Research and Development and Related Activities at Fujitsu Laboratories Overseas Bases

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As the core research and development (R&D) organization driving innovation in the Fujitsu Group, Fujitsu Laboratories (Japan) collaborates globally with three overseas research laboratories: Fujitsu Laboratories of America, Fujitsu Research and Development Center (China), and Fujitsu Laboratories of Europe. These overseas laboratories research and develop key technologies in close collaboration with Fujitsu Laboratories (Japan) while also pursuing standardization activities and original R&D projects reflecting the distinctive features of their regions. They also actively pursue open innovation through tie-ups with leading universities and research institutions in their respective areas. Furthermore, to support Fujitsu's business activities in their regions, they are committed to business incubation as exemplified by their collaboration with startup companies and introduction of advanced technologies through forums and exhibits. This paper introduces the research and development and associated activities at each of these overseas research laboratories, which play an important role in supporting the Fujitsu Group.

1. Introduction

Fujitsu promotes the development of a safer and more prosperous society by supporting people through the power of information and communications technology (ICT) and by developing innovative problem solutions. The core research and development (R&D) organization driving innovation and creativity in the Fujitsu Group is Fujitsu Laboratories (Japan), which works in collaboration with three overseas research laboratories: Fujitsu Laboratories of America, Fujitsu Research and Development Center (China), and Fujitsu Laboratories of Europe.

These overseas research laboratories were originally established to promote research using highly competent personnel and superior research institutions in their regions and to engage in original R&D projects reflecting the distinctive features of those regions. Later, in response to the globalization of business and the dawn of a global economy, these overseas research laboratories began to collaborate on cutting-edge research and development in line with global trends. More recently, they have been actively promoting business incubation to support Fujitsu business in their regions such as by forming tie-ups with startup companies and introducing advanced technologies at forums and exhibits.

Fujitsu Laboratories of America is based in a country known for innovative ICT and new business models. In addition to researching and developing advanced technologies that can be applied worldwide, it fosters new business through incubation activities that include outside investors and an internal business-startup system. Fujitsu Research and Development Center (China), meanwhile, is based in a country known for its remarkable economic growth. It aims its research and development efforts at China's massively growing markets while also promoting innovation in the development of technologies for markets that place a priority on speed and cost. Finally, Fujitsu Laboratories of Europe is engaged in cutting-edge research and development oriented to solutions in Europe, the Middle East, India, and Africa (EMEIA), a region consisting of many countries with diverse values and cultures. At the same time, it is working to raise the presence of Fujitsu in EMEIA by introducing advanced technologies as part of the Fujitsu World Tour held in each of those areas

and by participating in European projects.

In this paper, we introduce the research and development themes and related activities at each of these overseas research laboratories, which play a vital role in supporting the Fujitsu Group.

2. Fujitsu Laboratories of America

Fujitsu Laboratories of America (FLA) was established in Sunnyvale, California, in 1993. An additional facility was set up in Richardson, Texas, in 2002. Boasting about 60 researchers from 14 countries (about 70% of whom hold doctorates), FLA promotes R&D activities that leverage the distinctive regional features of Silicon Valley in Northern California and the Telecom Corridor in Texas.

The mission of FLA is to research and develop advanced technologies tailored to global needs and to become an incubator of new businesses in North America. To this end, FLA adopts the following three-step R&D scheme (**Figure 1**).

- Survey and disseminate latest ICT trends
- Foster innovation
- Business strategies

2.1 Survey and disseminate latest ICT trends

In this step, FLA searches out information essential to the formulation of Fujitsu R&D strategies and cultivation of new markets and promptly shares that information with appropriate personnel. It also selects and proposes themes that should be pursued. FLA closely collaborates with Fujitsu Laboratories (Japan) in these activities. It has also sponsored annual symposiums and forums for more than eight years to raise the presence of Fujitsu in North America.

