Ubiquitous Service Robotics

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Abstract: RT (Robot Technology) is expected to magnify the IT industry, which is characterized by the real time operation in the physical environment. Especially, integration of RT with ubiquitous computation technology will make a big impact on service industry. In this presentation, a concept of service media for ubiquitous service RT in the context of service engineering is introduced, which provides users with various services in a ubiquitous computing environment. Examples of ubiquitous RT devices called intelligent data carrier, and their application to user adaptive systems, rescue systems, and security systems are introduced.

Keywords: Service Engineering, Service Media, Ubiquitous Device, Intelligent Data Carrier, User Adaptive System

1 INTRODUCTION

RT (Robot Technology) is expected as a new breakthrough for better human life next to IT (Information Technology). Japan is extremely leading in the number of industrial robots in production and in use. However, the production of industrial robots has been saturated at the amount of 4 or 5 billion US$ per year for more than ten years[1]. In spite of the development and commercialization of pet robots, cleaning robots, entertainment robots, and humanoid robots by companies, considerable growth of the robot industry cannot yet be observed as a whole. On the other hand, production in tertiary industry occupies more than 70 % of the total GDP in Japan, and the proportion is still growing. Not only from the economical viewpoint but also from the ecological viewpoint, it is considered important to enhance the productivity of the tertiary industry in future. Taking account of such trend, service robots integrated with ubiquitous computing technology are expected to improve the robot industry.

In this paper, the services which can be provided by artificial systems are discussed. To provide appropriate services, the system must be intelligent enough to be adaptive to the user or its states. Ubiquitous robot technology is prospective technology to realize such adaptive service media.

2 Robots for Service Media

2.1 Service Engineering

Service Engineering[2] has been proposed to intensify service contents in product life cycle for dematerialization, namely products with more added values from knowledge and service contents rather than just materialistic values, which drives the shift from the mass production paradigm to the post mass production paradigm towards a sustainable society. The service engineering aims at systematization for the methodology to enrich the values of artifacts and artificial systems by services, and for the design and manufacturing process of artifacts and artificial systems which could provide users with services.

The value of the artifacts or the artificial systems depends on the users and their states, who evaluate the services. Taking account of the fact that the users are diverse and their states are changing, and the fact that there are lots of unknown factors and uncertainties associated with users and the environment, it seems impossible to design universal artifacts or artificial systems which can provide all the users with services with which all the users are satisfied. However, the artifacts or artificial systems are not always to be static. The design principle to make the artifacts or artificial systems flexible is effective to cope with the problem.

The Service Engineering focuses on the utilization of artifacts rather than the behavior of artifacts. Therefore, the service engineering is characterized by artifact design based on value evaluation of user's satisfaction instead of performance. Not only models of artifacts itself but also models of human (users) become important for design process of the artefacts in service engineering.

The service is defined as shown in figure 1. Service contents are transferred through the service channel from the service provider to the receiver, and the state of the receiver is changed by the service provision[2]. Though the definition explains general framework of the services, to realize concrete artifactual service systems, it is necessary to break down the functions required for the system.

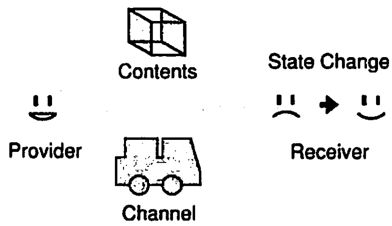


Figure 1. Definition of Service[2]

Yoshikawa classified the types of services into *massage-type* and *message-type*[3]. The former is one-to-one service which causes direct effect to the service receiver through physical interaction. The service provider and the service receiver should locate in the same place. The latter is one-to-many service which causes indirect effect to the service receiver through informational interaction. The receiver does not necessarily locate in the same place. In case the receiver locate in a distant place from the provider, any artificial media should transfer the service contents from the provider to the receiver.

Generally speaking, service is considered as provider's action which makes the users comfortable, relaxed, healed, relieved, cheered, luxury, satisfied, convenient, and happy, namely which turns the users into better states. The important point is that the value of the services depends on the users' subjectivity.

For users, the service provider is not always better to be human. Human provider may have limited power, ability, and reliability. There are also some cases that the provider is better to be artificial systems for the users in mental point of view (modesty, privacy, harassment, etc.). The service provision by artificial systems has advantages in efficiency, amplification, and reliability of services.

