An Inter-Organizational Software Architecture for Smart Mobility

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ABSTRACT
In this paper, the authors present *SMArch*, an inter-organizational software architecture for smart mobility, which can be defined as services coordinating multi-modal mobility. The architecture is extended from the Japanese system architecture for intelligent transportation systems (ITS), which is defined in 1999 and used for a reference giving a shared vision among stakeholders involved in ITS. Although the Japanese ITS architecture focuses road traffic only, *SMArch* focuses any mobility including not only road vehicles but also airplanes and ships. Moreover, *SMArch* introduces the service path concept, handles the itinerary as a series of mobility services and staying services such as lodging, dining and parking. Service coordinating agents present service path candidates satisfying the given traveler's requirements. The agents and other services interact to search for such service path candidates with the service path query language defined based on the service path concept and the information model defined in the *SMArch*.

CCS Concepts
• Software and its engineering → Software organization and properties → Software system structures → Software architectures → Object oriented architectures • Applied computing → Enterprise computing → Service-oriented architectures

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Keywords
smart mobility; architecture; ITS; MaaS

1. INTRODUCTION
Although there is no standardized definition, it must be acceptable that *smart mobility* means a set of services using information and communication technologies that coordinate multi-modal mobility for travelers with different attributes. Based on this definition, the authors discuss a software architecture for smart mobility in this paper.

Smart mobility applications of the above-mentioned definition have already been available to the end users as internet services such as map service, transfer guide service, *etc.* by many service providers. Moreover, APIs to access these services and to supply information needed by these services are also available with and without charge. These services evolve independently, continuously and rapidly in the smart mobility market in where many service providers are highly competing. In the smart mobility market, there are also many service providers that supply new services with additional values by combining these existing services as another kind of stakeholder.

However, there are no standardized or oligopolistic software architectures in the smart mobility market; thus, to provide its service continuously, each service provider has to implement *glue codes* that convert data representation or data model among its depending services and rewrite the codes on revision or abolishment of its depending services.

Considering the above-mentioned characteristics of the smart mobility market, the authors proposed a strategy to construct inter-organizational and intra-organizational software architectures in [1]. The inter-organizational architecture is introduced from standardized architectures for intelligent transportation systems (ITS) [2-4] to provide a shared vision in the smart mobility market. The intra-organizational architecture is constructed by each service provider. The microservice architecture style [5] is recommended for the intra-organizational architecture on where smart mobility services are implemented to follow rapid change of the market.

Since mobility is subject to local traffic, legal and cultural constraints, the authors decided to adopt the Japanese standardized architecture for ITS [4] as a basis to define an inter-organizational architecture for smart mobility in Japan. However, the Japanese ITS architecture has not been revised since its establishment in 1999; thus, it has already deviated from today's technology trend. This paper constructs an inter-organizational architecture for smart mobility, *SMArch*, by renovating the Japanese standardized architecture for ITS.

This paper is organized as follows: Section 2 describes the Japanese standardized architecture for ITS and its problems for use in smart mobility. Section 3 presents *SMArch*, an inter-organizational architecture for smart mobility. Section 4 introduces related work. Finally, Section 5 concludes the paper.

2. JAPANESE SYSTEM ARCHITECTURE FOR ITS

In this section, the authors introduce the Japanese national system architecture for ITS, which is a basis of *SMArch*, and describe its problems for use in the smart mobility market as an inter-organizational architecture.

2.1 System Architectures for ITS

Importance of the system or software architecture for transportation has been recognized in the field of ITS involved by various kinds of stakeholders including administrative agencies, road operators, transportation operators, automobile and road facility manufacturers, *etc.* since an early stage.

In the United States, National ITS Reference Architecture (or ARC-IT) [2] was defined by Department of Transportation in 1996. In Europe, European ITS Framework Architecture (or FRAME Architecture) [3] was defined in 2000. These architectures are basically used as references; that is, it is allowed to be tailored or adopted partially for specific application needs. Moreover, these projects provide tools to reference and use the architectures to ease their adoption. The architectures have been maintained and revised continuously to catch up the technical innovation. The latest version of ARC-IT and FRAME are 8.3 and 4.1, respectively.

