://twitter.com/1607505212466424	16.5.2018 14:16	https://twitter.com/1607505212466424	16.5.2018 14:16	https://twitter.com/1607505212466424	16.5.2018 14:16	https://twitter.com/1607505212466424	16.5.2018 14:16	https://twitter.com/1607505212466424	1
2137	boodarbican	boodarbican	No	Tweet	15.5.2018 10:32: mraha https://t.me/ceva	15.5.2018 10:32	https://twitter.com/16030770217897914	15.5.2018 10:32	https://twitter.com/16030770217897914	15.5.2018 10:32	https://twitter.com/16030770217897914	15.5.2018 10:32	https://twitter.com/16030770217897914	15.5.2018 10:32	https://twitter.com/16030770217897914	2
2138	boodarbican	janasads	No	Mentions	15.5.2018 10:20 RT @Janasads05: Ka fe ba @tTV_Slovenija raje ded.	15.5.2018 10:20	https://twitter.com/1604511481577078	15.5.2018 10:20	https://twitter.com/1604511481577078	15.5.2018 10:20	https://twitter.com/1604511481577078	15.5.2018 10:20	https://twitter.com/1604511481577078	15.5.2018 10:20	https://twitter.com/1604511481577078	1
2139	marj001	boodarbican	No	Mentions	16.5.2018 14:18 RT @Boodarbican: Na Tona lai, svorazaga govor	16.5.2018 14:18	https://twitter.com/16075484847221816	16.5.2018 14:18	https://twitter.com/16075484847221816	16.5.2018 14:18	https://twitter.com/16075484847221816	16.5.2018 14:18	https://twitter.com/16075484847221816	16.5.2018 14:18	https://twitter.com/16075484847221816	1
2140	marj001	janasads	No	Mentions	16.5.2018 10:27 RT @Janasads05: Ka fe ba @tTV_Slovenija raje ded.	16.5.2018 10:27	https://twitter.com/16012117097199461	16.5.2018 10:27	https://twitter.com/16012117097199461	16.5.2018 10:27	https://twitter.com/16012117097199461	16.5.2018 10:27	https://twitter.com/16012117097199461	16.5.2018 10:27	https://twitter.com/16012117097199461	2
2141	marj001	marg001	No	Tweet	15.5.2018 7:53: Gobiblen https://t.me/ceva	15.5.2018 7:53	https://twitter.com/1602631605954816	15.5.2018 7:53	https://twitter.com/1602631605954816	15.5.2018 7:53	https://twitter.com/1602631605954816	15.5.2018 7:53	https://twitter.com/1602631605954816	15.5.2018 7:53	https://twitter.com/1602631605954816	1
2142	janasads	slovenskavojaka	No	Mentions	15.5.2018 9:16: NAPREJ 2. https://t.me/ceva	15.5.2018 9:16	https://twitter.com/1601307407921104	15.5.2018 9:16	https://twitter.com/1601307407921104	15.5.2018 9:16	https://twitter.com/1601307407921104	15.5.2018 9:16	https://twitter.com/1601307407921104	15.5.2018 9:16	https://twitter.com/1601307407921104	2
2143	magj001	slovenskavojaka	No	Mentions	15.5.2018 18:08 RT @Janasads05: NAPREJ ZASTAVA SLAVELJ Ponozni	15.5.2018 18:08	https://twitter.com/1601307407921104	15.5.2018 18:08	https://twitter.com/1601307407921104	15.5.2018 18:08	https://twitter.com/1601307407921104	15.5.2018 18:08	https://twitter.com/1601307407921104	15.5.2018 18:08	https://twitter.com/1601307407921104	1
2144	janasads	nova24tv	No	Mentions	15.5.2018 7:29 RT @Nova24TV: Ustani pravni jurj Toplak resno	15.5.2018 7:29	https://twitter.com/1602917321931937	15.5.2018 7:29	https://twitter.com/1602917321931937	15.5.2018 7:29	https://twitter.com/1602917321931937	15.5.2018 7:29	https://twitter.com/1602917321931937	15.5.2018 7:29	https://twitter.com/1602917321931937	11
2145	janasads	janasads	No	Tweet	15.5.2018 10:28: Ned oti je https://t.me/ceva	15.5.2018 10:28	https://twitter.com/1606120708205206	15.5.2018 10:28	https://twitter.com/1606120708205206	15.5.2018 10:28	https://twitter.com/1606120708205206	15.5.2018 10:28				

Source	Target	Type	Id	Weight	relationship
mal_#	jalla_inancc	Directed	0	1.0	Mentions
rehabibomer	indriyapri	Directed	1	1.0	Mentions
rehabibomer	slonuk	Directed	2	1.0	Mentions
perih2017	starkkaeds	Directed	3	1.0	Mentions
capcaperati	perih2017	Directed	4	1.0	Mentions
capcaperati	starkkaeds	Directed	5	1.0	Mentions
avri	revianapriat	Directed	6	1.0	Mentions
icoenerius	demasapri1	Directed	7	1.0	Mentions
icoenerius	jozbascah	Directed	8	1.0	Mentions
vanegonk	jozbascah	Directed	9	1.0	Mentions
ingepanc	julka	Directed	10	1.0	Mentions
lurakizaki	24ur_com	Directed	11	1.0	Mentions
lurakizaki	rtu_dloventia	Directed	12	1.0	Mentions
lurakizaki	lunawidya	Directed	13	1.0	Mentions
lurakizaki	annaviv246	Directed	14	1.0	Mentions
lunazambrooc	lulubati	Directed	15	1.0	Mentions
irisli	jalla_inancc	Directed	16	1.0	Mentions
gasper_ossald	igrggibec	Directed	17	1.0	Mentions
napsarom	julka	Directed	18	1.0	Mentions
janv2012	jalla_globe	Directed	19	1.0	Mentions
fatidus1	slonger	Directed	20	1.0	Mentions
nululuRyator	julka	Directed	21	1.0	Mentions
harryoffredon	soniblgg	Directed	22	1.0	Mentions
pappi	medega_7	Directed	23	1.0	Mentions
luridferjan	rov427bu	Directed	24	1.0	Mentions
luridferjan	luruseah	Directed	25	1.0	Mentions
lidsic	rov427bu	Directed	26	1.0	Mentions
dgantisek1	luruseah	Directed	27	1.0	Mentions
tyliva/7479384	ibobes18	Directed	28	1.0	Mentions
unpake	rtu_dloventia	Directed	29	1.0	Mentions
stevantario	lebo	Directed	30	1.0	Mentions
plendibuh	starkkaeds	Directed	31	1.0	Mentions
siroventana	hulhanc	Directed	32	1.0	Mentions
siroventana	jalla_inancc	Directed	33	1.0	Mentions
siroventana	hadars	Directed	34	1.0	Mentions
transdantub	lunaprasidder	Directed	35	1.0	Mentions
huam_0209	revivur1023	Directed	36	1.0	Mentions
gagang31	jalla_inancc	Directed	37	1.0	Mentions
panesli	muskahe	Directed	38	1.0	Mentions
lunayminastiy	lbn	Directed	39	1.0	Mentions
lunayminastiy	toddahfbc	Directed	40	1.0	Mentions

Figure 5. Link table in Gephi software.

Figure 6 presents the implementation of CSV file with a node and link table and converting them into a node structure and a list of links in the data structure. We added both lists to the Graph object to obtain social network data in a format, suitable for entering the input parameters of the shortest path search algorithms. The test included performing the Dijkstra and BFA for the first node in the list and measured the execution time of each algorithm. By repeatedly performing the test over all the nodes of the graph, we received the following results: in 20 trials, the JUnit test was performed on all graph nodes and the run times were recorded. The results were statistically analyzed using the SPSS software tool and found that a relatively small social network (848 nodes and 2156 connections) already slows down the implementation of the BFA. The mean value presents the average time of finding the shortest path among users. The BFA takes about 22 seconds to calculate the shortest path between all graph nodes, while the DA calculates the shortest path for all graph nodes to an average of about 50 ms. The DA is, therefore, a better option for finding the shortest path among users on social networks.

When reviewing the results of the implementation of both algorithms, both the DA implementation and the BFA implementation are not capable of correctly processing the loops that were created in the social network simulation by posting tweets (posting a tweet creates a connection to the beginning and end at the same node). Also, both implementations are not capable of correctly processing multiple equally directed connections between two nodes.

```

@Test
public void testRunSimulation()
{
    CSVParser parser = new CSVParser();

    List<Node> nodes = parser.parseNodesFileWithLabels("./src/resources/slovenijaNodes.csv");

    Graph graph = new Graph(nodes.size());
    for(Node node : nodes)
    {
        graph.addNode(node);
    }

    List<Edge> edges = parser.parseEdgesFileWithLabels("./src/resources/slovenijaEdges.csv", graph);

    for(Edge edge : edges)
    {
        graph.addEdge(edge.getSource(), edge.getDestination(), edge.getWeight());
    }

    long elapsedTime = 0;

    System.out.println("Bellman-Ford algoritem:");
    Date startDate = new Date();
    Algorithm bellmanFord = new BellmanFord();
    for(Node node : nodes)
    {
        bellmanFord.calculateShortestPathFromSource(graph, node);
    }
    Date endDate = new Date();
    elapsedTime = endDate.getTime() - startDate.getTime();
    System.out.println("Bellman-Ford elapsed time: " + elapsedTime );

    System.out.println("Dijkstra algoritem:");
    startDate = new Date();
    Algorithm dijkstra = new Dijkstra();
    for(Node node : nodes)
    {
        dijkstra.calculateShortestPathFromSource(graph, node);
    }
    endDate = new Date();
    elapsedTime = endDate.getTime() - startDate.getTime();
    System.out.println("Dijkstra elapsed time: " + elapsedTime );
}

```

Figure 6 Test of the shortest path search algorithms performance on social network data.

We have found that for finding the shortest path, these types of links are unnecessary and misleading. In the case of multiple connections between two points, the shortest path will always follow the link that has the lowest weight, so all other duplicate links can be removed. We also do not need loops to connect to the same node, since in the case of a positive loop weight, the shortest path will never go through the loop. If the loop has a weight equal to 0, we have an infinite number of shortest paths, which causes the algorithm to never terminate, so even in this case, it is necessary to remove such a link. The negative weights on the Dijkstra loop do not allow the algorithm, and the BFA reports the existence of a negative cycle, which makes it impossible to calculate the shortest paths, so also in this case, it is necessary to remove such a link. Only by removing these types of links, the shortest path finding algorithms worked correctly.

Statistics			
		Bellman-Ford (ms)	Dijkstra (ms)
N	Valid	20	20
	Missing	0	0
Mean		22309,90	50,25
Median		22353,50	50,00
Mode		21672 ^a	46
Std. Deviation		340,686	6,112
Variance		116067,147	37,355
Range		1493	22
Minimum		21672	42
Maximum		23165	64

a. Multiple modes exist. The smallest value is shown

Figure 7 Statistics of the results of action research in the SPSS software tool.

3. Results

This paper addresses three main topics: (1) which are the most common methods for finding the shortest path, (2) analyzing and comparing the two most common ones and (3) applying the SPP methods on an example of a social network. By reviewing the literature, we checked which methods are used to find the shortest path and determined the usage frequency of each SPM and defined which of them are used in social network analysis. We found that the most commonly used shortest path search and chose the Dijkstra and Bellman-Ford algorithm for more detailed examination by employing a comparative analysis, we determined the properties of each algorithm. The findings of the comparison are shown in Table 1. The advantage of the DA is its speed of operation and ease of implementation. While the advantage of the BFA is the ability to enter negative link weights and optimize performance on graphs with many links. The disadvantage of the DA is not allowing the insertion of negative link weights, while the main disadvantage of the BFA is its less rapid operation and relative implementation complexity. There are different implementations for both algorithms depending on the data structure in addition to using, storing and processing data.

Based on the comparison of the chosen algorithms, practical use of both algorithms was evaluated. Regarding the Dijkstra algorithm, we have found that there are several different ways of implementing the algorithm, which differ from each other in the choice of the data structure for operation with a node table and a table of connections. We also found that the DA runs very fast and has the most optimal performance for graphs with few links. Regarding the Bellman-Ford algorithm, its use in practice is similar to DA. There are several implementation methods for the BFA as well that vary depending on the data structure selected for node and connection operations. The experiment results show that the BFA runs slower than the DA, which is the result of an additional implementation phase that checks for the existence of a negative cycle. Also, because of multiple bypassing all links, the BFA has the most optimal performance for graphs with many links.

4. Conclusions

The paper addresses the question of whether the aforementioned short-path search algorithm can be applied to the problem of social networking. We conducted an action survey to test the implementation of DA and the BFA on the real Twitter social network. We found that in the case of the Twitter social network, there are loop links to the same node and multiple links between two nodes that are not capable of being properly processed by the algorithms and therefore return the wrong result of finding the shortest path on the social network. For such a result, all links need to be removed, which leads to the conclusion that Dijkstra and Bellman-Ford can only be partially applied to a specific example of a social network. In this paper a literature review was performed to find existing SPP methods, focusing mainly but not exclusively on the SNA domain. The search focus was limited to SPP methods, not considering methods and algorithms, which are used primarily for other purposes and are potentially also appropriate to find links within the social networks field

Finding the shortest path is a time-consuming task, however an important task in today's fast-changing economy with many social networks, which are integrated with all aspects of our lives, in all possible domains; from social to professional. To find the most influential users within a network or connect the two suitable nodes in the most optimal way possible provides a strategic advantage of businesses as well as saves and smartly uses resources.

The addressed problem of finding the shortest path is solvable with many methods and approaches, however, we chose to investigate the solutions from the field of operational research, addressing most used shortest path methods. Since there are several possible solutions and in this paper, two were included, this presents one of the main limitations of this paper. The results show that among the two chosen ones, the Dijkstra algorithm is the faster algorithm and thus suitable for smaller social networks.

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The analysis of reliability and objectivity of information that can be found on the Internet

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Abstract. The article deals with the analysis of reliability and objectivity of information that can be found on the internet and the objectivity and reliability of such information is compared to the system's behavior. The terms "useful" and "useless" information have been introduced. On the basis of Shannon's law of connection between information and entropy, as the measure of system's organization the notion of information chaos is analyzed, it illustrating growth of entropy in such system. The work comprises a graphical interpretation of various events with Lars Onsager's curves. Described is the parameter which has to discern authentic useful information available for analyzing and obtaining new knowledge from false and biased. A variant of the general scheme of the dynamic information system of the Internet, reflecting the appearance of inaccurate information, is given. The analysis of experts' evaluation of the internet users' reaction on appearance of false, biased or unreliable information showed that young users were oriented largely on emotional content, while the scientific society preferred reliability, objectiveness and authenticity of information.

Keywords. Internet, global information space, Shannon's law, false information, experts' evaluation, entropy, reliability, objectivity

1. Introduction

In recent years, the Internet has become one of the main sources of news and other information for many people (media channels, news portals, social networks, Youtube). They allow you to see the coverage of events taking place in the world from different points of view, quickly and conveniently receive any thematic information. Along with this, the global information space of the Internet is increasingly used to spread various rumors, fraudulent and other inaccurate information, as well as political propaganda. Information can be distorted both by an intruder pursuing his own selfish goals, and by ordinary users who inadvertently disseminate inaccurate information by posting data obtained from unverified sources on their pages. All this can have an impact on social, political, economic stability.

Reliability and objectivity of information that can be found both on the Internet and outside of it have always been paid much attention to in scientific and other publications [1-7], still, the data regarding the comparison of objectivity and reliability

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of such information with the system's behavior, particularly, how the system's organization and its entropy, as a measure of its regulating and disordering can be compared to it are quite scarce.

The same can be applied to false, untruthful and biased information the contemporary Internet is deluged with. According to the research by IDC nearly 95% of information found on the Internet is not source information. In essence, it is not original reposted information, really inessential, i.e. it's useless for the society, as it can be termed as misinformation because it is biased or false. Only 35% of information, available on the Internet can be processed analytically, though just 1% of information has been analytically processed.

We must not forget that the aggregate information volume of the Internet can now exceed 40 terabytes [8]. We may assert, paraphrasing the words of David Sarnov, the honorary doctor on New York, Columbia and other world universities that "Knowledge in its essence is neither good, nor bad, its value could be measured how it is applied". It can be just for information found on the Internet, when it is applied.

Consequently, in the current situation, when the number of intentional and unintentional threats to violate the reliability of information increases, and at the same time, there are no built-in assessment mechanisms available to an ordinary user in the Internet services, it becomes necessary to create a system for monitoring the objectivity and reliability of information.

2. The main material

2.1. Literature review

In article [9], it is proposed to evaluate information posted on the Internet by calculating the sum of points according to four criteria: the degree of identification of the site owner, motivation to provide reliable information, relevance of information and the quality of the output data. This method is easy to use, but it is not universal and is more suitable for evaluating scientific information.

Work [10] is devoted to training the organization of the process of searching for information on the Internet. The author proposes to determine the reliability of information, taking into account its completeness, integrity and truthfulness. The most difficult task is to determine the truth of the information, and as a solution, the article proposes to evaluate the reliability of the source as a whole. A source can be considered credible if it belongs to a scientific, educational, or government organization. Otherwise, the analysis of links to the used data sources can be used as a method for assessing the truth of information. However, often sites do not contain links to the sources used, and in this case it is necessary to assess how reliable the information presented on the site on a topic known to the user is. Based on this, the user can later draw conclusions about thematically related information, the reliability of which he needs to evaluate. To solve this problem, it is proposed to use the Mamdani controller of the fuzzy logic apparatus. The disadvantage of this approach is that the user may not always have enough information to assess how true any information on the desired topic is, and, therefore, in this case, he will not be able to judge the reliability of the information in the source as a whole.

Contemporary Internet users do not value knowledge, as information giving "food for the mind" they seem to prefer information that creates some mood, some

impression, relations or desire, i.e. information with simplified social content, which is not rendered through texts, but preferably through images, pictures, video rows, in which the written contact form can be lost. Here, the ways of deliberate sense distortion of the original information can be applied as one of the objective tools, in order to adjust it to the mood or other simplified user's needs, quite often it could be distorted information, fakes, misinformation, information lies. It all is in great regular demand and finds the corresponding response in the Internet.

Quite arbitrary separation of information into useful and useless can, for example be determined by the probability formula by M. Bongard [8], still it has to be expressed in Shannon's law on connection between information and entropy, it being a measure of the system's organization, in investigations of other authors, like [11,12]. Claude Shannon showed that information growth was lost uncertainty, while regulated information was antipode of entropy growth [13]. He introduced one more notion of entropy-events entropy, having shown that entropy could be sufficient information measure, thus differing it from differential entropy, related to changing information values. At that event's entropy is measured by information that could be obtained as a result of the occurrence of this event, it can be measured in bytes and is equal to it. Information on the Internet is always of eventual character. So, we may depend upon the fact that events entropy is directly related to the object of our investigation.

We will show, that in some consecutive event s row (α_i), the information flow is, on the whole, nothing but expression of a sequence of some independent events. Then, in accordance with the well-known law, information is determined as:

$$I(\alpha_n) = -k \cdot \sum_{i=1}^n p(\alpha_i) \log_2 p(\alpha_i), \text{ bit} \quad (1)$$

where $p(\alpha_i)$ – is the probability of α_i information event among n-multitude of other ones, connected with this system; k – is a coefficient, expressing relations between entropy units and information in the formula.

At that, according to Shannon, average entropy of $H(\alpha_n)$ event is equal to the information that leads to this event only (it follows from the law)

$$H(\alpha_n) = I(\alpha_n). \quad (2)$$

The system with well-arranged information may be considered as organized, having some minimal entropy for the case. Vice versa, it's logical to think that distorted and not arranged information is to certain extent connected with growth of entropy. There is even quite an objective notion of information chaos, expressing, according to Shannon, growth of entropy in such system.

2.2. The objective of the investigation

The objective is to propose one of the possible ways of separating information within the Internet space, according to its quality with subsequent information objectification of analytical character.

To achieve this goal, the following tasks were solved during the research:

1. Divide the general information flow into useful and useless information; give a verbal definition of these terms, which in the future will make it possible to systematize information flows in the global information space of the Internet.

2. Based on Shannon's law on the connection of information with entropy, as a measure of the organization of a system, consider the concept of information disorder, reflecting the growth of entropy in such a system.

3. Introduce the concept of a weighting factor that should distinguish information available for analysis and for obtaining new knowledge from inaccessible for this.

4. Consider a variant of the general scheme of a dynamic information system of the Internet, reflecting the appearance of inaccurate information.

5. Conduct an analysis of the expert assessment of the reaction of certain groups of Internet users to the appearance of distorted or inaccurate information; the groups should include average users, young people from among students, scientists.

2.3. Presentation of the main material

We are interested in this work in distorted or false information and its influence upon organization of the information space. It is also information, though it is of low quality and not adapted to usual analytical application.

If we exclude the probabilistic approaches, introduced, for instance, by M. Bongard, A. Kharkevich, Y. Hintikk and their followers, then, in the notional sense we may assert that information possess qualitative character only in case it is suitable for analysis and further application with the aim of obtaining some new knowledge for learning and analyzing, so, when human brain can generate new knowledge, useful for the mankind from the existing information. It is difficult to overestimate the analytical character of information, contained in the Internet, despite the fact that it is contradictory to gradual loss of interest in the web to significant, sense content in favor of sensual perception of information. An opposite opinion can be met in literature, which can be quoted in this form: "knowledge is but an instrument for emotions and sensuality", trying to bring the contemporary Internet to into the number of its allies. Knowledge and analytical information becomes at that secondary, as it depends on the user's mood. This position has the right to exist only until the society acquires a new order for further development. It is bound to require new knowledge, appearance of new laws, development of the natural science and society to the degree, which man may deserve, with the level of his outlook and degree of his claims to the biotope.