While the conventional engineering is considered as science on how to design and generate artificial systems to realize required function according to the users' needs and requirement, the service engineering is considered as science on how artificial systems are interacted with and used by users to relish services. In the conventional engineering, models of artificial systems to be designed and generated are indispensable to evaluate the function and performance of artificial systems. On the other hand, in the service engineering, models of humans who use the artificial systems are also indispensable to evaluate the satisfaction of users.

For service engineering, it is very important to understand general characteristics of users. The users are dynamic, which move in an environment, and quite subjective depending on the personalities or their states. Therefore, the service systems should cope with the following features of users;

(1) spatial diversity,
(2) real time requirement or demands, and
(3) subjectivity.

This means that the service system should cover the large space where the users may move around, respond quickly to users' dynamic requirements and demands to provide services in real time, and estimate the user's features and states to provide appropriate services adaptively for individual care.

2.2 Concept of Service Media

The service engineering focuses on artifacts or artificial systems which provide users with the services. The artifacts or artificial systems play a role of media which transmit services from the human who designs and generates the service (service designers, service developers, service producers, service generators, etc.) to the human who utilizes and relishes the service (service receivers; users). We may not be conscious of the media of services explicitly because the media may be embedded in the artificial environment surrounding us.

There are two difficulties to design such media for services. The first difficulty is the *ambiguity of needs*. Even though products are designed and produced based on needs or demands of the users who want services, the needs or demands are generally quite ambiguous and changing. This causes uncertain and unreliable market prediction and estimation, and accordingly, production of un-desired products, which may result in increase of the waste. This means if the function of media is simplex and static, risks may not be avoided, that is the media to be designed may not provide enough services to be satisfied by users.

The second difficulty is the *time delay of service provision.* The needs or demands are momentarily changing. If it takes time to produce or switch the services according to the users' request, it causes the time delay until the service provision, and the services may be of disuse when they are provided.

Consequently, it is important to recognize the required services exactly, and provide the required services promptly. The required services depend on the users, their states, and their environment, which I call *service desire factors*. To achieve real-time service systems, it is important to accelerate the flow of information on the service desire factors from users to service providers. The acceleration could be realized by a mechanism which allow users to input the information or a mechanism to detect and recognize the service desire factors, a mechanism to feed the input or recognized service desire factors back to service providers in real time, and a mechanism to transmit the produced service to the users within desired timing.

To overcome the difficulties mentioned above, the media which are equipped with these mechanisms should be intelligent so that the media can exchange the information on service desire factors to share interests on the service to be provided in real time and give and take services. Here, I define such intelligent systems as *service media.* To achieve the real time supply of desired services, it is expected to incorporate an autonomous mechanism to control services according to the recognized service desire factors within the service media. Figure 2 show the concept of the service media. For users, the service media is just a part of environment, and the services are given through the artificial environment.

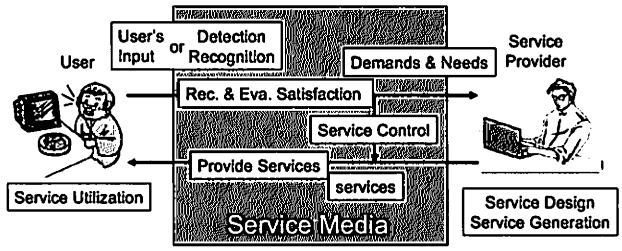


Figure 2. Concept of Service Media

2.3 RT as Service Media

The service media should be artificial systems which have information processing function for human interface to receive users' input, to detect and recognize the service desire factors, to exhibit them to service providers, to transmit the service contents from the service providers to the users, or to determine the service to be provided and to control the behavior of the service media autonomously.

Service robots and ubiquitous computing devices are considered to be the very important components of the service media. Even though a user moves around in an environment, the robot could access or the devices could cover variety of locations of the user by its mobility, communicate with the user, recognize the service desire factors on the user, and provide services. Technically, it is difficult in a real environment for a simplex service robot to execute safe and reliable motion in an uncertain environment where the robots operate together with human. This difficulty, however, can be solved by integrating with or utilizing ubiquitous computing technologies.