2.2 Foster innovation

FLA energetically pursues the research and development of pioneering technologies befitting North America (and Silicon Valley in particular) in collaboration with universities and other companies (venture startups, etc.). Its research themes take on the configuration shown in **Figure 2**.

2.2.1 Platform Research

In platform research, FLA promotes advanced development of servers and optical transmission

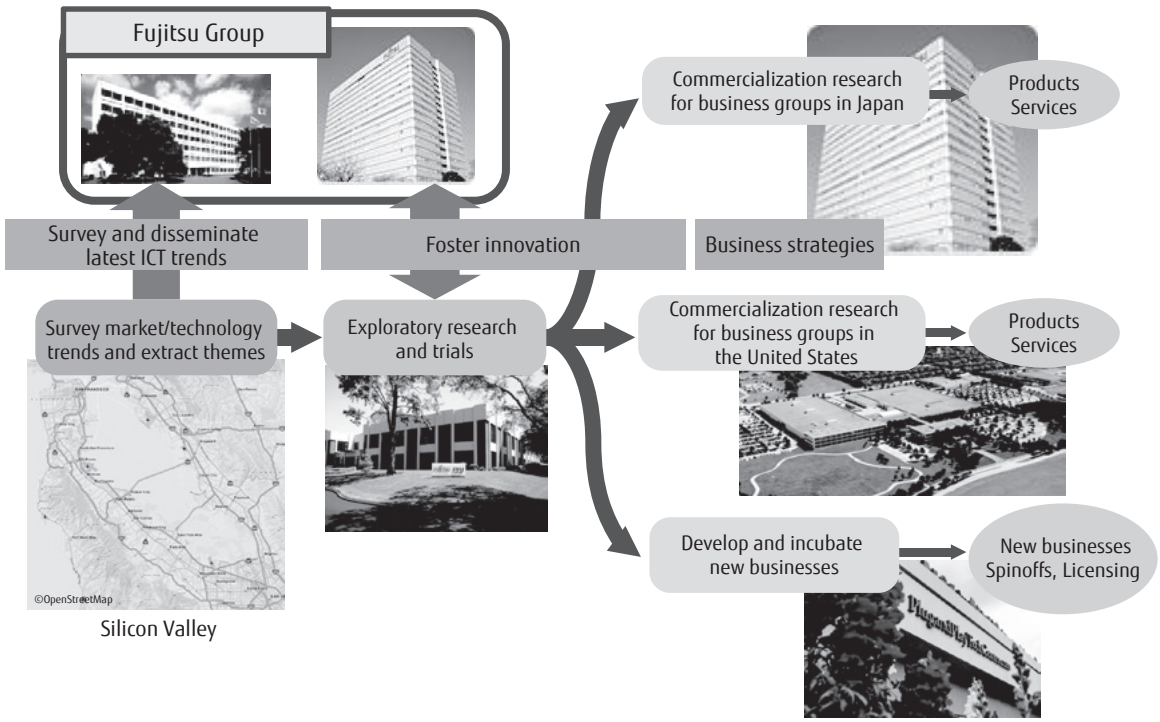


Figure 1
FLA R&D scheme.

equipment and engages in standardization activities in close collaboration with various business groups.

In the area of high-speed links, FLA plays a part in the development and product application of high-speed interconnects for servers, while in the area of networks and dense wavelength division multiplexing (DWDM), it is pushing research on the architecture of next-generation optical transmission equipment. Furthermore, in software validation, FLA has developed a system called KLOVER[1)] for automatically generating test data with the aim of achieving universal validation of developed software (firmware) and improving the reliability of Fujitsu products. The KLOVER system is illustrated in **Figure 3**.

In the areas of security and standardization, FLA is performing fundamental research on an ambitious system that will use FLA program analysis technology to statically and dynamically discover vulnerabilities in application software and revise programs automatically.

In these activities, FLA is engaged in technology exchanges and joint research with the University of Texas at Dallas, the University of California, Berkeley, Stanford University, and other universities to accelerate the research and development process.

