Research on the Cooperation Mechanism of Vehicle-Infrastructure Cooperative Autonomous Driving Cloud Edge Scene

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Abstract—At present, vehicle-infrastructure cooperative automatic driving is one of the hot technologies in the development of industry and technology, which is vigorously pursued by traffic participants and practitioners, and is also one of the technical fields that many scientific research institutions focus on. In addition to the single vehicle intelligent technology route, the vehicle-infrastructure automatic driving technology route represented by China is increasingly recognized by everyone, especially the cloud edge end technology which constitutes the technical framework of vehicle road collaborative automatic driving. The text will discuss the cooperation mechanism in the cloud edge scenario from the key technologies of vehicle road cooperative automatic driving and road classification, so as to find the best technical scheme.

Keywords—cooperation mechanism; vehicle-infrastructure coordination; autonomous driving; cloud edge scene

1 INTRODUCTION

This study analyzes the technical difficulties in the information interaction between intelligent vehicles and vehicle-infrastructure collaborative autopilot based on the cloud edge collaboration scenario of vehicle road collaborative autopilot that is widely concerned in the current industry and industrial development, Select typical road traffic scenarios (such as urban intersections, expressway merging and diverging areas, tunnels, viaducts, blind areas of vision, dangerous sections, bad weather, etc.) common in the operation environment of intelligent vehicles, and explore the cloud (intelligent network connected cloud control platform), edge (intelligent road infrastructure and edge computing unit, etc.) in the process of safer and more efficient operation of intelligent vehicles under different levels of road infrastructure and different traffic scenarios.[1] The cooperation mechanism between the end (intelligent vehicle and roadside interaction infrastructure) can further explain how smart vehicle single vehicle intelligence and vehicle road cooperative automatic driving can better cooperate and their respective division boundaries in different scenarios from the application perspective, and through the construction of the cloud edge scene cooperation system architecture of vehicle road cooperative automatic driving, in the process of intelligent vehicle's own perception, decision-making and control The control intervenes in the integration service of road vehicle collaboration in different dimensions, in order to improve the popularization of the application of vehicle road collaboration automatic driving technology and provide theoretical and practical support for safer transportation.[2]

ICICA 2022, December 02-04, Chongqing, People's Republic of China

DOI 10.4108/eai.2-12-2022.2328012

2 RESEARCH STATUS

In recent years, domestic and foreign traditional engine manufacturers, new forces of vehicle manufacturing and other start-up enterprises have been highly interested in the research of automatic driving technology, and the research and development investment is also increasing year by year. In particular, new energy vehicles with intelligent driving ability, such as Tesla, NIO, XPENG and Li Auto, are favored by consumers. Intelligent vehicles with automatic driving function have become the priority choice for people to buy and travel.

As single vehicle intelligence can not perfectly adapt to all road driving environments, and there are difficult scenarios such as over the horizon perception, blind areas of vision, ghost probes, etc., Thus, many units at home and abroad are studying how to make full use of core key technologies such as roadside perception fusion and road classification in vehicle-infrastructure cooperative automatic driving, so as to make up for the ability of single vehicle intelligence and better provide passengers with more efficient and safe travel services.

3. CLASSIFICATION STANDARD

3.1 Automatic Driving Classification Standard

In the future, transportation will be an industrial development state in which "wisdom" roads and "smart" vehicles develop synergistically and promote each other. The "wisdom" road is to build different levels of roadside intelligent infrastructure according to the road traffic environment and the actual scene. It gives the road infrastructure the ability of digitization, networking and intellectualization. Like a neural network that can sense the urban traffic operation situation, it can provide reliable perception and control decision-making information to the vehicles. The "smart" car is also the intelligent connected car. The document "smart car innovation and development strategy issued by China points out that by 2025, the technical innovation, industrial ecology, infrastructure, regulatory standards, product supervision and network security system of China's standard smart cars will be basically formed, and the smart cars that can realize conditional automatic driving will achieve large-scale production. To realize the market application of highly autonomous intelligent vehicles in specific environments. By 2035, China's standard intelligent vehicle system will be fully completed. At the same time, in terms of the classification of automotive driving automation, in 2014, the society of Automotive Engineers (SAE) International Society of automotive engineers developed a set of classification standards for autonomous vehicle, SAE J3016 classification and definition of standard road vehicle automation system [3]. The description of automation is divided into five levels, namely, driving assistance, partial automation, conditional automation, highly automatic driving and fully automatic driving. In 2021, China also promulgated the recommended national standard for classification of automobile driving automation (GB/T40429-2021), which classifies the driving automation level into six levels based on six elements, of which level 0-2 is driving assistance. The system assists human to perform dynamic driving tasks, and the driving subject is still the driver; Level 3-5 is automatic driving (Level 3 conditional automatic driving has fault takeover requirements, which is controversial in the industry). The system performs dynamic driving tasks instead of human under the design and operation conditions. When the function is activated, the driver is the system [4]. The classification of automobile driving automation is shown in Fig.1.