3 Ubiquitous Service Media

3.1 Technology for Ubiquitous Computing

Ubiquitous computing was proposed as a concept that computers are embedded everywhere[4]. TTT (Things That Think) and the Oxygen project are also considered a similar concept[5][6]. The computer is downsized, its energy consumption is reduced, and communication function is incorporated. These concepts are now approaching to the reality. The computer chips may soon be embedded in all the objects and things in the environment.

IT (Information Technology including computers and network technology) brought the networked environment to our living environment. In the area of home appliances in Japan, the ECHONET Consortium was founded in 1997 to develop software and hardware to support a home network[7], which is in the same context of domotics or home automation.

Miniaturization and functional advancement of IT devices have been promoted. Compact PDA's have commonly been used, not to mention that the cellular phones have established their position and been diffused in the modern society. These devices provide users with various functions and convenient services in connection with the global network.

In addition to IT, the great progress in RF-ID (Radio Frequency Identification) technology was made recently. Various types of tiny IC chips with erasable ROM and RF communication module and their applications have been commercialized and become popular. The Auto-ID Center was founded in 1999[8], and the Ubiquitous UD Center was also founded in Japan in 2003[9], where a new network infrastructure using RF-ID is discussed, which will make it possible to identify any object anywhere in the world.

Not only for identification but also for collecting sensory information, sensor nodes or micro servers for sensor networks have actively been developed, which can construct ad hoc network by wireless communication and share and integrate distributed sensory information. Mica Mote is a tiny device for the wireless micro servers for smart dust[10]. T-Engine Forum was founded for promotion of development of intelligent micro server platforms[11].

We have developed Intelligent Data Carriers and their applications from 1993[12], which is a portable electronic data carrier device with functionality of information storage (rewritable nonvolatile memory), information processing (MPU), local contactless data exchange (RF-ID week radio communication), power supply (battery - optional), and external ports (I/O interface - optional). Various types of the IDC have been developed so far. The structure of the IDC and a photo of tiny IDC for experimental mouse management is shown in fig. 3.

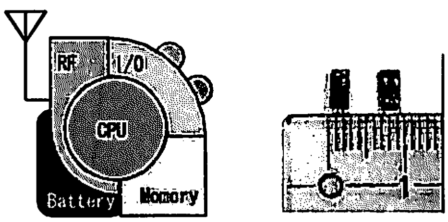


Figure 3. Structure of IDC (Intelligent Data Carrier) and tiny IDC for experimental mouse management

3.2 Utilization of Ubiquitous Computing Technology

The ubiquitous computing technologies for ubiquitous computing are expected in following three means for service media:

(1) Environment-Embedded Service Media

To deliver the services which a user want to the user within desired timing, it is required for service media to recognize the service desire factors on the user. Utilization of a ubiquitous devices embedded in the environment is effective to the recognition with covering the whole space within which the user may move around

Detection and recognition of targets by multiple sensing agents have been discussed in the field of distributed sensing and distributed autonomous robotic systems. For a closed space, detection and tracking of a user, and recognizing user's state have been discussed in research on Smart Room, Robotic Room, Intelligent Space, etc.[13][14][15] It is expected to expand these technologies to an open environment, and to make them compatible with the conventional and on-going ubiquitous networks.

(2) Ubiquitous Computing Infrastructure for Service Robots

Even though autonomous function of robots have been improved, it is still hard to realize autonomous service robots which operate in the home environment as service media with human safely and reliably. As special tracks for Japanese bullet trains (Shinkansen) or roads and traffic systems for automobiles, arrangements in environment has to be considered if we design a viable mobile system. Utilization of ubiquitous computing environment is crucial in this sense.

Figure 4 illustrates the concept of an IDC, which consists of a number of IDCs embedded in the environment (wall, floor, obstacles, objects, etc) and reader/writer devices. Each IDC manages and processes local information depending on specific place or objects. Robots can communicate with the IDCs via a reader/writer device provided with each robot, and extract/add/update the local information in IDSs through local radio communication. Or, the IDCs inform the robots of the necessary local information for navigation or task execution, and mediate the knowledge or commands stored by a robot to other robots.

In the environment of home, welfare facility, etc., home appliances which have additional function to detect users' behaviors and to communicate with outside via network is being commercialized. These networked and intelligent home appliances are also regarded as a kind of ubiquitous environment. These technologies are basically developed in the context of telematics, domotics, home automation[16]. These technologies, however, must be of high affinity with service robots, while robot appliance is defined a part of home appliance.