2.2.2 Solutions Research

In solutions research, FLA has established smart energy, healthcare, and open education as major research themes, which are particularly in demand in the United States and meaningful in that their development is expected to precede that in Japan.

In the "solutions for energy distribution" theme in the smart energy field, FLA has led the drafting of specifications (OpenADR2.0b) for the optimal distribution of electric power by coordinating the supply side and consumption side using a technology called demand response (DR). It has also developed the world's first prototype system incorporating this technology.[2)]

Next, in data-driven life innovations under healthcare solutions, FLA has succeeded in quantifying stress felt by people in the real world[3)] and has begun work on using this technology to advise people on how to improve their quality of life. An example of stress measurement is shown in **Figure 4** for the case of a round trip between an employee's home and office. In the figure, a thicker line represents a more relaxed state. It can be seen that the employee is more relaxed at points closer to home on the return trip and always tense on the trip to work.

In open education solutions, FLA is researching and developing a new education system using the Massive Open Online Course (MOOC) model now gaining popularity in the United States.

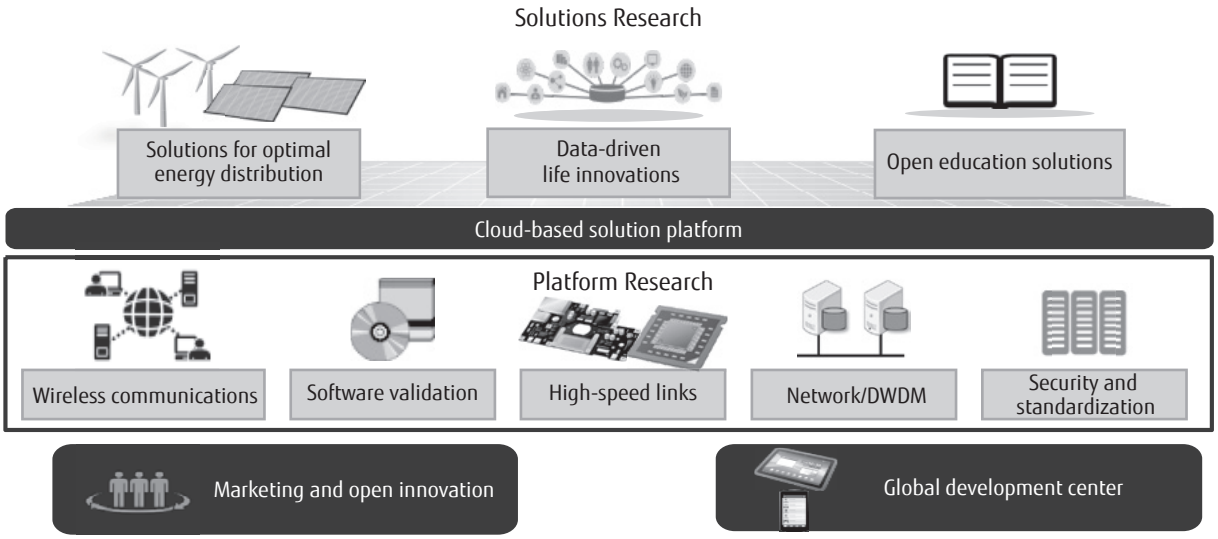


Figure 2
Configuration of FLA research themes.

