RESEARCH ARTICLE

Intelligent System Architecture Based on System Theory

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Abstract

Intelligent system is a research field that attracts much attention at present. Most of the researches on intelligent system focus on intelligent technology and its application. However, an intelligent system is first of all a system, which means it should have the characteristics of a system. Design of conventional system is mainly function- or task-oriented, and adaptation to environment is passive, static and regular. However, intelligent system is faced with a complex, random and dynamic environment, and has dynamic interaction with the environment. Behind this interaction behavior is a fusion of perception, cognition, and decision-making processes, supported by multi-source information fusion techniques. Therefore, intelligent system design needs to be oriented towards system behavior, where information fusion plays a crucial role in integrating heterogeneous data for coherent situational awareness. This paper will examine intelligent system from the perspective of system behavior characteristics, and put forward a new definition of intelligent system based on information fusion principles. The core feature of intelligent system is intelligence, which relies on advanced fusion algorithms to combine sensory inputs, knowledge, and contextual information. To construct an intelligent system, we develop a framework of five core capabilities, aligning with the traditional Chinese philosophical fusion of knowledge and action – the Unity of Knowledge and Action. Finally, we give a design case of an intelligent system (intelligent vehicle) to demonstrate the practical viability of the proposed architecture and concept, highlighting the role of multi-modal fusion in perception and decision-making.

Keywords: intelligent system, system architecture, system theory, information fusion.

1 Introduction

Since artificial intelligence(AI) took inception in the 1950s [1–3], despite several setbacks, it has enjoyed rapid development in terms of theories, technologies, and products, on the one hand due to the development of computer technology, network technology, sensor technology, brain science, etc., and on the other hand driven by a growing social and economic demand. A key enabler of this progress

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is information fusion, which integrates data from multiple sources to improve system reliability and decision-making accuracy. Now AI is present in almost all sectors and has profoundly affected the development and progress of human society. In particular, the success of the artificial intelligence product AlphaGo in defeating the Go world champion has made people realize the tremendous ability that AI can unleash beyond human beings, where fusion of Monte Carlo tree search and deep learning played a pivotal role. The combination of artificial intelligence technology, information fusion methods, and systems (products) gives rise to the concept of "intelligent systems". Intelligent system is a system using intelligent technology. The current intelligent cars [4] and intelligent robots [5] are actually cars and robots with limited level of intelligence, which are not intelligent systems in the strict sense. Our ultimate goal is intelligent systems. But there is no clear and authoritative definition of intelligent system yet. A commonly used definition is "an intelligent system is a computer system capable of intelligent human behavior" [6], but this definition is too general. What is intelligent behavior? Is it a conventional computer system? One root cause of the lack of a clear definition of intelligent system lies in the lack of thorough understanding of the nature of intelligence and systems.

At present, researches and introduction of intelligent systems [7–10] are mainly focused on the composition and function of function- or application-oriented intelligent systems and application of intelligent technology in system. However, we believe that intelligent system is first of all a system, that is, it should have the characteristics of a system. Therefore, the study of intelligent system should not only start from intelligent technology and intelligent theory, but also start from system theory. So what are the differences between intelligent systems and conventional systems? This is a question that needs to be answered first. Second, intelligent system itself is a new concept, different from either objective technology systems including mechanical system, and computer system, or subjective cognition system of human [11–13], rather, it is a new type of system combining objective perception and subjective cognition. Therefore, the system theory itself needs to evolve and update. Intelligent systems differ from conventional ones mainly in cognition and behavior. This paper will examine intelligent systems from the perspective of system cognition and system behavior characteristics. The core feature of intelligent system is intelligence. To construct an intelligent system, we have developed the concept of five core abilities of intelligence [14, 15], which coincides with the traditional Chinese concept and way of understanding the world called "Unity of knowledge and action". Finally, we give a design case of an intelligent system (intelligent vehicle) to demonstrate the practical viability of the proposed architecture and concept.

2 Basic Theory

2.1 System theory and system concept

The idea of systems has a long history, but systems theory, as a science, was pioneered by the Austrian-American Ludwig von Bertalanffy. In 1969, he published General Systems Theory: Foundations, Developments, and Applications [16], which began the development of systems theory that continues to this day. Modern system theory has been further enriched by information fusion methodologies, particularly in handling uncertainty and conflict resolution in multi-sensor environments.

In General Systems Theory, Bertalanffy put forward some relatively complete concepts and methods of systems theory for the first time, among which there is definition of a system: a system is an organic whole of several interacting components. The wholeness and organicity of system are clearly defined in this definition. Bertalanffy also pointed out that "the whole is greater than the sum of its parts". This is not only about the existence of system as a whole, but, more importantly, its being a whole gives emergence to things that do not exist in the individual components: new characteristics and capabilities. This trait came to be known as emergence [17]. After that, research on system continued to go deeper, such as Bogdanov's dissipative structure theory [18], Haken's synergetic theory [19], Renetom's mutation theory [20], etc., thus forming a relatively complete system theory. Chinese scientists also play an important role in the development of system theory. Academician Qian Xuesen, the father of China's missile and pioneer of China's system engineering, incorporated the hierarchy of systems into the definition of systems [21] and proposed the concept of complex giant systems. He believed that systems are open and exchange material, energy and information with the external environment.