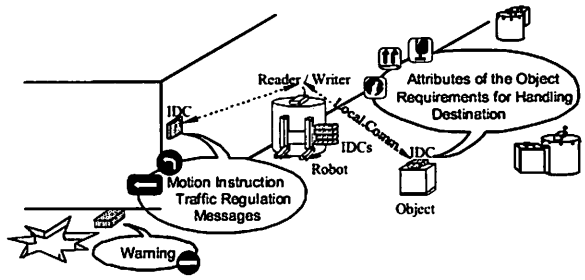


Figure 4. Concept of Ubiquitous Computing Environment with IDCs

(3) Personal User Assistant

Users do not always have skill or knowledge to connect to the service media easily. It is important to consider technically and commercially viable human interfaces which facilitate the user's input to the service systems, and deliver service information to the user in the forms which can fit each individual user. One of the solutions is to attach a tiny ubiquitous device to each user, which stores personal information and help the user to receive favorable services.

Though PDA has basically such function, it is still expected to improve the friendliness and convenience for ordinary users from young people to aged people. Technology for wearable computers including HMD, are useful for the personal user assistant to display the service information in a ubiquitous environment.

3.3 Configuration of Service Systems Utilizing Ubiquitous Devices

In case that we utilize local data storages, local information processing devices, and local communication networks, such as RF-ID, IDC, etc., it is important to recognize the variety of system configuration. The service system consists of a user, a service media, and an environment. If we call *tag* for local data storage, and *Reader/Write(R/W)* for the device to read the data from the tag or to write data into it, the following configurations and applications are expected:

(a) Tags on the users and the environment, and R/W on service media

A service media, such as a service robot, can move in an environment, and behave with recognizing the objects or users in the environment by reading data in tags to provide services according to the recognized information.

(b) Tags on the environment and the service media, and R/W on the users

A user wears a device with R/W, such as wearable computer with head mount display, can move in a environment, and get useful information or behave with acquired information from the environment or service media by reading data in tags through the R/W.

(c) Tags on the users and the service media, and R/W on the environment

An environment can be intelligent enough to monitor the behavior of users or service media by reading data in tags, and control the environment according to the recognized information as the results of the monitoring.

4 Examples of Utilization of Ubiquitous Devices for Service

I introduce examples of IDC (ubiquitous device) applications which are utilized for service media and ubiquitous computing infrastructure for service robots.

4.1 Robot Operation in Ubiquitous Computing Infrastructure

The ubiquitous computing infrastructure where IDCs are arranged in an environment is useful for a mobile service robot to localize itself[17]. By storing location data is in each of IDCs, the robot can correct position errors by utilizing the IDCs as landmarks.

The algorithm of self-localization is very simple. While a mobile robot operates in the environment, it keeps estimating self-position by odometry, which is inaccurate, as well as broadcasting calling message to IDCs by the local radio communication. When the robot happens to enter the local communicable range of an IDC (about 1-3 [m]), it detects the IDC by receiving a response. The robot can calculate the positional errors by reading the absolute location data in the IDC, measuring relative position between the robot and the IDC using vision and internal sensory data as shown in figure 5. Figure 6 shows experimental results of motion trajectory of a mobile robot by only deadreckoning with odometry (a) and by navigation with self-localization using IDCs. In contrast to the result (a) where the positional error is accumulative, the result (b) proves the self-localization using IDC is very effective for reducing positional errors.

Since it is possible to write information in IDCs additionally by robots, the IDC can also be applied to sharing information or knowledge in a distributed and local manner within a multi-robot environment[18]. Namely, a robot can accumulate any local or object-specific information or knowledge, which is useful only locally, on an IDC placed at the location or on the object, and other robots which approach to the location or objects can extract and utilize it as ants' chemical trails (pheromone).