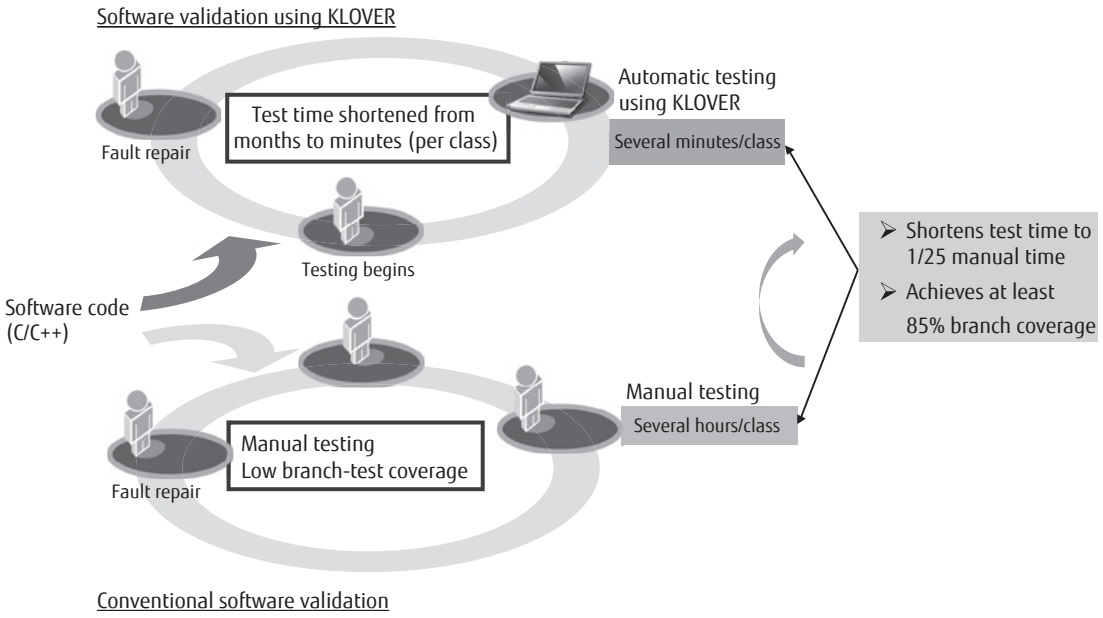
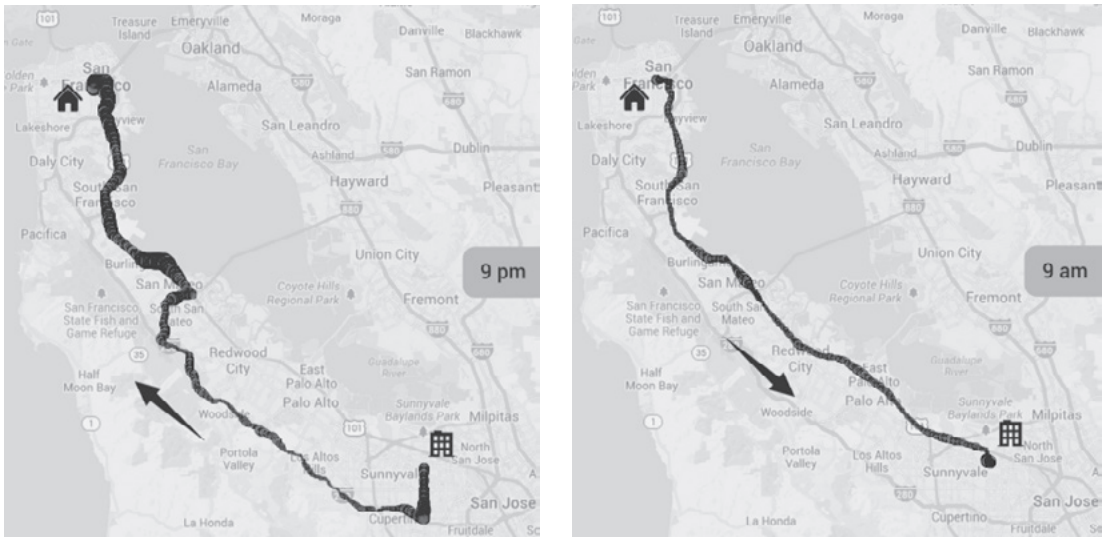


Figure 3
Overview of KLOVER.



Returning home　　Going to work

Figure 4
Quantification of stress.