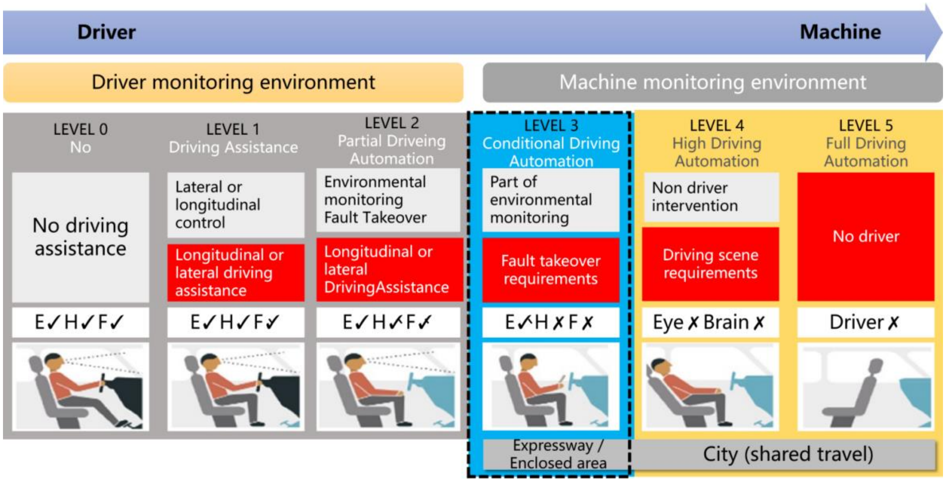

Fig.1 Taxonomy of Driving Automation for vehicles

3.2 Road Classification Ctandard

C2C-CC (CAR 2 CAR Communication Consortium, C2C-CC) was established in 2002. It is a European Union composed of top parking lots, parts suppliers and research institutions, aiming to promote the application of V2X technology in Europe, reduce traffic accidents and improve traffic efficiency. C2C-CC proposes different data based on C2X interaction, and divides the Internet application service into four levels, namely: basic data interaction, transmission data interaction, intention and collaborative data interaction and full automatic driving. The classification idea reflects the characteristics of phased development and backward compatibility, and also shows that the level of vehicle road collaborative automatic driving is a gradual upgrading process. Synchronization also reflects the technical development trend of gradual evolution of intelligent road infrastructure [5].

In 2016, China launched the technology roadmap of intelligent connected vehicles (1.0), aiming to clarify the core technology and implementation path of intelligent connected vehicles, and proposed to divide the level of networking into three categories, namely, Internet auxiliary information, data upload or download. Networked collaborative awareness, V2X is used as early warning and decision input. Network joint collaborative decision and control, V2X collaborative decision and control. In 2019, the China intelligent connected vehicle industry innovation alliance timely organized industry forces to launch the revision of the intelligent connected vehicle technology roadmap (2.0), which was released at the 2020 world intelligent connected vehicle conference. This is a top-level design document that sets the development route, strategy and objectives of the intelligent connected automobile industry in the next 15 years at a time when the automobile industry is undergoing the most profound transformation in the past century and the intelligent connected automobile is considered as the focus of future competition[6].

The introduction of road intelligent infrastructure classification and autonomous vehicle classification standards will greatly promote industrial development and technology iteration speed. However, the intelligent connected vehicles will not be able to operate safely and efficiently under all driving conditions in the short term. In a long period of time in the future, the hybrid of intelligent connected vehicles and ordinary vehicles will be a normal situation. In this case, it is particularly important for the road intelligent infrastructure sensing system how to effectively make up for the lack of environmental sensing ability of autonomous vehicle under certain traffic scenarios through the construction of road infrastructure.