In Japan, the national system architecture for ITS [4] was defined by five administrative agencies involved in ITS: National Police Agency, Ministry of International Trade and Industry, Ministry of Transport, Ministry of Posts and Telecommunications, and Ministry of Construction. It considerably contributed to construct a common vision on ITS among many stakeholders regulated by these different authorities as its intent; however, it has not been revised so far. The architecture can no longer cover recently emerged services and technical concepts.

2.2 Overview of the Japanese ITS Architecture

The Japanese ITS Architecture defines user services, a logical architecture, and a physical architecture.

User Services: The architecture supposes 9 service domains, 21 user services under the domains, 56 specific user services under the user services, and 172 sub services under the specific services. The user services under each domain are separated based on their objectives. The specific user services under each user service are separated based on difference of circumstances or targets of the same service. The sub services under each specific service are detailed and decomposed functions for the specific service. Figure 1 shows the 21 user services under the 9 service domains.

User Services
- 1. Advanced navigation
  - 1. Traffic information
  - 2. Destination information
- 2. Automatic fare collection
  - 3. Automatic fare collection
- 3. Assistance for drivers
  - 4. Road condition information
  - 5. Hazard warning
  - 6. Driver assistance
  - 7. Automated driving
- 4. Traffic management
  - 8. Road traffic optimization
  - 9. Road traffic regulation information on traffic accidents
- 5. Efficient road management
  - 10. Efficient road maintenance
  - 11. Special purpose vehicles management
  - 12. Traffic regulation information
- 6. Assistance for public transportation
  - 13. Public transportation information
  - 14. Assistance for operation of public transportation
- 7. Efficient operation of commercial vehicles
  - 15. Assistance for operation of commercial vehicles
  - 16. Automated driving of commercial vehicles
- 8. Assistance for pedestrians
  - 17. Route guidance
  - 18. Hazard prevention
- 9. Assistance for emergency vehicles
  - 19. Automated emergency notification
  - 20. Navigation for emergency vehicles
- 21 Using services in the advanced information and communication society

Figure 1. Service Domains and User Services

Logical Architecture: The logical architecture defines an information model and a control model. The information model defines information needed to realize the user services as class diagrams. On the other hand, the control model represents flows of the information defined in the information model and their processes to realize the user services as diagrams equivalent to the data flow diagram used in structured analysis. The control model represents which sort of information is transferred among the processes only. The control model describes the objective of the process by its name, but not show the design or implementation of the process at all.

Physical Architecture: The physical architecture defines physical deployment of the processes defined in the logical architecture with considering non-functional requirements such as technical feasibility, responsibility and safety. The whole of ITS is roughly decomposed into the person, the vehicle, and the road in the Japanese ITS architecture; moreover, each of them is decomposed into further sub systems responsible for processes defined in the logical architecture. The physical architecture is defined in an abstracted manner not to depend on specific systems and devices.

2.3 Problems of the Japanese ITS Architecture

The Japanese ITS architecture has not been revised so far; however, its significant portion is still possible to reference since it is defined in an abstracted manner. The authors found the following problems of the architecture to use for smart mobility purposes.

The architecture cannot handle multi-modal mobility. The architecture focuses road traffic as its scope, especially interaction among the human, the vehicle, and the road. In its definition of the user services and logical architecture, vehicular mobility is treated as primary but other type of mobility as subordinate. The architecture defines services such as providing information about other transportation to drivers, but limited to information services. The architecture never covers multi-modal mobility services that handle public transportation such as trains, airplanes and ships as well as private transportation such as taxi, rent-a-car/bicycle and car sharing in a comprehensive manner. The logical architecture basically models cars only for the vehicle, drivers and pedestrians only for the human, and car's and pedestrian's roads for the road. The logical architecture does not model the human as other roles such as passengers and the roads for vehicles other than the car such as airways and seaways.

The architecture cannot model MaaS. The architecture was designed in the context of ITS before emergence of the MaaS concept; thus, it focuses services to coordinate the human and vehicle traffic and optimize road use, not services to coordinate services on human mobility as business.

The architecture is rigid and monolithic. The architecture comprehensively covers services that could be envisioned under the technical environment at the era of its establishment and, based on the user services, its logical and physical architectures are defined in a rigid and monolithic manner. However, rigid and monolithic architecture makes it difficult to revise the architecture in an agile manner along with change of the technical environment due to tight coupling of components. Moreover, without the business unit responsible for maintenance of the architecture, it cannot be expected to have opportunity renovating the architecture.