2.3 Business strategies

In close collaboration with Fujitsu Group companies in Japan and the United States, FLA is making inquiries both inside and outside the company as to the potential effectiveness of research results. Examples of such targeted results include the high-speed interconnects and KLOVER system mentioned above.

At the same time, FLA is promoting its own business incubation activities by leveraging the distinctive ecosystem in Silicon Valley (aggressive investors such as venture capitalists and angel investors, top-class personnel, experienced advisors, etc.) and an internal

business-startup system. For example, FLA is studying the possibility of incubating businesses using stress quantification and OpenADR2.0b as core technologies.

2.4 Summary

North America has traditionally been thought of as a region giving birth to new ICT trends, but more recently, it has also come to be called an originator of new business models. Apple, Google, and Facebook are just a few examples. Fujitsu, as well, seeks to leverage the benefits of this region and develop advanced technologies while also fostering innovation through business incubation activities.

3. Fujitsu Research and Development Center (China)

Established in 1998, Fujitsu Research and Development Center (FRDC) is Fujitsu's largest overseas research laboratory with about 120 employees at present. It is headquartered in Beijing and has offices in Shanghai and Suzhou.

The mission of FRDC is to "make Fujitsu internationally competitive through research and development." To fulfill this mission, FRDC serves as an offshore R&D base supporting Fujitsu products and services of the future, investigates market and technology trends in China, and engages in research and development of technologies and services targeting Chinese and overseas markets. FRDC is organized into three research sections targeting communication technology, information technology, and media platform technology. The communication technology section researches and develops next-generation wireless systems, sensor networks, and optical communication systems and helps standardize the developed technologies. The information technology section researches and develops information-processing technologies such as knowledge processing and machine learning based on the Chinese language. The media platform technology section researches and develops large-scale video monitoring and video compression technologies. Among these endeavors, we will here introduce the "act local" research activities targeting the Chinese market.

3.1 Human resources and localization

FRDC's young and exceptional researchers, which includes holders of doctorates from Peking University and Tsinghua University and a second-place winner of China's Mathematical Olympiad, are a valuable asset. FRDC also has connections with the Chinese government and more than 30 leading universities, and its annual "China Technology Forum" targets industry, government, and academia.

With only three Japanese employees, a key strength of FRDC is locally rooted research and development and business support targeting the Chinese market. For example, FRDC's character-recognition technology was highly evaluated by the Chinese government in benchmark testing held for selecting the handwritten character recognition technology to be used in China's 2010 national census. As a result, FRDC beat out other competitors in obtaining this business, which demonstrated that the Chinese government is willing to adopt differentiating technology applicable to the Chinese market. As it turned out, the National Bureau of Statistics of China reported that FRDC's optical character recognition (OCR) technology achieved an accuracy of 99.94% in the reading of about 800 million forms in the national population census.

Business connections, prompt delivery, and low-cost services are dominant themes in the Chinese market. By using the knowledge gained through experiences such as the one described above, Fujitsu, as a foreign company in China, believes in the importance of making inroads into the Chinese market. Fujitsu uses a differentiating technology that meets Chinese needs as a weapon and that cannot be imitated by other companies, making best use of highly qualified local talent.

3.2 Development of differentiating technology through large-scale trials

In addition to existing differentiating technology, FRDC is engaged in research and development that fosters innovation based on large-scale trials with an eye to the large-scale features of the Chinese market. Three current R&D projects at FRDC exemplify this R&D effort: digitization of historical documents, character recognition using artificial intelligence (AI) technology, and large-scale video monitoring solutions.