To talk about system, we must talk about system environment. A system environment is something that surrounds the periphery of a system, which is "just outside the edge of the system" but is related to the system [22, 23]. The environment can be regarded as the sum of all external factors that the system depends on to exist and evolve, and also the collection of various factors that exist around the system and are related to the system. As an open system, the system acts on the environment through system behavior, and the environment responds to and gives feedback to the system, and the system ADAPTS to adjust its function, structure, parameters and behavior. In a sense, the characteristics, structure, capability and value of the system are determined by the environment. In John Holland's Hidden Order: Adaptation Creates Complexity [24], he proposed the concept of Complex adaptive system (CAS), in which there are systems composed of a large number of agents who interact, learn from and adapt to one other. The study of complex adaptive system focuses on the complexity, emergence and adaptability of system, and considers the internal rules and changes of system from the perspective of dynamic interaction with environment.

The characteristics of the system include wholeness, emergence, purpose and adaptability to the environment.For a simple system, system wholeness, emergence and purpose are deterministic and static. Its capabilities can be enhanced by hardware, the interaction with the environment is programmed, and the rules are set in advance by human according to their own purposes or interests. However, when the environment is complex, random and dynamic, the system changes/upsize or downsize its structure, components, rules, and order in order to adapt to the environment, thus becoming more complex. At this stage, simply adding more hardware no longer helps improve the system, the required new capability should be formed through "software" on the common resource platform. As the system evolves, it relies less on human wisdom. Instead, the "wisdom" of the system will fill in and play. Thus, an intelligent system is born.

2.2 Intelligence

Humanity's distinction as preeminent beings in nature stems from our highly developed intelligence, which comprises two integrated components: cognitive faculty ("wisdom") encompassing perceptual awareness, mnemonic retention, and analytical reasoning – fundamentally constituting our capacity to comprehend reality – and executive capability ("ability") manifesting through linguistic articulation and goal-directed actions. This synthesis of cognitive processing and behavioral implementation forms operational intelligence: a systemic empowerment that enables the emergence of capacities to interpret, adapt to, and transform our environment. Characteristically human endeavors – including labor, knowledge acquisition, and symbolic communication – universally demonstrate this inseparable unity of mental computation and physical enactment, an evolutionary exclusivity that defines behavioral intelligence as the hallmark of human cognition.

And every activity (behavior) of human beings has its own intention in the leading, which means human activities are purposeful, conscious, active, rather than unintentional, or passive. Intention is a behavior tendency, and the reaction tendency of the individual to the object of intention. In other words, intention is the preparation state of behavior, which prepare an individual to make a certain response to the object of intention. Behind intention is everyone's common knowledge of the world, world model and world view, common sense, belief system (culture), values, sense of teamwork, etc., as well as individual needs, wishes, emotions, ideals, etc.

The source of intention is thought. Thinking is the core of human intelligence and an important feature that distinguishes human from other animals. "Man is a thinking animal," and without thinking there is no human intelligence. With thinking, human beings can form a variety of more complex intentions to dominate human activities, showing the unique conscious initiative of human beings. With thinking, human beings can explore the mysteries of nature and discover the laws behind natural phenomena. With thinking, human beings can invent various technologies, break through the limitations of their own organs of understanding and action, and greatly improve the ability to transform the world. Human ability to think is acquired through learning and training. Being able to learn is also a typical feature that distinguishes humans from animals. Animals also have certain learning skills, which are mainly to adapt to the environment, while the purpose of human learning is not only to adapt to the environment, but also to transform the environment. Therefore, human learning is often carried out in the continuous interaction with the environment, and is an active behavior. The result of learning is the acquisition of information and knowledge, the construction of models, and the formation of social perspectives. In short, human intelligence is a kind of wisdom and ability oriented to behavior, intention, thinking and learning.

The subject of intelligence is human, and there may be machines as intelligent as human beings in the future: agents. Machine intelligence is an imitation of human intelligence. The goal of agent is to become like people, and to have some of the intelligence of people. But until such machines emerge, and even after agents emerge, people are still the subject of the entire system. Therefore, when we talk about agents, we cannot but talk about the so-called interaction between agents and people: the integration of human intelligence and machine intelligence. Thus, the definition of human-machine intelligence is put forward:

Human-machine intelligence is the ability of learning, enquiring, thinking and discerning and decision-making produced or provided by the agent through continuous interaction and perception with the external world.

The five capabilities in this intelligence concept of intelligence are:

1. Learning ability: the ability to selectively memorize and form information and knowledge about the external world through interaction with the environment;
2. Problem finding ability: the ability to find the gap between reality and the ideal goal;
3. Thinking ability: the ability to analyze, compare, judge and associate external information with existing knowledge;
4. Discerning ability: the ability to discern the merits and demerits, strengths and weaknesses of various choices or schemes made in response to the environment;
5. Behavioral decision-making ability: Forming behavioral decision-making ability.

These five abilities are not only coincide with the "Unity of knowledge and action" put forward by ancient Chinese philosophers, but also reflect the idea.

2.3 Intelligent System

All intelligent systems need to be built on an open system with shared resource and data and comprehensive functions. The powerful data computation, transmission and storage capabilities of the open system are necessary conditions for the operation of intelligent systems.

Early stage systems are functional systems designed to achieve one or several functions, and a system with multiple functions is called a comprehensive system. Functional systems are function-oriented. Further there are task-oriented systems, which perform tasks through “programmed” organic combination of different functions, or in other words, the system selectively executes functions to accomplish the task. Whether it is a functional system or a task-oriented system, their goals are static, predetermined or pre-set. In contrast, the goal of an intelligent system is open, and the system sets new goals (finding problems) as environment or task changes, and rearranges functions (thinking) for the new goals, evaluates various arrangements (identification), and determines the optimal behavior plan (decision) from them. The intelligent system also has the ability to improve itself, which is called learning.