3. SMARCH: ARCHITECTURE FOR SMART MOBILITY

Considering the problems of the Japanese ITS architecture mentioned in the previous section, the authors renovates the Japanese ITS architecture and define *SMArch*, an inter-organizational architecture for smart mobility.

3.1 Policy of Architecture Construction

Many services that can be regarded as smart mobility services have already been launched in the market by service providers. Considering that, it is meaningless to redefine and standardize the control model of the logical architecture and the physical architecture of the Japanese ITS architecture. This is because these existing services have been evolving individually and continuously with concealing their implementation from the outside. In addition, users of the services are interested in the functions and quality of the services to be provided, and in many cases, they are not interested in implementation of the services. Modeling of data exchanged among services is more important to combine these existing services, which is represented as the information model of the logical architecture.

Therefore, the authors adopt a policy of applying the minimum and necessary modification to the information model of the logical architecture to define *SMArch*.

3.2 Making the Vehicle and Path Multi-Modal

In the Japanese ITS Architecture, the link is limited to the road and the means of transportation are limited to cars and pedestrians traveling on roads. *SMArch* comprehends links other than roads and means of transportation on the links including trains, airplanes, ships *etc.* and treats them same as roads and road transportation on the road.

The Japanese ITS Architecture defines links as Class *Link* and its sub classes and the means of transportation as Class *Mobile* and its sub classes. *SMArch* extends these classes as shown in Figures 2 and 3, respectively.

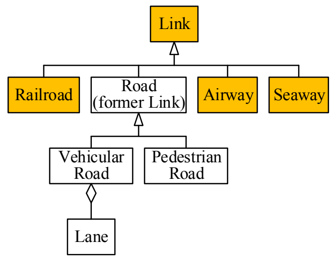

Figure 2. Information Model of the Link

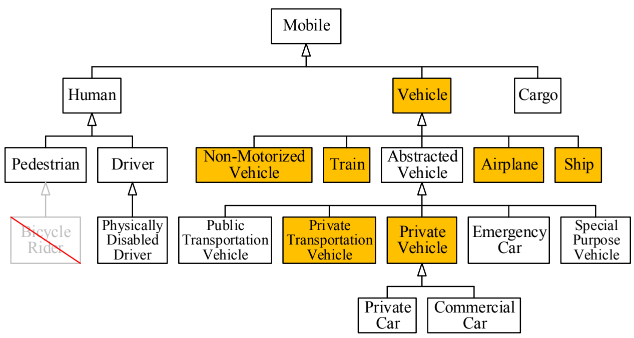

Figure 3. Information Model of the Mobile

i) Class *Link* representing roads only in the Japanese ITS Architecture is renamed *Road*, and Classes *Railroad*, *Airway* and *Seaway* are added in the same abstraction level as *Road*. Class *Link* is newly added as an abstract class of these classes.

ii) Classes *Non-Motorized Vehicle*, *Train*, *Airplane*, and *Ship* are newly added as means of transportation and Class *Abstracted Vehicle* is also added as an abstract class of these classes. The sub class of *Vehicle* is basically defined from the viewpoint of differences in the link that the means of transportation uses, namely *Road*, *Railroad*, *Airway* and *Seaway*.

iii) In the Japanese ITS architecture, Class *Bicycle Rider* is a sub class of Class *Pedestrian* and eventually Class *Human*. *SMArch* defines it as Class *Non-Motorized Vehicle*, a sub class of *Vehicle*. This is because there is already a rental bicycle service that can drop off by using smartphones, and in the future, if there is a revision of the law, mobility that does not need licenses such as electric kick boards can be commercialized in Japan.

iv) Class *Private Transportation Vehicle* is added as a sub class of Class *Abstracted Vehicle*. The private transportation vehicles, such as taxis, car shares and rental cars, are not regularly operated like public transportation vehicles, but are shared concurrently with third parties and can be used for private transportation if a contract is established.

v) Class *Private Vehicle* is added as an abstract class of Classes *Private Car* and *Commercial Car* of the Japanese ITS architecture. The private car means a car owned by an individual or corporation and used for private mobility at any time.