3.2.1 Digitization of historical documents

The Chinese government is strongly supporting the cultural preservation efforts involving the

digitization of the more than 50 million historical documents in China. Such digitization requires a considerable amount of human labor, so there is a need for increasing the efficiency and lowering the costs of this work. To enable the digitization of large-sized historical documents using a compact scanner, FRDC developed image synthesis technology that stitches together two scanned images (**Figure 5**).[4] This technology is targeted at both photographs and video. In both cases, a uniform geometric conversion is applied to the overlapping area of two images for stitching purposes. However, it is unable to correct for the distortions and wrinkles characteristic of historical documents that come with aging and has not achieved a level of quality deemed necessary for preserving important materials. In FRDC's newly developed technology, the first step is to search the overlapping area of two images for a stitching seam that minimizes distortions and wrinkles. The next step is to stitch the two images along this seam by applying a local geometric transformation that does not disturb the linear arrangement of text lines and the frames about graphics. This technology will make it possible to digitally preserve precious materials, which is becoming a matter of urgency in China. These materials include old newspapers and maps that date back more than 60 years from the Republic of China era.

3.2.2 Character recognition using AI technology

FRDC has developed handwritten character recognition technology achieving the best accuracy in the field by using AI technology (deep learning) that emulates the functions of the human brain. The conventional approach to recognizing individual handwritten characters is to determine the direction and number of strokes making up a character as character features. This method has problems since it cannot recognize greatly deformed characters and requires time for learning characters to raise recognition accuracy. With such problems in mind, FRDC developed mechanisms for learning character features in more detail and at higher speeds by using AI technology that emulates human brain processes.[5),6)] This approach shortened character learning time to about 1/17 that of the conventional approach and achieved recognition accuracy of 94.8%, which was good enough to take first place in a handwritten (Chinese) character recognition contest held in 2013 at the International Conference on Document Analysis and Recognition (ICDAR), the largest conference in the field of document image processing. FRDC expects this technology to raise the efficiency of data input when digitizing handwritten characters on forms and other media.

Figure 5
Preservation of historical documents.

3.2.3 Large-scale video monitoring solutions

1) High-speed fire detection technology

Forest fires covering an area of from 60 000 to 140 000 km^2 occur annually throughout the world, creating a need for early detection and extinguishing. In China, as well, there are about 9000 forest fires a year, resulting in the loss of forest area equivalent to about 130 km^2. In light of this situation, FRDC developed technology for automatically detecting fires that uses image sharpening and object recognition as base technologies (**Figure 6**). This technology has come to be adopted in Hubei province in China after completing forest-monitoring trials there and in Fujian province after achieving a detection accuracy of 99.36% against a benchmark established by a customer from that area. The key feature of this technology is high-accuracy smoke/fire detection based on image processing that removes fog and smog, which can degrade visual recognition in outdoor monitoring, and sharpens smoke and fire.[7)] In addition, this technology optimizes computation-intensive video processing through an original high-speed algorithm, which enables real-time analysis by software.

Figure 6
Forest fire monitoring.

2) Traffic-monitoring video analysis technology

In China, there are more than 150 million automobiles on the road, and congestion and traffic accidents have become a major issue (60 000 deaths annually, 92% of which are caused by traffic violations). To raise the efficiency of current monitoring work based on visual means, FRDC developed technology for analyzing camera images in real time to automatically detect abnormal situations, congestion, etc. This technology first extracts the features of a recognition target, analyzes its trajectory of motion, and extracts object attributes, position, direction, speed, etc. It then compares that data with rule data and detects traffic violations or abnormalities with high accuracy by software means. A high-speed algorithm enables real-time processing of multiple camera images using only a personal computer server.

3.3 Refining technology for global needs

As shown by the examples above, China is a place where talented personnel can repeatedly perform large-scale trials. This means that technology developed in China can be refined for the global market. The technologies developed in China's unique environment, where the features of a developed and a developing country coexist, prioritize speed and cost, so they are well suited to developing counties. Moreover, this environment can also give birth to products having high cost-performance, which have the potential to disrupt markets in developed countries. With this in mind, FRDC seeks to foster innovation in technology and product development.

4. Fujitsu Laboratories of Europe

Fujitsu Laboratories of Europe (FLE) was established in 2001 in the London suburbs as a research institution covering the EMEIA region centered on Europe. FLE researchers represent more than 15 countries and most hold a doctorate in their fields of specialization, making for a research and development environment with great diversity. It plays three roles within the Fujitsu Laboratories global network.

