Digital Twin Computing Initiative

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Abstract

Digital twins, which connect the real world with cyberspace, have been achieved through advances in the Internet of Things and other information and communication technologies. NTT announced its Digital Twin Computing Initiative in June 2019 [1] for envisioning a future in which the digitalization of all types of objects (things) and their fusion with the real world accelerates in parallel with the evolution of the network and computing environment. This article provides an overview of this initiative, describes the scope of its application, and presents its architecture and main issues surrounding implementation.

Keywords: digital twin, cyberspace, virtual societies

1. What are digital twins?

Digital twins have been gathering attention as a means of linking the real world with cyberspace thanks to progress in information and communication technology (ICT). A digital twin is a mapping process that accurately represents in cyberspace the shape, state, function, etc. of a real-world object (thing) such as a manufacturing machine in a factory, airplane engine, or automobile. The use of digital twins makes it possible to analyze current conditions, make predictions, and simulate various scenarios with respect to things in cyberspace. It also enables the benefits of advanced ICT to be fed back to things in the real world in diverse ways, such as by using the results of processing in cyberspace to intelligently control those real-world things.

As digital twins are created for all types of things in the real world, we can expect a growing demand for large-scale simulations through the recombination and interaction of many and varied digital twins beyond those conventionally used in industry. For example, such simulations could start with units of industrial machines and reproducing manufacturing lines to an entire factory or even an entire supply chain including logistics. They could also reproduce an entire city by recombining buildings, roads, automobiles, residents, etc. However, conventional digital twins are only created and used for specific purposes on a field-by-field basis, so this type of unrestricted recombination and interaction of things has been difficult. Regarding human digital twins, the focus has been on reproduction in physical terms based, for example, on physiological measurement data. As a result, simulations related to social behavior, such as human communication, have been difficult to conduct.

2. What is Digital Twin Computing?

Digital Twin Computing (DTC) that we envision is a major expansion of the conventional digital twin concept. It is a new computing paradigm that enables reproduction of the real world on a totally new scale and level of accuracy by freely recombining various types of digital twins and performing diverse operations on them. It can also enable mutual interactions in cyberspace that include the inner state of humans, i.e., thoughts and decisions of individuals, above and beyond the physical reproduction of the real world (**Fig. 1**).

A key feature of DTC is the ability to arrange a variety of digital twins in cyberspace and create a single world, i.e., a virtual world, driven on the whole by the mutual interaction among those digital twins. To enable various types of digital twins to be freely recombined and subjected to analysis, trials, and predictions, we will develop a common means of performing large-scale and complex interactions among digital twins. In addition to digitalization of the real

