# Reliable AI that Develops the Society

● Takao Mohri ● Nobuhiro Yugami ● Seishi Okamoto

**AI technology is playing a key role in the digitalization and transformation of many aspects of business and society. Since people support large segments of business and society, this transformation needs to be driven by an optimal combination of the best features of people and AI and the provision of high value. Fujitsu Laboratories is researching and developing AI technology on the basis of a human-centric way of thinking. The objective here is not just technology that can demonstrate a level of performance equal to or greater than experts but also that to explain AI output results, which is essential for establishing a close collaboration between people and AI. This paper describes an overall view of FUJITSU Human Centric AI Zinrai. It then introduces advanced technologies that focus on learning such as Deep Tensor, knowledge processing such as knowledge graphs, and "Explainable AI" that combines those technologies using practical examples in fields such as medical care and security.**

## 1. Introduction

AI is a key technology for innovation in all kinds of scenarios in industry and society. In recent years, it has become possible to handle large volumes of data and use large amounts of computing resources, and there have been advances in learning technologies such as deep learning. As a result, many examples that rival or even exceed the capabilities of human experts have begun to emerge. However, there is still strong dependence on humans to pre-process the data, to organize problems into a form that an AI can solve, and to interpret the results output by the AI.

However, now as ever, society and industry are supported by people. Even if some processes are replaced by AI in the future, people will still be central. Still, environments in society and industry continue to change radically, and there are limitations to bringing about such innovation with people alone. For this reason, the knowledge, creativity, and know-how of people need to be integrated with AI technologies.

This paper first describes Fujitsu Laboratories' concept of Human Centric AI. It then introduces some practical examples we have co-created with customers using advanced learning technologies like deep learning and Deep Tensor, and knowledge processing technologies such as knowledge graphs. Finally, we introduce "Explainable AI," a technology to explain the results output by AI, which is crucial for optimal integration of humans with AI.

## 2. FUJITSU Human Centric AI Zinrai

Fujitsu Laboratories has been conducting R&D on AI technologies since the 1980s. In 2015, we announced FUJITSU Human Centric AI Zinrai, which consolidates and organizes these AI technologies.[1] In Fujitsu Laboratories' vision of Human Centric AI, people are at the center, and AI exists to extend human capabilities. With humans at the center, we seek to optimize entire systems that use combinations of people and AI.

An overall image of Zinrai is shown in **Figure 1**. The figure shows typical processes combining real world entities like people, businesses, and society, with AI technologies. Sensing in the real world produces data that is perceived and recognized. This part utilizes technologies such as image and speech processing and emotion inference. The data obtained by sensing and recognition is then processed to produce knowledge. This part utilizes knowledge processing technologies such as natural-language processing, knowledge processing and discovery, and pattern discovery. Finally,


FUJITSU SCIENTIFIC & TECHNICAL JOURNAL, Vol. 54, No. 5, pp. 22–29 (October 2018)
**Cutting-Edge R&D**