- Center of Excellence (CoE)

  Perform cutting-edge research and development not only for Fujitsu and Fujitsu Laboratories (Japan) but for the world as well
- EMEIA contributions

  Make direct contributions to Fujitsu business in the EMEIA region
- Group collaboration

  Share in some of the research now in progress at Fujitsu Laboratories Group and make good use of FLE personnel and technologies and the R&D network built up in the EMEIA region

4.1 Research and development overview

There are four key R&D areas at FLE, each with its own research division or group.

- Big data analysis: Data Analytics Research Division
- 5G (5th generation) wireless: Future Networking Research Division
- High-performance computing (HPC) applications: Technical Computing Research Group
- Digitalized manufacturing: Engineering Cloud Research Group

In addition, the Research Transformation & Innovation Group is in charge of R&D strategy, transformation of technology into business, and open innovation. In activities that go beyond the framework of individual groups pursuing their own research in parallel, this group is promoting and applying technologies for data and privacy protection now a target of regulation and legislation in the European region.

4.2 Overview of research areas

4.2.1 Big data analysis (EMEIA contributions, group collaboration)

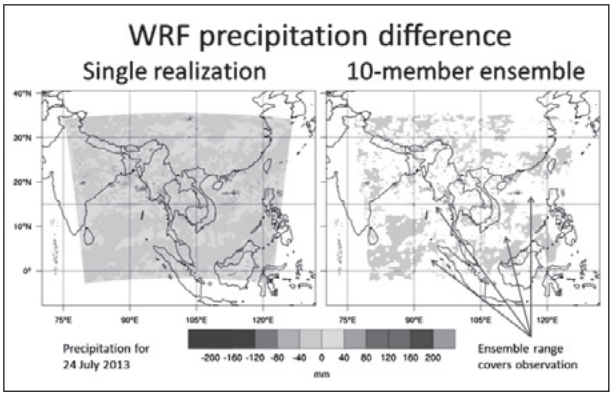
Amid the growth of business using big data, FLE continues its research and development of a platform for big data analysis that it began five years ago. The focus is on a data format called Linked Data, which represents the connections between information, and on the processing of Web and SNS information, which is difficult to represent relationally. FLE has developed a platform called BigGraph to handle this information in a more efficient manner. The concept and processing system of BigGraph is centered about LOD4ALL (a platform for handling open data described in the Linked Data format) provided by Fujitsu. FLE is developing platform technology for achieving even more advanced analysis and is promoting the application of big data analysis to diverse fields including healthcare, finance, energy, and protection of the natural environment.

4.2.2 5G wireless (group collaboration)

"5G wireless" is the next-generation wireless system scheduled to begin service around 2020. It will provide a high-speed, low-delay, and large-capacity service superior to 4G while also becoming an infrastructure for the Internet of Things (IoT), which will connect not just people to people but also people to things and things to things. FLE is developing technologies essential to 5G and is planning to participate in standardization activities from 2016. At the same time, FLE considers that connecting things via the network and having them exchange information will greatly affect not only how we view communications but also the way in which information is handled and the way in which people live. With this in mind, FLE is engaged in research activities toward the cultivation of new business to support the role that Fujitsu intends to play in 2020. FLE is also participating in the 5G Innovation Centre established by the University of Surrey as a founding member. This Centre provides FLE an opportunity to engage in discussions and technology development with telecommunication carriers, research institutions, communications solutions enterprises, measurement device makers, and user companies.

4.2.3 HPC applications (CoE, EMEIA contributions)

There is a high demand for advanced science and technology computing in Europe and the Middle East, and the supercomputer business is consequently doing well in those areas. FLE has a history of developing simulation technology in the fields of oceanography, living organisms, and biotechnology and of developing technology for running such simulations at high speed on supercomputers. These technologies are being collected in the Fujitsu Laboratories Group centered about FLE and are playing an important role in Fujitsu's supercomputer business. In this regard, concerns about climate change have recently intensified around the world, generating a growing demand for meteorological simulations. FLE was quick to establish technology (ensemble prediction) (**Figure 7**) to meet this demand and is working to leverage it in business negotiations and apply it to disaster prevention and mitigation solutions.



