Scenario-Driven Cyber-Physical-Social System: Intelligent Workflow Generation Based on Capability

Yi Li
Zhejiang University
Hangzhou, China
22251190@zju.edu.cn

Xinkui Zhao*
Zhejiang University
Hangzhou, China
zhaoxinkui@zju.edu.cn

Chen Chen
Zhejiang University
Hangzhou, China
chenc68@zju.edu.cn

Shengye Pang
Zhejiang University
Hangzhou, China
pangsy@zju.edu.cn

Zhengyang Zhou
University of Science and Technology of China, Hefei, China
zzy0929@ustc.edu.cn

Jianwei Yin
Zhejiang University
Hangzhou, China
zjuyjw@cs.zju.edu.cn

ABSTRACT

Cyber-Physical-Social System (CPSS) is a pioneering solution in Crowd Computing, which integrates heterogeneous resources from cyber, physical, and social spaces, possessing collaborative capabilities in perception, computation, and control. However, existing CPSSs usually confine their functionality to rigid scenarios or tasks, and often oversimplify human resource modeling that fails to dynamically recognize human capabilities. In this work, we propose a Scenario-Driven CPSS to enable an adaptive resource choreography across scenarios. More concretely, we leverage temporal environments to identify events and disassemble these events into workflows, triggering the execution of corresponding capability units, where the capability units abstract the shared functionality of heterogeneous resource groups. Meanwhile, we improve the pre-assuming human capabilities to construct the relationship between human and their capabilities during the execution of workflows, sufficiently promoting human intelligence. Our real-world demo on fire rescue demonstrates the effectiveness of the solution.

CCS CONCEPTS

• **Human-centered computing → Ubiquitous and mobile computing systems and tools**.

KEYWORDS

Cyber-Physical-Social System, Crowd Computing, Resource integrating, Self-Organized Task execution

ACM Reference Format:

Yi Li, Xinkui Zhao, Chen Chen, Shengye Pang, Zhengyang Zhou, and Jianwei Yin. 2024. Scenario-Driven Cyber-Physical-Social System: Intelligent Workflow Generation Based on Capability. In *Companion Proceedings of the ACM Web Conference 2024 (WWW '24 Companion), May 13–17, 2024, Singapore, Singapore.* ACM, New York, NY, USA, 4 pages. https://doi.org/10.1145/3589335.3651246

*Corresponding author: zhaoxinkui@zju.edu.cn

WWW '24 Companion, May 13–17, 2024, Singapore, Singapore.

ACM ISBN 979-8-4007-0172-6/24/05
https://doi.org/10.1145/3589335.3651246

1 INTRODUCTION

The development of edge intelligence have broken down the information isolation between cyber, physical, and social spaces. Human communities, web services, and physical entities are extensively and deeply interconnected, propelling humanity into the era of cyber-physical-social intelligent interconnection [1]. The traditional system architecture is inadequate to integrate resources across cyber-physical-social spaces, which mainly focuses on the web service while neglecting other elements [2, 3]. Therefore, an urgent question arises, *How to build a Cyber-Physical-Social System (CPSS) that integrates heterogeneous resources to achieve efficient collaboration and self-organization of resources?*

Actually, the exploration of fundamental mechanisms such as collaborative intelligence is crucial for CPSS [4, 5]. Although various methods have been proposed to build CPSSs, they generally suffer two common drawbacks, i.e., **rigid system scenarios** and **preconceived approaches for human modeling**. Xiong et al. proposed a traffic CPSS [4] that collects data from social networks for traffic monitoring. Zamfirescu et al. presented a human-centric cyber-physical reference model in which individuals are not merely users but also influential elements that shape the overall behavior of the system [6]. He et al. first introduces a comprehensive framework for constructing and executing CPSSs. In their work, they abstract human, web service, and device as unified system resources and propose a resource-capability operation framework to realize a collaborative workflow over heterogeneous cyber-physical-social entities [7]. This conceptual approach provides valuable insights to advance resource modeling within CPSSs. However, these solutions not only require manual setup of workflows before constructing cyber-physical-social scenarios, but also oversimplify the consideration of human capabilities. Thus, it limits its applicability to only fixed cases and lacks the human interaction capability within CPSS. We argue that human capabilities should not be pre-defined or estimated like devices or web resources. Instead, human capabilities should be self-discovered based on the context and requirements, and a more multidimensional and comprehensive analysis is required to understand the relationship between human and capabilities. To this end, it is vital to design a flexible construction that is centered around *scenario-driven system*, which incorporates human intelligence and can be well generalized to all scenarios.