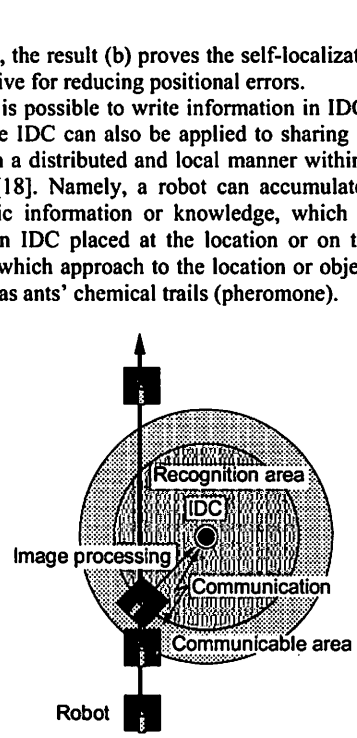
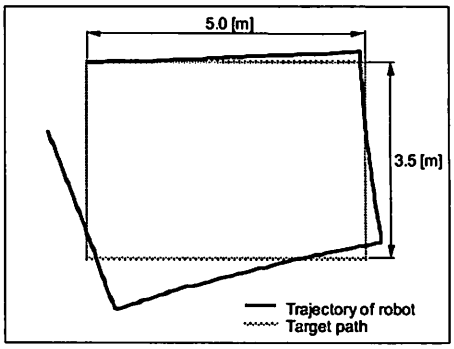
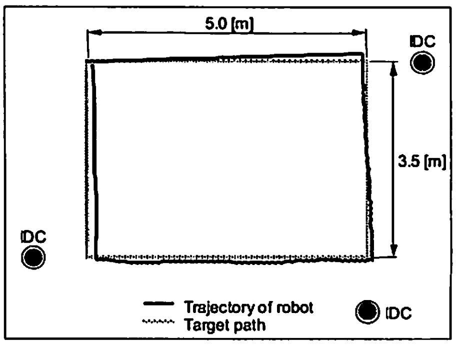


Figure 5. Relative Position Measurement to an IDC



(a) With only odometry



(b) With error compensation using IDCs

Figure 6. Experimental Result of Motion Trajectory of a Mobile Robot

Figure 7 shows an example of multi-robot operation with sharing map information by using IDCs assuming unknown maze-like environment Figure 8 shows the experimental setup using omni-directional autonomous mobile robots

As a result of experiments, it was verified that IDC enables local environmental knowledge management and sharing for multiple robots, and is effective for their cooperative search in unknown environment.

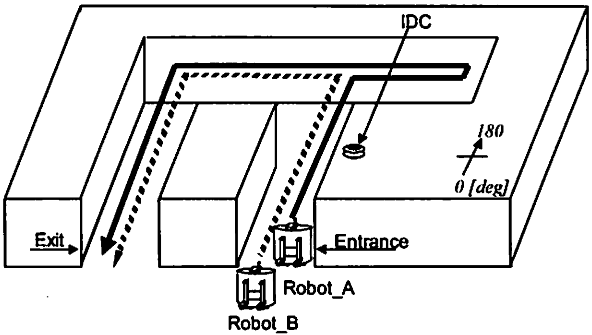


Figure 7. Information Sharing via IDC Embedded Environment

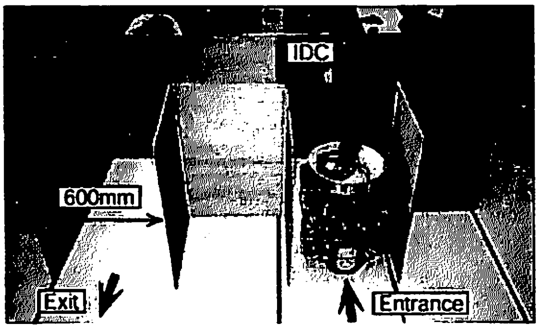


Figure 8. User Adaptive Guidance Robot

4.2 User-Adaptive System using Ubiquitous Devices

The artificial systems including the robot systems should act up to the human intention. To enhance the human friendliness of the artificial systems, we propose to utilize the ubiquitous device as means to recognize the individuals and to equip the system with a mechanism to serve according to each individual, which is called as user-adaptive system. The personal properties, preference, historical data, handicap, etc. can be stored in the personal IDC, which is carried by the person. The artificial systems provided with an equipment to read the personal data by local radio communication can be designed to behave according to the personal data. Figure 9 shows an example of user-adaptive systems, which is a guidance robot adaptive to the visitors. The robot changes the speed and judges the usage of auditorial guidance according to the information (visitor's category and his/her handicap information) stored in the IDC carried by the visitor.