Let us try to represent in a quite simple form the original information in the form of some useful substance for man, presenting opportunities for own analytical comprehension and interpretation in human brain. Such comprehension is bound to lead to appearance of new information. Let us call it useful information, unlike information, which, as a rule, does not give any "food for thought" and does not allow to get any new knowledge when it is analyzed by human brain. Let us call it useless information, as it is not necessary because it somehow differs from the useful information and it distorts man's perception of the world, complicates his communicative processes, hampers rationalism and to some extent the constructive sociality in the society. We can maintain that this information, useless for brain does not promote organization of the information system. It seems that this useless information, in the form of a simplified assumption regarding equiprobable outcomes for the system's entropy can be linked with its vector changes, particularly, with the

system missequencing. If the absence of the growth of entropy from the initial state H_0 to some subsequent H_1 , state, as a result of appearance of information I_1 , can be compared to $-I'_1 = H'_1 - H_0 > 0$ expression, then the opposite logics, regarding appearance of distorted information (misinformation and false information, useless for the system) I'_1 can have the right to exist, as there happens to be some entropy growth $-I'_1 = H'_1 - H_0 > 0$.

The theory of information entropy characterizes uncertainty, due to the absence of information on the system state. Unreliable information increases this uncertainty in strict correspondence with Shannon's logics, so it leads to growth of the system's entropy.

C. Shannon, for example, shows that entropy's measure is one of the factors of uncertainty about the reliability of information $\Delta H \sim -(I_{rel} - I_0) > 0$ [13]. It is connected with the difference between two information types regarding the event (I_0) and its part (I_{rel}), which arises no doubts (i.e. is precisely well-known and is reliable enough). So growth of the system's entropy is linked with unreliable information, requiring additional rechecking.

In the volume of the "digital universe" it is suggested to consider as quality only the information which is capable of giving opportunities of its application for analytical treatment appearance of new knowledge, promoting some growth of the organized character of the system. Low grade information, in its turn, is the information incapable of giving opportunities of getting new objective knowledge, not promoting the organized character of the system, the level of the system's organization being determined by alternations in its entropy.

Not plunging into the semantics of expressions, as there are enough works, devoted to it, we will limit our claims and reduce to the sign of correspondence between quality and usefulness of information. We will stress here that division of information into useful and useless can be conventional only, even in the interpretation given here. Any information can be an object of the corresponding analytical comprehension in human brain for certain conclusions, even if they contain a negative result.

Such division, applied for the material under consideration will allow systematizing of the information flows in the global information space, providing for the user some opportunities, either positive or negative. In a more general case, when we have to deal with information events of different probability, which are consecutive and supplement each other the equation (1) acquires the well-known view:

$$I(P) = -P(\alpha) \log_2 P(\alpha) - [1 - P(\alpha)] \cdot \log_2 [1 - P(\alpha)]. \quad (3)$$

This dependence, in graphical interpretation (Fig.1) is quite comparable to phenomenological curves of Lars Onsager, marked with dotted lines in Fig.1 for the system arranged within the area of weak thermodynamic no equilibrium and described with general equation $\Delta[H] = \sum_{\alpha=2} J_{\alpha} I_{\alpha}$, in which thermodynamic flows J_{α} and forces I_{α} are generalized in such a way that

$$J_1 = J_{11}I_1 + J_{12}I_2 = 0, \quad (4)$$

$$J_2 = J_{21}I_1 + J_{22}I_2 \neq 0. \quad (5)$$

Now, let us introduce the notion of weigh coefficient, related to false, incorrect and distorted information in the form of relation $\mu = \frac{P(\alpha_-)}{P(\alpha_0)}$, and its relation to reliable and true information in the form of $1 - \mu = \frac{[P(\alpha_0) - P(\alpha_-)]}{P(\alpha_0)}$.

In Figure 1 there are these dependences in general view, that differ in their integral are by the value of

$$\Delta = \pm(I_0 - H_1) = \pm[\alpha \cdot I(\rho_\alpha) - (1 - \mu) \cdot H_0]. \quad (6)$$

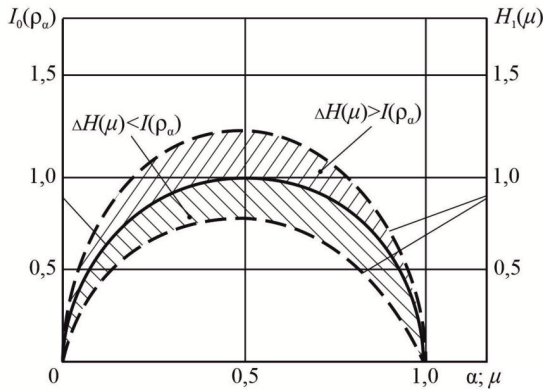


Figure 1. Graphical interpretation of entropy of an event and entropy of thermodynamic system in the area of weak no equilibrium.

Index “0” is here related to the entire information volume, while “-“ index – to information of distorted view; $I_0 = H_0$ is related to the general state of information and the corresponding entropy of the events in the system.

The parameter μ from equation (6), in its essence should differ information, available for analysis and obtaining new knowledge from information unfit for it and, thus, it helps to tell useful information from useless and distorted.

To confirm the what we have mentioned above we’ll show that if $\Delta > 0$, then, entropy of the system, containing in its volume some distorted information, less than the general information volume in the system ($H_1 < I_0$), and on the contrary, if $\Delta < 0$,

then the entropy of the system with distorted information exceeds the entire mass of the data contained in this system ($H_1 > I_0$). In the first case the system is stable to deformations; in the second case it is not stable. In other words, unreliable and distorted information hampers the growth of the system organization and reduction of the events' entropy.

Taking into account that Internet exists as a receiving and transmitting information system (Figure 2), having its original (let us designate it as I_0) information and its received information (I_1), as well as the corresponding passing channels, we will apply the theory of entropy analysis of digital data [14] for determining the role of distorted information in this global information system.

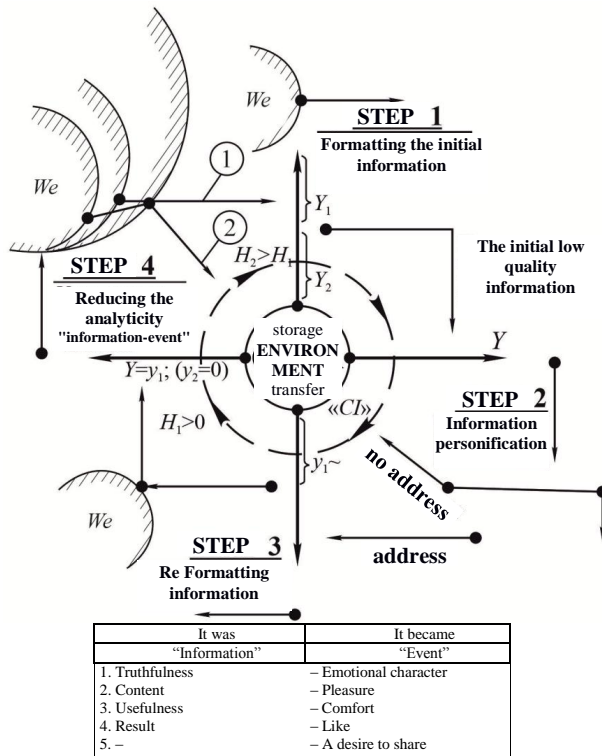


Figure 2. A variant of the general scheme of dynamic internet information system, showing appearance of false information (We – the users area(source of information); "CI" – the complete cycle of low quality information circulation; 1 – Emotional reaction for the event; 2 – Propagation in the net)

By introducing an auxiliary variable (z) for evaluation of standard distribution of random value for n events with zero average value and singular dispersion $z(n) = N(0,1)$ we will receive

$$I_x(n) = k[\alpha z(n) + (1-\alpha)N(0,1)] = \alpha k z(n), \quad (7)$$

$$I_y(n) = k[\alpha z(n') + (1-\alpha)N'(0,1)] = \alpha k z(n'). \quad (8)$$

The existence of the auxiliary variable shows a tense connection between variable multitudes of events n and n' in the form of received and transmitted information.

The original data in the form of I_x и I_y variables depending upon the coefficient of connectivity (α), compiled on the basis of selection of the events, connected with false information (the information that was not confirmed or was denied afterwards), contained in Internet regarding COVID 19 epidemic, available for users within the specified time span are represented in Fig.3. The time interval of information selection is 10 months of the year of 2020 (March-December). The overall number of information events for entropy analysis was 205, from that number there were 172 events connected with false or distorted information, fakes or errors.

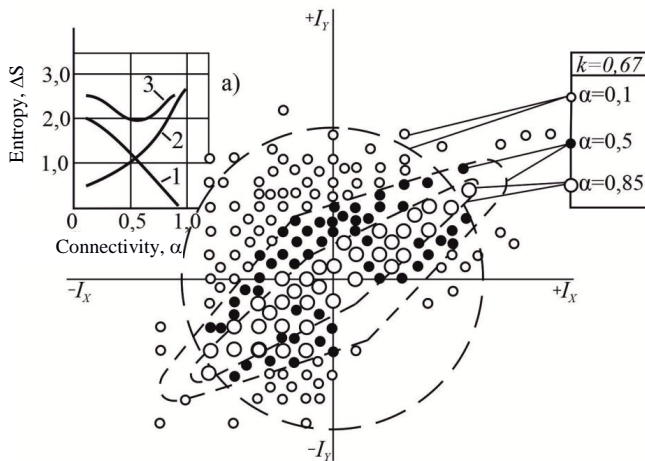


Figure 3. The diagram of the distribution of I_x and I_y variables for different values of α (designations in the text)

With the increase in connectivity between the variables in distorted events information areas of linearization $I_y(I_x)$, become obvious, especially at $\alpha \rightarrow 1$. The

dependence of entropy of information upon the connectivity of the variables of input and output of the information system gives us distinct difference in the form of curves (1) and (2) in Fig.3 and, accordingly, those, connected with distorted information.

If with the growth in connectivity of true information its entropy is decreased, then, for false information this dependence has to be simply the opposite. There exists the area for each the aggregate information placed on the Internet per a certain time interval is minimal (see Fig 3, a), but its quite bigger than entropy of unambiguously reliable information, compared to it. It proves that any distorted information for an Internet user is a reason of destruction of organization of the information system in which such user is.

Thus, the quality of information, its error (unreliable, distorted or false) part is an essential obstacle for application of such information with constructive purposes. This peculiarity of the information field in the Internet is likewise evaluated by its users, representing more typical groups, it being confirmed by the results of experimental researches.

Now let us evaluate the results of the poll, investigating response reactions of separate groups of Internet users on appearance of false or unreliable information. Classification of types, reasons and ways of revealing disbelief in Internet systems in accordance to some selected data [15,16,17,18,19,20], and the so-called factors of disbelief to information in arbitrary view is summarized in Table1. The poll experts were:

- 111 average statistical users of Internet and social networks, including persons, trained professionally;
- 122 young studying persons of 10th and 11th school forms and university students, whose age does not exceed 25 years;
(these two expert groups have, according to their data have little need in analytical treatment of information they are interested in Internet)
- 67 among research workers, whose age is over 25 and who have a need in analytical processing of information with the objective of generating new information on the basis of the original information, i.e. in obtaining new knowledge.

Each expert had the right to evaluate the value of any three factors, taken from the list of suggested, the maximal rating was 60 points. The experts' marks underwent analytical processing, as specified [21]. The results (see Table 1) are represented in the form of specified values of mathematical anticipation and its average quadratic inclination and are illustrated in Figure 4 graphically.

The experts' evaluation Y defines indirectly the volume of distorted information, roughly calculated by the experts which the Internet users may face. It is quite a subjective index and conventionally can be divided into two parts $Y = Y_1 + Y_2$, where Y_1 – is the volume of distorted information confirmed afterwards, Y_2 – is the volume of potentially distorted information that eventually proved to be correct (see Figure 2).

The analysis of experts' research showed that young users, who are inclined towards sensual emotional content practically do not perceive the factors group 1÷6, as menacing to its interests in Internet, while representatives of the science circles were not worried by the 8÷10 factors, that are in their turn vital for young persons. It can be explained by different interest vectors among these users groups. The science circles of

the Internet are interested in reliability, authenticity and transparency of information, contained in the sources and authors' competences.

Table 1. Classification of the factors of disbelief X to the Internet information in expert evaluations of Y-users

#	Disbelief factors, X	Experts' evaluations, Y points			
		Average users	Young persons	Researchers	
1	Literary errors, distorting the sense of the text	22,55±3,41	5,1±2,21	34,3±5,83	
2	Sense distortions in the main text, substandard text, loss of informational sense	22,5±4,01	4,9±1,29	37,9±9,11	
3	Information without reference to sources; unverifiable information	21,4±2,16	7,2±2,54	40,2±3,45	
4	Transparency of submitted information	26,1±4,87	12,6±4,34	39,8±6,44	
5	Reliability of basic information sources	20,9±1,64	7,9±1,19	39,3±5,12	
6	The depth of assimilation of information by its author	28,9±5,42	11,2±2,33	42,1±6,11	
7	Consistency of questionable information	25,8±7,77	12,4±3,14	27,9±5,27	
8	Flood manifestations, wipes, non-thematic information	35,1±4,63	26,9±4,74	12,5±3,41	
9	Click bait	36,4±1,88	29,9±3,84	13,2±2,55	
10	Direct information deception, false information, fakes	41,9±5,75	48,9±5,17	7,5±1,14	
11	Opportunities to protect against misinformation on the Internet,%	Yes	6	12	31
		No	89	77	58
	Return to censorship,%	Yes	4	–	45
		No	88	95	51

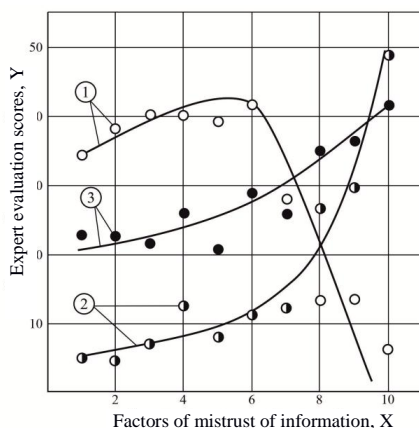


Figure 4. The results of an expert assessment of the factors of mistrust in information resources on the Internet. 1 – group of scientists, 2 – group of young users, 3 – group of average users.

The analysis of experts' research showed that young users, who are inclined towards sensual emotional content practically do not perceive the factors group 1÷6, as menacing to its interests in Internet, while representatives of the science circles were not worried by the 8÷10 factors, that are in their turn vital for young persons. It can be explained by different interest vectors among these users groups. The science circles of the Internet are interested in reliability, authenticity and transparency of information, contained in the sources and authors' competences.

An average internet user is less anxious about those groups of factors, because of his lack of professionalism and emotional perception, evaluating those hazards nearly equally. The group of factors 7-9 is most equally evaluated by the group of experts. False information, fakes, floods less worry the world of scientists than ordinary Internet users because there are fewer examples of such negative phenomena there, in comparison with social information space.

89% of experts of the first group, 77% - of the second group and 58% - of the third group do not see real opportunities of protecting Internet space from appearance of distorted information. While 45% of users of the third group see the way out in restoration of censorship, at least in scientific and public publications, it was being unacceptable variant for the bulk (88-95%) of the alternative internet users.

3. Conclusion

On the whole, it may be concluded that false information on the internet in its numerous forms comprises a great part of information and even nowadays is becoming an obstacle for further development of the information space, if it's reasonable enough to consider it to be one of the most important sources of organization and development of the contemporary society. It can be testified by the objective entropy processes, connected with information flows of different quality, that are present in the internet, as well as the results of sociologic polls, conducted among representatives of different groups of users.

Controlling the reliability of information on the global Internet is currently a very urgent task, since more and more people are becoming active users, and at the same time the number of threats is constantly growing.

The society has not invented the ways of ensuring reliability for the global information space yet; however, it has to be found, sooner or later, including, with the help of the criteria of organization of information systems.

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The research the problem of the efficiency of bitcoins: the energy costs for the generation of this cryptocurrency on a global scale

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Abstract. The work is devoted to the problems of efficiency of bitcoins, especially power inputs due to generating of this cryptocurrency. Nowadays the problems of mining power input efficiency seem to have passed from a comparative problem to the problem of existence of this blockchain technology, requiring a different engineering policy or different managerial decisions. The comparative analysis of bitcoins generating power input and the world's power input has shown that there are almost no trustworthy methods of evaluating input power for blockchain technologies. This problem is solved by application of contemporary methods by setting up big mining companies, located in areas with cheap electric energy and free power balance, possessing their own technological resources and thinking of creating alternative power capacities for mining objectives. At that the state systems start to introduce various limitations for power capacities used for cryptocurrencies including quotas and price privileges. Represented are the results of the analyses of the dynamics of alternation of the main parameters, influencing power consumption at generation of bitcoins on the basis of available literary data and own investigation. Given are the results of calculations regarding bitcoin generation, the costs of consumed electric power per mining of one bitcoin. A more objective index of bitcoin power consumption is suggested, it being correlated with its unit and the unit of heshrate e_h , showing that $N_{bc} \cdot LgH$ duplex is constantly growing despite a decrease in general mass of generated bitcoins, while the relative bitcoin energy consumption decreases with time, still such decrease happens slower than the growth of its market value.

Keywords. bitcoin energy consumption, blockchain technologies, cryptocurrency mining, power input efficiency, power consuming, heshrate.

1. Introduction

Bitcoin, though its creators are convinced of its exceptional decentralized and inclusive systematic character, actually possesses one quite centralized controlled function. This is technological energy consumption, which is controlled and in case some effort is exerted can give information, regarding the state of the system, being the dominant factor for the system. Miner's activity is reduced to selecting all variants to solve the task of determining the necessary hash. Such work requires:

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- access to the source of electric power;
- corresponding capacity of computer hardware;
- operation velocity;
- hashing volume.

Access to electric energy appears to be the weakest spot for the blockchain technology. Mining can't be done without application of electric power sources.

Energy consumption remains so far an insurmountable obstacle for development of the blockchain technologies, alongside with acquisition of costly mining equipment. According to the data provided by I. Kaminski the average amount of power, consumed on mining operations throughout nowadays world can be compared with energy consumption on the island of Cyprus [1]. Dino Mark Angaritis believes that in 2015 the average number of solutions with regard to hash search for each mining problem was equal to 3·10²⁰ hashes, it being beyond the capabilities of many types of computer resources [2]. The data regarding power consumption on mining operations, provided by different sources differ very much, just showing quite a big value, that could be compared with the level of power consumption of such countries like Switzerland, Kuwait [3], Austria, Argentina [4, 5] et al. A. De Vries, the creator of Diginomist index believes that with application of the most up-to-date computer hardware at least 15·10⁶ MWt·h. of the world electric power has to be consumed on mining, even the figure 30·10⁶ MWt·h. is not the limit, as the system of nowadays mining, including its operational modes is a kind of a «black box» [6]. According to the data provided in [7] generating of 18 million of bitcoins, already completed, required about 20·10⁶ MWt·h. or 0.13% of the total world's energy consumption. According to the data, mentioned in [8] at the total world energy consumption of 158·10⁹ MWt·h, generation of bitcoins cost only 9.6·10⁶ MWt·h. or just 0.006% of the world's consumption. According to the data, provided by A. Narayan [9] in 2018 1,8·10⁶ MWt·h. of energy was spent on bitcoins. In 2019 году according to the data, provided in [10] the general consumption on bitcoins was equal to – 53·10⁶ MWt·h. The data, provided by M. Straube, the German mathematician [11] the annual world's energy consumption is at least 14·10⁶ MWt·h. According to the words of the scientists, working at Lawrence Laboratory in Berkley it was supposed that by the year of 2020 energy efficiency of the branch could grow by 45%. The specific growth was equal only to 3-5%.

In general such numerous comparative evaluations can provide information verifying the fact that there are practically no reliable methods of evaluating power consumption at mining and in general for the blockchain technologies.

Transition of mining procedures to big specialized companies, possessing tremendous technological resources leads to the fact that many countries start to imitate access to the sources of electric energy for them. The farms, as a rule, are set up in the regions with cheap electric energy and free energy balance. Still, China. Embracing more than 80% of the world mining market introduced limitations on energy resources used on crypto-currencies, not only in limits, but also in privileges in price policy. Some US states, Canadian, Italian, suppliers gradually introduce such limits for their mining farms and special «workshops» that include a great number of powerful video cards. The mining companies are seriously considering the problems of creating powerful energy capacities of their own, especially for mining objectives.

2. The main material

With the increase in the volume of operational stock of bitcoins, involved into work, the task of selecting variants of hash search becomes more complicated, its record length grows, making the task of searching a hash-reply much more difficult, thus requiring an essential increase in power consumption. Just within the period between 2016-2020, according to the data mentioned in [12], bitcoins hashing operations became 5 times more complicated, it inevitably caused a substantial growth in power consumption.