These patterns of intelligent systems are designed to simulate human intelligent behavior. Intelligent system has traditionally been defined [6] as:

An Intelligent system is a computer system that produces intelligent human behavior.

In other words, intelligent systems are computer systems loaded with human intelligence patterns. Conventional information systems rely on human in task application, function play and dynamic construction. Human is a part of the external environment to the system. Although human-computer interaction, human factor engineering and human in the loop are sometimes emphasized, after all, the system and human intelligence are two independent entities. In intelligent systems, human wisdom is endowed to the system, and the system has wisdom. However, this definition is too general and vague, and does not demonstrate how the two kinds of intelligence are coordinated and complementary.

A more detailed definition is given in reference [7]. An intelligent system is an artificial system that (1) operates as an agent,i.e., the system perceives its environment, acts in the environment and interacts with other agents, and (2) exhibits rational behavior, i.e., the system acts rationally (to maximize the success of its tasks) and shows rational thinking (justifies beliefs through reasoning).

This definition clearly points out that intelligent systems have perceptual and behavioral relationships with the environment, as well as the behavioral rationality behind them. But on this basis, three aspects must be added: (1) all actions should be unified under the overall goal, and this goal is governed by strategy or value; (2) What supports perception and action is cognition, and perception-cognitive-behavior should be considered as a whole. This is the embodiment of "knowing and doing together". (3) Intelligent system is not only the emergence of function and form, but also the emergence of behavior.

Therefore, we give the definition of intelligent system from the perspective of system characteristics:

Intelligent system is an open information fusion system characterized by behavior goals based on strategy and value, perception-cognition-behavior integration through multi-level fusion, behavior emergence and active adaptation to the environment. The system employs hierarchical fusion architectures, including sensor-level fusion for raw data integration, feature-level fusion for pattern recognition, and decision-level fusion for optimal action selection. Intelligent systems are information systems. But there are major differences between intelligent systems and conventional information systems:

(1)Objects

Intelligent system is based on knowledge, whereas conventional system is based on data. Intelligent systems deal with objects including not only data, but also knowledge. The ability to represent, acquire, access and process knowledge is one of the main differences between intelligent systems and conventional systems. Therefore, an intelligent system is also a system based on knowledge processing, which requires the following facilities: knowledge representation language to represent knowledge; tools to organize knowledge; methods and environment for establishing, maintaining and inquiring knowledge base; reuse of existing knowledge.

(2) Problem solving methods (processing result)

ntelligent systems often adopt artificial intelligence as a problem solving approach to obtain results. Compared with conventional system, they have three obvious characteristics: the problem solving algorithm is often non-deterministic or heuristic; The solution of the problem depends on knowledge to a large extent; The problems of intelligent systems tend to have exponential computational complexity. Problem solving approaches usually adopted by intelligent systems can be roughly divided into three categories: search, inference and planning.

(3) Application ability

Another important difference between intelligent systems and conventional systems is that intelligent systems are aware of their situations (adapt to the environment). The so-called situational awareness means that it can perceive the real world and abstract it into knowledge, and adapt to the changes of the scene through interaction. This interaction involves perceiving, learning, reasoning, judging and acting accordingly. This is often referred to as self-organization and adaptability.

(4) The goal of problem solving

Intelligent system has values which prioritize one goal as the overarching goal in pursuit of overall optimum. Conventional systems are based on rules and set goals.

(5) Design philosophy

Intelligent system is behavior oriented, while conventional system is function oriented and task oriented.

3 Architecture of the intelligent system

Intelligent system consists of agent(s) and non-agent(s). At least one agent is necessary, where as non-agents are not a necessary condition. An intelligent system can be without non-agents.

3.1 Agent

Agent [25–27] is an important concept in the field of artificial intelligence. Any independent entity that can think and interact with the environment can be abstracted as an agent. An agent can be a software that can act autonomously, or it can be a hardware entity. There are different definitions of an agent, one of which is an entity that resides in the environment, interprets data from the environment that reflects events occurring in the environment, and performs actions that have an impact on the environment.

In this definition, an agent is seen as an entity that "lives" in the environment. The agent can continuously perform three functions:

1. Sensing dynamic conditions in the environment
2. Performing actions that affect environmental conditions
3. Reasoning to interpret perceived information, solve problems, generate inferences, and determine actions

Agents can be regarded as subject objects in intelligent systems. However, they have both similarities with and great differences from objects. Agents have identity, state, behavior and interface just as objects do. Agents differ from objects mainly in the following aspects:

1. An agent has intelligence, usually has its own knowledge base and inference machine, and this knowledge base is obtained and evolves through the agent's own learning, whereas a general object does not have this feature.

2. An agent can autonomously decide whether to respond to information from other agents, whereas an object must act according to the requirements of the outside world. That is to say, an agent system can encapsulate behaviors, but objects can only encapsulate states instead of behaviors. Behaviors of an object depend on the external call of methods; Or a general object is more of a tool or method.

3. There is communication between agents, usually using a communication language that supports knowledge transfer. The communication between agents is often the transfer of knowledge, while the communication between general objects is often the transfer of data or information.

However, the agent can be regarded as a special kind of object, that is, the object with mental state and intelligence. An agent itself can be constructed by object technology, and most of the agents have adopted object-oriented technology. Characteristics of the agent itself make up for the shortcomings of the object technology, and become another leap in the computer field following the object technology. The global wave of research in agent is rising, researchers in computer, artificial intelligence and other industries are conducting more in-depth research on the technology, and are introducing it to their own research fields, providing new tools for solving practical problems in production more effectively.