Based on the theoretical research and practice of the classification of intelligent networked vehicles and road intelligent infrastructure, when carrying out the research on the industry and technology of vehicle road collaborative automatic driving road, it is necessary to analyze in close combination with different traffic scenarios. Different types and quantities of front-end sensor devices and edge computing units will be deployed at different road levels. Therefore, when we discuss the research on the key technologies of Vehicle-Infrastructure Coordination Autonomous Driving, we will mainly focus on the road level C or above (including level C), that is, the trusted perception information of roadside infrastructure will be transferred to the intelligent networked vehicles as the basis for decision-making. Therefore, according to the research results and practice of road intelligent infrastructure classification, it can be seen that the key traffic application scenarios of urban road traffic include intersections and blind spots in complex traffic environment; The key traffic application scenarios of Expressway include junction area, blind area of vision, sharp curve, tunnel, bridge, dangerous road section, etc. [2]

4 KEY TECHNOLOGY

4.1 Evolution of Vehicle-Infrastructure Collaboration Autonomous Driving Technology

At the same time, there are also government departments and third-party institutions that provide policy-making and supporting services throughout the upstream, middle and downstream, including standards organizations, intellectual property rights, testing institutions, industry associations, scientific research institutes, testing institutions, industrial alliances, etc. around the large map of the vehicle-infrastructure coordination autonomous driving industry.

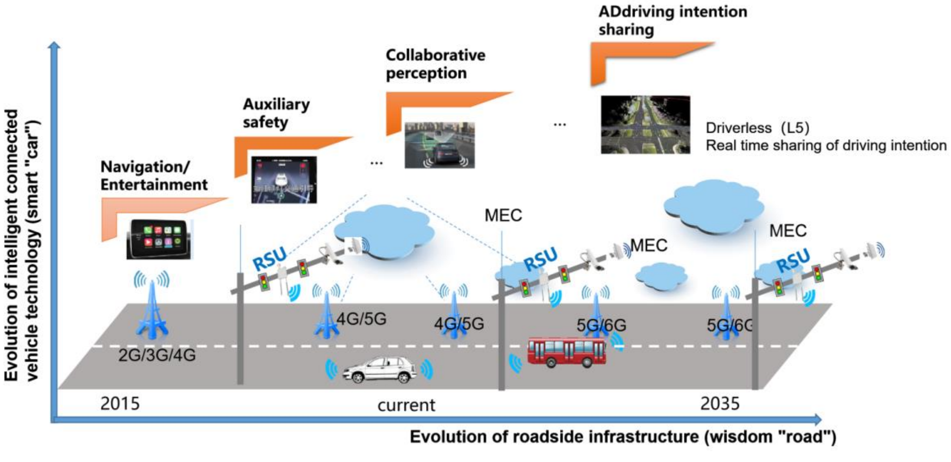

Fig.2 Evolution of Vehicle-Infrastructure Collaboration Autonomous Driving Technology

The good development of the vehicle-infrastructure coordination autonomous driving technology industry requires the coordinated development of roadside infrastructure (wisdom "road") and intelligent networked vehicle technology (smart "car") to promote each other, complement each other's advantages, and learn from each other's strengths. Only in this way can we build an integrated development mechanism across communication, transportation, automobile, new materials and other fields, and promote the sound and rapid implementation and large-scale application of the vehicle road collaborative automatic driving solution in China. The evolution route of vehicle-infrastructure coordination autonomous driving technology is shown in Fig.2.

4.2 Roadside Fusion Sensing Technology

Vehicle-infrastructure cooperative automatic driving is a research work of automatic driving related technologies based on "smart road". Therefore, according to the classification standard of intelligent infrastructure, roadside infrastructure with different levels and functions can be deployed for different road environments and grades. The construction of C1 digital signs, markings and signal systems in the intelligent infrastructure class C traffic information digital classification method; C2 global over the horizon perception (over the horizon event perception); The B-level collaborative perception classification provides full scene / holographic perception (accurate target perception based on the sun's perspective); The class a collaborative control category provides swarm intelligence path planning and guidance services.