The average transactions time of a regularly scheduled unit, determining the velocity of these operations has varied since 2012 within rather wide limits [12, 13] depending on the system load. A steady dynamics (see Fig.1) can be observed only due to appearance of new mining devices and technologies, for instance, during the period of active mining by private participants in 2012-2016 (area I) on the basis of the first GPU-video cards in the first decade of this century, when mining farms amalgamated, or during the period between 2017-2020 (area III), when more powerful mining machinery emerged: the up-to-date ASIC (Application Specific Integrated Circuit mining), especially well-known ASIC Antiminer S9, Bitmain S9, system, Bitmain S9, «cloud» mining, more traditional Antiminer S7, Antiminer D3, by Bitmain company [14], using Scrypt algorithm. In general the contemporary bitcoins mining is executed by the devices, the aggregate capacity of which exceeds $9 \cdot 10^3$ MWt.h.

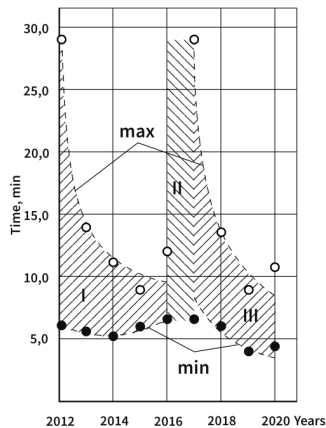


Figure 1. The dynamics of the average duration of a transaction and confirmation of a mining unit (the data provided by [13] source)

The dynamics of average daily transactions since 2012 is represented in Fig. 2. The aggregate bitcoins hashing only between April 2019 and March 2020 was within the

values of 40 TH/s to 100 TH/s, the difficulty of the mining problem being increased by 2.5 times [16]. Undoubtedly, we should expect growth in power inputs per a unit of cryptocurrency, the design data are shown in Fig. 3.

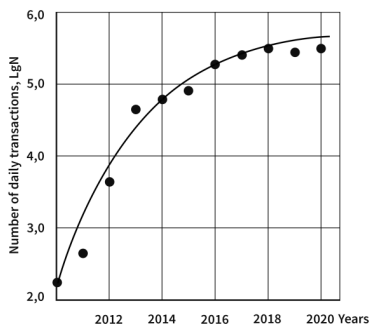


Figure 2. The dynamics of daily confirmed transactions in the bitcoin system (the data taken from [15] source)

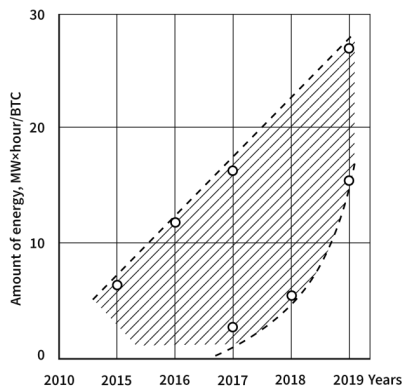


Figure 3. The design bitcoin annual power consumption

In 2010 hash rate of mining of one unit, consisting of 50 bitcoins was equal to $1 \cdot 10^{-11}$ TH/s, or per one bitcoin $0.2 \cdot 10^{-12}$ TH/s [17]. Later, after every of 250 thousand of generated units (12.5 million bitcoins) system required a new unit size, consisting of 25 bitcoins, hash rate each of them amounted to $1.4 \cdot 10^{-11}$ TH/s [18, 19], while after 2015 for each of 12.5 unit bitcoins that figure was equal to $4.5 \cdot 10^{-11}$ TH/s.

The growth in enumeration of possibilities for the search of a new hash also required an increase in engineering power consumption (see Fig. 4a). It's logical to maintain that reconsideration of the volume of one unit in favor of its preservation or increasing can promote energy saving, so this variant may be worth discussing. Hashrating of such volumes is beyond the opportunities of private miners and for larger companies it means variants enumerating, expressed by the figure with 21 zeroes (zeta) and at such capacity the last bitcoins have to require $n=1 \cdot 10^{24}$ hashing units (see Fig. 4b).

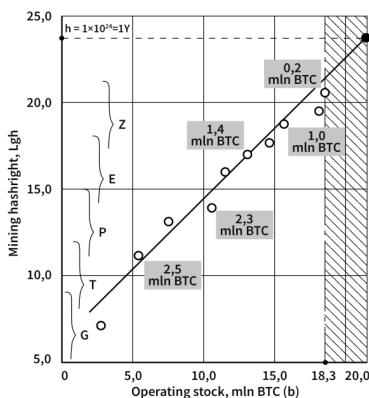
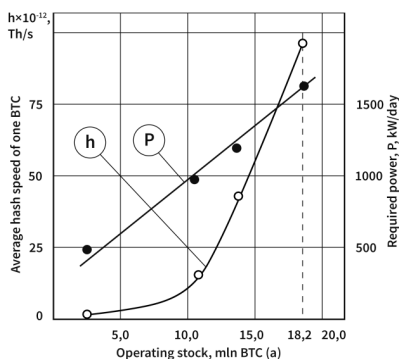


Figure 4. Dynamics of hashing of one bitcoin and requirements in powerful equipment (a) for ensuring the necessary hashrate capacity, depending on application of the entire operation resources of bitcoins (b) (acc. to the data, provided in [20] source)

With regard to the fact that all participants must their hashing apparatuses working 24 hours a day we are able to evaluate energy consumption both of transacting and mining. In practice miners' operating modes (except the companies dealing with professional mining) are far from being uniform, it making any balance calculations of integral inputs power merely evaluative. It can be shown that such calculations are far from being real. That is the reason why it is very difficult to select an objective system of evaluating power inputs for the blockchain technology. Due to the efforts by Michel Rauchs from Cambridge Centre of Alternative Finances there appeared an index of energy consumption by bitcoin CBECI (Cambridge Bitcoin Electricity Consumption Index), it helped aided to launch in real time the meter of total energy consumption in the network of bitcoins.

Today, it's the most efficient method and real data on power inputs in the blockchain technologies. In March 2020 (when the article was written) that index was fluctuating within $(33.5 \div 96.1) \cdot 10^6$ MWt-h [6], it being 0.21% of the world's energy supplies [21]. It was shown that in a year $12.5 \cdot 6 \cdot 24 \cdot 365 = 657$ thousand bitcoins are generated, thus in 2020 one bitcoin requires 96.4 MWt-h. (though the design data, see Fig.3 give the result two times less as compared to the data supplied in that source). At the average price of 1 KWt-h \$0.07 the costs of power inputs on mining of one bitcoin is \$48.20. According to the data provided by M. Rauchs power inputs per one bitcoin [6] in 2018 were equal to 33 MWt-h. and its price was \$2.310. This figure is quite comparable to our evaluations (see Fig.3). Growth both in power inputs per one bitcoin and the power input share in its production cost is evident. Despite growth in the volume of hashing and energy value of each subsequent bitcoin total consumption of electric energy on mining operations in the system of bitcoin are systematically reducing (Fig.5). The reason is restricted only by the opportunities, provided by the designers of up-to-date mining facilities.

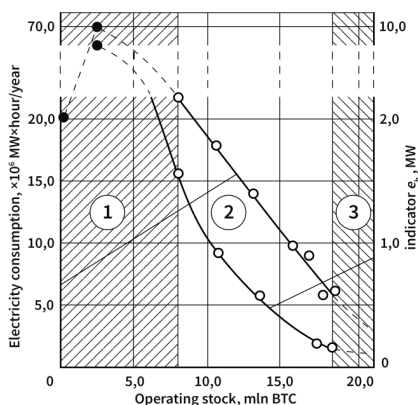


Figure 5. The dynamics of energy consumption of the bitcoins market in 2000- 2020 and energy value of one bitcoin: 1 – the area of evaluating data; 2 – area of the design data; 3 – the forecast area

Professional mining becomes more and more oriented on small methods of energy saving, for example, application of PoS (Proof-of-Stake) system, instead of the algorithm of conclusive consensus of PoW (Proof-of-Work) type, as a way of reduction in energy consumption by mining equipment and ensuring the system safety. It should be noted that the schedule (see Fig.5) does not take into account such events like, for example, bankruptcy of Mt. Gox company, and losses of more than 750,000 bitcoin units in 2014, or release of the final version of Bitlicense, development of the bitcoin project in 2015, or the scandal with «Silk Road» web-site in 2013, when the system of bitcoins was used for drugs trading, and these certainly influenced the dynamics and energy of hashing and supporting of transactions in the system.

The dimensional quantity of energy consumption reflects more precisely the value of generated power inputs of bitcoins, it should be brought in correlation not only to one bitcoin, but also to one hash rate in its logarithmic expression (1):

$$e_h = \frac{E}{N_{bit} \cdot LgH} \quad (1)$$

The formula takes into account not only reduction of the number of generated bitcoins in time interval, but also growth in volumes of the required hashrate within this interval. These indices are interrelated and they accompany further development of the blockchain technology of bitcoin. e_h index, unlike power input shows in the schedule the opportunity for minimal satiation of bitcoin power input with approximation to the specified limit of 21 million bitcoins (see Fig.5). The terms of bitcoin technology presume that $N_{bit} \cdot LgH$ duplex constantly grows, reducing the mentioned figure of bitcoin power inputs, simply by its existence.

On the other hand, according to the data provided by Digiconomist, in 2019 there were around 100 million of financial transactions for one bitcoin. The share of traditional financial instruments is 500 billion transactions per year. i.e. 5,000 times bigger. But for one traditional financial transaction about $3 \cdot 10^{-7}$ MWt-h of energy is consumed, while for mining of one unit (9 bites) as we have calculated – $96,4 \cdot 10^3$ MWt-h. Thus, 100 million of transactions require nearly $1 \cdot 10^4$ MWt-h of energy (without mining), while 500 billion of traditional financial operations require $15 \cdot 10^4$ MWt-h.

It should be noted there that with approximation to the sacred figure 21 million of bitcoins, power input of each of them increases in geometric series and $150 \cdot 10^6$ MWt-h landmark will be achieved very quickly. Even now it is evident that the growing complexity of bitcoin mining must be correlated with its power inputs, which has gradually become a natural limitation for any blockchain systems. Generating of 2.758 thousand bitcoins (approximately 99.8% of the entire pool of bitcoins), remaining prior to 2032, by extrapolating to the present-day situation can require energy consumption exceeding $0,9 \cdot 10^9$ MWt-h, and it is likely to be 4.3% of the world's energy consumption and will be equal to losses on goods production 50 billion dollars' worth. This, actually, is payment for confidence. It is not paid attention to nowadays, as 80% of bitcoins are in work and energy collapse cannot be seen so far.

Mining of bitcoins in 2015 – 2020 grew from 13.1 to 18.2 million of units of the virtual currency, while energy consumption grew from $4,5 \cdot 10^6$ MWt-h to $20 \cdot 10^6$ MWt-h, i.e. by more than four times. Nevertheless bitcoin profitability remains exceedingly

high. For an average price of 1 KWh. \$0.05 – 0.07 energy expenses on one bitcoin are about \$2.160, at the market price of this crypto-currency within \$6.5÷8.7 thousand.

3. Conclusion

Despite the systematic growth in hashing volumes and energy value of each generated bitcoin in the system of this blockchain technology there happens to be reduction of total power inputs. With regard to popularity and prospects of development of bitcoin, opportunities for decentralization and confidentiality at obtaining this product, already praised by millions of people, we can rightfully expect appearance of more energy efficient technologies, simple and convenient, capable of providing a great number of users with opportunities of creating local systems of distributed register.

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Digital Priority Management Mechanisms in the Goal-Setting System of Enterprises as a Component of Economic Security

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Abstract. The article deals with issues related to the creation of digital mechanisms for managing the priorities of goals in enterprises in the context of inter-goal conflicts. A system-dynamic model of a system for forming and serving a queue of goals has been developed and it has been shown that with an average load of such a system, even at 90%, large delays in the execution of goals are already observed. It is also shown that the introduction of a feedback mechanism through goal priority management can significantly increase the effectiveness of the goal setting system. The concept of goal priority is proposed as a complex parameter consisting of 10 components that form the static, dynamic and purchase parts of the priority. A digital mechanism for the formation and management of enterprise priorities is proposed. The obtained results make it possible to increase the economic security of the enterprise due to better coordination of strategic, operational and tactical goals, as well as to accelerate management processes and increase their transparency.

Keywords. Goal-setting, goals, priority, management, system dynamics, economic security, digitalization

1. Introduction

The digital economy is based on digital transformation - this is the transformation of existing analog products, processes and business models, which is based on the effective use of digital technologies. Transformational processes associated with the use of digital technologies, like any other transformations, carry with them the likelihood of risks and real threats to the economic system of an enterprise. The most significant digital changes affect the area of economic security, since the high openness of enterprises to the external environment entails a number of threats and risks to their activities.

One of the most important aspects of ensuring the economic security of a business entity is due to goal-setting processes. It is the goal setting that determines the global goal of enterprises, is the foundation for the formation of reserves in passive and active adaptation to internal and external threats, determines the directions and methods of using resources, directs the definition of planned indicators, etc. On the contrary, erroneous goal setting acts as a limitation on the introduction of innovations in enterprises, causes a significant number of deviations and imbalances in production and

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Thus, the purpose of this article is to substantiate and form digital mechanisms for managing the priorities of goals at enterprises in the context of inter-goal conflicts.

2. Literature review

Currently, many scientific works are devoted to the study of enterprise goal-setting systems [9-12]. Business managers often spend a lot of time arguing about the meaning of goals and objectives, although from a practical point of view this usually does not matter. According to Doran, in some cases, the objectives are short-term, and the goals are long-term, in others - vice versa [5]. It is useful to separate these concepts, but only at the administrative level. That is why enterprises need to implement a goal-setting system. The introduction of this system must be implemented simultaneously with the addition of other market functions [13]. The methods of such systems are considered in the works of many domestic and foreign scientists [1-4]. So Mikhailik in his work proposes to consider the structure of the goal as a combination of parameters that set the result, time, resources, priority rank and connection with goals and values of higher levels [14]. At the same time, Bossidi L. and Charan R. suggest focusing on improving the goal-setting culture, and Donets (Donets, 2012) suggests using a fuzzy logic model to achieve goals, the structure of which can be changed and used at enterprises in various fields [3; 15]. Based on the foregoing, despite the large number of studies, it is important to create new methods for managing priorities in the goal setting system.

3. Results and discussion

The practical experience of enterprises shows that in a situation where a unit is not able to perform all the tasks assigned to it at the same time, many managers choose tasks based on the principle of "the least evil". That is, the goals, the failure of which will be followed by minimal sanctions, are postponed indefinitely.

The very existence of the described problem indicates the absence of a feedback between the recipients and sources of goals in the system of goal-setting of enterprises. We illustrate this with the help of Fig. 2.

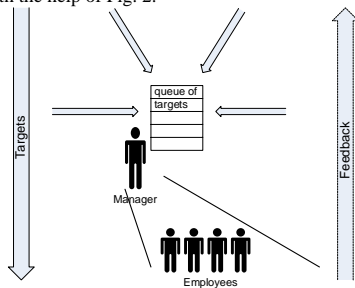


Figure 2. Mechanism for forming a queue of targets.

When setting goals for the unit, both senior managers and peer managers proceed only from their tasks. At the same time, the total number of goals set for the unit, and their relationship with the available resources, is practically not taken into account, which leads to the problems described above.

Let us substantiate this statement with the help of a simulation experiment. To do this, we use a dynamic simulation model made in accordance with the methodology proposed by J. Forrester [17] and implemented in the PowerSim package (Fig. 3).

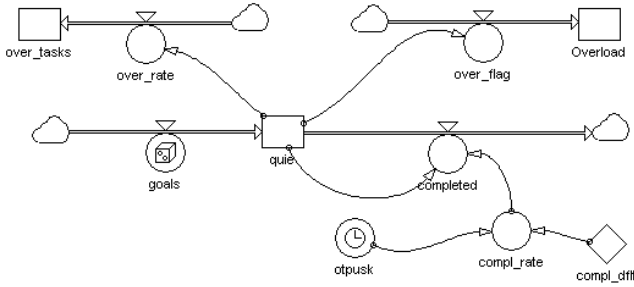


Figure 3. Model of formation and maintenance of the queue of targets.

The model shown in fig. 3 implements the approach to the goal-setting system as to a queuing system. At the same time, the simplest principle of forming and servicing a queue of goals is considered, according to which goals are executed as they arrive. This principle is known as "first in first out" (FIFO). To simplify the model, we will assume that all goals have the same complexity and the same time is required to achieve them. We will provisionally take 1 month as the modeling period. The arrival of goals in the queue is determined by the variable goals, which in this model is a random variable with a normal distribution.

Execution of targets from the queue is limited by the completed variable, which corresponds to the throughput of the OU. Periodically, the capacity of the department decreases due to illness, vacations and other reasons. In the proposed model, this is implemented by introducing an additional variable otpusk subtracted from the throughput of the department. The otpusk variable is activated every three months. Consider the behavior of the model for the following values of the main parameters (Table 1).

Variable	Setting method	Comment
goals	<i>NORMAL(90, 10)</i>	normal distribution with mathematical expected value 90 and standard deviation 10
compl_dftt	100	unit throughput standard value
otpusk	<i>PULSE (10,3,3)</i>	every three months, the capacity of the department for 1 month is reduced by 10

The results of experiments with the model (Fig. 3) using the parameters indicated in table 1 are shown in Fig. 4.

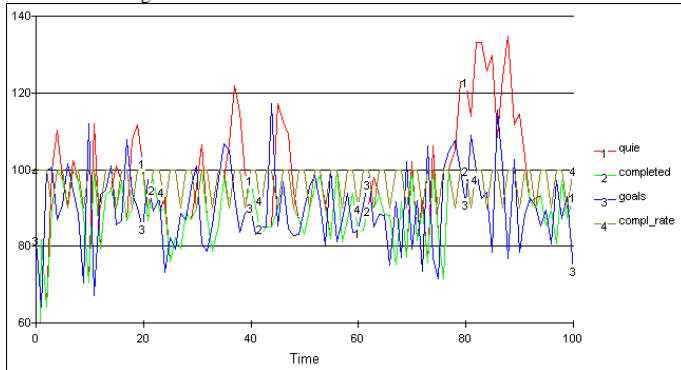


Figure 4. Simulation results for goals = NORMAL(90, 10)

As can be seen from Fig. 4, even with an average flow of applications at the level of 90% of the throughput of the department, there is periodically a significant excess in the number of applications in the queue of the throughput of the department, which can be observed over a long period.

Let us now consider the behavior of the model with an increase in the mathematical expectation of the flow of requests from 90% throughput to 95%. As you can see, this value is still less than the average throughput, even taking into account its periodic deterioration given in the model. The graph reflecting the simulation results is shown in Fig. 5.

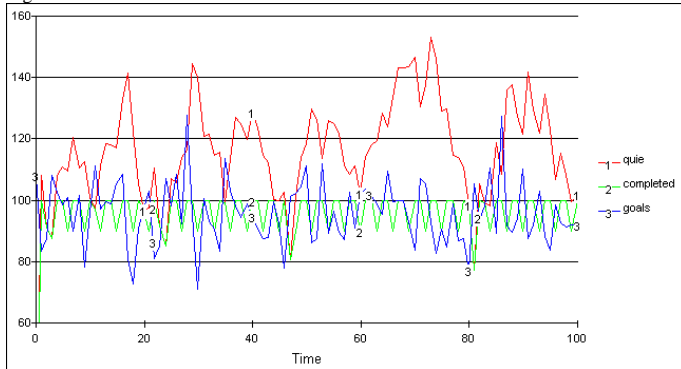


Figure 5. Simulation results for goals = NORMAL(95, 10)

As can be seen from Fig. 5, for a significant part of the model time, the number of applications in the queue is significantly greater than the throughput of the unit, and at times their ratio exceeds the level of 140%, which is the equivalent to a delay in the fulfillment of goals up to half a month. The collection of experimental statistics and its analysis showed that under such conditions, on average, in 71% of cases, the number of applications in the queue exceeds 100.

Traditional ways to solve the problem of staff shortages to meet the goals set for the unit are hiring new employees, or increasing the productivity of existing ones. The latter can be carried out both intensively, through training in new methods of work and the introduction of advanced technologies, and extensively, through overtime work. All these methods have significant drawbacks, which are expressed in increased costs, or an increase in social tension in the team, and ultimately lead to a decrease in the economic security of the enterprise. Therefore, the solution to the problem must be sought from the side of reducing the load on the unit.

Let us consider the possibility of introducing feedback into the model considered above. To do this, we introduce a mechanism that identifies the overload of the queue and corrects the flow of requests. The modified model is shown in Fig. 6.

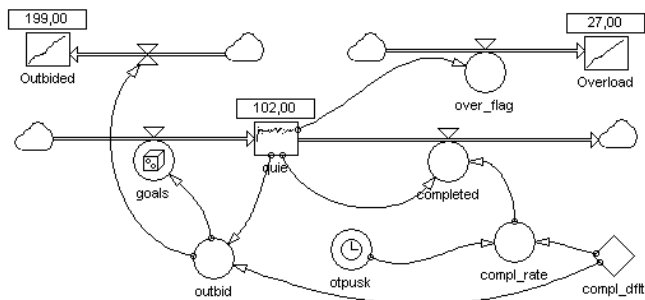


Figure 6. Model of formation and maintenance of the queue of targets with feedback.