The architecture of agents is built on the pattern of human intelligent behavior with information fusion as its core enabling technology. According to the human intelligent behavior pattern, the agent can be composed of the following six parts: intelligent sensing subsystem with multi-sensor fusion capabilities, intelligent decision-making subsystem with evidence combination algorithms, executive subsystem, autonomous learning subsystem with federated learning, integrated resource platform and knowledge base with fusion-based knowledge graph. The relationship between them is shown in Figure 1. The most important change from the traditional architecture is the addition of an autonomous learning subsystem that emphasizes the strategic goals/value culture that governs intelligent decision making, supported by continuous fusion of experiential data and real-time observations.

(1) Smart sensing subsystem

The intelligent sensing subsystem consists of a intelligent sensing module and a joint information acquisition module, namely sensing and knowing.

The intelligent sensing module is mainly composed of various sensor arrays and corresponding pre-processing circuits. Different from conventional sensor arrays, a intelligent sensor array is a "intelligent skin" array with reconfigurable formation, adjustable scale and adaptive array parameters, which can independently change the formation, array size and array performance according to the changes of task goal or environment.

The joint information acquisition module is the use of sound, light, magnetic and other methods to jointly observe, acquire and image the target and the environment. Different from conventional information acquisition methods which focus on the target of interest, joint information acquisition focuses more on the observation, analysis and discrimination of the environment including the target.

(2) Intelligent decision-making subsystem

The intelligent decision-making subsystem is the core of the agent. In the intelligent decision subsystem, the three processes of "enquiry", "thinking" and "discriminating" of intelligence are fully presented. "Enquiry" is to identify problems and set or adjust goals through situation analysis and assessment. The target-environment fusion image derived from the intelligent sensing subsystem is used to analyze and evaluate changes in the environment, quickly identify the threatening environment, and formulate or adjust the goal; "Thinking" and "discriminating" are both intelligent decision-making processes. "Thinking" is to make use of existing knowledge to analyze, compare, judge and associate external information, so as to obtain the correct results for the external environment and the next prediction; "Discrimination" is that the system puts forward different problem solving solutions (task planning) for the implementation of new goals, and carries out strategy selection and

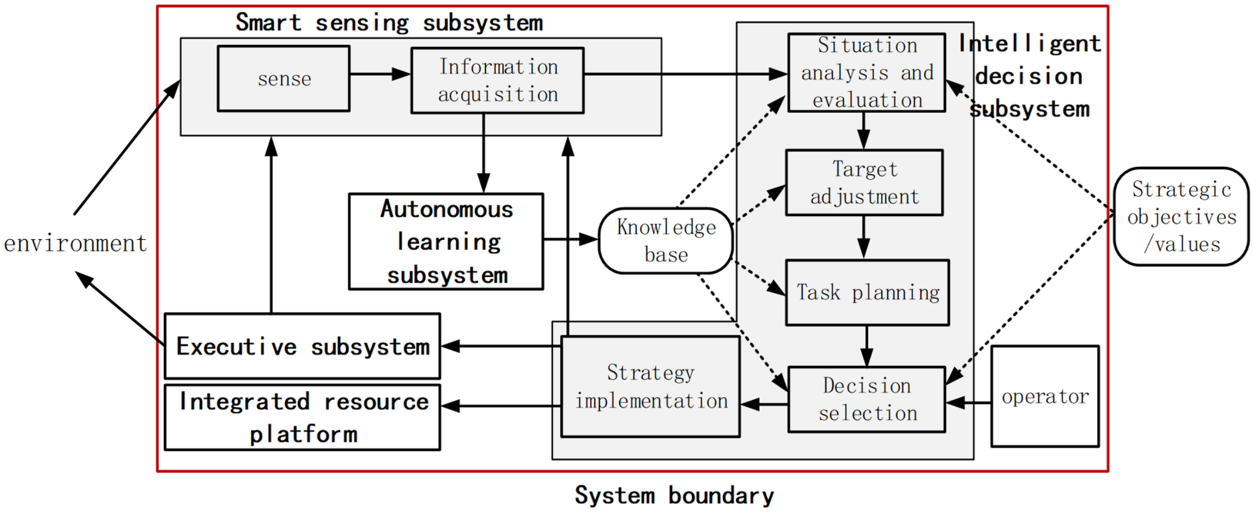

Figure 1. Intelligent system composition diagram.

parameter calculation for these different task planning, and forms decision results together with human (man-machine integration), and finally forms the implementation plan. The process of "enquiry", "thinking" and "discriminating" is not only dependent on the knowledge of the knowledge base, but also governed by the strategic goal/value culture.

(3) Executive subsystem

The executive subsystem implements the "actions" of the intelligent system. Executive subsystem is an active behavior. Internally, it can coordinate and adjust the setup and operation of intelligent sensing subsystem and integrated resource platform, such as controlling the formation and layout of sensor array and the allocation of resources in the system. Externally, actions can be applied to change the environment and the objects in the environment. For example, in the vehicle-mounted system, active behaviors include the active emission of signals to detect the environment, changing the route of the vehicle and other behaviors.

(4) Autonomous learning subsystem

Autonomous learning subsystem is the cornerstone of an agent. Learning is present all the time, which means the content of learning is mainly from the whole-process data formed in joint imaging of target and environment, and the data is screened through expert evaluation, external data synthesis and other means to form a data accumulation database. New knowledge is formed through machine learning and data mining, and the existing knowledge base is updated. The updated knowledge enters the decision-making network.