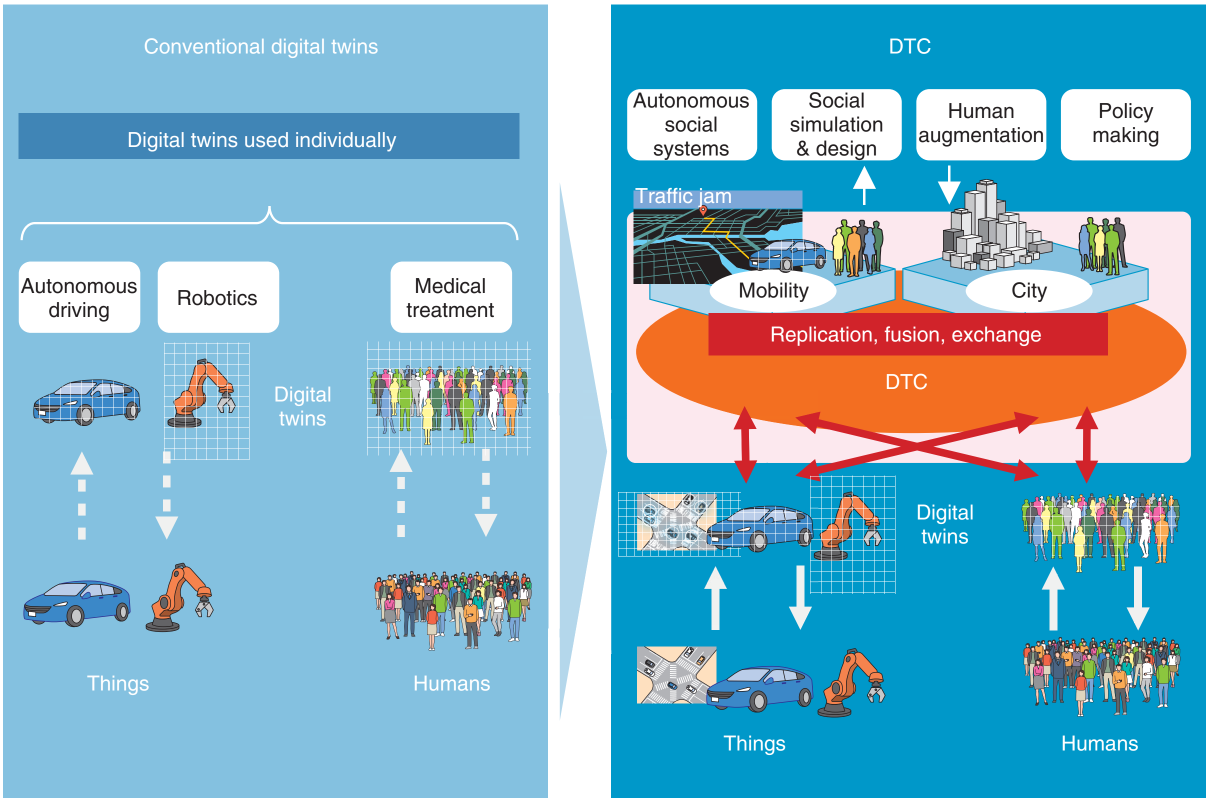

Fig. 1. Concept of Digital Twin Computing (DTC).

world as it actually is, DTC will make it possible to configure a virtual society with environmental conditions different from the real world and with things that do not exist in reality. This, in turn, will make it possible to conduct experiments and trials for a world that does not really exist, as in the design of a future society.

Another feature of DTC is digital twin operations that enable digital properties, such as replication and processing, to be used to the fullest. These operations can be used, for example, to replicate digital twins any number of times and conduct a variety of trials or to exchange or converge some of the constituent elements of different digital twins to create digital twins having properties that do not exist in reality (derivative digital twins). Combining derivative digital twins and constructing a virtual society can expand real-world functions and interaction.

Yet another key feature of DTC and a major challenge is the reproduction of the inner state of humans. For example, with respect to social aspects such as human behavior and communication, reproducing and representing in cyberspace the thoughts and decisions of individuals should enable interaction based on diversity arising from individuality (personality) in contrast to interaction between individual digital twins with no personality based solely on statistically rounded-off values. This feature is described in detail in the article "Challenges Facing Human Digital Twin Computing and Its Future Prospects" [2] in this issue.

With DTC, the plan is to create diverse virtual societies in which all types of things and people interact in sophisticated ways beyond the constraints of the real world and to extend and transcend the real world by fusing together virtual societies. The aim is to expand human possibilities by extending the range of human activities as far as virtual societies and to create innovative services that could not have heretofore been achieved such as social design and decision-making support for solving complex social problems through large-scale simulations or future predictions.