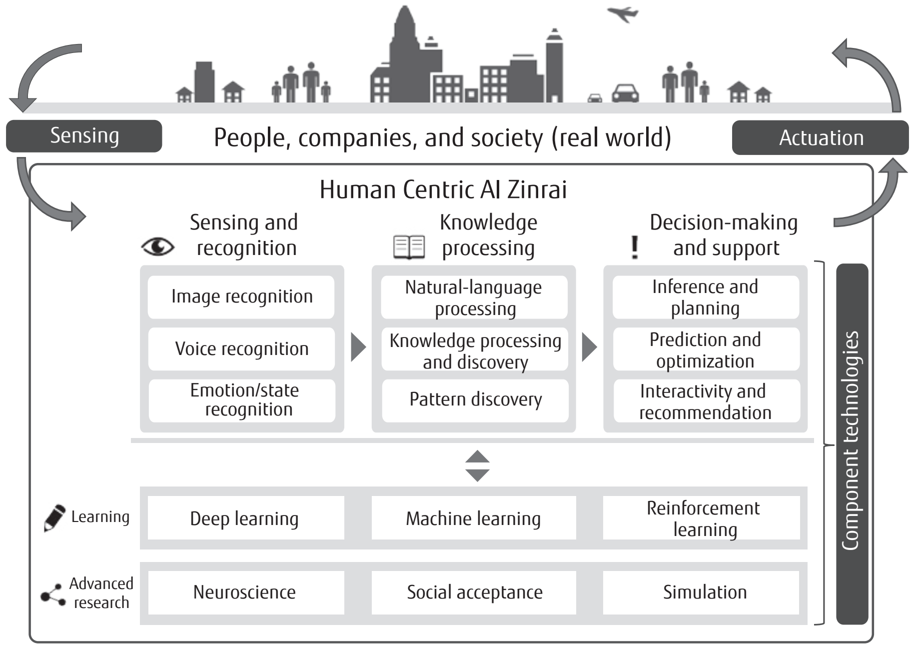


**Figure 1**
**Overview of FUJITSU Human Centric AI Zinrai.**

the knowledge gained is used to make decisions and provide support, producing in work in the real world. This part uses technologies for scheduling and optimization, and others such as dialog interfaces.

Underlying all of these are learning technologies such as deep learning. The results from AI processing are applied in the real world, influencing people, businesses, and society to complete the loop of innovation.

## 3. Learning technologies for numerical and image data

### 3.1 Deep learning overview

Deep learning is the learning technology that has been the driving force behind the recent boom in AI. With conventional machine learning, human researchers first extract feature values from data, which are then used for training an AI. As such, effective learning was dependent on whether researchers could define feature values suitable for learning.

In contrast, deep learning uses multi-level neural networks and is able to extract feature values from data automatically. In many cases, the accuracy of discrimination using these extracted feature values also exceeds that using feature values defined by experts. This has resulted in a breakthrough that has overcome bottlenecks in conventional machine learning. Deep learning has had a strong impact, particularly in areas such as image recognition and speech recognition.

However, while deep learning is effective with data of fixed size and structure, such as images, it is not so effective with other types of data, such as time-series data and graph data. Fujitsu Laboratories has been developing technology to extend deep learning and enable it to learn accurately from such types of data.

### 3.2 Deep learning with time-series data

With time-series data, the amount of data normally increases at fixed time intervals, as with the values obtained from an accelerometer. With this sort of data, it is difficult to determine when the phenomenon to be observed starts and when it ends, or how long it will last. This has made it difficult to determine what segments of data should be used as input for deep learning, as is done with fixed-length image data. For example, there are large and complex fluctuations in time-series data from sensors in IoT devices, so it has been difficult to classify such data accurately using deep learning and other forms of machine learning.

Fujitsu Laboratories has developed a deep learning technology that is able to classify time-series data automatically with high precision, utilizing chaos theory and topology.[2] It is known that when changes in time-series data are plotted on a graph using chaos theory, a locus representing a characteristic of the operation of the mechanism being measured is drawn. We treat this locus as a graphic, topologically analyzing characteristics such as the number of holes and overall shape, and transforming it into a characteristic vector representation. We then apply deep learning to realize a highly accurate classification. Using this method, we have achieved an inference accuracy 20% to 25% higher than that of other existing methods for applications including inferring behavior from gyro-sensor data and inferring current state from brain waves.

### 3.3 Collaborative research with Shimadzu Corporation

Fujitsu Laboratories has been conducting research in collaboration with Shimadzu Corporation, applying deep learning to the analysis of results from a liquid chromatography-mass spectrometer from Shimadzu Corp. (**Figure 2**).[3]

Liquid chromatography-mass spectrometers are used for research and quality control in many fields, and as their sensitivity and speed of analysis has increased, they are producing increasingly large quantities of data. Measurements are output in the form of chromatograms, which are interpreted by reading features such as waveform widths and peak heights in a process called peak picking. Because of the increase in data, this peak-picking process by skilled workers has become a bottleneck.