Note that the *link* is a way that the *mobile* can pass through and is not a concept representing each service of public transportation such as trains, buses, airplanes, and ferries passing through the link. Public transportation services are modeled as services as described later. In the case of trains and buses, there are physical links, that is, railroads and roads. In the case of airplanes and ferries, there are links if there are regular or temporary services of them.

3.3 Travel as a Service Path

In the Japanese ITS architecture, the route is modeled as a travel path of vehicles or pedestrians moving on roads from the origin to the destination. *SMArch* generalizes the concept of the route on the time axis. In concrete terms, *SMArch* models a route as a path from one point in space and time to another point in another space and time.

Movement in space is regarded as demand and supply of *mobility service*, and movement from a spacial and temporal point to another spacial and temporal point without movement in space is regarded as demand and supply of staying service. For example, the spacial movement by public transportation means the demand and supply of the mobility service and lodging at the hotel and dining at the restaurant correspond to demand and supply of staying services. Although it is not actually demand and supply of the service, traveling by car or bicycle by the moving person is regarded as a mobility service in which the service provider and user are identical (that is, self-service). By this modeling, a series of moving and staying starting at a certain spacial and temporal point and ending at another spacial and temporal point, namely an itinerary, can be regarded as a *service path*, a series of demand and supply of services.

With the concept of the service path, *SMArch* can handle MaaS and various services in the same framework as mobility. Note that the service mentioned here is not an information service but a service physically provided in the real world.

Figure 4 shows the information model related to the service and Figure 5 shows the concept of the service path. Classes *Spatial and Temporal Point*, *Service*, *Mobility Service*, *Staying Service* and *Service Path* are added to the information model of the logical architecture of the Japanese ITS architecture. For each vehicle, a sub class of *Mobility Service* is added to represent a mobility service by the vehicle; for example, *Train Mobility Service*, *Bus Mobility Service*, *Air Mobility Service* and *Ship Mobility Service* are defined for public transportation, *Taxi Mobility Service*, *Car Share Mobility Service* and *Rent-a-Car Mobility Service* for private transportation, and *Private Car Mobility Service* for private vehicles. One service of public transportation or one contract of private transportation is an instance of these classes. For the staying service, sub classes are defined for different purposes such as accommodation, dining, parking, refueling and sightseeing.

Services may be provided conditionally. For example, one air mobility service can be provided if cancellation happens for the same flight. In case of the one-way car sharing service presented in [6], one car share contract can be established if somebody acknowledges to drive and drop off a car to the specified place. To model conditional supply of the service, *SMArch* defines Class *Supply Condition* whose instance is attached to a *Service* instance.