3. Application areas and use cases

Application areas and use cases of DTC are shown

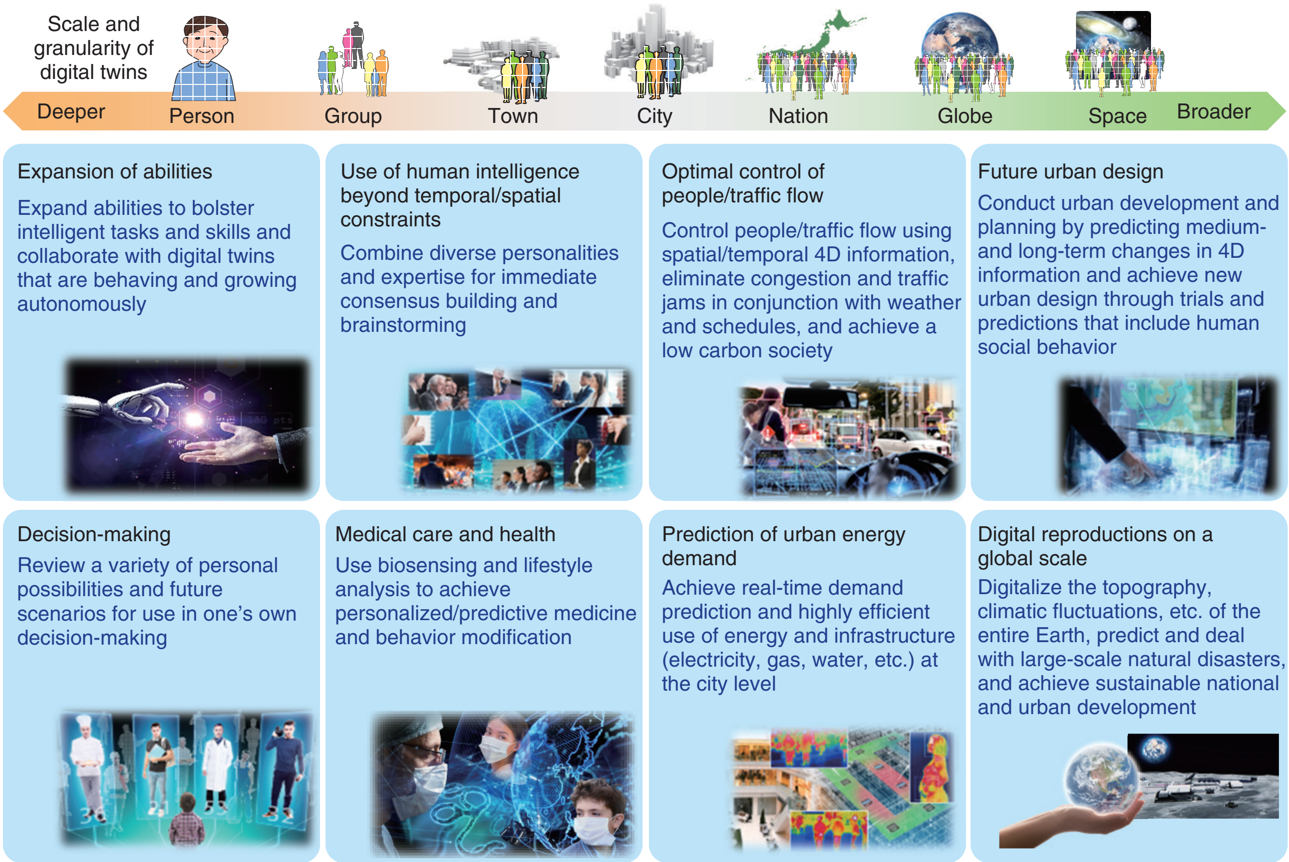

Fig. 2. Application areas of DTC.

in **Fig. 2**. In DTC, digital twins of diverse scale and granularity can be taken up from a deep micro level, such as a single person, to a broad macro level, such as a human group, city, nation, and even the entire globe. Therefore, the following use cases in a wide range of applications can be considered.