In our collaborative research, Shimadzu Corp. developed technology that generates data to compensate for inadequacies in our training data. Fujitsu Laboratories developed technology to convert features in the liquid chromatography output into images and extracts features that are used to gain expert know-how for analysis. The resultant automatic peak-picking technology has shown potential to yield accuracy that is comparable to skilled workers.

## 4. Learning technologies for graph data

### 4.1 Deep learning for graph data

Graph data is structured with many nodes connected

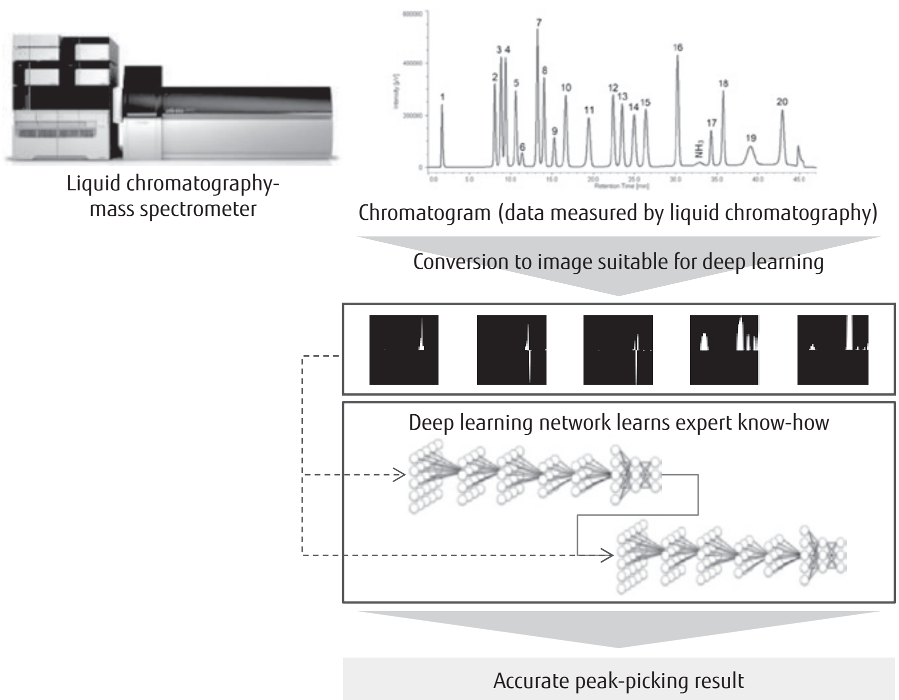


**Figure 2**
**Application of deep learning to liquid chromatography results.**

by links in a network, and can be used to represent many types of real-world data. However, unlike an image, it does not have a fixed data size or structure, so it has been difficult to process it in its usual form with deep learning.

To resolve this issue, Fujitsu Laboratories has developed Deep Tensor.[4),5)] We convert graph data to a uniform representation called a tensor, and use it to apply an extended version of error back-propagation, which is a method used in deep learning. This has made highly accurate classification of graph data possible with deep learning.

### 4.2 Application for increasing accuracy of malware attack detection

Cyberattack techniques have become increasingly sophisticated recently. In particular, targeted attacks use specialized malware to penetrate systems, so it is becoming important to take measures after being infected. However, the methods, frequency, and scope of attacks by the infecting malware change with time. Furthermore, this activity is intermingled with everyday network communication, so complex analysis of various malware behaviors is needed to detect it.

With Deep Tensor, Fujitsu Laboratories has been able to increase its accuracy in detecting attacks by malware that have infected networks in enterprises and other organizations.[6)]

We have developed technology that extracts various features from time-series log data, which uses Deep Tensor to learn relationships among them. This has enabled us to successfully learn about relationships among behaviors of infecting malware, such as the types, number, intervals, and order of behaviors, and to ascertain features of the malware (**Figure 3**). In experiments to distinguish network traffic from ordinary work and attacks by malware, we were able to learn how to trace multiple changes over time, and detect attacks with a high accuracy of 93%.