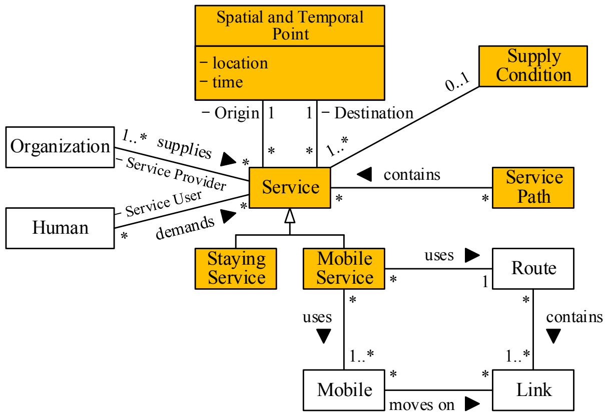

Figure 4. Information Model Relating to the Service

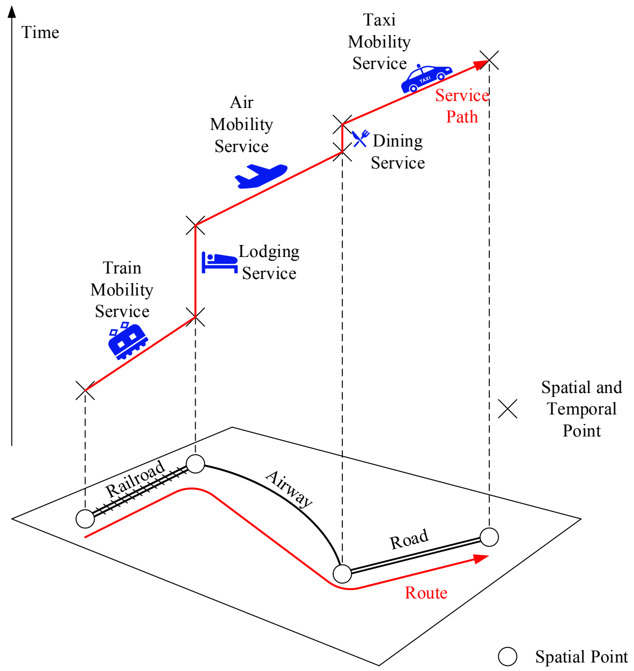

Figure 5. Concept of the Service Path

3.4 Fork and Join of the Service Path

It is possible that multiple services are demanded and supplied in parallel while travelling as in the following example:

- A train service and a parking service are demanded and supplied in parallel if the traveler uses park-and-ride.
- A lodging service and a parking service are demanded and supplied in parallel if the car traveler makes lodging.

- A car rental service and a self-driving service are demanded and supplied in parallel if the traveler uses rent-a-car.

To represent such services demanded and supplied in parallel, the concept of fork and join of the service path is introduced in *SMArch*. The fork concept corresponds to the initiation of parallel services at a certain spatial and temporal point and the join concept corresponds to the synchronized termination of the parallel services at another spatial and temporal point. Figure 6 is an example representing a park-and-ride service as a service path using the fork and join concepts.

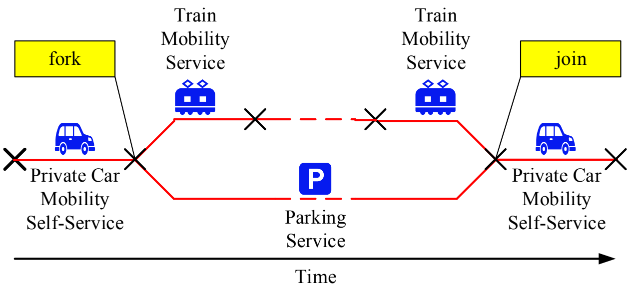

Figure 6. Service Domains and User Services

3.5 Service Coordinating Agent

Smart mobility defined in this paper, namely a set of services that coordinates multi-modal mobility, is realized as a *service coordinating agent* that presents service path candidates satisfying the given traveler's requirements.

In the Japanese ITS architecture, user services are defined comprehensively, such as the user services in the advanced navigation domain shown in Figure 7. However, it seems that such rigid definition makes the architecture difficult to be revised in agility. Service providers are competing fiercely for creating novel service paths with combining existing services. Therefore, *SMArch* dares not define services in a rigid manner to enable agile creation of new services in response to changes in the technology environment.

Instead, *SMArch* requires to respect the information model and service path concept described above as a common language used in service coordinating agents and information services trading mobility/staying services by their providers to ensure data exchange among them. Freedom on implementation of the service coordinating agents enables their independent and agile evolution. The service coordinating agent adds constraints according to the service it provides to the given SPQL description, if necessary, and searches for service path candidates satisfying the constraints. In the search, the service coordinating agent throws an SPQL description for an external service such as a service provided by public transportation on the service path, and obtains partial service path candidates that can satisfy the original constraints.

Requirements on the service path given to the service coordinating agent is described in a service path query language (or SPQL) defined based on the *SMArch* information model and the service path concept. The SPQL describes the origin and the destination spatial and temporal points with zero or more spatial and temporal waypoints and constraints that the services in the service path candidates must satisfy, as in the example show in Figure 8.

- 1. Advanced Navigation
  - 1. Traffic Information
    - 1. Real-time navigation for drivers
      - 1. Real-time optimized route information
      - 2. Real-time road traffic information
      - 3. Travel time information on the traffic jam
      - 4. Navigation of the selected route
      - 5. Route sharing with travelling vehicles
    - 2. Facility information for drivers
      - 6. Operation information on public transportation
      - 7. Parking lot information
      - 8. Reservation of the parking lot
      - 9. Transfer information of public transportation at the time of trouble
    - 3. Route information before departure
      - 10. Optimied route information before departure
      - 11. Road traffic information before departure
    - 4. Public transportation and facility information before departure
      - 12. Operation information on public transportation before departure
      - 13. Parking lot information before departure
      - 14. Reservation of the parking lot before departure
  - 2. Destination information
    - 5. Destination information before departure
      - 15. Detail information and reservation of the facility before departure
      - 16. Facility information for physically disabled people, senior people and infants before departure
    - 6. Real-time destination information for drivers
      - 17. Real-time detail information and reservation of the facility
      - 18. Real-time facility information for physically disabled people, senior people and infants
      - 19. Real-time weather information for specific areas
    - 7. Destination information provided at the service area, rest area etc.
      - 20. Detail information and reservation of the facilities provided at the service area etc.
      - 21. Facility information for physically disabled people, senior people and infants provided at the service area etc.
      - 22. Weather information for specific areas provided at the service area etc.