- Digitalize advanced decision-making processes and expert skills and feed results back to real people and things to reduce personnel training costs and deal with labor shortages
- Hold conversations with *multiple future selves* that simultaneously lead multiple lives to provide detailed support for making choices in one's real life
- Hold high-speed debates among digitalized experts in various fields to quickly derive responses to disasters, accidents, crime, etc. according to current conditions
- Control people/traffic flow using spatial/temporal fourth-dimensional (4D) information to eliminate congestion and traffic jams in conjunction with weather and schedules and achieve a low-carbon society
- Conduct trials and make predictions of medium- and long-term social activities in a city and simulate the views of future inhabitants then feed the results back to urban designers to plan appropriate urban development
- Digitalize the topography, climatic fluctuations, etc. of the entire Earth and predict and deal with large-scale natural disasters to achieve sustainable national and urban development

4. Architecture and main issues surrounding implementation

DTC generates digital twins through the sensing of real-world things and humans, generates derivative digital twins through digital twin operations, and constructs virtual societies that recombine them then feeds the results of those virtual societies back to the real world. The layered structure shown in **Fig. 3** and

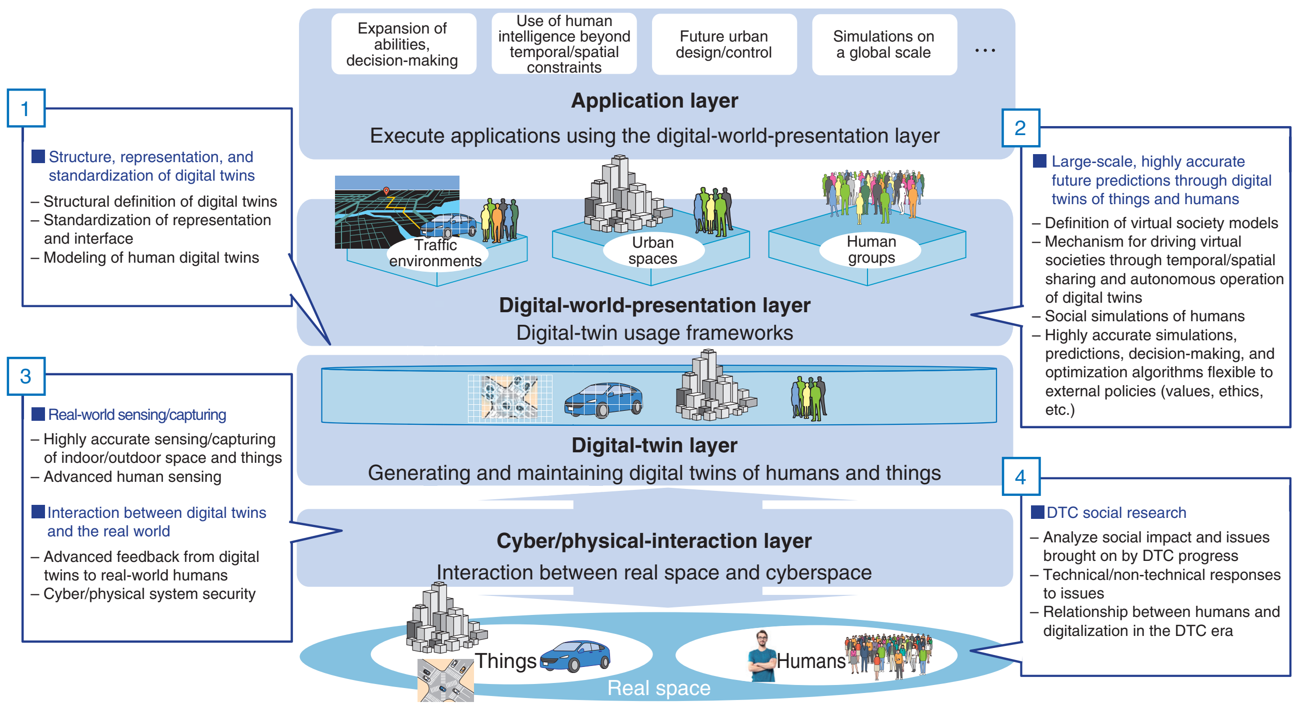

Fig. 3. DTC architecture and main issues surrounding implementation.

summarized below is assumed with this DTC architecture.