## 5. Knowledge processing technologies

### 5.1 Knowledge graphs

Knowledge graphs gather information from sources such as the Internet or within an enterprise, and connect it together with relations that represent meaning. Over approximately 20 years since beginning research on the Semantic Web[7)] in 1998, Fujitsu

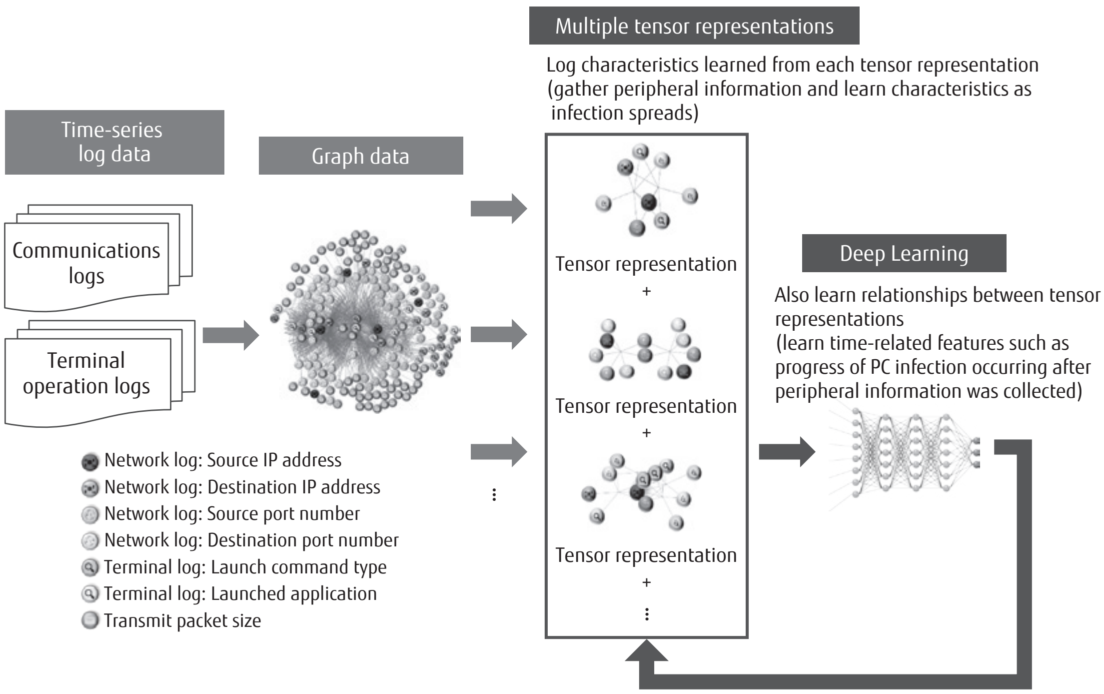


**Figure 3**
**Application of Deep Tensor to malware intrusion detection.**

Laboratories has conducted R&D and accumulated technologies for representation, analysis, and high-speed processing of knowledge graphs.

For knowledge graphs, technology for making interconnections among distributed, individual items of knowledge is important. Fujitsu Laboratories has developed technology that infers similarity among data on the basis of similarity of representation or data structure, and automatically draws relationships with other existing data created separately.[8]

Fujitsu Laboratories has also developed technology and infrastructures for searching and using linked open data (LOD), which is open data with linked interrelationships. Since 2014, we have led the industry in providing the LOD4ALL platform enabling the use of LOD free of charge. LOD4ALL gathers and stores open data encompassing tens of billions of items distributed on the Internet and makes them searchable.[9] With LOD, links tend to concentrate around certain data, so we focused on that characteristic when implementing distributed processing and cache structures, which has enabled us to implement a high speed search five to ten times faster than earlier methods.