To effectively overcome the aforementioned drawbacks, we propose a **Scenario-Driven CPSS**, which enables adaptive resource choreography, where we designate the common function over heterogeneous resources as the capability in our work. Our work facilitates the autonomous discovery of the relationship between human and capability and enables adaptive capabilities based on scenarios. Specifically, we obtain events from the temporal environment twin constructed by integrating heterogeneous cyber-physical-social resources' sensing data. Subsequently, we disassemble these events into workflows to trigger the execution of corresponding capability units. Furthermore, during the execution of workflows, we conduct multidimensional and comprehensive analysis of human to establish links among capabilities. Thereby our study empowers the autonomous extension of human capabilities based on the context and specific requirements, achieving dynamic resource choreography. We especially implement a real-world system on fire rescue scenario. By leveraging environmental information, the system can generate and execute workflows, which adaptively orchestrates heterogeneous resources according to different scenarios associated with environmental factors. The improved accuracies on both selection of facilities and human force assignment for efficient fire rescues demonstrate the effectiveness of our proposal.

2 RELATED WORK

Existing CPSSs can be broadly classified into two types: **Data-Centric** architectures and **Human-Centric** architectures.

Data-Centric architectures leverage cyber, physical and social space resources within a scenario to gather environmental information and schedule resources based on analysis. For instance, Costanzo et al. developed the Wi-City-Plus architecture [8] to support the mobility and logistics needs of urban mobile users. Xiong et al. proposed a traffic CPSS [4] that collects data from social networks for traffic monitoring. Amin et al. utilized CPSS to analyze and predict hotspots in smart cities, addressing complex network criticality issues in telecommunications infrastructure [9]. Human-centric architectures primarily focus on incorporating human as integral components in the system's operation. For example, Scheuermann et al. introduced the CHEST system, which aims to monitor and alleviate physical stress on workers in harsh and hazardous environments through the use of wearable devices and smart textiles [10]. Fang proposed a human-centric cyber-physical system [11] where sensors collect environmental and human data in smart home environments, and the data is analyzed to optimize energy consumption and improve human comfort. These two types of CPSSs do not specifically emphasize resource choreography, which is the core objective of the CPSS. To achieve resource choreography, Dai et al. proposed a novel resource choreography method and introduced a knowledge-driven service choreography engine to handle requests from human or devices. It automatically collects information by dynamically assembling services [12]. He et al. presented a comprehensive resource choreography framework that covers modeling, application, and execution [7].

However, previous works suffer from two shortcomings, i.e., **fixed scenarios** and **oversimplified human modeling**. Current CPSSs often define all operational workflows, which limit the system to fixed scenarios and tasks, resulting in lacking flexibility. Similarly, the system's modeling of human is often rigid and oversimplified, with predefined and enumerated human capabilities, disregarding the diverse nature of human abilities. In contrast, we identify events within environments and disassemble identified events into workflows, allowing adaptive capabilities based on scenarios, which effectively addresses aforementioned challenges.

3 SYSTEM ARCHITECTURE

The overall architecture of our system is depicted in Figure 1. The key components are four-fold, i.e., Resource Modeling, Crowd Sensing, Workflow Disassembling and Task Execution.