Figure 7. User Services, Specific User Services and Sub Services of the Advanced Navigation Domain

```
select from "Fukuoka"@2020/02/13/10:00
via "Fukuoka Airport"
  composed-by {TrainMobilityService,
SelfMobilityService}
via "Tokyo Int'l Airport"
  composed-by {AirMobilityService}
to "Tokyo Station"@2020/02/13/16:00
 composed-by {TrainMobilityService}
```

Figure 8. Service Path Query Language

4. RELATED WORK

Faro *et al.* proposes a layered software architecture for ITS consisting of four layers: semantic, application, monitoring, and communication layers [7]. The communication layer is responsible for data exchange among sensors, actuators, and mobile users' devices. The monitoring layer collects user location and traffic condition data. The application layer maps proprietary data provided by the monitoring layer into a standard format, RDFS (Resource Description Framework Schema). The semantic layer retrieves and processes the data in RDFS as requested by applications in a PROLOG-like query language. Thus, the architecture is designed as ontology-oriented knowledge base.

Illari *et al.* presents *SemanticMOVE*, a framework to manage mobility data and exploit them at the semantic level [8]. The architecture has three layers: mobility data collection, semantic mobility management layer, and semantic mobility application layers. The mobility data collection layer collects and aggregates primitive mobility data from various mobile devices. The semantic mobility management layer gives semantics to mobility data based on semantic concepts and ontologies. The semantic mobility application layer implements various smart mobility applications utilizing semantic information provided through API by the semantic mobility management layer.

Marchetta *et al.* propose a layered software architecture for smart mobility services in S^2-Move project [9]. The architecture is organized by three layers: presentation, core, and data layers. The presentation layer is responsible for interfacing between users and the platform. The core layer provides core functions for smart mobility services such as map generation, data collection, and user management. The data layer is storage for mobility data from various sources. The architecture focuses mobility aspect only and basically map-oriented. It produces a rendered map or machine-readable data based on the collected and stored data as requested by users.

All of these works focuses mobility itself; that is, they try to construct a framework to collect mobility data, analyze data to retrieve abstract information, and present them to users for various purposes. On the other hand, *SMArch* is service-oriented. It focuses services provided by and with mobility and tries to integrate mobility and other services. However, the approach to use a query language to know possible services the user request is same as [7]. [7] searches for mobility paths, while SMArch searches for service paths.

5. CONCLUSION

In this paper, the authors proposed *SMArch*, an inter-organizational architecture for smart mobility. In defining *SMArch*, the authors decided not to construct the architecture from scratch, but to extend the Japanese ITS architecture defined in 1999. The Japanese ITS architecture consists of user service definition, a logical architecture, and a physical architecture. The information model of the logical architecture was reused to define *SMArch*. Since the Japanese ITS architecture exclusively focuses road traffic, in order to handle other kinds of mobility, *SMArch* adds Class *Link* abstracting any kind of ways including roads, railroads, airways and seaways and Class *Vehicle* abstracting any kind of vehicles including cars, trains, airplanes and ships.

SMArch considers both mobility and any services demanded and supplied during the travel as service and models the itinerary as a service path, a series of service demand and supply. The smart mobility service can be recognized as a service for searching for a service path that satisfies requirements of the traveler. In *SMArch*, the service coordinating agent presents smart mobility services in cooperation with other information services. Requests to the service coordinating agent are given in description in the service path query language, which is designed based on the *SMArch* information model. *SMArch* standardizes only data exchange between agents and services, that is, queries in the service path query language, and hides implementation of the agents and services. That allows agents and services to evolve without affecting each other.

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