(5) Knowledge base

Knowledge base includes not only long-term culture, rules, strategic goals, tactical methods, etc., but also short-term knowledge about current goals and environments. The knowledge base of the agent needs to be updated in real time, that is, the knowledge grows through continuous learning and practice.

(6) Integrated resource platform

Every behavior needs the support of resources, and the integrated resource platform provides resources for processing, storage, transmission and performs resources allocation.

3.2 Intelligent system organization structure

Intelligent system in its narrow sense can refer to only one agent. The intelligent systems currently under development are actually agents, such as intelligent cars. An intelligent system in its slightly broader sense is one agent plus several non-agents. Non-agent is an extension of some function or tool or means of an agent. An advanced intelligent system should be a more intelligent complex system composed of multiple agents and multiple non-agents. For example, a swarm of intelligent drones operating together.

In many cases, agents themselves contain non-agents. Therefore, there is no need to separate the two absolutely. When a non-agent and an agent are highly coupled, the non-agent can be regarded as part of the agent, and the agent is further regarded as a highly aggregated subsystem, which is highly loosely coupled with other subsystems.

Figure 2 illustrates the organizational structure of various intelligent systems. The first architecture, depicted in Figure 2(a), features agents of equal

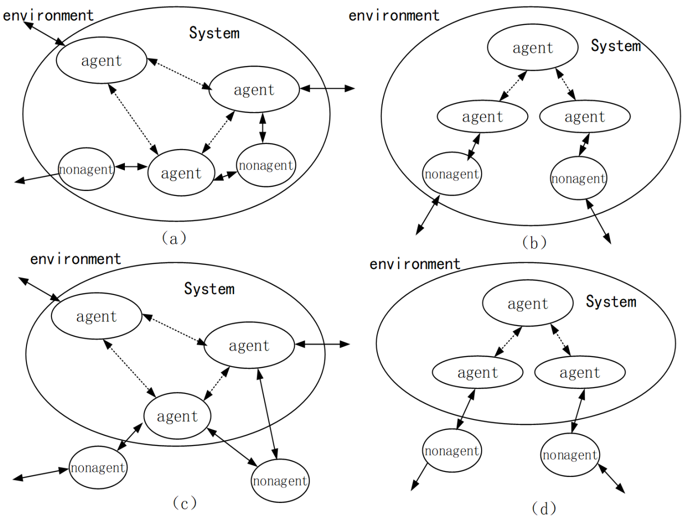

Figure 2. Architecture of several intelligent system.

status but with distinct roles and functionalities. The collective behavior of these agents defines the system's operation, hence it is referred to as the joint architecture. The second architecture, shown in Figure 2(b), is characterized by a hierarchical structure where one agent assumes a leadership role, managing and controlling the other agents. The latter two architectures, presented in Figure 2(c) and Figure 2(d), contrast with the former by their treatment of non-agents. These architectures regard non-agents as components of the environment rather than integral parts of the system. This perspective enhances the system's stability and allows for greater accessibility and diversity among non-agents.

4 System features of intelligent system

In traditional theory, system has two major attributes: function and form [22]. But it is not enough for intelligent systems to have these two properties, there should also be a behavioral property [23]. In the following, we discuss the integrity, emergence, purpose and environmental survivability of behavior.

4.1 Integrity of intelligent behavior

Intelligent system not only has formal integrity and functional integrity, but also has behavioral integrity. Behavior is expressed as thought and action. Then the behavioral integrity of intelligent system includes thinking integrity and action integrity.

Thinking integrity refers to the integrity of thinking processes from stimulation to decision making within an intelligent system. The intelligent system interacts with the environment, receives stimulation from the environment, perceives the change of the environment consciously or unconsciously, and obtains information about the environment through sensors. After that, the intelligent system, as an agent, will also complete the process of problem finding, goal resetting, task planning, strategy selection and decision implementation. In non-intelligent systems, these processes are done by the person operating the system.The entire internal behavior process is shown in Figure 3.

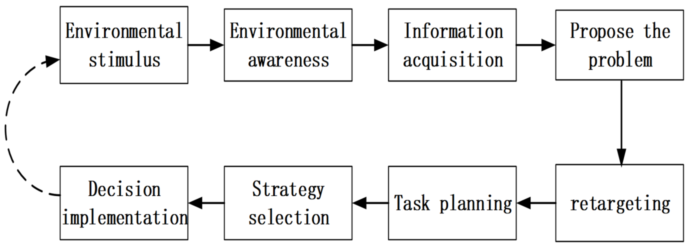

Figure 3. Comprehensive internal behavioral process of the intelligent system.

The behavior of an intelligent system consists of a series of actions that are completed in an orderly manner according to some rule or procedure. This order reflects the integrity and continuity of the action in time and order, as shown in Figure 4. Action integrity is an organic whole formed by the cooperation and synergism of the action processes executed outside the intelligent system. Continuity of action refers to the continuity of action in time and space.For example, if a person decides to do a certain thing, such as crossing the street, he would first walk to the side of the road, observe the traffic on the road, and when after confirming that there is no car passing or that the car poses no threats, he steps forward. When walking, one should constantly observe the surrounding situation, choose an appropriate route, and ensure that he reaches the other side of the road safely. In the process of walking, the feet, hands, and the whole body are naturally coordinated. The whole action of crossing the road is organic and unified, if a link is missing or a link is not coordinated, the effect of behavior will be biased or compromised. The actions are not only interconnected with one another, but also have a dynamic linkage in time sequence, which is not an aspect that non-intelligent systems need to consider.