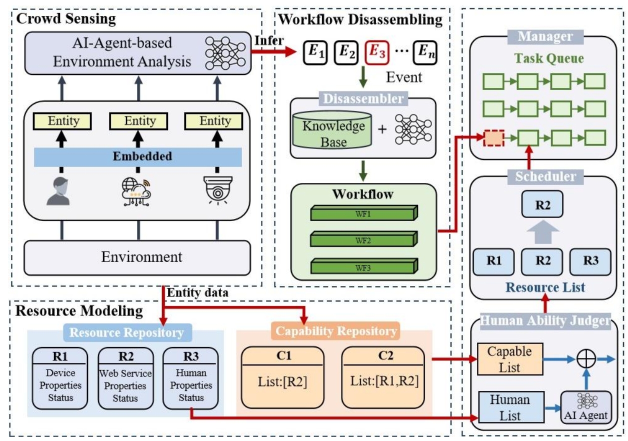

Figure 1: System architecture of Scenario-Driven CPSS.

Resource Modeling. When the resources within the scenario are registered in the resource repository and the capability repository, they are abstracted and will be managed uniformly.

Crowd Sensing. The resources within the scenario report data to the system, allowing environment analyzer to obtain events occurring in the environment, which are then handed over to the task disassembler.

Workflow Disassembling. Events are disassembled into executable workflows within the system by utilizing either the AI agent or the knowledge base.

Task Execution. By invoking the execution of the corresponding capability units, the workflows within the task manager are advanced.

4 SYSTEM DESIGN

4.1 Design overview of Scenario-Driven CPSS

To overcome the limitations associated with CPSSs primarily designed for specific scenarios or tasks, we propose a Scenario-Driven CPSS. Specifically, our system analyzes the events and send them into task disassembler. Then they are intelligently disassembled into workflows using AI agents in conjunction with knowledge base, storing in task manager and sequentially invoking the corresponding capability units. When a specific capability unit is invoked, the AI agent analyzes the data of all human in resource repository, establishing the list of resources that are equipped with this capability. Next, we will elaborate above designs respectively.

4.2 Resource modeling for Scenario-Driven CPSS

In our research, we draw inspiration from the Resource-Capability framework introduced in He et al. [7] to effectively manage and utilize the capabilities of heterogeneous resources in our CPSS. This framework provides a structured methodology for defining and categorizing the capabilities of resources involved in our system.

Each resource corresponds to a specific entity within the scenario, while a capability represents a functionality shared by a group of heterogeneous resources. A resource can be associated with multiple capabilities, and conversely, a capability can be linked to a group of resources possessing the same functionality.

Rather than focusing on specific resource entities, our system operates at the granularity of capability units when achieving changes in certain states. The system only needs to notify the capability unit responsible for the desired change to execute the corresponding functionality, without concerning itself with the specific resource entity. For instance, if the system requires a cup of coffee, it will notify the capability unit responsible for *coffeeMaking*. Subsequently, it will receive a cup of coffee, with the other modules of the system remaining unconcerned about the underlying process. Therefore, in our work, three categories of entities in our system, namely human, web services, and devices, are all treated as resources. Since the functionalities of web services and devices are predetermined, we can explicitly list their capabilities during resource registration. This includes specific provided APIs, handled data types, required inputs, outputs, and other relevant details. As a result, direct relationships can be established among cyber services, physical resources and their capabilities.

4.3 Enhancing human capabilities during execution

Actually, explicitly incorporating human capabilities during execution plays vital role for building an intelligent CPSS. Given the uniqueness of human, we argue that specifying or just listing all the capabilities of human during resource registration [7] is not sufficient. To address the challenge of oversimplification in modeling human resources in CPSS, we propose an approach to dynamically build relationships between individuals and capabilities.