In this model, the remaining unfulfilled requests are removed from the queue. An analysis of the results of experiments with the model showed a significant reduction in queue overload, which can be interpreted as an improvement in the quality of goal execution. The graph of changes in the model variables with a mathematical expectation of the flow of applications of 95% is shown in Fig. 7.

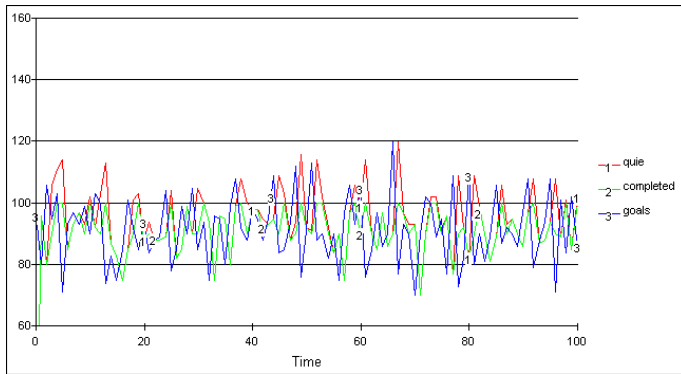


Figure 7. Simulation results in a feedback system with goals = NORMAL(95, 10)

As can be seen from the comparison of the graphs in Fig. 7 and Fig. 5, there has been a significant reduction in queue congestion and the associated delay in the execution of goals. The collection of experimental statistics and its analysis showed that under such conditions, on average, only in 29% of cases the number of applications in the queue exceeds 100, and for all 100 periods of model time, on average, only 243 applications were postponed, which corresponds to the postponement of 2% -3% of incoming goals.

Thus, simulation modeling of the processes of formation and achievement of goals made it possible to prove the feasibility of introducing feedback through the management of goals priorities between performers and their management. Let us now consider approaches to the implementation of digital mechanisms for managing priorities in the goal-setting system of an enterprise.

Obviously, the purpose of creating such mechanisms should be to provide the possibility of sorting goals according to a certain set of criteria that determine the relevance of its implementation by a given unit. When forming such a set of criteria, the following principles should be followed:

- 1) justice;
- 2) minimizing inter-target conflicts and other causes of target dispersion;
- 3) each given goal must be achieved sooner or later (if its cancellation is not initiated by an authorized person);
- 4) balanced use of resources;
- 5) minimum overhead costs;
- 6) improving the priorities of the goals of managers, which are characterized by better goal setting (taking into account errors in goal designations)
- 7) the ability to determine the signs of priority goals, depending on the situation;
- 8) the possibility of operational management;
- 9) ensuring the coherence of the tree of enterprise goals (strategic, tactical and operational);
- 10) the ability to integrate into existing HRM and ERP systems.

To implement these principles, planning mechanisms should take into account the following factors:

- whether the process of achieving the goal is limited by the work of other departments;
- the length of time each process waits;
- the total running time of each process and the estimated time required for each process to be completed.

When forming a digital priority control mechanism, we will be based on the fact that the goal structure (g) can be considered as a set $g=\{v,r,t,gr,l\}$ of parameters that specify:

- result (v);
- resources (r);
- time (t);
- priority rank (gr);
- connection with the goals and values of higher levels (l).

Note that a similar goal structure has already been proposed in the scientific literature [18]. However, until now, studies in this direction were of a conceptual nature and did not explain how the goal priority rank is formed. Obviously, the priority rank assigned by the leader is subjective and must be supported by objective data. In other words, the overall goal priority can be viewed as a combination of subjective priorities (assigned by the will of enterprise managers) and objective priorities assigned within the goal management system.

Thus, when using only formal information about the target in the format of the set $g=\{v,r,t,gr,l\}$, it is not possible to obtain a satisfactory solution to the problem. Therefore, to increase the diversity of information about the goal, it is necessary to expand the list of components that determine the priority of the goal.

Within the framework of the problem under consideration, we can propose to classify the priority components into deserved and purchased parts. In addition, components can be static or dynamic. By default, they are assigned on a formal basis, but can also be adjusted in situations where it is necessary to increase the priority of certain goals. Thus, the overall goal priority should consist of static, dynamic, and purchased parts.

Static priorities are assigned initially and do not change. When setting them, a formal mechanism is used, based on the analysis of the structure of the goal, the conditions for its formation, and historical data. The setting of these priorities occurs when a target is entered into the system and is not associated with high costs. However, it should be borne in mind that such a mechanism is not flexible enough, since it does not respond to changes in the environment.

Dynamic priorities increase the flexibility of the system, as they provide an opportunity to provide an adequate response to changes in the situation, as a result of which the initial value of the process priority can be changed to a new, more appropriate value. The dynamic component of the target priority is constantly changing due to automatic recalculation.

Purchased priorities allow concerned leaders to increase the priority of certain goals and achieve them faster for an "extra fee". Each leader can raise the priorities of the goals, to the extent of his competence. At the same time, in order to exclude abuse of this opportunity, a limit on raising priorities should be introduced. The value of such a limit should be determined individually for each manager based on the analysis of his activities.

Thus, the priority of the target (parameter gr) can be defined as

$$gr = f(\{u_s\}, \{u_d\}, \{u_p\}) \quad (1)$$

where $\{u_s\}$ – set of static priorities,

$\{u_d\}$ – set of dynamic priorities,

$\{u_p\}$ – multiplicity of purchased priorities.

In this case, the greater the value of the gr parameter, the higher the target is in the execution queue.

Consider the composition of the components that form the priority of the goal (Table 2).

Table 2. Components that form the priority of the goal

№	Name of the component	Designation	Type	Limits of change
1.	Start priority	u_1	Static	0..200
2.	Source bonus	u_2	Static	0..50
3.	Bonus for the quality of goal formation	u_3	Static	0..20
4.	Parent Goal Priority Bonus	u_4	Static	0..100
5.	Bonus for time in line	u_5	Dynamic	0..∞
6.	Situational bonus	u_6	Dynamic	-100..100
7.	Penalty for conflict	u_7	Dynamic	-∞..0
8.	Similar task bonus	u_8	Dynamic	0..50
9.	Penalty for correction	u_9	Dynamic	-50..0
10.	Purchase bonus	u_{10}	Purchased	0..∞

The starting priority ($u1$) is set when the goal is formulated and entered into the goal setting management system. At the same time, the maximum priority value that can be set depends on the relative position of the target source and target recipient within the organizational structure of the enterprise. This value will be the highest for units connected by a direct hierarchical relationship. The manager setting the goal can choose a starting priority value ranging from 0 to the allowed maximum value. It is possible to have both a direct numerical assignment and the use of fuzzy terms: “very important”, “important”, “medium significance” and the like.

The source bonus ($u2$) is set automatically and reflects the internal rating of the manager who sets the goal. The higher this rating, the faster the goals set by this leader will be fulfilled. The rating, in turn, depends on the quality of his goal-setting, in particular, on the assessments that his actions received post factum, on how fully the goals are formulated, what specific weight is occupied by α -goals, and the like. The initial determination of the value of this bonus is made by experts. In the future, its value is reassessed 1-2 times a year.

The bonus for the quality of target formation ($u3$) is set automatically depending on how complete the target parameters are. The purpose of introducing such a bonus is to improve the quality of goal setting in the enterprise. Managers of all ranks should be informed that the completeness of setting a goal is directly related to the speed of its implementation. In addition, statistics on this bonus is used when revaluing the source bonus.

The bonus for the priority of the parent target ($u4$) is set depending on whether the parameter 1 is set in the target structure and what priority the parent target (GI) had at the time the current target was queued. The introduction of this bonus stimulates the decision

maker to accurately set the parameters of goals, and also makes it possible to ensure the coherence of the tree of enterprise goals. In particular, goals related to ensuring the economic security of the enterprise have an increased priority.

The bonus for time in queue (u_5) changes dynamically, increasing from 0 for the time the target is in the queue for execution. The presence of this component as part of the priority ensures that the target in the queue will be completed. Indeed, since this bonus does not have a limit value, sooner or later it will reach a value that allows the target to reach the top of the execution queue. If during the waiting time the goal has lost its relevance, it can be removed from the queue.

The situational bonus (u_6) is set by the top management of the enterprise or authorized persons and allows group management of priorities by increasing or decreasing priorities along the branches of the goal tree. When setting this bonus for a certain goal, the system looks for sub-goals associated with it and automatically changes their situational bonuses. The penalty for conflict (u_7) is set automatically or manually by a higher manager if the combination of information flow values excludes the full execution of some incoming (GI) or single-level (GL) goals of the goal-setting subject, that is, in the event of a conflict. In this case, the execution of one or more conflicting goals can be forcibly delayed for an indefinite period until the conflict situation is resolved.

The similar task bonus (u_8) allows you to improve the performance of the process of executing goals (mostly single-level ones) through the use of pipeline processing principles. As is known and scientifically proven, labor productivity in the simultaneous performance of similar tasks is significantly higher than when they are performed separately [19-20]. This bonus can be set both manually and automatically if the data available in the system are sufficient to identify such tasks.

Target Adjustment Penalty (u_9). When implementing a priority management system, it is important to minimize the system's vulnerability to misuse. In particular, the possibility of adjusting the target parameters should be limited in order to avoid cases of complete reworking of tasks that are close to the exit from the queue. To do this, you can either completely prohibit the adjustment of the main parameters of the target, or introduce a "penalty" for each adjustment.

The purchased bonus (u_{10}) allows each manager to exercise his right to choose his primary goals. To do this, each manager, depending on his position in the organizational structure of the enterprise, is awarded a certain number of bonuses, which he, at his discretion, can use to increase the priorities of the selected goals. The frequency of bonus accrual can be a calendar month, a week, or another period, if this is due to the peculiarities of the production process. It should be noted that the purchase bonus can be set by managers either for the goals set by them, or for the goals of subordinate managers located lower in the tree of goals.

Goal priority is defined as the arithmetic sum of all the listed components:

$$g^r = u_1 + u_2 + \dots + u_{10}. \quad (2)$$

The mechanism for managing the priorities of goals can thus be represented as follows (Fig. 8).

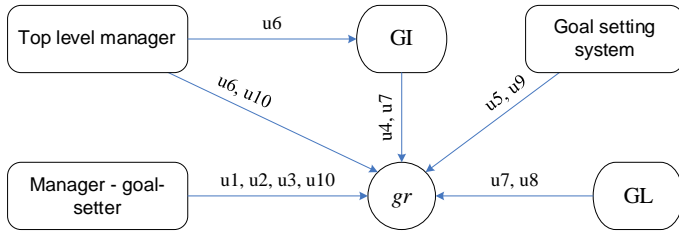


Figure 8. Digital mechanism for managing priorities in the enterprise goal-setting system

The considered mechanism for the formation and management of goal priorities is quite flexible and can be implemented gradually, as the process of enterprise management is digitalized and the possibilities of goal-setting management are expanded. Thus, the automatic setting of bonuses u_2, u_4, u_6, u_7, u_8 is possible only after the accumulation of a sufficient amount of information in the system and the implementation of methods for processing it, allowing to assess the quality of goal-setting of individual managers, the coherence of goals, their impact on the economic security of the enterprise and other characteristics.

Priority management allows you to ensure better connectivity of the tree of enterprise goals, that is, it provides a link between the strategic, tactical and operational goals of the enterprise, as well as group management of the priorities of individual branches of this tree.

It should be noted that the considered goal priority management mechanism, although it is quite universal, is primarily focused on enterprises with a hierarchical management system. In addition, the enterprise must be large enough to afford the costs of implementing the goal-setting system and training to work with it. Therefore, for other types of organizational structures, or for relatively small enterprises, the described mechanism should be modernized taking into account their features. In particular, the following simplified options can be proposed:

1. A system based on source priorities. In such a system, for each unit, the priorities of the sources of goals are determined, that is, the principle of determining the sequence of fulfillment of goals obtained simultaneously from different sources is set. In fact, this corresponds to the "source bonus" u_2 (see Table 2). Execution is carried out starting from the goals received from the highest priority source. After they are exhausted, they move to a source with a lower priority, and so on. The disadvantage of such a system is that the goals of sources with low priorities may remain unfulfilled.
2. Using the principle of queuing "Last in, first out" (Last In First Out - LIFO). In this case, the most relevant target of each source is the target sent for execution the last. The fulfillment of the goals is carried out in accordance with the priorities of the sources, similarly to paragraph 1.
3. Manual control mode. In this case, at the beginning of each working day, each manager chooses the most relevant ones from the list of goals set by him. The fulfillment of the goals is carried out in accordance with the priorities of the sources, similarly to paragraph 1.

Based on simulation experiments, the article substantiates the need to use digital mechanisms for managing priorities in the goal-setting system of large enterprises. It is

shown that the absence of such mechanisms leads to a large delay in the fulfillment of goals, which negatively affects the economic security of the enterprise. An increase in the effectiveness of goal setting after the introduction of feedback on the priorities of goals is shown.

The structure of the digital mechanism for managing the priorities of goals is proposed, as well as its main components that form the information base of the goal-setting system are described.

The implementation of the proposed digital mechanisms for managing the priorities of goals will increase the efficiency of the enterprise management system and their economic security. Subsequent research in this direction should provide for a detailed integration of the proposed mechanisms into the enterprise management system and bringing them to the stage of practical implementation.

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Temporal-transition & Differential Computing for Health-related Phenomena in Transmitted Diseases and Health situation-change Mapped onto 5D World Map System

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Abstract. It is significant to detect, estimate and predict “Human-health situations” and “a spread of transmitted disease” with past and current data of health-related phenomena. Temporal-transition and differential computing realizes semantic interpretations for situation changes in two phenomena with “temporal-length” in “specific situation”. The “temporal-length” in “specific situation” is used to compare two phenomena in multiple contexts in semantics. We present a new Temporal-transition Differential Computing Model for detecting, estimating and predicting “Human-health situations” and “a spread of transmitted disease.” This model defines “temporal-transition data structure” for expressing past and current data of health-related phenomena with temporal-axis, and two processes for Human-Health Semantic Space Creation and Semantic Computing with dimensional control mechanism.

Keywords. Semantic Search, Semantic Computing, Medicine, Medical Data, Big Data, Biographical Data, Vital Data, Sensing, AI, Cyber-Physical System, Visualization, Data Mining, SDGs

1. Introduction

Semantic interpretations and global phenomena-recognitions for “Human-health situations” and “a spread of transmitted disease” are essentially important to realize early-caring for Human health and early-estimation for a spread of transmitted disease in nature and societies.

Our semantic computing method[9,10,12] and 5D World Map system [1,2,3,4,5,6,7,8] are applied to health-health analysis in the contexts of personal health-situation and a spread of transmitted disease. Although the survival rate of patients is improving due to the emergence of new drugs and the development of new treatments, a

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worldwide perspective suggests that the number of patients will continue to increase. There is no change in the situation where the foundation of a healthy healthcare measure is required. It has been proven in many diseases that the earlier the stage, the better the survival rate of patients. The fact is that future disaster control is focused on prevention and early detection.

In this paper, we propose a new Temporal-transition Differential Computing Model for detecting, estimating and predicting “Human-health situations” and “a spread of transmitted disease.” This model defines “temporal-transition data structure” for expressing past and current data of health-related phenomena with temporal-axis, and two processes for Human-Health Semantic Space Creation and Semantic Computing method with dimensional control mechanism.

- Process-1: Semantic Space Creation of “ n -dimensional health-analysis universe”
- Process-2: Context-specific distance computing in the context-dependently-selected subspace from the semantic space S :

We also realize the dynamic evaluation and mapping functions of multiple views of temporal-spatial metrics, and integrate the results of semantic evaluation to analyze transmitted disease-spreading. Our semantic associative computing is used in 5D World Map system [1,2,3,4,11] for realizing the concept that “semantics” of environmental multimedia information resources, according to the “context”. The main feature of 5D World Map system is to create world-wide global maps and views of global and local situations expressed in multimedia information resources (image, sound, text and video) dynamically, according to user's viewpoints. Spatially, temporally, semantically and impressionably evaluated and analyzed environmental multimedia information resources are mapped onto a 5D time-series multi-geographical space. 5D World Map system applied to environmental multimedia computing visualizes world-wide and global relations among different areas and times in disease and environmental aspects, by using dynamic mapping functions with temporal, spatial, semantic and impression-based computations [5,6,7,8].

2. A Temporal-transition Differential Computing Model

In this section, we propose a new Temporal-transition Differential Computing Model for detecting, estimating and predicting “Human-health situations” and “a spread of transmitted disease.” This model defines “temporal-transition data structure” for expressing past and current data of health-related phenomena with temporal-axis, and two processes for Human-Health Semantic Space Creation and Semantic Computing method with dimensional control mechanism.

It is essentially important to analyze the semantics of relationship between two antagonistic phenomena along with time, especially in the field of designing computing model for human health. We realize it by our new quantification method of the relationship between two phenomena in the following subsections.

2.1. *Input Data Structure of the Computational Model of Temporal Differential computing:*

We define the input data structure of our model as the following two parameters, and the two phenomena can be mapped onto the 2-dimensional graph with vertical and horizontal axes, as shown in Figure 1.

- (1) Phenomenon-1 parameter (vertical axis) with time-series TS1(horizontal axis)
- (2) Phenomenon-2 parameter (vertical axis) with time-series TS2(horizontal axis)

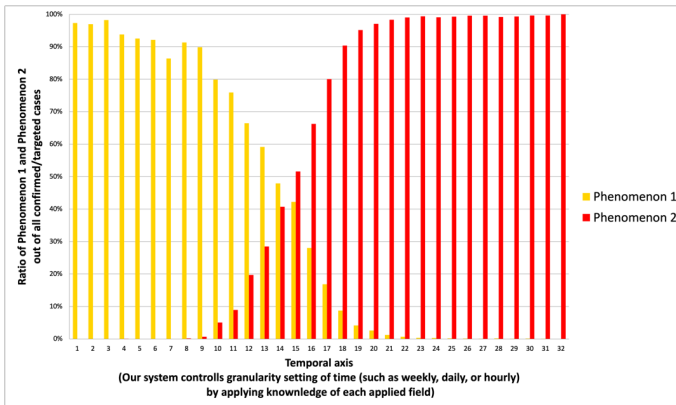


Figure 1. Input Data Structure of the Computational Model of Temporal Differential computing

2.2. *Data Definition from the input data (Extract the “Crossing Point”)*

The two phenomena showed in the section 2.1 can be compared and analyzed along the time series as TS1 and TS2, and the two phenomena’s time-lines are crossing at a point P at the time t_m , shown in Figure 2.

P: (t_m , ratio-m)

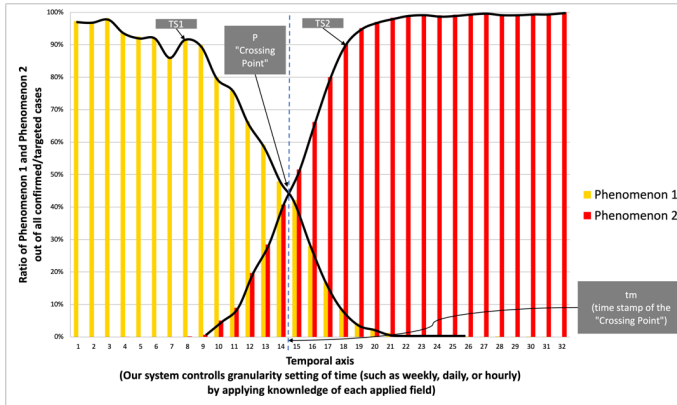


Figure 2. Key Data Extraction from the input data (Extract the “Crossing Point”)

2.3. Key Area Definition from the input data and Crossing Point by our new Temporal-transition Differential Computing (Extract the Area-A, B, C, D)

Our key area extraction consists of following three steps, and shown in the Figure 3.

- 1) Set “Ratio-domain” by specific knowledge on each field with analytical-max ratio and analytical-min ratio to be analyzed (can be drawn by two horizontal lines)
- 2) Coordinate Crossing-Point (can be drawn by a vertical line), which are perpendicular line on the above pm
- 3) Extract the time point of four intersections (can be drawn by four vertical lines), which are analytical-max ratio and TS1, analytical-max ratio and TS2, analytical-min ratio and TS2, and analytical-min ratio and TS1.

The Ratio-domain setting is formalized as follows.

Ratio-domain: (max-ratio, min-ratio)

The meanings of those steps are corresponding to express the following key features of health analysis by differential phenomena-transition computing for transmitted disease and health situation-change.

- Two different phenomena are changing and replaced along the time-line, as Figure 1. Vertical line expresses the value of phenomenon (Amount of diseased people and personal health-parameter value)
- 4 areas (A, B, C, D), a single crossing point(P) and central line(L) are indicated in advance for expressing two phenomena-change.