### 5.2 Trials held at Clínico San Carlos

In one application of knowledge graphs, a new healthcare system has been prototyped to support a rapid decision making process for doctors, and trials were conducted at Clínico San Carlos in Spain.[10] Fujitsu Laboratories developed this system through a collaboration with specialists in the field of psychological pathology at Clínico San Carlos. To meet the requirements of medical clinics in Spain, Fujitsu Laboratories' knowledge graph and anonymization technologies were combined and applied in the healthcare field.

For these trials, we built a system with a knowledge graph containing links among individual data items from sources, including anonymized data from over 36,000 patients and a database of medical papers. In the field tests, the risks of suicide, alcohol dependency, and drug dependency were computed with an accuracy greater than 85%. In the past, this type of data was only available in paper form, and various materials recorded in different formats also had to be investigated. These trial results showed that we were able to reduce the time doctors spent selecting patient records to less than half. This increased the potential for doctors to spend time with patients and should lead to improvements in medical care.

## 6. Explainable AI

### 6.1 Technologies for implementing Explainable AI

As discussed above, AI technologies such as deep learning and knowledge graphs are advancing, and as they are being applied in various fields, the increasingly black-box nature of AI is a significant concern. If a reason or basis for a response given by an AI could be given, people could understand the AI and trust it. Also, explaining reasons for a decision made by an AI not only fulfills the duty of explaining the reasons to customers, but could also provide new discoveries for humans, leading to improvements in the AI technologies themselves. Explainable AI could be viewed as an essential technology for the optimal collaboration between humans and AI.

Accordingly, Fujitsu Laboratories has developed technology that uses knowledge graphs to explain Deep Tensor inference results as a way to implement Explainable AI[11)–13)]. As shown in **Figure 4**, this technology consists of two technologies, inference factor identification to explain the reasons for an inference, and basis composition to explain a basis for the result.

For each input data set, inference factor identification performs a reverse search of the Deep Tensor output results to identify multiple factors that have a strong influence on reaching the result. Information related to each of these factors can then be found by comparing them with the knowledge graph. Basis composition searches the graph structure, using multiple inference factors as clues, to find information that is closely related to the inference factors that have been identified, thereby composing a basis for the inference.

### 6.2 Applications in genomic medicine

Fujitsu Laboratories collaborated with the Japan Agency for Medical Research and Development (AMED) and Kyoto University to apply Explainable AI in the field of genomic medicine. The objective of this collaboration was to make investigative work by specialists in genomic medicine more efficient through the introduction of Explainable AI.