During the execution of the workflow, the corresponding capability unit is invoked, and the system traverses and evaluates the human resources within the scenario. We consider AI agents as the most effective tool currently for analyzing and understanding humans from a multidimensional perspective. Therefore, we input basic information and additional details about human, such as name, gender, age, occupation, experience, certifications, etc., into the AI agent. This enables the agent to analyze whether an individual possesses a specific capability. If possesses, a relationship is established between that capability and the individual. For example, consider a person who has a deep understanding of the working principles of electrical devices and has experience in troubleshooting electrical faults, even though they may not have any certificate about electrician. Despite this, it can be deduced that they possess the capability to repair electrical appliances. The evaluated list of human resources is then merged with the existing resource list, achieving better utilization of human intelligence.

With aforementioned designs, our system achieves dynamic expansion of human capabilities during the execution and intelligent generation of workflows, achieving better utilization of human and proper resource choreography based on different scenarios.

5 DEMONSTRATION

In this section, We demonstrate how our system runs in the **Smart Building Fire Rescue Scenario**.

Assuming our system is running in a smart building, where the devices inside the building are managed by the system. For a specific room, the resources have been registered and added to resource repository and capability repository, which are managed and scheduled by the system. Table 1 shows the resource and capability repository in this scenario. Location, Professsion and Certificate are separately abbreviated as *Loc*, *Prof* and *Cert* in this table.

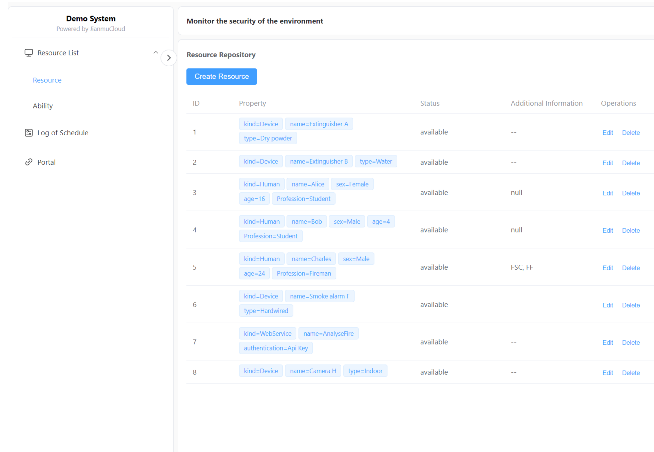

Figure 2: UI for Resource Repository.

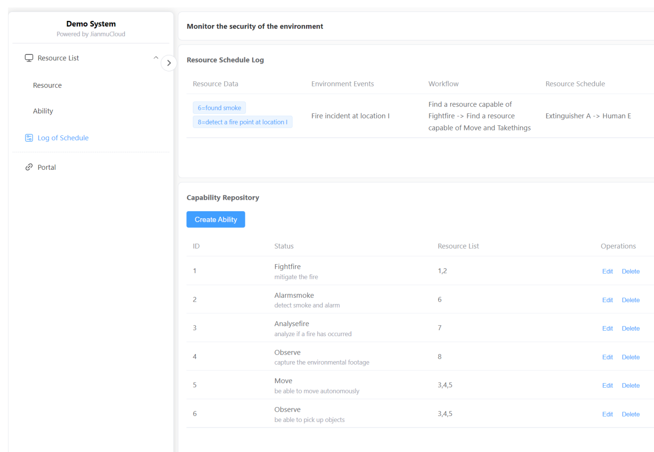

Figure 3: UI for logs and Capability Repository.

Resource Modeling. By modeling the resources within the scenario, we establish the corresponding resource and capability repository. For the *Fightfire* capability unit, the resource list includes Extinguisher A and Extinguisher B. For the *Alarmsmoke* capability unit, the resource list includes Smoke alarm F. For the *Analysefire* capability unit, the resource list includes Web service G. For the *Observe* capability unit, the resource list includes Camera H. However, Human C, D, and G are not associated with any specific capabilities.

Crowd Sensing. Smoke alarm F detects smoke and sends a smoke signal, while Camera H observes a fire situation at location I. The coordinates and event are uploaded. The system updates the environmental information and hands it over to the environmental analyzer, which identifies the event as *Fire incident at location I*.