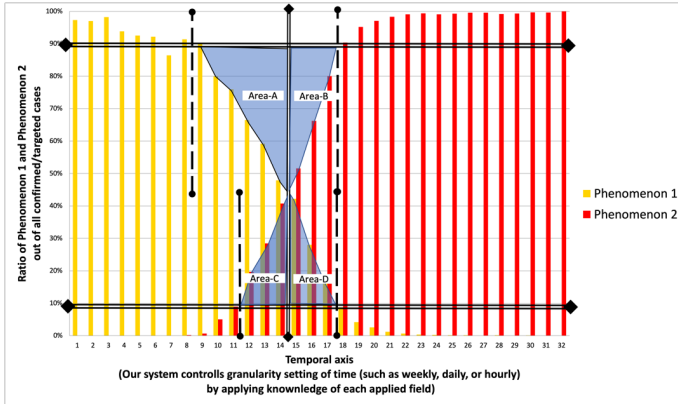


Figure 3. Key Area Extraction from the input data and Crossing Point by our new Temporal-transition Differential Computing (Extract the Area-A, B, C, D)

2.4. Quantitative Feature Definition of each Key Areas (Area-A, B, C, D) by our new Definition of Temporal-Ratio Differential Computing

- Temporal-differential computing:

Area-A size: (1)

(ratio-1(max-ratio(ex. 90%), ratio-2: 80, - - -, , ratio-m: ratio at P)

Δt_i (at ratio-i) = $|t_m - t_i|$ (or Δt_i (at ratio-i) = $|(t_{i+1}) - t_i|$)

Δt_j (at ratio-j) = $|t_m - t_j|$

Δt_m (at ratio-common of P) = $|t_m - t_m| = 0$

$NewAF(t) = \sum_{i=t1, t_m} (\Delta t_i)$

Area-B size:

(ratio-1: 100(or Max), ratio-2: 90, - - -, ratio-m: ratio at P)

$$\Delta t_i \text{ (at ratio-}i\text{)} = |t_m - t_i| \text{ (or } \Delta t_i \text{ (at ratio-}i\text{)} = |(t_{i+1}) - t_i|)$$

$$\Delta t_j \text{ (at ratio-}j\text{)} = |t_m - t_j|$$

$$\Delta t_m \text{ (at ratio-common of } P\text{)} = |t_m - t_m| = 0$$

$$\text{newBF}(t) = \sum_{i=t_1}^{t_m} (\Delta t_i)$$

Area-C size:

$$F(t) = \sum_{i=t_1}^{t_n} (\Delta t_i * \Delta \text{ratio-}i)$$

(ratio-1: 0(or Min), ratio-2: 10, - - -, ratio-m: ratio at P)

$$\Delta t_i \text{ (at ratio-}i\text{)} = |t_m - t_i| \text{ (or } \Delta t_i \text{ (ratio-}i\text{)} = |(t_{i+1}) - t_i|)$$

$$\Delta t_j \text{ (at ratio-}j\text{)} = |t_m - t_j|$$

$$\Delta t_p \text{ (at ratio-common of } P\text{)} = |t_m - t_m| = 0$$

$$\text{newCF}(t) = \sum_{i=t_1}^{t_m} (\Delta t_i)$$

Area-D size:

$$F(t) = \sum_{i=t_1}^{t_n} (\Delta t_i * \Delta \text{ratio-}i)$$

(ratio-1: 0(or Min), ratio-2: 10, - - -, ratio-m: ratio at P)

$$\Delta t_i \text{ (at ratio-}i\text{)} = |t_m - t_i| \text{ (} \Delta t_i \text{ (ratio-}i\text{)} = |(t_{i+1}) - t_i|)$$

$$\Delta t_j \text{ (at ratio-}j\text{)} = |t_m - t_j|$$

$$\Delta t_m \text{ (at ratio-common of } P\text{)} = |t_m - t_m| = 0$$

$$DF(t) = \sum_{i=t_1}^{t_m} (\Delta t_i)$$

2.5. Analysis/Comparison of the Feature of the Four Areas (in the two phenomena (between the Area-A, B, C, D), or the feature of the combination of the four areas (between a certain Area-A, B, C, D and the other Area-A, B, C, D)

(1) Temporal-ratio Differential Computing

Temporal-ratio differential computing is defined in the following formula:

Comparison at Area A:

Virus-differential:

$$D1 = \text{AreaSizeDifference}(AF1(t), AF2(t)) = (AF1(t1-1)-AF2(t1-2), AF1(t2-1)-AF2(t2-2), \dots, (AF1(tm-1)-AF2(tm-2)))$$

- (2) Semantic Geo-Temporal Visualization Analysis is mapped onto 5D World Map between two phenomena:

Gio-differential computing function:

Gio-Difference(GeoPlace(AF1(t)), GeoPlace(AF2(t))) \rightarrow mapping to Geo-Temporal Visualization on 5D World Map

3. Experiment Study of Mapping Actual Phenomena on the Temporal-transition Differential Computing Model

We realized our experimental study by applying current COVID-19 pandemic data of infection disease as the actual phenomenon. In the Experiment-1 and Experiment-2, we applied following data published on the website of the UK Government [13], and in the Experiment-3, we applied actual data tested and analyzed in a Japanese hospital and a laboratory.

- Experiment-1 (larger area analysis in European country):
 - o TS1: Phenomenon-1 (Ratio of weekly confirmed cases of a certain variant (alpha) in all variant cases) in one of the European countries (UK)
 - o TS2: Phenomenon-2 (Ratio of weekly confirmed cases of another variant (delta) in all variant cases) in one of the same European countries (UK)
- Experiment-2 (smaller area analysis than Case-1 in European city):
 - o TS1: Phenomenon-1 (Ratio of weekly confirmed cases of a certain variant (alpha) in all variant cases) in one of the European countries (London, UK)
 - o TS2: Phenomenon-2 (Ratio of weekly confirmed cases of another variant (delta) in all variant cases) in one of the same European countries (London, UK)
- Experiment-3 (smaller area analysis realized in Asian city with three variants):
 - o TS1: Phenomenon-2 (Ratio of weekly confirmed cases of another variant (alpha) in all variant cases) in one of the Asian Cities (Saitama, Japan)
 - o TS2: Phenomenon-3 (Ratio of weekly confirmed cases of another variant (delta) in all variant cases) in one of the same Asian Cities (Saitama, Japan)

As from the expert knowledge of the infection disease and pandemic situation, we set the Ratio-domain as follows in this experiment.

Ratio-domain: (90%,10%)

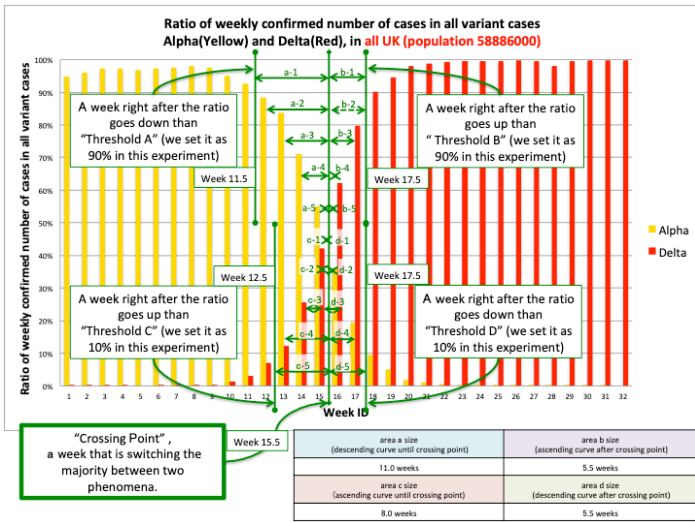


Figure 4. Result of Experiment-1 (larger area analysis in European country): TS1 is corresponding to the Phenomenon-1 (Ratio of weekly confirmed cases of a certain variant (alpha) in all variant cases) in one of the European countries (UK). TS2 is corresponding Phenomenon-2 (Ratio of weekly confirmed cases of another variant (delta) in all variant cases) in one of the same European countries (UK).

In the Experiment-1, we could define P (“Cross Point”) at week 15.5 as the TS1 and TS2 replaced between week 15 and 16, and we also could define time point of four intersections which are analytical-max ratio and TS1 as week 11.5, analytical-max ratio and TS2 as week 17.5, analytical-min ratio and TS1 as week 17.5. Then we realized to quantify the feature of Area-A as 11.0 weeks, Area-B as 5.5 weeks, Area-C as 8.0 weeks, and the Area-d as 5.5 weeks. The result of this experiment showed in the Figure 4.

In the Experiment-2, we could define P (“Cross Point”) at week 14.5 as the TS1 and TS2 replaced between week 14 and 15, and we also could define time point of four intersections which are analytical-max ratio and TS1 as week 9.5, analytical-max ratio and TS2 as week 16.5, analytical-min ratio and TS2 as week 12.5, and analytical-min ratio and TS1 as week 16.5. Then we realized to quantify the feature of Area-A as 24.0 weeks, Area-B as 9.0 weeks, Area-C as 7.5 weeks, and the Area-d as 10.0 weeks. The result of this experiment showed in the Figure 5.

In the Experiment-3, we could define P (“Cross Point”) at week 16.5 as the TS1 and TS2 replaced between week 16 and 17, and we also could define time point of four intersections which are analytical-max ratio and TS1 as week 13.5, analytical-max ratio and TS2 as week 16.75, analytical-min ratio and TS2 as week 13.5, and analytical-min ratio and TS1 as week 16.75. Then we realized to quantify the feature of Area-A as 9.0 weeks, Area-B as 1.25 weeks, Area-C as 7.0 weeks, and the Area-d as 1.25 weeks. The result of this experiment showed in the Figure 6.

Size of the Area-A is corresponding to the strength of the TS1 to remain against the expanding forces of TS2 before P (“Crossing Point”). Size of the Area-B is corresponding to the strength of the TS2 to expand against the TS1 after the P (“Crossing Point”). Size of the Area-C is corresponding to the strength of TS2 to expand against the TS1 before the P (“Crossing Point”). And the size of the Area-D is corresponding to the strength of TS1 to remain against the expanding forces of TS2 after the P (“Crossing Point”).

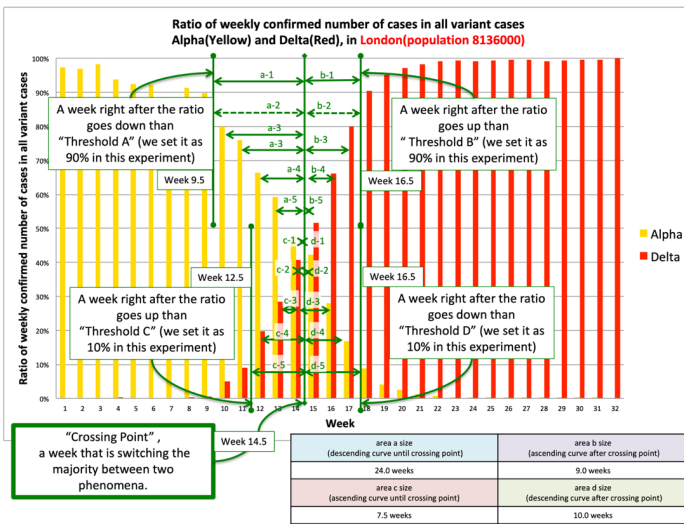


Figure 5. Result of Experiment-2 (smaller area analysis in European country): TS1 is corresponding to the Phenomenon-1 (Ratio of weekly confirmed cases of a certain variant (alpha) in all variant cases) in one of the European cities (London, UK). TS2 is corresponding Phenomenon-2 (Ratio of weekly confirmed cases of another variant (delta) in all variant cases) in one of the same European cities (London, UK).

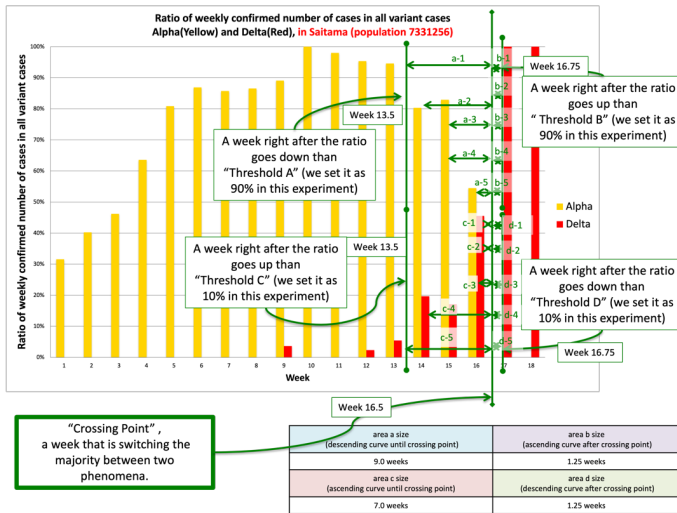


Figure 6. Result of Experiment-2 (smaller area analysis in a city in Japanese): TS1 is corresponding to the Phenomenon-1 (Ratio of weekly confirmed cases of a certain variant (alpha) in all variant cases) in one of the Japanese cities (Saitama, Japan). TS2 is corresponding Phenomenon-2 (Ratio of weekly confirmed cases of another variant (delta) in all variant cases) in one of the same Japanese cities (Saitama, Japan).

By comparing the results of Experiment-1, Experiment-2, and Experiment-3 by applying the four area sizes, the results showed following feature.

- By comparing area size of the Area-A shows that data in UK (larger area and including country side) express higher strength of the TS1 to remain against the expanding forces of TS2 before P (“Crossing Point”) than the data in London, UK (smaller area and only the urban area). For the experiment by applying the infection disease, the population and the density is one of the important factors to remain against the other expanding variant.
- By comparing area sizes of Area-A and Area-B in both Experiment-1 and Experiment-2 shows that the both Area-A are larger than both Area-B. For the experiment by comparing alpha variant and the delta variant in the same infection disease (COVID-19), the expanding force of the TS2 is stronger than the TS1.
- The size of Area-B and Area-D in Experiment-3 shows remarkably smaller comparing to the other Area-B and Area-D in Experiment-1 and Experiment-2. By comparing the area sizes of different areas in the experiments, the result shows clear difference of speed of the replacement from TS1 to TS2 in the context of spreading of infection disease.
- From these results, our Temporal-transition Differential Computing Model shows feasibility to calculate feature of rapidness of replacement between

TS1 and TS2 by applying the all the sizes of Area-A, B, C, and D, to calculate feature of strength of the TS2 (increasing trend) for replacement with TS1 by applying the Area-C and Area-B, and to calculate feature of persistence of TS1 (decreasing trend) by applying Area-A and Area-D.

4. Spread-Visualization of transmitted disease on 5D World Map System

We have introduced the architecture of a multi-visualized and dynamic knowledge representation system “5D World Map System [3-6]” applied to environmental analysis and semantic computing [7-12]. In this section, we apply this system to Human-health situations with past and current data related to “Human-health situations” and “a spread of transmitted disease”. The basic space of this system consists of a temporal (1st dimension), spatial (2nd, 3rd and 4th dimensions) and semantic dimensions (5th dimension, representing a large-scale and multiple-dimensional semantic space that is based on our semantic associative computing system. This space memorizes and recalls various multimedia information resources with temporal, spatial and semantic correlation computing functions, and realizes a 5D World Map for dynamically creating temporal-spatial and semantic multiple views, applied for various “Human-health situations” and “a spread of transmitted disease.”

We have introduced the architecture of a multi-visualized and dynamic knowledge representation system “5D World Map System,” applied to environmental analysis and semantic computing. We have realized human-health situation mappings to 5D World Map system to recognize and interpret the spread of transmitted disease, as shown in Figures 7,8,9,10.

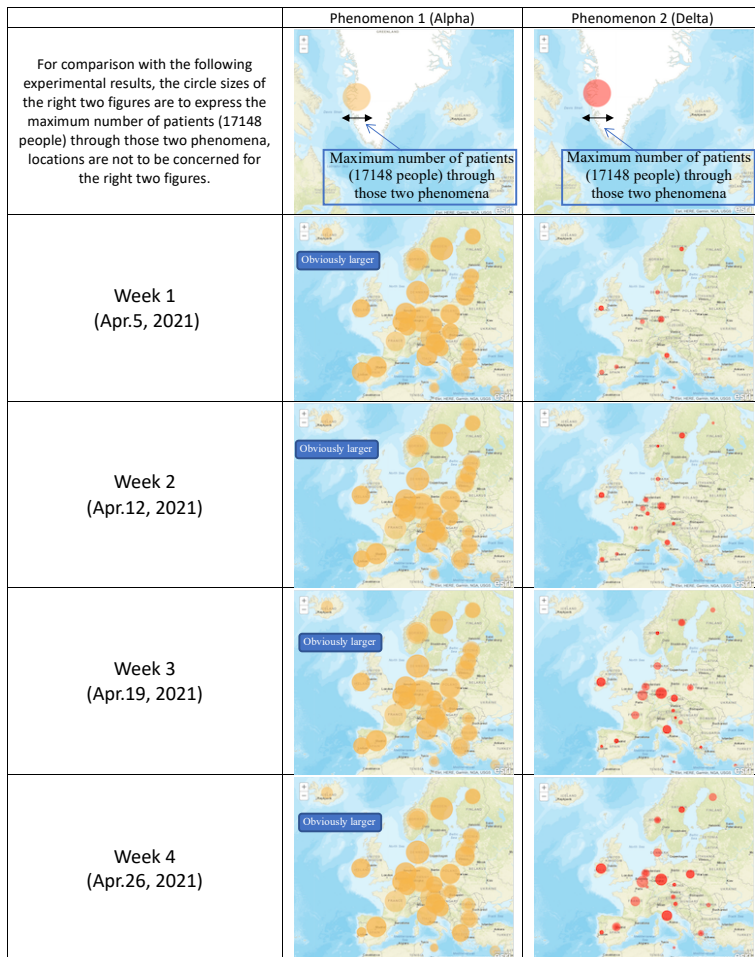
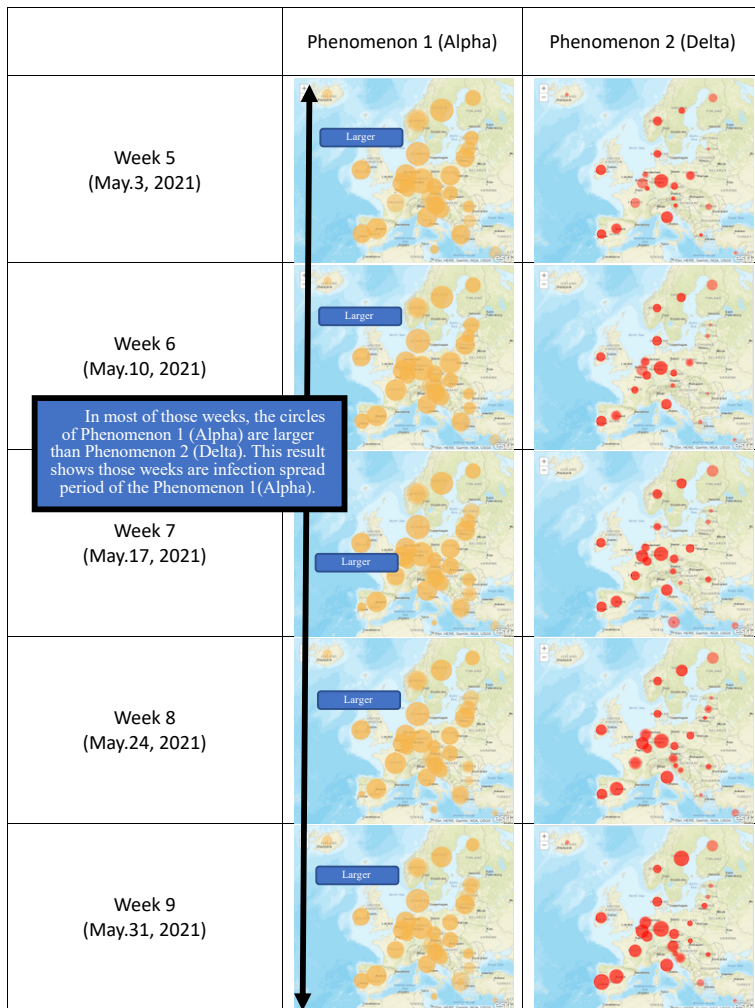


Figure 7. Result of semantic visualization on 5D World Map regarding temporal transition of two phenomena to analyze visually how it replaces along with time. The left column shows “Phenomena 1” and the right column shows “Phenomena 2”. Size of the circle corresponds to the ratio of weekly number of confirmed cases in each country with the highest number of confirmed cases as the maximum size (shown in the first row). We can visually analyze by comparing right and left column, to discover the time point of replacement, speed of spreading, and forces between the two phenomena. The result of weeks 1 to 4 visually shows that the Phenomenon 1 (Alpha variant) spreads larger infection clearly than Phenomenon 2 (Delta variant). Those weeks are corresponding to the “Area a” and “Area c” of our formulation.



In most of those weeks, the circles of Phenomenon 1 (Alpha) are larger than Phenomenon 2 (Delta). This result shows those weeks are infection spread period of the Phenomenon 1(Alpha).

Figure 8. The result of weeks 5 to 9 visually shows that the Phenomenon 1 (Alpha variant) is keep spreading infection and the Phenomenon 2 (Delta variant) starts increasing. Those weeks are also corresponding to the "Area a" and "Area c" of our formulation.