Among them, C1 is basically characterized by digitization and networking of roadside signs and markings. It can change the positions and signal states of signs and markings that can only be perceived passively by the naked eye or automatic driving vehicles into the positions and states that can be actively informed to automatic driving vehicles or cloud platforms, and realize the information interaction between vehicles and roads at the digital level of traffic informatization. From C2 to higher-level cooperative perception level B and cooperative control level a, it is necessary to endow roadside vision, hearing and other perceptive abilities and intelligent network connected cloud control brain to process the perceived information through technical means such as camera, laser radar, millimeter wave radar, microwave, geomagnetic, environmental perception and V2X communication network, so as to realize the goals of roadside agile perception, rapid transmission, timely processing and cooperative control. To achieve this goal, roadside fusion sensing technology is one of the main technologies. Generally speaking, roadside intelligent infrastructure deploys a variety of sensors according to road classification standards and application scenarios. Multi-sensor data fusion is a multi-level and multi-level data processing process, which automatically detects, correlates, correlates and estimates the data from multiple sensing devices. The data processing methods in multi-sensor data fusion are essentially different from the classical signal processing methods. Due to the diversity of multi-sensor devices and the richness of functions, the data processed by data fusion has high complexity and non-linear relationship, and data fusion can be processed at different information levels such as data level, feature level and decision level.

4.3 Automatic Driving Technology at Vehicle

4.3.1 Perceptual System

Through literature review, ZHEN Xiantong [7] introduced the working principle, advantages and disadvantages of the on-board sensors (camera, laser radar, millimeter wave radar, ultrasonic radar, inertial navigation) of autonomous vehicle and their applications in autonomous vehicle, the calibration of sensors, computer vision and neural networks, environmental perception and recognition, Apollo data sets and semantic understanding of complex scenes, Finally, the basic theory of multi-sensor fusion and the pre / post fusion technology of multi-sensor are briefly introduced. DAI Yaping [8] introduced the basic architecture and theoretical system of multi-sensor system data fusion, and introduced the intelligent scheme based on probability theory in detail. The application of intelligent methods based on genetic algorithm, neural network, particle swarm optimization and Bionics in data fusion is introduced, and the application of deep learning theory in data fusion is introduced in combination with the hot spot of artificial intelligence development in Vehicle-Infrastructure Coordination Autonomous Driving. Finally, the design and implementation of multi-sensor data fusion robot platform are systematically described. LUO Junhai [9] proposed to plan multi-source sensors in terms of time, space and task. The best planning method is to arrange the sensor detection mode with the largest increment of system detection information as the implementation scheme of the next system according to the characteristics of sensors carried by multiple systems. At the same time, from the perspective of system information acquisition, target detection in the monitoring area, continuous tracking of moving targets and attribute identification of targets are the key contents of Hardware sensing equipment is the physical basis of the sensing system, mainly refers to various on-board sensors, including on-board cameras (surround view cameras, long focus cameras), lidar, millimeter wave radar, infrared sensors, sound, GPS, inertial navigation, multi-sensor fusion system, multi-source information interaction system, etc., which constitute the eyes and ears of autonomous vehicle. Generally speaking, the higher the quality of the original data of the on-board sensor, the lower the difficulty of the sensing system in data processing and analysis. The acquisition of high-quality sensing data cannot be separated from the excellent performance and reliable quality of the on-board sensor hardware equipment. Due to the different materials, processes and working principles of different sensors, these sensors can show their best state and advantages in different use scenarios. Various sensors can collect local information of their own range, and these information can complement each other and achieve redundancy. Multi sensor fusion can make full use of the advantages of various sensors, and can significantly improve the redundancy and fault tolerance of the system, thus ensuring the timeliness and correctness of decision-making. Multisensor fusion technology is the mainstream environmental sensing technology adopted by autonomous vehicle.information will be conducive to the improvement of system information increment.

The vehicle-infrastructure coordination autonomous driving sensing system integrates the feedback content of various sensors on the vehicle, determines the category and position of objects in the digital image, and predicts the size and position of objects in subsequent frames. At the same time, traffic status information is obtained through network communication of vehicle road coordination (V2X, information interaction between vehicle and the outside world).

Environmental awareness is a relatively complex system, which requires a variety of on-board sensors to acquire the information of the surrounding environment in real time, process and analyze the original input data through their respective algorithms, and output the most reasonable decisions. Therefore, the environmental awareness system is a highly integrated machine of hardware sensing devices and sensing software technology algorithms.