WRF: Weather research and forecasting

Figure 7
Rainfall forecast using ensemble prediction technology.

4.2.4 *Information-based manufacturing: (group collaboration)*

At FLE, researchers have developed manufacturing analysis technology and multi-physics simulation technology covering multiple physical models and multiple physical phenomena such as structure, heat, and electricity. These technologies are being incorporated into the Engineering Cloud, Fujitsu's manufacturing solution. Moreover, advancement of the Industrie 4.0 (Germany) and industrial internet (United States) concepts indicates that manufacturing and ICT enterprises are finally joining hands to achieve information-based manufacturing. FLE is focusing on Industrie 4.0 and is collaborating with Fujitsu Technology Solutions (Germany) in an attempt to redefine Fujitsu's manufacturing technology within the framework of Industrie 4.0.

4.3 EMEIA contributions

The EMEIA region boasts sales second only to Japan within the Fujitsu Group. Most of those sales come from businesses that provide products and services for constructing an information infrastructure. FLE is working to raise the profile of Fujitsu in the EMEIA region. In particular, FLE is striving to make customers and potential customers aware that Fujitsu is an innovation-driven enterprise and is working to put Fujitsu on a path toward creating business in the "information" and "people" domains, as described in the Fujitsu Technology and Service Vision.[8)]

To further raise the profile of Fujitsu, FLE participates in the annual Fujitsu World Tour centered on the EMEIA region.[9)] FLE is in charge of exhibiting select technologies from its research groups and of holding advanced technology sessions. In FY2014, it participated in Fujitsu World Tour events covering seven countries. As a result of promoting Fujitsu as "a driver of innovation," the number of participants increased significantly over the previous year in all countries, and all events were well received.

FLE also holds the annual Fujitsu Innovation Gathering as an original FLE event (**Figure 8**). This event is held at one of the Fujitsu World Tour locations to introduce Fujitsu research activities. It was held in Dublin (Ireland) in FY2013, Helsinki (Finland) in FY2014, and Madrid (Spain) in FY2015, receiving praise at each of these locations. The event in Spain

Figure 8
Panel discussion by FLE at Fujitsu Innovation Gathering.

was especially noteworthy as it announced the initial results of projects launched the year before in collaboration with Fujitsu Spain and major Fujitsu customers in Spain. Each of these projects represented efforts at cultivating the "information" domain as a new business domain in the EMEIA region.

Another FLE contribution to the EMEIA region is its participation in European projects. In Europe, a massive research program called Horizon 2020 was launched in FY2014 with total funding of about 80 billion euro. The aim is to increase the competitive power of Europe in science and technology. The launching of this program set off a flurry of applications from European research institutions, resulting in severe competition compared to past European projects. Amid this race, proposals submitted by FLE together with research partners in the fields of smart energy and next-generation wireless came to be adopted. The next-generation wireless project may pave the way to new business models. Results from both of these projects will be coming forth from now on. In this way, FLE is contributing to the further development of science and technology in Europe and to Fujitsu business in the European region.

5. Conclusion

This paper introduced Fujitsu's overseas research laboratories: Fujitsu Laboratories of America, Fujitsu Research and Development Center (China), and Fujitsu Laboratories of Europe. The highly competent personnel at these research bases are developing cutting-edge technologies independently and in cooperation with

leading research institutions and universities. They also support Fujitsu business endeavors in their regions by disseminating information through technology exhibits and forming tie-ups with business groups. Looking to the future, Fujitsu's overseas research laboratories will continue to engage in research and development and associated activities that foster innovation toward a prosperous and reassuring future for everyone.

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