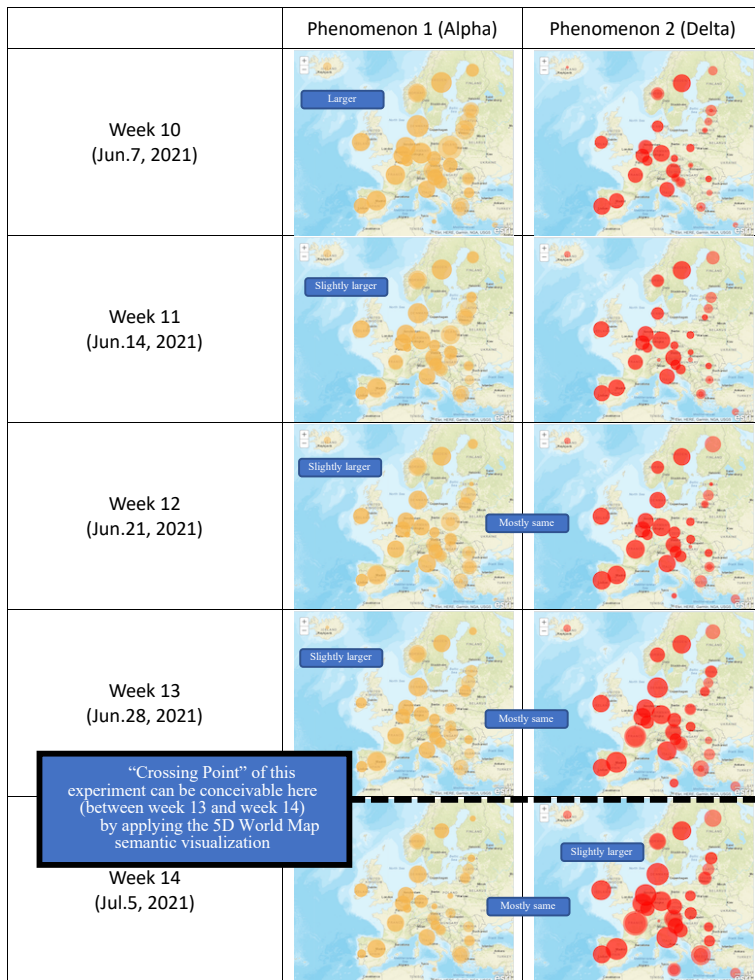
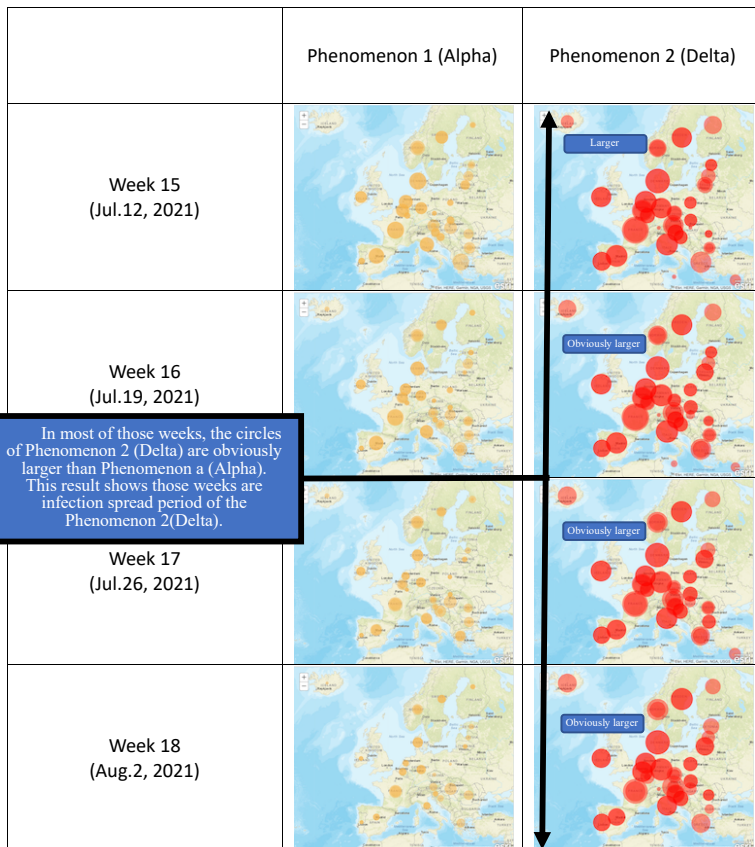
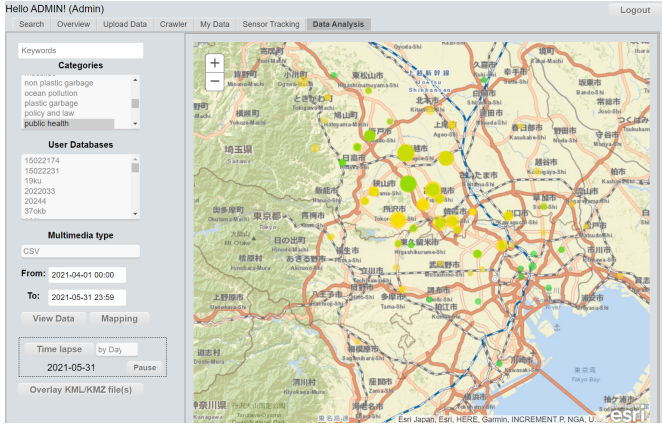


Figure 9. The result of weeks 10 to 13 visually shows that the Phenomenon 1 (Alpha variant) the Phenomenon 2 (Delta variant) are mostly same spread, and on week 14 the majority of the number of patients switched from Phenomenon 1 to Phenomenon 2. We can visually analyze that the “Cross Point” around EU between the Phenomenon 1 and the Phenomenon 2 appeared on between Week 13 and Week 14.

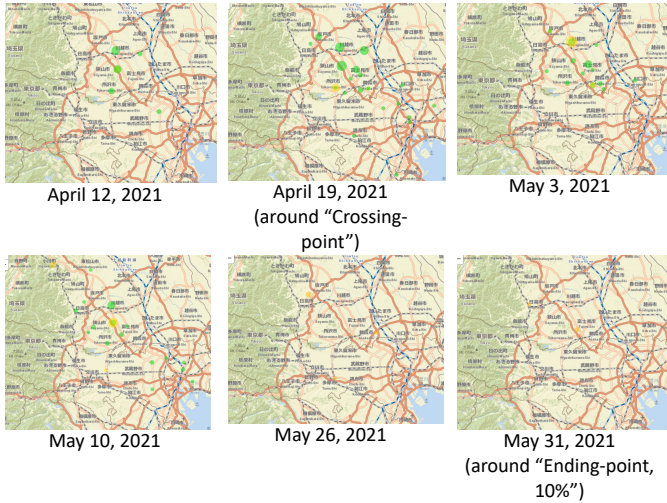


In most of those weeks, the circles of Phenomenon 2 (Delta) are obviously larger than Phenomenon 1 (Alpha). This result shows those weeks are infection spread period of the Phenomenon 2(Delta).

Figure 10. The result of weeks 1 to 4 visually shows that the Phenomenon 2 (Delta variant) spreads larger infection clearly than Phenomenon 1 (Alpha variant). Those weeks are corresponding to the “Area b” and “Area d” of our formulation.



(a)



(b)

Figure 11. Visualization of daily numbers of positive cases of E484K (green marker) and N501Y (yellow marker), tested at a hospital in Saitama, JAPAN: (a) all-at-once mapping results from April to May, 2021, (b) daily-number mapping results from April to May, 2021.

Figure 11 shows the visualization results daily numbers of positive cases of E484K and N501Y tested at a hospital in Saitama, JAPAN described in Section 3.3. The green marker represents “Phenomenon-0” (Japan-original variant, E484K), and the yellow marker represents “Phenomenon-1” (Alpha variant, N501Y). Size of the circle corresponds to the daily number of confirmed cases in each city in Saitama prefecture, Japan. We can visually analyze the transition-phenomena by discovering the crossing-point of replacement, speed of spreading, and forces between the two phenomena. We can observe that the Phenomenon-0 (Japan-original variant) exists relatively long and the transition to Phenomenon-1 (Alpha variant) as a majority is gradual. These results are corresponding to the size of “Area (B)” and “Area (D)” of our formulation.

5. Conclusion

We have presented a new Temporal-transition & Differential Computing Model for detecting, estimating and predicting “Human-health situations” and “a spread of transmitted disease.” This model defines “temporal-transition data structure” for expressing past and current data of health-related phenomena with temporal-axis, and two processes for Human-Health Semantic Space Creation and Semantic Computing method with dimensional control mechanism.

We have also realized the dynamic evaluation and mapping functions of multiple views of temporal-spatial metrics, and integrate the results of semantic evaluation to analyze transmitted disease-spreading. 5D World Map system applied to transmitted-disease to visualize world-wide and global relations among different areas and times in disease and environmental aspects, by using dynamic mapping functions with temporal, spatial, semantic and impression-based computations.

As our future work, we will extend our 5D World Map System to new international and collaborative research and education for realizing mutual understanding and knowledge sharing on global human-health issues in the world-wide scope.

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Steps to Emotion Corpus Creation in Thai: An Exploration of Thai Emotion Wordlists, Depression Corpus and Facial Expression in Speech Situation

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Abstract. In this paper, we proposed a two-phases project on emotion corpus creation based on multi-knowledge of cognitive semantics, discourse analysis, paralinguistics, and computer science. Data were gathered from Thai lexicon of five main Thai dictionaries and thesaurus, in addition of written and spoken texts of people with depression in Thai and facial expression with speech situation. We found that semantic primes and features of each emotion were needed to be a guideline of emotion categorization in Thai context. We introduced the step-by-step methods of the first phase to create Thai emotion corpus both verbal and nonverbal corpus. The way to classify emotion corpus by focusing on the specific text of depression as well as to find the guidelines of labelling facial expression in the situation of specific emotions was explored. Lastly, the step of creating emotion corpus in the second phase was introduced with some suggestion and discussion.

Keywords: Emotion classification, Emotion corpus, Facial expression, corpus creation

1. Introduction

We live in the world of emotions. The world we live in has a half of emotions. Denzin [1] points out the emotion is a lived, believed-in, situated, temporally embodied experience that radiates through a person's stream of consciousness and transformed the reality of a world that is being constituted by the emotional experience (p.66). Emotion words have been a focus of research interest in many fields of study, including psychology, literary study, linguistics and natural language processing. Previous studies about emotion among Thai researchers have focused generally on the basic sentiment analysis as polarized system of positive, neutral, negative preferences, or cognitive linguistics, i.e., conceptual metaphor of emotions. Among other studies, research of Angkapanichkit, Rojanahastin and Intasian [2] pointing out the significance of language and emotion in people with depression narratives, emotion corpus should be established in Thai language to lead to develop tools and techniques for emotion detecting in Thai communication. As more demand for natural language processing (NLP) to develop Artificial Intelligence (AI) in Thailand, it becomes increasingly necessary to study at ways of dealing with corpus creation. However, lack of

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emotion corpus and there is few research to create Thai emotion corpus and to systematically categorize emotion in terms of basic emotions, not sentiment. To fill this gap, we propose our research project on creation of Thai emotion corpus both verbal and nonverbal corpus.

Our project entitled ‘Thai Emotion Corpus Creation’ is a sub-research project of **AI Ready City Networking in Research University Network - RUN**, funded by Thammasat University Research under the TSRI (Contract No. TUFF19/2564). The project is on-going process to explore Thai Emotion Dataset. This project brings together expertise in cognitive semantics, discourse analysis and multimodal Thai linguistics, Data Science and Computational Linguistics to investigate emotion language both verbal and nonverbal, and to produce a dataset to put alongside the emotion corpus creation in Thai language databases. In this paper, we present the first phase of study to introduce step-by-step verbal and nonverbal emotion corpus creation in Thai language.

This paper is organized as follows. In Section 2 we showed some works related to development and analysis of Thai corpus and emotion. In section 3, we demonstrated steps and methods of emotion corpus creation. Finally, in section 4, we proposed some ideas for further works of the second phase and the conclusions.

2. Related works

2.1 Corpus, natural language processing and emotion

Corpus is defined as an availability of suitable data in machine-readable authentic texts [3] and is designed to be the representative of a particular language. Xiao [4] states that corpus size is hard to define since it depends on the purpose of the research study, and corpora play an important role nowadays in natural language processing (NLP) research and computational linguistics as well as linguistic studies, particularly corpus linguistics.

Linguistically, emotions have strong linguistic choice that express people voice and tone of the text [5]. Emotion analysis is increasingly important due to digital communication. Online system and Artificial Intelligence program can be a support system for people interaction and emotions. The great challenge of automatic emotion recognition and detection tools by focusing on emotion words and nonverbal data is increasing. Recent research has focused on emotion corpus building with multi-perspective annotation by following emotion theoretical idea of emotion and its causes [6]. Russo et al. [7] built a corpus of Italian newspaper articles annotated with emotion key words and emotion cause phrases. Many works on Chinese corpus construction have been developed. Gui et al. [8] constructed emotion-cause-annotated corpora for Chinese. Chen et al. [9] adopted a rule-based approach based on linguistic patterns to detect emotion causes in the annotated Chinese corpus. Also, Gui et al. (2017) [10] presented a question-answering approach to emotion cause extraction,

2.2 Thai Corpus and Emotion

Several corpora in Thai have been built and made available to the science and technological community, such as National Electronics and Computer Technology Center - NECTEC. The applications of emotional expression and interaction are diversifying. For

example, e-mental healthcare for auto-screening and detecting symptoms of people with depressive disorder through Facebook Messenger called *Jubjaj Bot*, has developed by Mahidol University research group [11].

Hardly, emotion corpus and emotion wordnet were found in Thai researchers. Mostly, Thai Wordnet building, and construction were proposed. Leenoi et al. [12] stated a standard for building Thai Wordnet with a bi-directional translation method as well as Akaraputthiporn et al. [13] constructed the wordnet by using a bi-directional translation approach. Thoongsup et al.) [14] proposed Thai wordnet construction by applying the semi-auto alignment method. A few numbers of research study have been considered emotion in the field of cognitive linguistics. Metaphor and emotion words in Thai texts were investigated. For example, Tawichai [15] used cognitive semantics to describe basic emotion words derived from physiological effect which made meaning extension in Thai. Conceptual metaphor was mainly approach to study metaphor and emotion in Thai, e.g. Emotion metaphor [16], anger metaphor [17], fear metaphor [18], suffering metaphor [19], happiness metaphor [20], love metaphor [21]. All of those works on emotion metaphor in Thai were influenced by the work of Kovecses [22], [23].

2.3 Emotion

Concepts of emotion are historically considered. The terms are varied used in the semantic domain of emotion, such as affection, feeling, mood, and sentiment. Emotion in terms of evaluation perspective as positive, negative, or neutral attitude is sentiment. Thus, the studies which rely on attitudes and evaluation so-called sentiment analysis [24].

Sentiment analysis and Emotion analysis have been popular and widely applied from psychological and cognitive science to computer science. Both emotion and sentiment are quite similar in a way of studying feeling and affection, but its focus is different. As stated above, sentiment analysis mainly targets the attitudes on polarity of positive, negative, or neutral. Most of Thai emotion recognition applications were sentiment analysis in this sense. Unlikely, emotion analysis is mainly focusing on emotions, particularly basic and circumplex model. Although emotion analysis and sentiment analysis are dealing with the evaluative and expression of language, but sentiment analysis is not enough appropriate way for specific purposes dealing with emotion classes, such as fear, anger, sadness etc., especially, the task for mental healthcare intervention development.

To the best of our knowledge, there is no research to systematically categorize basic emotion in Thai or to classify emotion words to create emotion corpus. Also, to our review of previous studies in Thailand and others, our work is the first research on emotion recognition and classification by tracking verbal and nonverbal data to consider the emotion aspects of Thai people. Unfortunately, emotional texts were generally classified into six basic emotions but for categorization of verbal emotions into such emotion classes has not yet been clear.

Additionally, emotional text, such as depression text, should be a main resource for exploring how emotion words working. There is no depression corpus from people with depressive disorders available in the public domain as of now. We take this opportunity to introduce a corpus, comprising diaries and interviews of 40 depressed students from the

previous research of Angkapanichkit et al. [25], added by four depressed-experiencing authors of autobiographic books to facilitate further research and development. Also, this paper provides a practical explanation of the steps involved in creating a specialized corpus and wordlist with tagged emotion. The following is intended as an introductory, step-by-step, practical guide for whom is interested in creating a verbal and nonverbal emotion corpus.

3. Steps to verbal and nonverbal emotion corpus creation

The main objective of this paper is to introduce steps to create emotion corpus in Thai both verbal and nonverbal corpus. For our first phase of study, we have explored Thai emotion lexicon and the way to categorize emotion words by focusing on the specific corpus of depression. In addition, we have figured out the guidelines of labelling and annotation for facial expression within the speech situation of specific emotions.

As stated above, our project is divided into 2 phases dealing with different data processing. The first phase is about setting the overview of emotion in Thai concepts and data resources both verbal and nonverbal. Then, exploring Thai lexicon, wordlists and specific texts related to basic emotion along with audio-visual data to set a primary standard guideline for emotion classification. The second phase is about constructing verbally and nonverbally emotion dataset and setting a standard guideline by tracing another emotional text of people in the university campus. The overview of steps for creating emotion corpus of our first phase is shown in figure 1.

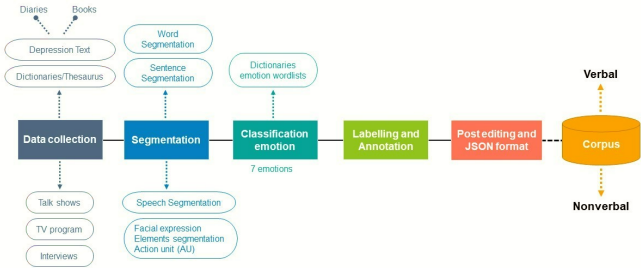


Figure 1. The steps of emotion corpus creation on the first phase

3.1 The first step: Data collection

Our task has started with data collection as the first steps of creating emotion corpus. What we have taken on data collection was the task of dividing data into linguistically meaningful units. The lowest level is representing the lexicon or words from Thai standard resources, i.e., dictionaries and thesaurus, phrases and sentences or utterance in conversation consisting of one or more words. Normally, words, phrases, and sentences, as consisting of text, are the fundamental units of language processing for segmentations and tagging such as part of speech tagging. As a very first step of this project, we intend to explore how many words which their meaning related to emotion were collected in Thai vocabulary database, and how we can classify them into basic emotions. The guideline system for both verbal and nonverbal emotion database should be appropriately established.

Thus, purposively, verbal data were collected from 2 main resources. The first resource was from the standard dictionaries and thesaurus. All of them are the main source of reference to Thai language. Name list of dictionaries and thesaurus used in our project are in Table 1.

Title	Cover picture
<i>Khlangkham</i> (Thai Thesaurus) (2019 version)	
Dictionary of the Royal Institute (2011 version) [RI]	
Dictionary of Thai New Vocabulary by the Royal Institute volume 1 (2010 version) [NV-1]	
Dictionary of Thai New Vocabulary by the Royal Institute volume 2 (2009 version) [NV-2]	
Dictionary of Thai New Vocabulary by the Royal Institute volume 3 (2010 version) [NV-3]	

Table 1. Thai dictionaries and Thesaurus

The second resource was texts related to emotional expression. Verbal texts were narratives and interviews of people with depression. Nonverbal data were collected from the public resources, i.e., TV talk shows program and movie star interviews, by considering relevant facial expression with emotional speech situation. All speech and interviews were transcribed into conversational style of text by using speech-to-text of Google ready program.

Topic-oriented texts in this project were carefully and systematically collected since they were dealt with emotional expression. On the first start, verbal texts selectively were about the personal life of depressive disorder. Text genre can be defined as autobiographical narratives which were published and unpublished. All texts were produced by Thais who have experienced depression, such as the bachelor's degree students, actors, businessman etc. Nonverbal data were considered as multimodal texts, or audio-visual texts. Text genre was defined as speech in interaction with specific emotional expression. Nonverbal data have to be tracked both verbal speech unit and facial expression unit separately.

Data selection

The data of Thai vocabulary we retrieved from 5 main dictionaries and thesaurus were labelled as emotion words by the first two Thai native speakers. Eventually, the number of predefined words that contained emotions was 7,040 words out of about 71,000 words in total. These predefined wordlists will be reconsidered to be classified basic emotions when we all set the guideline for emotion categorization later. Amount of word count and emotion wordlist are shown in Table 2.

Resources	Amount of lexicon	
	Word count	Emotion Word
<i>Khlangkham</i>	25000	3750
[NV-1]	1000	574
[NV-2]	1000	238
[NV-3]	1000	346
[RI]	43000	2132
Total	71000	7040

Table 2. The amount of word count and emotion wordlists in Thai Dictionaries

Moreover, to investigate more closely Thai emotion language, we have to take the texts related to emotion into account. We have considered that emotion corpus creation in this

project is a small but well-controlled corpus. Thus, exclusively composed of selective emotional texts from narratives, interviews, and short essay as well as autobiographic books were included. The verbal data were selected from 40 depressed student narratives and interviews. All texts were sampled from the corpus of previous research project on *Language, Communication and Depression* [25]. Four published books written by Thai authors who were experiencing with depression belong to the genre of autobiography. Totally, in the first stage, verbal text related to the topic of depression consisted of 19,940 sentences, and 212,170 words contained in the data selection. All the text lists with amount of word and sentences are shown in Table 3.

Text list	Word count	Numbers of sentence
<i>Sam Wan Dii Sii Wan Sao</i> (Three Good Days, Four Sad Days)	22,878	2,000
<i>Depression Diary</i>	30,415	2,860
<i>Manus Suem Sao kap Rueng Lao Sii Khao Dam</i> (People with Depression and the Black-and-White Story Telling)	41,741	3,881
<i>Tai Roy Kreet</i> (It's all about the Cut)	26,469	2,566
Narratives and interviews of 40 students with depression	90,669	8,633
Total	212,170	19,940

Table 3. Depression text with word count and numbers of sentences

Furthermore, the second phase of this project, short essays and interviews of students, lecturers, and staff of Thai university under the emotion screening test of the Depression, Anxiety and Stress Scale -21 (DASS-21) test have been in the process of collecting.