- Real space: Consists of things and humans existing in the real world and the real space that includes them
- Cyber/physical-interaction layer: Provides functions for collecting essential data to generate digital twins through the sensing of things and humans in real space and functions for feeding the results of trials and predictions in virtual societies back to the real space
- Digital-twin layer: Stores collected data, models, etc. and generates and stores digital twins using those data
- Digital-world-presentation layer: Generates derivative digital twins by performing operations (replication, fusion, and exchange) on digital twins stored on the digital-twin layer and creates virtual societies by combining derivative digital twins
- Application layer: Implements and executes applications using the digital-world-presentation layer

The following summarizes the main issues that need to be addressed to achieve DTC including the above use cases in accordance with this architecture.

(1) Structure, representation, and standardization of digital twins

On the digital-twin layer, there is a need for a structural definition, representation format, and standard interface for digital twins as frameworks for mutual interaction among digital twins, which is the aim with DTC. In addition, the constituent elements of human digital twins including reproduction of a person's inner state and individuality must be defined and technology for modeling and reproducing humans from sensing data must be established.

(2) Large-scale, highly accurate future predictions through digital twins of things and humans

On the digital-world-presentation layer, there is a need for a model definition of virtual societies as a place that recombines various types of digital twins and for a mechanism that can drive virtual societies based on temporal/spatial sharing and mutual interaction among those digital twins and on the autonomous operation of individual digital twins. Social simulation methods targeting human communication, such as conversation and consultation, as well as group behavior must also be established based on reproducing the inner state of humans. Based on all the above, there will be a need to establish highly accurate simulations, predictions, decision-making, and optimization algorithms that can derive appropriate calculation results flexible to external policies on social norms, values, and ethics. These needs are described in the article "Digital Twin Computing of Things Opens Up a New Society" [3] in this issue.

(3) Real-world sensing/capturing and interaction between digital twins and the real world

On the cyber/physical interaction layer, there will be a need for highly accurate sensing and capturing of not only of spaces and static subjects, such as outdoor buildings, roads, and indoor structures, but also of dynamic subjects such as moving cars. To enable a human digital twin to reproduce the user's inner state and individuality, there will also be a need for advanced human sensing technology that can integrate measurement data from wearable devices, cameras, and microphones and behavior data on the Internet, etc. There will also be a need for feedback methods using advanced human-machine interaction devices to feed experiences in cyberspace back to real-world humans and to enable activities in virtual societies via digital twins and expansion of real-world abilities through the help of cyberspace. These needs are described in the article "Approaches to Cyber-physical Interactions Linking the Real World and Cyberspace" [4] in this issue.

Finally, in the world of DTC that promotes the fusion of the real world and cyberspace, there will be an even greater need for cyber/physical system security.

(4) DTC social research

There will be a need to analyze the social impact and issues brought on by progress in DTC, such as privacy concerns, risk of digital crime, ethical concerns in relation to future predictions, free will, personal responsibility, and transformation of values in a borderless digital society, and to deal with these issues in technical and non-technical ways. To gain social acceptance of DTC, cultural and sociological studies must also be conducted on the new relationship between humans and digitalization. Please refer the article "Social Issues with Digital Twin Computing" [5] in this issue for more details.

5. Conclusion

As described above, the issues that must be tackled to implement the DTC initiative are extremely broad in scope. NTT laboratories aim to solve these issues and implement the DTC initiative in society through collaboration with a wide range of experts in science and technology and diverse partners in industry. For more details on the DTC initiative, please see the Digital Twin Computing white paper [6].

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He received a B.S. in mathematics from Waseda University, Tokyo, in 1994, and a Ph.D. in informatics from the Graduate University for Advanced Studies, Kanagawa, in 2008. He joined NTT Human Interface Laboratories in 1994 and studied media processing technologies, content distribution systems, artificial intelligence, and their applications. He was seconded to the Ministry of Internal Affairs and Communications of Japan from 2007 to 2009, where he was responsible for policy making and promoting national information security policies. He is working on research and development of the concepts and technologies for Digital Twin Computing.