In non-intelligent systems, the system is merely a tool, and there is no action design and execution. In intelligent systems, the choreography of actions is a very important thing.

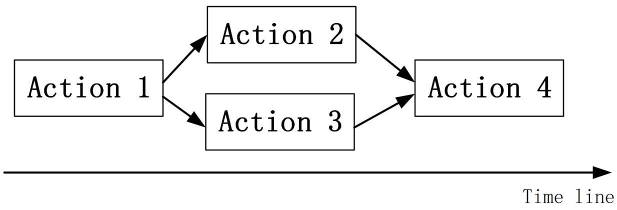

Figure 4. Action process of intelligent system.

4.2 Purpose of intelligent behavior

Both thinking and action have a purpose, and this purpose is called the behavioral purpose.

A non-intelligent system is a tool whose purpose is to make itself have a certain function and to make that function optimal and reasonable. For example, the purpose of an ordinary car is to provide a tool that can transport people or goods from one place to another, so we consider more in the design of the car speed, passenger capacity, fuel consumption, safety, reliability and other aspects.

Intelligent systems are concerned with how to use other systems as tools. Elements that embody the purpose of the behavior are specific to the behavior. Taking a intelligent car as an example, its purpose is to achieve unmanned driving in the shortest time and safest way on the road in real and complex conditions. Also included are strategies in response to emergencies, superb evasive ability as well as accurate, effective and rapid response ability. In other words, an intelligent car not only drives itself from one place to another autonomously, but also respond correctly to pedestrians, road signs, buildings, trees, and so on. The second point is obviously more difficult than the first, because the second point involves not only the purpose, but also value judgment.

It can be seen that compared with non-intelligent systems, intelligent systems pursue the best accessibility of behavioral purposes instead of mere technical advancement of the system itself. Its purpose has a higher level, and its goals directly correspond to the core mission, strategic goals, values, and culture. Intelligent system goal is a multilevel target system. High-level goals guide and instruct low-level goals, and the completion of various low-level goals is the basis for the achievement of high-level goals. Figure 5 is the target architecture for an intelligent system. Level 0 objectives are generally core mission tasks, strategic objectives, culture, rules, legal norms, etc. These goals are not only to guide individual intelligent systems, but also to guide the goals of intelligent systems families and future system development. The next several layers are the goals of specific intelligent systems. The first layer is the behavioral goal layer, the second layer is the task goal layer, the third layer is the functional goal layer, and below that are the goals of the entities that are components of the system. On the basis of general systems, the intelligent system adds the first layer: the behavior target layer.

Behavioral goal is the ultimate goal to be achieved or pursued by the system in the overall activity, so it is not a specific goal to be achieved by a system or a class of systems, nor is it a phased goal to be achieved by the system in a certain period, but the goal to be achieved by all systems participating in the behavior, and it is also the goal to be achieved consistently by these systems. For example, the behavioral goals of a intelligent car include the correctness of the car's path selection, driving safety, and the rapidity and accuracy of responding to emergencies.The behavior target can be decomposed according to different dimensions such as time, behavior type and scene.

Another characteristic of intelligent system goal is the dynamic nature of goal. In fact, intelligent systems find problems or possible risks in the process of continuous interaction with the environment. In order to solve this problem or avoid risks, it is necessary to monitor the changes of the environment at any time, analyze and evaluate the accessibility of environmental changes to the realization of the goal, adjust the goal adaptively according to the evaluation results, and propose strategies and measures to achieve the goal. The process of dynamic target establishment and adjustment is shown in Figure 6.

4.3 Emergence of intelligent behavior

In addition to the emergence of function and form, intelligent systems also produce the emergence of behavior. Behavior emergence refers to the phenomenon that the macroscopic behavior of a system (which can be a group system composed of multiple agents or a complex physical entity system) is spontaneously generated by the simple local interaction between individuals in the system and the interaction between individuals and the environment. This macro behavior is not set by central control or pre-programming, but occurs naturally during the operation of the system.

Of course, behavioral emergence can either make the system have behavioral emergence through human operation, that is, people apply the results of thinking

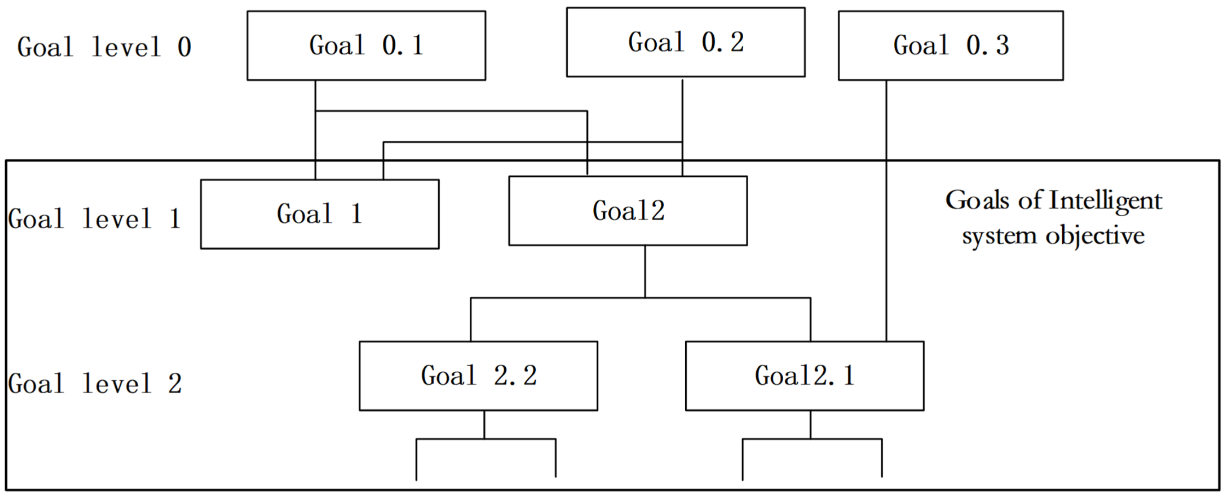

Figure 5. Intelligent system target architecture.

to the machine, or the intelligence of both humans and machines can jointly determine the emergence of the entire behavior.