For Deep Tensor training data, we used a

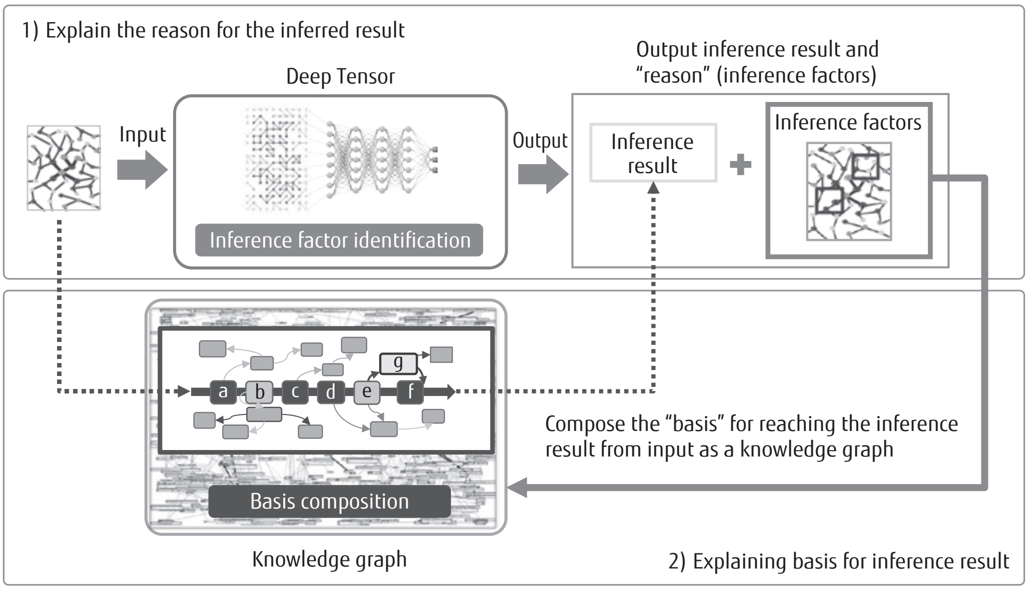


Figure 4
Technology realizing Explainable AI.

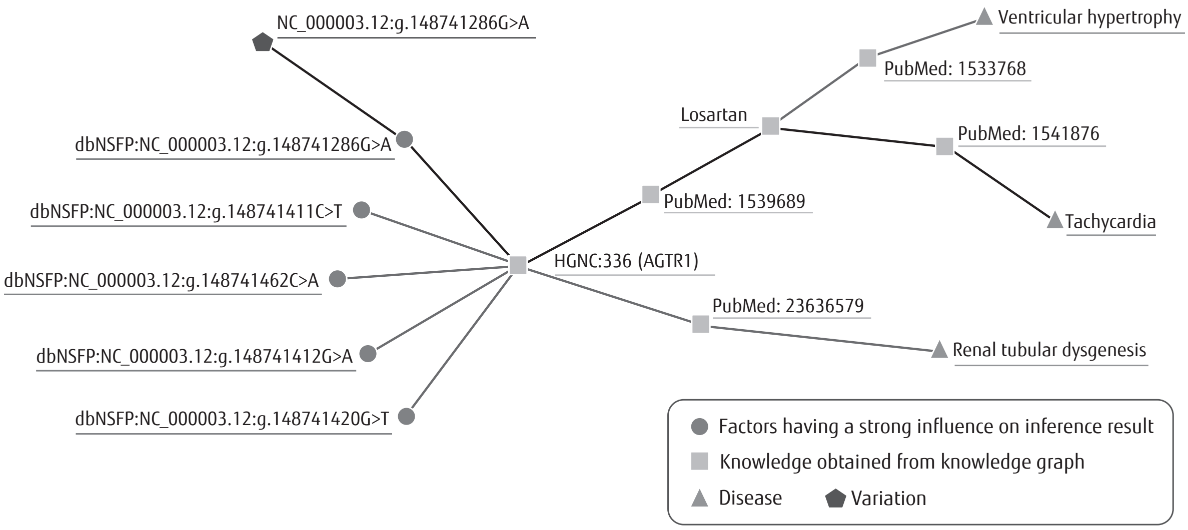


Figure 5
Concrete example of basis path from Explainable AI.

knowledge graph that we built from sources including public bioinformatics databases and databases of medical publications. We then searched for a supporting basis for phenomena among Deep Tensor output results if the relationships were only partially known, and verified whether the associations were valid.

**Figure 5** shows the result of performing Deep Tensor training with relations between genetic variations and pathologies, built from public databases, and selecting factors and a basis for an inference from academic papers and relational information. For an inferred genome variation (pentagon), multiple factors having significant effect on the inference result were identified (circles), together with bases that provide academic backing selected from sources such as medical publications using the knowledge graph (squares), and candidate diagnoses (triangles). In this way, a path providing an explanatory basis can be found, connecting the input (a genome variation) with the output (a pathology) of the AI. This can greatly reduce the amount of work involved in identifying and verifying pathologies related to genomic variations.

## 7. Conclusion

This paper described the latest AI technology from Fujitsu contributing to innovation in society and industry, along with examples of applications.

Some of the data used to verify the effects in the field of genomic medicine were obtained as results of joint research with Kyoto University within the "Program for an Integrated Database of Clinical and Genomic Information" at AMED under Grant Number JP18kk0205013.