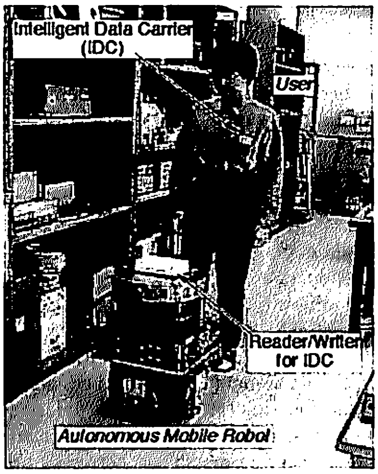


Figure 9. User Adaptive Guidance Robot

4.3 Victim Search System for Rescue

A ubiquitous device for rescue assist has been developed, which is shown in fig. 10[19]. This device is equipped with a speaker to speak to victims and microphone to record the voices of victims. The ubiquitous device is scattered in houses or buildings, and when an earthquake destroys them, it is buried in the detritus with victims. When the device is activated from outside, e.g. from a blimp operating in the air on the surface of damaged area, this device starts autonomous action to speak to victims, record sounds, and transmit the sound data to the rescue center.

Figure 11 are photos of a device called rescue communicator and a blimp (air vehicle) for relaying information for victim search. The voice data recorded in the device for rescue are uploaded to the blimp and transmitted to any station for their analysis.

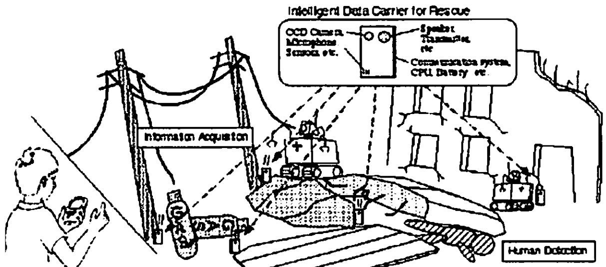


Figure 10. Concept of Ubiquitous Computing Environment for Rescue.

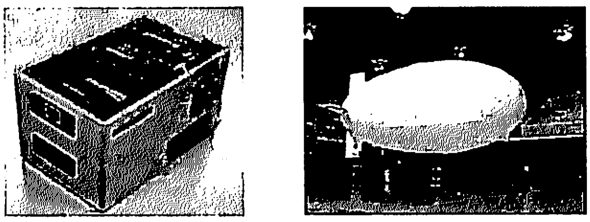


Figure 11. Rescue Communicator and Blimp for Relaying Information for Victim Search

5 Issues for the future

For future evolution of technology on development of service media, and service robots in ubiquitous computing environment, I'd like to point out some key issues to be attacked and solved.

The most important issue for service robots is safety and reliability. Even though the environment for the service robots is arranged as infrastructure for the robots by ubiquitous computing technology, they should operate within user's living environment. The robots should cope with physical interaction with users with high safety, and operate in an uncertain environment with high reliability. Technology for improving friendliness with human is urgent to develop, which is related to the research on human interface, virtual reality (augmented reality), human modeling (biomechanics, digital human, etc.), kansei engineering, etc.

Security and privacy protection in ubiquitous computing environment remain as essential issues. The permanent connection of all the nodes of service media via networks brings danger of possibility on private information leakage. Technology for identification, authentication, encryption/decryption should be discussed in service media development.

Wireless communication technology plays very important role in ubiquitous service media. Though RF-IF, weak radio wave, specified-low-power radio wave, Bluetooth, Radio LAN, PHS (Personal Handy Phone System), cellular (mobile) phone, etc. are available in Japan for wireless communication to develop a system for service media, it is not convenient because the use of radio wave is strictly regulated by the law about radio wave in Japan. Deregulation is crucial to promote the technological evolution of service media.

6 Conclusions

Service robots are expected as a new market to encourage the robot industry in a coming aging society. In this paper, a concept of service media in the context of service engineering was introduced, and service robots as components of service media in a ubiquitous computing environment were discussed with presenting current trends and technology on ubiquitous computing, and introducing application examples of ubiquitous devices for service robots and service media.

When we design the realistic artificial system which provides services including service robots, it is crucial to discuss not only intelligent function of service robots but also harmonization of robots, users and the environment taking account of the up-to-date progress of related technologies.

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