(1) Humans use machines, so that machines show emergence. A hair dryer itself is a machine that generates hot air. When used by a human, a hair dryer can be used to dry hair and clothes, or be used as a small air pump to blow dust away for cleaning, or be used as a heater to remove the moisture between layers of an insulating bowl, or even used as a simple physiotherapy instrument to treat headache or shoulder pain. This level demonstrates the integration of human intelligence and machines.

(2) Humans give machines a certain automatic ability. The machine can make corresponding actions according to the pre-set program. Automated production lines are a good example. An adaptive algorithm is a set of instructions for executing events that can change in an environment or context. The overall structure of the adaptive algorithm is fixed, but the parameters can be adjusted according to the difference between the output result and the set goal, so as to approximate the set goal. This level demonstrates the self-adaptability of machine.

(3) Humans give machines a certain degree of autonomy. The machine can make decisions and respond according to pre-set rules. The machine can change its behavior based on rules within a certain range. For example, when a car finds an obstacle in front of it, it can start the collision avoidance or braking function. At this level, the machine has autonomy.

(4) Humans give machines certain learning and thinking abilities. The machine can learn from different external environmental stimuli, find the optimal strategy through learning and respond to it. At this level machine has intelligence.

(5) Machines and humans have a high degree of interaction. That is, human intelligence and machine intelligence are highly integrated and mutually complementary, and machine and human have the same behavioral capacity.

4.4 Environmental survivability of intelligent behavior

Intelligent system is a fully open and interactive system with the environment, is a system in the

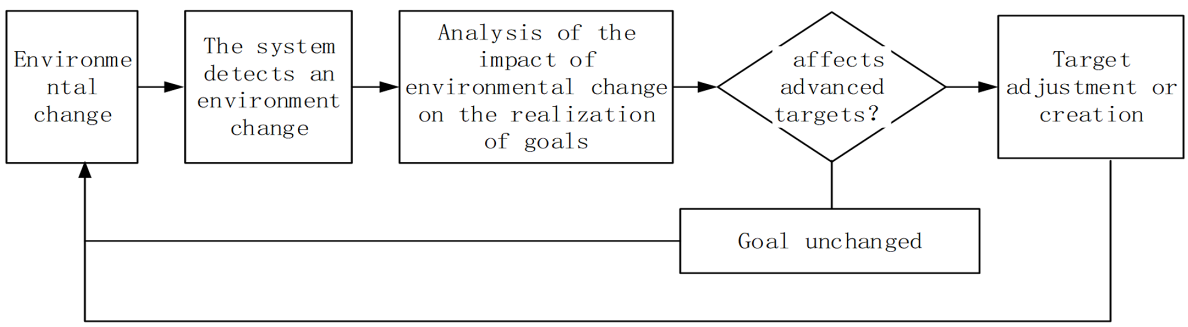

Figure 6. Dynamic establishment and adjustment of intelligent system goals.

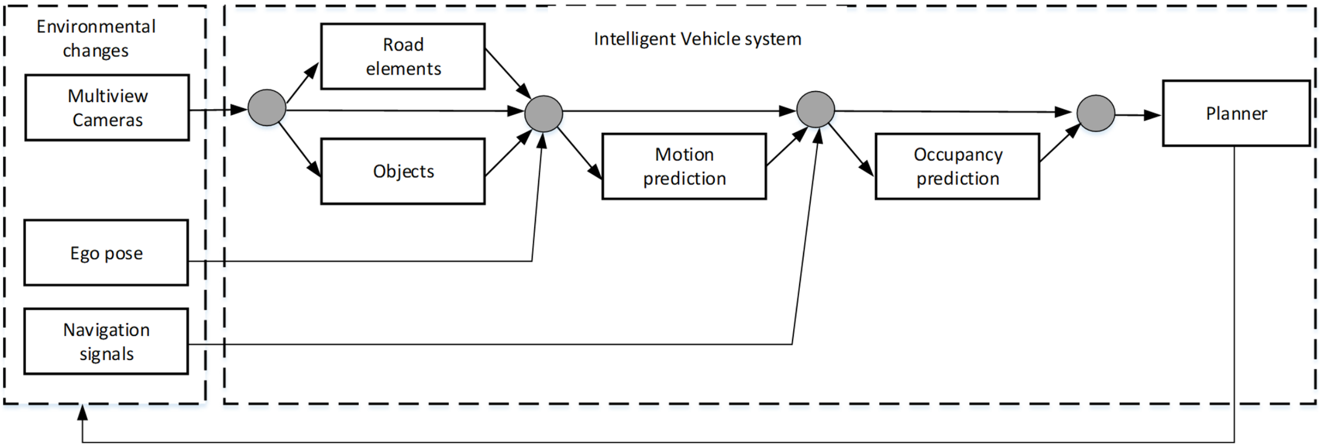

Figure 7. Architecture of autonomous driving for intelligent vehicles.

environment and as a part of the environment, it monitors the environment continuously and responds with corresponding actions. In the same time, it gradually establishes its own activity planning to cope with possible future changes in the environment. Integrating environment into intelligent system means that the interaction and function of the intelligent system and the environment have the same goal, integrity and emergence.