3.2 The second step: Segmentation

Word and sentence segmentation could not be independent from one another. As being typologically isolating language, Thai language is challenged the segmentation task since there is unobscured sentence boundary. Tokenization of words, and utterance (for the case of nonverbal data) known as tokens, is explicitly marked in the speaking system with high frequency used, final particles such as *kha* (female polite particle), *krap* (male polite particle), the topic marker such as determiner *nii*, *nan*, or punctuation of pause. For the writing system, sometimes there are no distinct between word boundaries and phrases, particularly noun groups and noun phrases.

In the first start of segmentation, all text data were cleaned and manually segmented by researcher and Thai language experts. We used the program as automatically tool for word segmentation. The tool required input raw data in text file (.txt format) with its metadata appeared on the beginning of the text file. The text was read by program tool and part-of-speech tagging (POS tagging) using ORCHID program. All tagged files can be retrieved by the users. Example of .txt file format is shown for a word segmentation and POS tagging in Picture 1.

```

%ประเภทงานเขียน: หนังสือ
%ชื่องานเขียน: มนุษย์ชิมเต๋ากับเรื่องเล่าสีดำ
%ตอนที่: 1
%ผู้เขียน: นายพันดำ
%เพศของผู้เขียน: ชาย
%เนื้อหา: โศกชิมเต๋ำ
%ปีที่พิมพ์: 2563
%สำนักพิมพ์: 13357
%ISBN: 978-616-93544-1-3
%จำนวนหน้า: 224

มนุษย์ชิมเต๋ำกับเรื่องเล่าสีดำ
มนุษย์ NCMN
<S>ชิมเต๋ำ NCMN </S>
กับ RPRE
เรื่องเล่า NCMN
<S>สี NCMN
ดำ VATT </S>
EOS
บทที่ 1
บท NCMN
ที่ PREL
<Space> PUNC
1 DCNM
EOS
ตอนที่ 1 ความจริงจากความสูง 69 เมตร
ตอนที่ NCMN
<Space> PUNC
1 DCNM
<Space> PUNC

```

Picture 1. Example of .txt file with word segmentation and POS tagging by ORCHID program

3.3 The third step: Emotion classification

Concept of emotion as people's thought and experience from Ekman [26] is the main consideration and can be helpful for our project since we have taken into account both verbal and nonverbal emotion corpus. We employed Ekman's classification of six basic emotions [27] namely *anger*, *fear*, *disgust*, *joy or happiness*, *sadness*, *surprise*, and plus *neutral* as addition of the class *contempt* and *other emotion* that expressed in the text which cannot be reliably categorized into one of the basic classes. Ekman [27] also, claims that human has

facial expression set of basic emotion as biological response in interaction. We can describe human emotion through facial movement by using the Facial Action Coding System (FACTS) to annotate the components of facial muscle movements called ‘Action units’ (AU) [27]. Following the FACTS as our primary guideline, facial expression from audio-visual data were classified to 7 basic emotions. In Table 4 shows the example of emotion facial expression classified by Action Unit (AU) along with speech situation of a Thai movie star interviewed on TV entertainment news and talking about her little kid in school. The utterances and key words were translated into English in order to easily understanding for international readers.

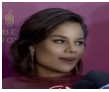

Utterance	Time	Key words	Emotion	Sub-category	AU
She said she wanted to be the leader of her class in school	0.00.32	She/said/ I/am/the leader	Neutral	neutral	AU6+AU12 
On that day, she was the only one in the class	0.00.36	She/was alone/the class	Joy	humor	AU6+AU12 

Table 4. Example of emotion classification by using Action Unit

For the verbal emotion guideline, we determine emotion semantic primes by applying Natural Semantic Metalanguage (NSM) [28], lexical semantics [29] and cognitive semantics of conceptual metaphor theory [30-31]. These semantic approaches were employed to distinguish word meaning and to interpret metaphorical meaning of words related to emotion. For example, the semantic relations of antonym *Ron* ‘hot’ and *Yen* ‘cool’ can signal metaphorical meaning of emotion. The conceptual metaphor of temperature HOT IS ANGER is normally interpreted by Thai people such as the compound word *Hua Ron* (literally *Hua* ‘head’ *Ron* ‘hot’) conveys metaphorical meaning as anger. Unlike, *Yen* can be signaled emotion of happiness and neutral when being in compound word as *Chai Yen* (*Chai* ‘heart’ *Yen* ‘cool’) which means calm or patient which is categorized by semantic feature of basic emotion ‘neutral’. When appearing in the expression ‘*Yuu Yen Pen Suk*’ which has literal meaning as ‘being good, feeling happy’, *Yen* in this sense is classified as emotion ‘happiness’. Differently, the adverbial phrase of ‘*Yen Waap*’ (metaphorical meaning as ‘feeling scared’) or sentence-like *Mue Yen* (literally *Mue* ‘hand’ *Yen* ‘cool’) is signaling physical response of scaring. So, the word ‘*Yen*’ can be classified various emotions depending on its contextual meaning.

verbal and nonverbal emotion lexicon completely classified. All corpus is labelled manually by researchers, Thai language experts and native Thai volunteer.

In doing corpus annotation, we bear in mind that language, cognition and culture affect how emotion is perceived and expressed in an interaction. We have carefully selected three natives to label: 1) Thai language experts, 2) researcher and 3) native volunteer. Every annotator is required to be (1) a native Thai speaker, and (2) knowledgeable and understandable of Thai culture of communication. With these requirements, we try to ensure that the annotator can observe emotion facial expression in addition to recognizing the emotion words appropriately. To ensure consistency, we have each annotator to label the full corpus including wordlists in Thai dictionaries and our lexicon. Before annotating the corpus, the annotators will be briefed and given a document of guidelines for emotion classification. The document provides theoretical background of emotion categorization as well as a number of examples and wordlists.

3.5 The last step: Post editing

To ensure that our output data of all annotated emotion and classified wordlists are well identified and completed as much as possible, all data have to be edited. Three Thai linguistic experts will be required to consider the result of all annotated data and emotion words classification. Some ambiguity and overlapping of emotion in sentences, phrases or words have to be detected and clarified. After fully edited, all data will be transformed into JSON format at the end. Computer Scientist is needed for this latter part.

4. Conclusion and Future work

We have introduced our two-phase research project on emotion corpus creation in Thai language. The main purpose of this project is to construct emotion corpus available for AI development. Another purpose is to set the standard guideline for verbally and nonverbally categorizing emotion language by using linguistic-based knowledge such as cognitive semantics for contributing a clear definition of basic emotions in Thai context. What we have described is an on-going process of creating corpus at the first phase. Steps for working have been developed a primary guideline to establish a suitable way to classify seven basic emotions for both verbal and nonverbal data. This project is a multi-knowledge based varied from textual oriented approach of cognitive semantic, discourse analysis to applied linguistics such as paralinguistics, to psychological and to computer science approach. Our dataset was lexicon gathered from the main resources of Thai language references, i.e., dictionaries and thesaurus, along with topic-oriented text of depression. Nonverbal data of the first phase using the public audio-visual text from TV programs to find the tentative guideline of categorizing and classifying facial expression within speech emotion situation. This made our project different from other projects on emotion corpus and facial expression identification.

To achieve a better and clarified classification of emotion corpus, we have to collect verbal and nonverbal data from other resources. In the second phase, nonverbal data will be

collected from volunteer who are systematically induced emotion by psychologist. Facial expression with AU labelling and speech categorization have been done via video clips. Verbal data will collect from topic-related-emotion text of short essay and interviews of students, lecturers, and staff of Thai university campus under the emotion screening test of the Depression, Anxiety and Stress Scale -21 (DASS-21) test. These data have been in the process of collecting. Future work must be accomplished to enrich the corpus with a more important number of sentences and words as well as more annotations. Thai language experts and Thai native speakers will play an important role of annotation and editing corpus to contribute and to distribute emotion corpus in Thai natural language processing (NLP) and AI in the near future.

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Data Sensorium

Spatial Immersive Displays for Atmospheric Sense of Place

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Abstract. This paper describes about project “Data Sensorium” launched at the Asia AI Institute of Musashino University. Data Sensorium is a conceptual framework of systems providing physical experience of content stored in database. Spatial immersive display is a key technology of Data Sensorium. This paper introduces prototype implementation of the concept and its application to environmental and architectural dataset.

Keywords. immersive image, visualization, projection-based VR, locomotion interface

1. Introduction

Immersive image, such as 360-degree panorama, plays important rolls in visualizing environmental or architectural content stored in database. HMD (head-mounted display) is a typical device for displaying immersive image. It is a common device in VR(virtual reality) systems. VR has been popular not only in the field of entertainment but also in scientific research and industrial applications. However, HMD has several drawbacks. Firstly, HMD can only provide image to a single user that causes limitation in natural communication among multiple users. Secondly, HMD is tightly coupled to the user’s head so that it is uncomfortable for long term use. Thirdly, optical system of HMD is not sufficient for covering natural field of view of human eyes.

Spatial immersive display is an alternative of HMD. It is a room-like display composed of multiple large screens or curved screens[1]. Its advantages are fused together to overcome the drawbacks of HMD. Multiple users can go into the room-like display together and can physically interact among them. They don’t have to wear goggles. Room-like display can fully offer a natural field of view of human eyes.

Data Sensorium is a conceptual framework of systems providing physical experience of content stored in database. Spatial immersive display is a key technology of Data Sensorium. This paper introduces prototype implementation of the concept and its application to the projects running at the Asia AI Institute of Musashino University.

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2. Basic Concept of Data Sensorium

Data Sensorium aims to present data through physical experience of users. Its structure consists of three basic functions of “Sensing”, “Processing” and “Actuation”. Figure 1. illustrates framework of the Data Sensorium. Sensing subsystem captures multi-dimensional data of specific places. 360-degree cameras or 3D scanners are used for the sensors. Processing subsystem memorize and visualize multi-dimensional data captured by the Sensing subsystem. Spatial immersive displays are used to present results of visualization. Actuation subsystem provides physical experience to the users. It employs various interface devices that cause actual movement of the users in the real world. One of the examples is a locomotion interface that create sense of walking. Spatial immersive displays may be located in various places in the world so that global collaboration using Data Sensorium can be achieved.

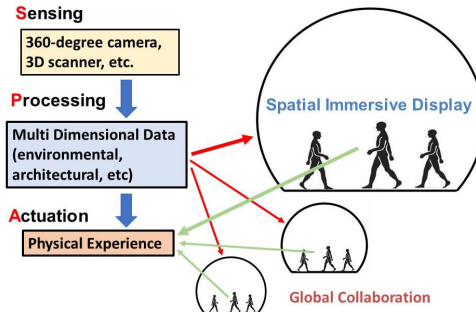


Figure 1. Framework of Data Sensorium

3. Prototype Implementation

3.1. Four-screens Configuration

We firstly tried rapid prototyping of a spatial immersive display by using 16:9 flat screens. Field of view of human eyes is 200 degrees horizontally. Thus, we employed four 120-inch screens for offering full field of view. These screens are arranged in pentagonal shape so that it offers 288 degrees field of view. Short focus projectors, Optoma GT1080, are put inside the screens.

This configuration is easy to setup and it can realize room-like display. Figure 2 shows overall view of the installation. We also developed the pentagonal-shape screens by using 85-inch monitors (Figure 3). Although each screen is smaller than the projection screen, this configuration is easier to install. It works even in bright room and it is actually working in Thammasat University.



Figure 2. Four 120-inch Screens Configuration



Figure 3. Four 85-inch monitors Configuration

3.2. Integration of Torus Treadmill with Four 120-inch Screens

The Torus Treadmill is a locomotion interface that creates sense of walking. Although traveling on foot is the most intuitive way for locomotion, proprioceptive feedback of walking is not introduced in most applications of virtual environments. We have been developing an infinite surface driven by actuators for creation of sense of walking[2]. Torus-shaped surfaces is selected to realize the locomotion interface. The device employs 12 sets of treadmills. Figure 4 illustrates basic structure of the Torus Treadmill. Each treadmill moves the walker along an "X" direction. These treadmills are connected side by side and driven in a perpendicular direction. This motion moves the walker along a "Y" direction. Combination of these motions enables the walker to omnidirectional walking. The walker can go in any direction while his/her position is fixed in the real world. Figure 5 shows overall view of the device.

We are planning to integrate the Torus Treadmill with the four 120-inch screens display as mentioned in the former section. Figure 6 illustrates combination of the Torus Treadmill and screens. Walking action is measured by a position sensor and image of virtual space is displayed according to the walking distance. This function provides physical walking experience in virtual environment.

Major application of the system will be art museum. Art museums not only provide each artwork but also whole space that include artworks. Thus, physical walking is essential to experience in art museums.

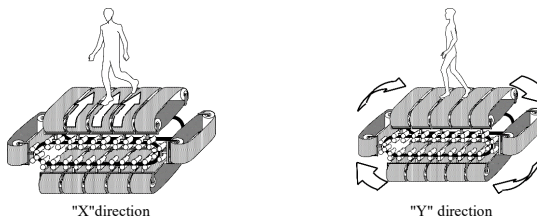


Figure 4. structure of the Torus Treadmill

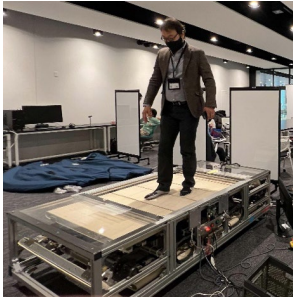


Figure 5. overall view of the Torus Treadmill

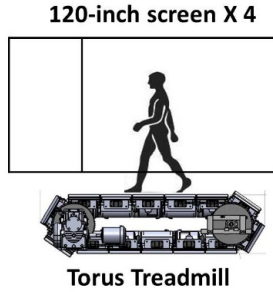


Figure 6. combination of the Torus Treadmill and the four 120-inch screens display

3.3. *atmoSphere Display - a spherical full-surround screen*

Sphere is an ideal shape for a full-surround screen. Distance between eyes and screen is constant in a spherical screen. Flat screens are easier to install but they have difficulty in offering vertical field of view. The four-screens configuration described in the section 3.1 can offer only 40 degrees vertically. On the other hand, vertical field of view human eyes is 125 degrees. We designed a spherical screen that offers 360 degrees horizontally and 135 degrees vertically. It is named “atmoSphere Display”. Figure 7 shows basic structure of the display. Diameter of the screen is 3.8m and overall height is 3.0m. It is designed to fit to the room of the Asia AI Institute of Musashino University. Four projectors thorough images to the spherical wall. Two projectors thorough images to the floor. Figure 8 shows overall view of the display. It is made of fabric screen. It is relatively easy to fabricate compared to solid screens. Another advantage of fabric screen is that it transmits light and sound. Full-surround screens often suffer from internal reflection that degrades the contrast of the image. Fabric screens provide solution for the internal reflection.

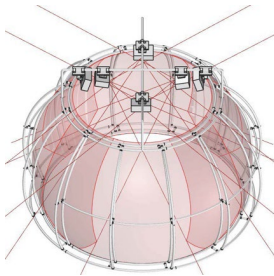


Figure 7. basic structure of the atmoSphere Display



Figure 8. overall view of the atmoSphere Display

4. Integration of 5D World Map System and Data Sensorium

It is significant to memorize those situations and compute environment change in various aspects and contexts, in order to discover what are happening in the nature of our planet. Kiyoki and Sasaki have proposed “5-Dimensional World Map System” [3]-[12] for integrating and analyzing environmental phenomena in ocean and land. This system is effective and advantageous to memorize environmental situations with Physical-Cyber integration to detect environmental phenomena as real data resources in a physical-space (real space), map them to cyber-space to make analytical and semantic computing, and actuate the analytically computed results to the real space with visualization for expressing environmental phenomena, causalities and influences. Currently, the 5D World Map System is globally utilized as a Global Environmental Semantic Computing System, in SDG14, United-Nations-ESCAP (<https://sdghelpdesk.unescap.org/toolboxes>) for observing and analyzing disaster, natural phenomena, ocean-environment situations with local and global multimedia data resources [9][12]. The 5D World Map System has also introduced the concept of “SPA (Sensing, Processing and Analytical Actuation Functions)” for global environmental system integrations, as a global environmental knowledge sharing, analysis and integration system [7][8][9].

4.1. 5D World Map System

We have introduced the architecture of a multi-visualized and dynamic knowledge representation system “5D World Map System [7]-[12],” which is applied to environmental analysis and semantic computing. The basic space of this system consists of a temporal (1st dimension), spatial (2nd, 3rd and 4th dimensions) and semantic dimensions (5th dimension), representing a large-scale and multiple-dimensional semantic space. This space memorizes and recalls various multimedia information resources with temporal, spatial and semantic correlation computing functions, and realizes a 5D World Map for dynamically creating temporal-spatial and semantic multiple views applied for various “environmental multimedia information resources.”

5D World Map System applies the dynamic evaluation and mapping functions of multiple views of temporal-spatial metrics, and integrate the results of semantic evaluation to analyze environmental multimedia information resources. The main feature of this system is to create world-wide global maps and views of environmental situations expressed in multimedia information resources (image, sound, text and video) dynamically, according to user's viewpoints. Spatially, temporally, semantically and impressionably evaluated and analyzed environmental multimedia information resources are mapped onto a 5D time-series multi-geographical space. The basic concept of the 5D World Map System has been introduced in [3]-[12]. The 5D World Map system applied to environmental multimedia computing visualizes world-wide and global relations among different areas and times in environmental aspects, by using dynamic mapping functions with temporal, spatial, semantic and impression-based computations [7]-[12].

4.2. Connection between Data Sensorium and 5D World Map System

The connection between Data Sensorium and 5D World Map System is implemented as a realization of 3D demand-propagation to local-spots for environmental-actuations on a Plastic Garbage Monitoring project in conjunction with Closing-the-Loop project by UN-ESCAP. Assuming an installation among multiple remote sites, the connection

between two systems is designed as shown in Figure 9. The connection between two systems is realized for the purpose of Plastic Garbage Experience Sharing and Collection - 360 area-atmosphere recognition with real local 360-degree images (taken by 360-degree cameras such as GoPro and Theta). It shows the future direction of 5D World Map System as a control center of "Plastic Garbage Discovery and Reduction" activities with advanced technologies in the field of AI, Big-Data Analysis, Machine Learning, VR/AR, IoT and Robotics.

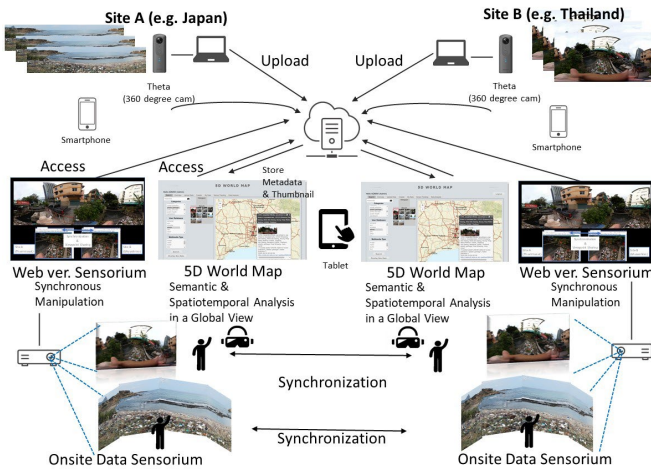


Figure 9. Connection between Data Sensorium and 5D World Map System and the Installation Structures in Remote Sites

5. Application to Virtual Museum

In the past few decades, many kinds of virtual museum have been discussed with the rise of technologies in virtual reality, and the term virtual museum is very wide that includes many technologies such as digital museum, electric museum, online museum, Web museum or cybermuseum[13]. For constructing various digital applications in a museum, a multidatabase system architecture for integrating digital archives of an art collection was proposed which is named Artizon Cloud[14]. For introducing the data sensorium concept to the virtual museum, *Art Sensorium Project* was launched in Musashino University. Two key technologies that we focus are as follows: 1) a multidatabase system architecture to integrate multiple art collections, 2) virtual space design and implementation for the data sensorium.

Fig.10 shows the multidatabase system of Art Sensorium. A purpose of the multidatabase system is to realize semantic computing environment for art by integrating multiple data archives of museum, and providing API to implement a variety of application.

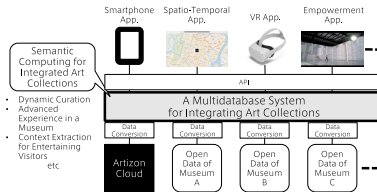


Figure 10. A multidatabase system architecture for integrating art collections

By introducing the data sensorium concept, many types of virtual museum are assumed possible to implement as Fig.11. The data sensorium is capable to project an artwork in real-size, and it could be used as a real-size art data browser as shown A in Fig.11, and to reproject past exhibitions in a cyberspace as B in Fig.11. Dynamic curation in a virtual space is a meaningful challenge to automatically generate an art exhibition for an individual according to one's mind or intension as C in Fig.11.

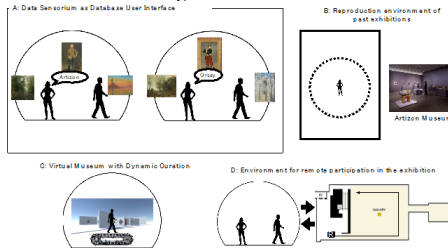


Figure 11. Assumed applications of Art Sensorium

Furthermore, multiple data sensoriums in distinct area in terms of culture are assumed to possibly provide cross-cultural communication by arts. Fig.12 shows assumed use cases of multiple data sensoriums in Japan and Thailand.