Explainable AI is a technology that is essential for innovating cooperation between humans and AI in society and enterprise. We will continue to advance our technical development with the cooperation of our customers, so that AI technologies can contribute to innovation in society and enterprise that focuses on people based on the Human Centric concept.

## References

1) Fujitsu: Fujitsu Takes Systematic Approach to Artificial Intelligence with "Human Centric AI Zinrai." *http://www.fujitsu.com/global/about/resources/news/press-releases/2015/1102-01.html*
2) Fujitsu Laboratories: Fujitsu Develops New Deep Learning Technology to Analyze Time-Series Data with High Precision. *http://www.fujitsu.com/global/about/resources/news/press-releases/2016/0216-01.html*
3) Shimadzu Corp., Fujitsu, Fujitsu Laboratories: Shimadzu, Fujitsu, and Fujitsu Laboratories Announce Results of Collaborative Research. *http://www.fujitsu.com/global/about/resources/news/press-releases/2017/1113-01.html*
4) Fujitsu Laboratories: Fujitsu Technology to Elicit New Insights from Graph Data that Expresses Ties between People and Things. *http://www.fujitsu.com/global/about/resources/news/press-releases/2016/1020-01.html*
5) K. Maruhashi: Deep Tensor: Eliciting New Insights from Graph Data that Express Relationships between People and Things. Fujitsu Sci. Tech. J., Vol. 53, No. 5, pp. 26–31 (2017). *https://www.fujitsu.com/global/documents/about/resources/publications/fstj/archives/vol53-5/paper05.pdf*
6) Fujitsu Laboratories: Fujitsu AI Increases Accuracy of Malware Intrusion Detection. *http://www.fujitsu.com/global/about/resources/news/press-releases/2017/0919-04.html*
7) W3C: Semantic Web *https://www.w3.org/standards/semanticweb/*
8) Fujitsu Laboratories, Fujitsu Research and Development Center, Fujitsu Laboratories of Europe: Fujitsu Laboratories Develops Technology for Automatically Linking with Open Data throughout the World. *http://www.fujitsu.com/global/about/resources/news/press-releases/2014/0116-01.html*
9) Fujitsu Laboratories, Digital Enterprise Research Institute, Fujitsu Laboratories of Europe: Fujitsu and DERI Revolutionize Access to Open Data by Jointly Developing Technology for Linked Open Data. *http://www.fujitsu.com/global/about/resources/news/press-releases/2013/0403-02.html*
10) Fujitsu Laboratories of Europe: Fujitsu's Human-Centric AI Helps Enable Faster, Improved Clinical Decision-Making. *http://www.fujitsu.com/uk/about/resources/news/press-releases/2015/pr-fle20161110.html*
11) Fujitsu Laboratories, Fujitsu: Fujitsu Fuses Deep Tensor with Knowledge Graph to Explain Reason and Basis Behind AI-Generated Findings. *http://www.fujitsu.com/global/about/resources/news/press-releases/2017/0920-02.html*
12) K. Maruhashi et al.: Learning Multi-way Relations via Tensor Decomposition with Neural Networks. Proc. of Thirty-Second AAAI Conference, Artificial Intelligence (AAAI 2018), 2018.
13) Fujitsu: "Dr who? Peering into the Black Box of Artificial Intelligence." Nature, No. 7685 (2017). *https://www.nature.com/collections/hshfngjxvb*

**Takao Mohri**
*Fujitsu Laboratories Ltd.*
Dr. Mohri is currently engaged in R&D on solutions utilizing AI.

**Nobuhiro Yugami**
*Fujitsu Laboratories Ltd.*
*Fujitsu Ltd.*
Dr. Yugami is currently engaged in R&D on learning technologies and knowledge processing technologies.

**Seishi Okamoto**
*Fujitsu Laboratories Ltd.*
*Fujitsu Ltd.*
Dr. Okamoto currently supervises the AI research at Fujitsu Laboratories.