Hardware sensing equipment is the physical basis of the sensing system, mainly refers to various on-board sensors, including on-board cameras (surround view cameras, long focus cameras), Lidar, millimeter wave radar, infrared sensors, sound, GPS, inertial navigation, multi-sensor fusion system, multi-source information interaction system, etc., which constitute the eyes and ears of autonomous vehicle. Generally speaking, the higher the quality of the original data of the on-board sensor, the lower the difficulty of the sensing system in data processing and analysis. The acquisition of high-quality sensing data cannot be separated from the excellent performance and reliable quality of the on-board sensor hardware equipment. Due to the different materials, processes and working principles of different sensors, these sensors can show their best state and advantages in different use scenarios. Various sensors can collect local information of their own range, and these information can complement each other and achieve redundancy. Multi sensor fusion can make full use of the advantages of various sensors, and can significantly improve the redundancy and fault tolerance of the system, thus ensuring the timeliness and correctness of decision-making. Multi-sensor fusion technology is the mainstream environmental sensing technology adopted by autonomous vehicle.[10]

4.3.2 Decision-making System

By consulting the literature, YANG Shichun [11] put forward the decision-making and control practice based on the Apollo platform through the analysis and discussion of global path planning, vehicle behavior decision-making, vehicle motion planning and autonomous vehicle control. At the same time, it also briefly analyzes the exploration and practice of international competitions, universities and institutions in the decision-making of autonomous driving behavior. For example, in the DARPA autonomous vehicle competition, the autonomous vehicle system junior of Stanford University decided the trajectory and operation instructions of autonomous vehicle by designing a series of costs and finite state machine (FSM); The autonomous vehicle system boss of Carnegie Mellon University analyzes the gap between lanes, and determines the triggering of lane changing behavior according to certain rules and some preset thresholds.

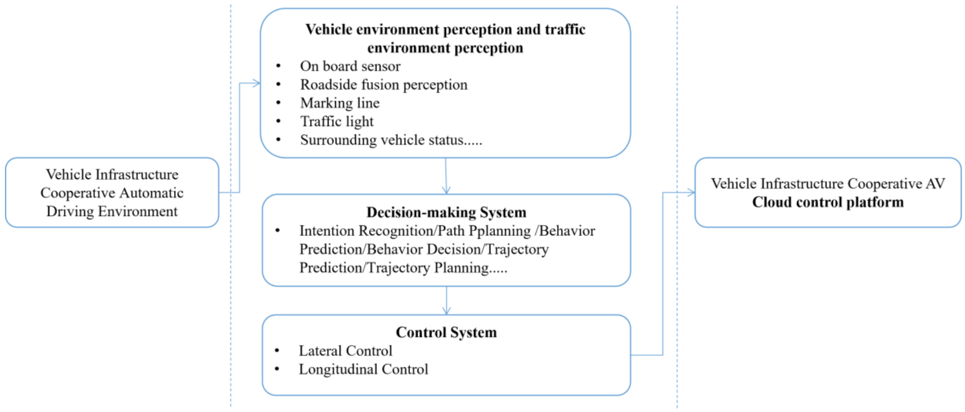

Fig.3 System Architecture of Vehicle-Infrastructure Collaboration Autonomous Driving Decision

Based on the information provided by the perception system, predict the changes of roads, pedestrians and vehicles, and make further driving decisions. The decision system plays the role of "brain" in the vehicle road cooperative auto drive system. This link gathers the important surrounding information sensed by the vehicle road cooperation autonomous vehicle, including not only the current speed, direction, position, lane and destination navigation information of the vehicle itself, but also the information of vehicles and pedestrians within a certain distance from the vehicle itself, as well as the real-time traffic status information collected through the communication information interaction of V2X network. The problem to be solved by the action decision-making system is to analyze and determine the control commands and Strategies of the driving action of the vehicle road cooperative autonomous vehicle based on the information input from the sensing system, so as to ensure that the vehicle road cooperative autonomous vehicle can adapt to the current road driving environment and reach the destination safely. The position of the decision system in the framework of the vehicle road cooperative auto drive system is shown in Fig. 3.