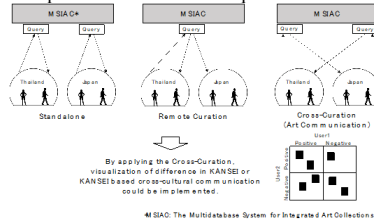


Figure 12. Assumed applications of Art Sensorium

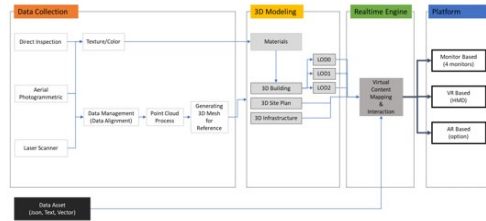


Figure 14. Modeling process of Thammasat Rangsit campus

Figure 15 show the visualization results on 4 surrounding screens to provide a room-like experience. After the image stitching process, Figure 15(a) shows the synchronized image controlled by the multiple points via the Internet. On each end, the users can control the view and point out the area of interest. The function allows the users to share their concerns in the same room-like experience. In addition, the models are smoothly augmented with the location sensitive information to realize the spatial experience to the users as shown in Figures 15(b). The example information of social media density is expressed in a form of augmented graph in Figure 15(c) to shown the SNS population in a specific moment.

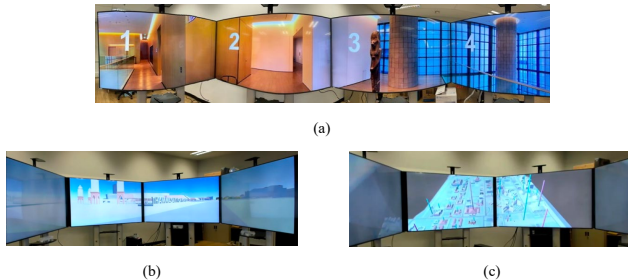


Figure 15. Modeling process of Thammasat Rangsit campus

As a result, Data Sensorium shows its potential in realizing the spatial immersive environment to relieve the limitation of using HMD, especially in the case of urban planning that needs a city scale environment sharing in the concept of AI City.

7. Conclusions

This paper has shown basic concept and prototype implementation of Data Sensorium. Its effectiveness is exemplified in three projects running at the Asia AI Institute of Musashino University. Future work will include further applications using new interface devices. Muscle training device is one of the examples.

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Permissions and Privacy Policies of mHealth Apps

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Abstract. The “free” business model prevails in mobile apps available through the major channels, hinting at the possibility that users “pay” for the use of the mobile apps by sharing their private data with apps’ developers and the platform providers. Several types of personal data and permissions of mobile applications were analyzed. We examined 487 medical and health related applications and extracted types of personal data and permissions from them. We implemented a privacy policy word processing algorithm, the purpose of which was to gain a better insight into the types of data collected. Using the results of the algorithm, we also performed statistical analyses, based on which we found that free mobile applications collect more data than paid ones. Interestingly, there are discrepancies between the permissions we obtained from the privacy policy texts and those stated on the Google Play website. A greater number of permission requirements emerged from the privacy policy texts than was shown on Google Play.

Keywords. privacy, mHealth, mobile applications, Google Play, permissions

1. Introduction

The field of personal data is an increasingly important topic in today’s information age. Almost every person today has a smartphone with several applications installed. Applications typically require the users to allow different permissions; apps access, store and process personal data based on those permissions. However, the users are generally unaware of what types of data and permissions they provide to mobile app developers and platform owners. Application developers, especially those using the “free” business model, finance their development by selling the acquired data [1-3]. This can violate human rights (the right to privacy) if users are unaware of it or it is being done without their explicit consent. A survey found that most privacy policy texts state that user data can be accessed by a third party, namely 71% on the iOS platform and 46% on the Android platform [4].

Furthermore, about 50% of the analyzed applications did not have a text on data privacy that could inform users about the use of their data [2]. Therefore, application developers and owners should be held accountable and minimize the damage resulting from inappropriate data processing. We should advocate for the participation of developers, platform owners, privacy policy writers, and other stakeholders so that they work together and adhere to standards.

In this work, we examined which app permissions users must give to each application for its use; these permissions are stated on the platform (Google Play). Next,

we analyzed the privacy policies, extracted the keywords related to permissions, and compared the expressed permissions on the platform with those extracted from the privacy policies. We were particularly interested in the categories of health-related applications (mHealth), as such data are particularly sensitive. Android (and iOS) platforms have the mHealth app category broken down into two separate categories, “Medical” and “Health & Fitness”.

In this paper, the research question is, how accurate are the stated lists of required permissions compared to those listed in privacy policies.

The rest of the paper is organized as follows. Section 2 presents the literature review dealing with medical apps, data collection, and privacy. In Section 3, we describe our research method and deliver the results. In Section 4, we conclude the paper with final remarks.

2. Literature review

Mobile applications related to health and healthy living (shorter “mHealth” for mobile health) are becoming increasingly popular. They provide the user with convenient and fast access to health and healthy living-related data. Although these applications bring many benefits to the user, they can also threaten the security and privacy of personal data. A 2015 Kerbs and Duncan survey found that 58% of U.S. citizens have health-related mobile apps installed on their phones [5]. They use mobile health applications for various purposes, such as lifestyle, diet, fitness, medication guidelines, diagnoses, various treatments, nutrition, etc. These applications improve peoples’ daily lives and reduce costs, but at the same time, they can collect large amounts of personal data [5]. Research in [20] showed that in a sample of 61 mHealth applications, all required access (permissions) to various services on the phone. Many of these apps also encouraged users to share their information online. About half of the applications reviewed did not have information on the privacy policy texts. In these texts, companies write how they will obtain, use, disclose and manage the user’s personal data. The privacy policies (should) also state to which third parties this information will be provided [2].

The results of the survey showed that 60% of users who download an app from the Google Play Store or iOS App Store decided not to install the app because it requires a lot of personal information from them; 43% of users chose to delete it application for the same reason [4]. Another study was done on a small number of selected applications for depression. In 116 applications, 4% of those that received a transparency rating according to their criteria were acceptable, and 28% received a questionable rating. However, other applications, which accounted for the majority, i.e., 68%, were assessed as unacceptable. Less than half of these applications (49%) had privacy policy text. Based on the research, it was found that apps on the App Store are more likely to contain privacy policy text than those uploaded to the Google Play platform. Applications requiring users to provide identification-related information are said to contain the text of the privacy policy in more cases than those that did not [6].

In an article [7], an online survey among students was conducted. The purpose of the survey was to find out how many students agree with the terms of use of the mobile app and the privacy policy texts without having to read them. The study also examined whether students grant any permission to application without rejecting it for security reasons. The survey was conducted on 170 students. The results showed that as many

as 62% approve the terms of use and the privacy policy without reading its text. The reason for this is mostly that the texts are too long. However, the results are quite different in terms of the permissions required by each application. As many as 92% of respondents said that they refuse an individual permit if they believe that the application used does not require access to that permission [7].

In a study [4], researchers found that more than two-thirds of the privacy policy texts analyzed in connection with mHealth applications stated that user data could be shared with a third party. The collection of personal data was mentioned in most of the texts analyzed. However, 29% of the total applications studied did not mention in the privacy policy texts what types of data they collect [4].

If mobile health applications were to be more widely accepted among users and in the health system, security and privacy issues would need to be addressed much more consistently and thoroughly [8].

In the following sections, we present a method of analyzing and comparing the permissions as stated in Google Play Store versus those extracted from the privacy policies texts.

3. Method

This section presents how we collected and analyzed the Google Play Store permissions and privacy policies of the studied applications.

3.1. Data collection and preparation

To obtain data, we used the software library `google-play-scraper` 8.0.4 [9]. With the help of this library, we created a program in the Python programming language that obtained application data from the Google Play Store website. The program downloads the data from the most popular applications from each selected category. Because we are interested in mHealth applications, we have chosen Medical and Health & Fitness categories. We identified 232 “Medical” apps and 255 “Health and fitness” apps.

We had several difficulties in retrieving the data from the website due to certain limitations that the Google Play page had. Namely, the site did not allow the bulk collection of data from our side. After a certain amount of transferred data it started to block access, so we had to transfer applications’ data gradually. We did this by downloading each category separately. Within the category, we further divided the downloading of data into free and paid applications. This was a very time-consuming process, as we were forced to set up a VPN to change IP addresses to allow for a seamless transmission. Program code 1 shows part of the entire program for obtaining Android applications. This procedure is the same for each category.

```

gplay.list ({
  category: gplay.category.HEALTH_AND_FITNESS,
  collection: gplay.collection.TOP_FREE,
  fullDetail: true,
  num: 160})
. then (apps) => {
  apps.forEach (function (element) {
    gplay.permissions ({appId: element ["appId"]}). then (permissions) => {
      permissions.forEach (function (permission) {
        element [permission ["type"]] = "yes"
      });
      android_health_and_fitness_free.push (element);
      // save to .csv
      (async () => {
        const csv = new ObjectsToCsv (android_health_and_fitness_free);
        await csv.toDisk ('./ android / android_health_and_fitness_free.csv',
          {allColumns: true});
      }) (); }); }); });

```

Program code 1: Acquisition of Android applications in the Health & Fitness category

Once we obtained the data of free and paid applications for each category, we then combined them into one .csv file. We discarded columns that were irrelevant for our research. We stored the list of all possible permissions, and those are required by each individual application.

However, only the URL link was present for the privacy policy text information, not the full privacy policy text. The URL link should lead to the page where this text is supposed to be located. We have created a new program that uses the Scrapy 2.3 software library [10] to download privacy policy texts. It does this by reading the URLs stored in the shared .csv file. A new column named PrivacyPolicyText is created in which the text is saved. The program cleans the content of each privacy policy text by removing the unnecessary HTML tags.

The exclusion criteria were that the app should have a privacy policy in the first place and be written in English. So, once we had all the app data collected in one file, we decided to manually review some of the privacy policy texts. We randomly selected twenty applications and read their privacy policy texts. In addition to the reading itself, we also observed how well the text is refined, and whether it contains any unreadable characters or not. After just a few texts, we discovered that the texts were not in the form we would have expected. Either they contained illegible characters or only parts of the text were downloaded or there were no texts at all. We then began to investigate the cause of this problem. We visited the URL link where the privacy policy text was supposed to be located manually. Many of the URL links did not work because the pages did not exist or were links to the main address page of a company and not to a subpage containing the text of the privacy policy. In some cases, the URL link did not lead to the app's page, but to the PDF document that contained that text. The Scrapy program did not copy the contents of a PDF document because it works only with the HTML structures. Another problem was that access to certain sites has been disabled for visitors outside the USA. This could be partially solved by using a VPN connection, but there were no software solutions for other previously mentioned problems. We were forced to find a solution.

The solution was to download all the privacy policy texts manually. We went through the list of all applications and visited their URL links, which should contain the texts of the privacy policy. If the URL link contained privacy policy text, we copied and pasted it into the appropriate location in our application file. If the URL contained a link to a PDF, we saved its textual contents to our .csv file. If the URL link led to the address page of the company that developed the application, we tried to find a link to a subpage on the page that would contain the text of the privacy policy and then copy and save it to our file. This manual process was very time consuming. It took about a month. With this manual process, we thus obtained many more privacy policy texts than we had in the automated process, and their content was readable and useful for further studies.

We ended up with a population of 80 and 55 apps with privacy policies in English in “Medical” and “Health and fitness” categories, respectively.

3.2. Data processing

We implemented our Privacy Policy processing algorithm for each of the 135 applications. In the article [11], the authors came up with the idea that the texts of the Privacy Policy could be processed using the `nltk` (Natural language toolkit) module [11]. With the help of this machine learning module, the authors of [7] analyzed the comments of the applications published on the Google Play. Namely, they wanted to find out which comments are related to the security vulnerabilities of the applications. This would make it easier for developers to find security vulnerabilities. They succeeded with the implementation of MARS (Mobile App Reviews Summarization). The latter uses the `nltk` module for its operation. Their algorithm works by first filtering and preprocessing comments, then breaking each sentence into words (tokenization), finding and removing irrelevant words (stop words) and the origin of the word (stemming) [11]. We used a similar process to implement our algorithm, as was also the case in other researches, e.g., [3, 6].

First, we prepared a list of synonyms for each of the permissions from the obtained list of all permissions. These synonyms were determined for each column separately. We did this by reading some of the privacy policy texts and looking for the information that appears in it and is tied to each column. E.g., for “Personal Name” we searched if a name is mentioned somewhere in the text. This could have come in a variety of forms, such as e.g. Personal name, First name, Given name, etc. All of these words represent synonyms for our “Personal Name” column, representing the fact that an app is collecting personal names. We determined synonyms for all columns. However, because we wanted to have as many synonyms as possible, we wrote a program that scraped the appropriate synonyms for a given word. So, in the JavaScript programming language, we created a web scraper using the `powerthesaurus-api 2.0.3` [12] library, which visited `thesaurus.com` and downloaded all its synonyms based on the input word. The synonyms returned from the web page were saved in a .txt file. These synonyms had to be reviewed manually because they were not all relevant. Some had nothing to do with the original word, so we excluded them.

Next, we did a pre-processing the text of the privacy policies. We redesigned the base text and a list of synonyms in a way that is suitable for processing with the `nltk` module. This step is very important, as such texts can be very long and demanding to process. The preprocessing process includes the following steps:

1. tokenization: each sentence in the text is broken down into several tokens or words, which will later be used in the process of removing irrelevant words (stop words) and converting to the origin of the word (stemming). Synonyms are also broken down into several tokens.
2. removal of stop words: there are many unimportant words in the text that do not help us much in analyzing and searching for personal data and permits. Examples of such words would be: 'i', 'me', 'my', 'myself', 'we', 'our', 'ours', 'ourselves', 'you', 'you're', '!', '!', '*', '...' We remove these irrelevant words from our text. All words are capitalized to lowercase;
3. stemming: we converted the word into the original form (root). An example would be the words "argue", "argued" and "arguing" - all of which change into the basic form of "argu" in this process [11].

Once we had all the data ready for processing, we were able to run the word search algorithm in the privacy policy texts.

The algorithm works by using a function that accepts as a parameter a pre-processed synonym for a particular column representing permission or personal data. It also accepts pre-processed privacy policy text for each application.

In general, the algorithm divides one initial field of synonyms into four fields containing strings with the same number of words. A similar thing happens with the pre-processed text of the privacy policy. The whole text is broken into strings in one word, two words, three words and four words. All of these differently long strings of words are each stored in their own box according to their length. The algorithm then first compares the contents of the synonyms field and the privacy policy text fields, which contain a one-word string. Each set of synonyms is compared to each set of privacy policy text. If it finds the appearance of a synonym in the text for an individual column, the function returns True, else False. If True is returned, the search is aborted and the same process is performed for the second column. This means that the same function is called again, which gets the same privacy policy text as the input parameter, but different synonyms belonging to the second column. In this way, the program is executed for all columns. However, if no synonym is found in the privacy policy text, the program returns False.

The search is repeated, so that the fields containing two words in the synonym string and two words in the string containing the privacy policy text information are now compared. Next, the search is repeated for a three-word string, and a four-word string. Based on our list of prepared synonyms, there was no occurrence of a synonym longer than four words.

Table 1 shows the results of running our algorithm on two test apps, with listed personal data and permissions, as detected through the privacy policies.

Personal data and permissions	Application name	
	ZOOM Cloud Meetings	Microsoft Teams
Calendar	True	True
Reminder	False	True
Contact	True	True
Photo	True	True
Bluetooth	True	False
Microphone	True	True
Camera	True	True
Location	True	True

Personal data and permissions	Application name	
	ZOOM Cloud Meetings	Microsoft Teams
HealthKit	False	False
Media Library	False	True
Motion	False	True
Documents	True	True
Language	False	True
Notifications	True	True
Personal Name	True	True
Age	True	True
Phone number	True	True
ID Card	True	True
E-mail	True	True
Physical address	True	True
Medical diagnoses	False	False
Medical ID numbers	False	False
Medical history	False	False
Insurance	False	False
User activity	True	True
Device info.	True	True
Payment	True	True
Social media	False	True
Ads	True	True
IAP	False	False

Table 1: A list of permissions and personal data for two test apps

3.3. Results

Firstly, we show the results of the analysis of the presence of privacy policies.

Category	Number and % of apps without a privacy policy
Health & Fitness	6% (15/255)
Medical	13% (30/232)
Total	9% (45/487)

Table 2: Apps without privacy policies

From Table 2 it can be seen that almost 10 percent of all apps did not have a privacy policy, or it was hidden in such a way that we could not have found it even after extensive search at the developer's website. This is a surprisingly high percentage.

Next, we checked which permissions apps generally request.

Permission	Health & Fitness	Medical
Calendar	58%	69%
Reminder	67%	80%
Contact	96%	95%
Photo	47%	39%
Bluetooth	9%	4%
Microphone	46%	61%
Camera	67%	71%
Location	89%	90%
HealthKit	15%	6%
Media Library	82%	64%
Motion	6%	4%
Documents	69%	71%
Language	33%	31%
Notifications	36%	39%

Table 3: Percentage of apps requiring a given permission

In table above, we can see that in general apps on the Android platform require quite a few permissions. Some of these permissions are required by almost all applications, for example for the Contact and the Location, more than 95% of applications require access to the user's contacts and more than 89% of applications require a user to be able to track her location.

Additionally, we checked whether there are any differences between paid and “free” apps.

Permission	Free apps	Paid apps	Chi-Square (value)	Sig.
Calendar	75%	34%	15,422	0,000
Reminder	86%	51%	8,942	0,003
Contact	94%	93%	0,005	0,942
Photo	58%	29%	9,667	0,002
Bluetooth	5%	3%	0,500	0,480
Microphone	71%	22%	25,817	0,000
Camera	84%	42%	14,000	0,000
Location	94%	78%	1,488	0,222
HealthKit	5%	2%	1,286	0,257
Media Library	75%	64%	0,871	0,351
Motion	7%	2%	2,778	0,096
Documents	79%	61%	2,314	0,128
Language	40%	27%	2,522	0,112
Notifications	45%	12%	19,105	0,000

Table 4: Percentages of required permissions, free vs. paid apps.

We can see in Table 4 that the percentages for requested permissions are higher for free applications. After conducting a Chi-square goodness-of-fit test analysis [13], we found that there are significant differences between paid and free applications for some permits: Calendar, Reminder, Photo, Microphone, Camera and Notifications. For all these permits, the p value was less than 0.05. Free apps require more specific permissions than paid ones.

The main part of our analysis was to check whether the stated requirements as listed in Google App Store website matched those found in privacy policies.

Permission	Percentage		Chi-Square (value)	Sig.
	Privacy Policy	Google Play		
Calendar	68%	12%	39,200	0,000
Camera	76%	58%	2,418	0,120
Contact	94%	35%	26,984	0,000
Device Info.	97%	41%	22,725	0,000
Location	73%	58%	1,718	0,190
Microphone	62%	40%	4,745	0,029
Phone	96%	46%	17,606	0,000
Media Library	73%	84%	0,771	0,380
Ads	80%	14%	46,340	0,000

Table 5: comparison of permissions, privacy policy vs. Google Play website

From the Table 5 above, we can see that the permissions stated on the Google Play website and those extracted from the privacy policy texts are quite different. The percentage shows the extent to which each permission is required in the privacy policy

texts and on the Google Play website. As we can see, the percentages are higher in the privacy policy texts of all permits. We performed a Chi-square goodness-of-fit test analysis and found that there are significant differences between for the following permissions: Calendar, Contact, Device Info., Microphone, Phone and Ads. For all these permits, the p value is less than 0.05.

4. Discussion and conclusion

In this paper, we analyzed 487 apps from Google App store with respect to the permissions these apps require. We compared the list of permissions the apps require as stated on the store's website to those discovered by analysis of the privacy policies.

The paper's novelty is in applying a (semi) automated linguistic analysis on privacy policies coupled with permission requirements analysis to unearth (deliberately!?) hidden information on which permissions apps really require. Best to our knowledge, no previous research on privacy policies was done using the specific linguistic technique on permissions. We limited our research to medical and health & fitness based apps because these apps in principle handle most sensitive data.

Generally, health related apps require all the "expected" permissions, such as calendar, reminders, documents. Surprisingly, though, not so many apps required the HealthKit permission, but on the other hand overwhelmingly required the location and contact data permissions. Surprisingly high is the requirement on camera permission.

The comparison of the list of permissions as stated on the Google Play Store and those identified to be needed through the privacy policy texts revealed a worrying fact: most apps require more permissions than stated, and the differences are quite high. For most permissions, the differences between the stated and the required permissions are statistically significant.

Again, the lenient regulations are not protecting users in the app markets. As with previous studies, large market players are not protecting users. Big players in the market have made the process of protecting personal data deliberately tricky, if not impossible, and are protecting app developers. It seems no one is checking the statements of permissions on the app store, and no one is checking whether a privacy policy is available. Sadly, almost 10 % of the analyzed apps did not have a privacy policy available.

More stringent regulations should be effected, requiring the big players and developers alike to fully disclose their policies with respect to private data, permissions they require, and to be fully accountable for the misleading information.

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