The relationship between system and environment is a process of gradual evolution, which also reflects the degree and way of interaction between system and environment.

(1) Matching. When the environment changes, the system changes with it. If we go out and find it raining outside, we take an umbrella for it. Matching is a passive adaptation.

(2) Environmental adaptation . We anticipate that the environment will change and prepare for it in advance. If we find dark clouds gathering in the sky, we expect rain in an hour, so we take an umbrella. Environmental adaptation is a kind of active adaptation.

(3) Intelligent adaptation. Anticipate the pattern of environmental change and actively adapt to change. Although the sky is clear outside, we foresee the possibility of rain based on the look of clouds, so we make preparations in case of rain, such as taking an umbrella with us, change our schedule, or choosing way of transportation (walking, driving, etc.).

5 An example of intelligent system: Intelligent vehicles

In recent years, intelligent vehicles have become the focus of research in the field of vehicle engineering in the world and a new driving force for the growth of the automotive industry [4, 28]. Intelligent vehicles are the forefront of intelligent systems and the most successful practice at present. A intelligent vehicle is a vehicle based on the latest technology, with a high degree of intelligence and autonomy. It can drive autonomously, sense and understand its surroundings, make decisions, and perform actions to ensure the safety and comfort of passengers. At present, great achievements have been made in the aspects of comprehensive environmental perception, planning and decision-making, and multi-level assisted driving. Taking SenseTime's intelligent vehicle as an example, we can roughly peek into the current progress of intelligent system and the preliminary application of system theory in building intelligent system architecture.

Figure 7 shows an abstracted pipeline of an intelligent vehicle system called UniAD, which integrates detection, tracking, mapping, trajectory prediction, occupancy grid prediction and planning into a system framework of perception-prediction-behavior decision making for the first time. And the use of planning oriented data-driven end-to-end deep, achieves an important breakthrough in autonomous driving technology. The multi-target tracking accuracy exceeds SOTA by 20%, the lane prediction accuracy is improved by 30%, the predicted motion displacement error is reduced by 38%, and the planning error is reduced by 28%.

The intelligent vehicle is an example that fully embodies the characteristics of an intelligent system with advanced fusion capabilities. It employs sensor fusion techniques to combine LiDAR, radar and camera inputs, uses temporal fusion for trajectory prediction, and implements decision fusion for path planning. This multi-level fusion architecture enables holistic environmental perception and robust decision-making under uncertainty.

(1) Integrity

Thinking integrity: Intelligent vehicles have a complete thought process inside. When driving, the intelligent vehicle senses the road, traffic signs and other vehicles through sensors. It passes this information to an internal computing system for real-time road condition analysis and vehicle position estimation.

Action integrity: The action of the intelligent vehicle is organically unified. When it decides to perform an action, such as changing lanes, it checks its blind spots to make sure there are no obstacles, then uses cruise control to smoothly change lanes. Throughout the process, the vehicle's acceleration, steering and braking actions are coordinated to ensure safety.

(2) Purpose

Intelligent vehicles act with a clear purpose. For example, its main behavioral purposes include ensuring the safety of passengers, efficient arrival at the destination, compliance with traffic rules, etc. These goals directly guide the behavior of the vehicle, such as when encountered with an obstacle, the car aims to safely navigate around it rather than collide with it.

(3) Emergence

Intelligent vehicle has behavior emergence. It can adjust its behavior to changes in the environment. For example, when it encounters an situation that it has never seen before, the intelligent vehicle will automatically identify the danger and plan a safe route to bypass the obstacle.

(4) Environmental adaptability

An intelligent vehicle is a highly interactive system with the environment. It uses multiple sensors, such as radar, cameras and lidar, to constantly sense the road, vehicles and pedestrians. When the environment changes, the intelligent vehicle can adapt and adjust its behavior, for example, in a traffic jam, it can choose the best path to reduce travel time.

This example highlights how intelligent systems can operate in complex environments and optimally meet the needs and safety requirements of passengers. This also shows that intelligent systems are constantly evolving to better serve human society.

6 Conclusion

Based on system theory, this paper explores the definition of intelligent system within the framework of system theory: An intelligent system is an open information system characterized by behavior goals based on strategy and value, integration of perception-cognition-behavior, behavior emergence, and active adaptation to the environment. It also compares the distinctions with conventional information systems. On this basis, the concepts of agent structure and system architecture are proposed. The design of intelligent systems is not only function-oriented and task-oriented but also behavior-oriented, that is, the behavior of the system constitutes the core and focus of intelligent system design. Therefore, we put forward a set of concepts such as the integrity of intelligent behavior, purpose, emergence, and environmental adaptability, which will offer a thinking paradigm for the design of intelligent systems. A practical case of intelligent vehicle demonstrates the feasibility of applying the above architecture and characteristics of intelligent system in reality, thus worth wider application.

Data Availability Statement

Data will be made available on request.

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Conflicts of Interest

Fuhu Chen is an employee of Hanjiang Laboratory, Wuhan, China, and the 715th Research Institute of CSSC, Hangzhou, China. Zhe Wang is an employee of Sensetime Technology Co., Ltd., Shenzhen, China.

Ethical Approval and Consent to Participate

Not applicable.

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