Based on the on-board perception information and traffic state information, the vehicle-infrastructure coordination autonomous driving decision-making system gathers information from different sources. Because complex and different types of information and traffic rules in different regions need to be considered, the vehicle-infrastructure coordination autonomous driving decision-making is usually difficult to solve with a simple data model.

4.3.3 Control System

By consulting the literature, WANG Pangwei [12] proposed a speed guidance method for networked vehicles facing urban trunk lines, including the speed guidance of the leading vehicle on the trunk line, the speed guidance of the following vehicle on the trunk line and the adaptive timing optimization method; At the same time, in terms of the dynamics model of the intelligent networked vehicle, by comparing the research results of domestic and foreign scholars, a simplified longitudinal dynamics layered model of the intelligent networked vehicle is proposed. From the perspective of implementation, the dynamics model of the intelligent networked vehicle is divided into three layers, namely, the lower control model (vehicle longitudinal dynamics model) The middle layer vehicle model (actuator model) and the upper layer control model (core control module, which refers to the control model of the vehicle against the base). GUO Konghui [13] established a relatively complete and systematic multi degree of freedom vehicle dynamics model in the process of studying the dynamic response of vehicles under steering drive and speed control. PHAM h[14] accurately described a multi degree of freedom vehicle dynamics model, which can accurately describe the vehicle dynamics characteristics. LI Bai[15] started with the decision-making and planning of a single vehicle, and characterized by fine modeling and efficient solution, respectively explained the collaborative decision-making and planning technology from the perspectives of robotics, numerical optimization, automatic driving and intelligent transportation, focusing on the collaborative decision-making and planning methods of intelligent networked vehicles under various traffic scenarios. YANG Shichun [10] proposed that, on the premise of finding the global optimal path and optimal decision-making behavior, given the combined shape and dynamic model of the vehicle, and based on the Apollo platform, a closed-loop process is formed from development to simulation and back to development, forming a continuous iteration and continuous optimization state.

The control system of the vehicle-infrastructure coordination autonomous driving is connected with the decision-making system through the bus, and accurately controls the driving actions such as acceleration degree, braking degree and steering range according to the bus control command issued by the decision-making system. The classical control theories in automobile motion control include seven kinds of automobile motion control theories such as PID (proportion integration differentiation) control (proportional control, integral control, differential control), fuzzy controller (FC), adaptive control, model predictive control (MPC), neural network control, sliding mode control (SMC) and robust control (RC).

To sum up, among the key technologies of vehicle-infrastructure coordination autonomous driving, perception mainly depends on AI (machine learning) decision-making. Through the continuous improvement of computing power and algorithms in recent years, the development maturity is good. The decision-making system is based on AI decision-making and rule (manual) decision-making, which is subject to high dynamic changes of the surrounding environment and road scene, and its development maturity is general. Due to the influence of single vehicle intelligence and changes in road traffic environment, the development maturity of rule-based (manual) decision-making before the control execution system needs to be improved; According to the on-board state perception and traffic state perception, the control execution system needs to drive the automatic driving vehicle to execute the control command driving action after the analysis of the decision-making system. At present, its development maturity is mainly focused on the level below L3, and it will take a long time to realize the higher-level vehicle-infrastructure coordination autonomous driving.

Due to the bottleneck of computing power and power consumption, scalability, test and road test costs, vehicle end hardware costs and modification constraints, the perceived development is relatively mature. However, ai artificial intelligence still has great development resistance, which brings "long-tail" problems for vehicle road cooperative autonomous vehicle.

5 SUMMARY

Therefore, in the actual traffic operation, the road conditions, pedestrian intentions, vehicle states, etc. are extremely complex. The roadside intelligent infrastructure and on-board computing unit need to process a large amount of heterogeneous data in a very short time and reliably transmit it to the vehicle control terminal in a very low delay manner, thus putting forward extremely high requirements for communication, network, computing power and algorithm. At the same time, in the process of vehicle-infrastructure coordination autonomous driving, it is necessary to conduct real-time information interaction with the surrounding roadside intelligent infrastructure. In addition, the vehicle end deep learning model is complex and the visibility of the model is low, so it is difficult to trace and improve the source after the error. Especially in the dynamic driving process of the vehicle, the whole process from problem discovery to error correction and improvement and correct execution of the control command driving action must be completed within milliseconds, This puts forward higher requirements for the reliability and stability of the whole system.

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