Table 1: The Resource and Capability Repositories.

Resource Entity	Capability	Properties
Extinguisher A	*Fightfire*	Loc: I; Status: Available;
Extinguisher B	*Fightfire*	Loc: J; Status: Available;
Human C	*Move*, *Takethings*	Name: Alice; Sex: Female; Age: 16; Prof: Student; Cert: Null; Loc: I; Status: Available;
Human D	*Move*, *Takethings*	Name: Bob; Sex: Male; Age: 4; Prof: Student; Cert: Null; Loc: H; Status: Available;
Human E	*Move*, *Takethings*	Name: Charles; Sex: Male; Age: 24; Prof: Fireman; Cert: FSC, FF II; Loc: I; Status: Available;
Smoke alarm F	*Alarmsmoke*	Loc: I; Status: Available;
Web service G	*Analysefire*	Status: Available;
Camera H	*Observe*	Loc: I; Status: Available;

Workflow Disassembling. The event is analyzed and disassembled into the following workflow: *Find a resource capable of Fightfire -> Find a resource capable of Move and Takethings*. This workflow is then added to the task manager for further execution.

Task Execution. The sub-workflow *Find a resource capable of Fightfire* is executed. By evaluating the resource capabilities, the resource list includes Extinguisher A and Extinguisher B. Using the scheduling strategy, Extinguisher A, which is closer to the fire, is selected. The indicator light on Extinguisher A turns on, and the capability unit completes its execution, providing the information of Extinguisher A as the output for the next sub-workflow. Next, the sub-workflow *Find a resource capable of Move and Takethings* is executed. Based on resource capability assessment, the resource list includes Human C, Human D and Human E. Using the scheduling strategy, Human E is chosen for the task. The information of Extinguisher A is sent to Human E. Upon completion of the fire-fighting task by Human E, an event signaling the completion of execution is triggered. Throughout the workflow execution, our system effectively selects suitable resources, particularly human. Once the execution process is completed, the environment returns to its normal state, thereby resolving the fire incident.

Fig 2 and Fig 3 illustrate resource repository, capability repository and logs in the scenario. In the log, we can observe the following information: data reported by resources, the analyzed events, the disassembled workflows, and the corresponding resource choreography. Finally, we conclude that the constructed demo illustrates the effectiveness of our Scenario-Driven Cyber-Physical-Social System.

6 DISCUSSION

Our proposed Scenario-Driven CPSS leverages the generation of corresponding events and disassembles them into workflows based on different scenarios, enabling adaptive resource choreography. However, our framework is built upon certain assumptions. Firstly, considering the current level of digitization in the reality, the software-defined method of managing resources remains a significant challenge. Therefore, we need to develop a more efficient approach to leverage AI agents for extracting capabilities from resources. This will contribute to the seamless integration of AI technologies into the resource management. Secondly, when utilizing human resources within the system, it is crucial to address the privacy and security concerns associated with personal information. Safeguarding sensitive data and ensuring the privacy of individuals involved in the system is of utmost importance. Therefore, we need to establish a robust and secure method for handling and storing personal information, better protecting the privacy rights of individuals.

7 CONCLUSION

We propose a **Scenario-Driven Cyber-Physical-Social System** that realizes adaptive services based on scenario and enables self-discovery of human capabilities. In summary, our system captures events in the environment, and disassembles them into executable workflows which trigger the execution of corresponding capability units, overcoming the limitations of fixed scenarios or tasks. Furthermore, we improve the modeling of human by incorporating AI agents during the execution of capability units that explicitly establishes relationships between individuals and their specific abilities. Finally, in **Smart Building Fire Rescue Scenario**, our system accurately identifies events in the environment and achieves resource choreography, demonstrating the effectiveness of design.

ACKNOWLEDGMENTS

This work was supported by the National Key R&D Program of China (2022YFF0902702), and the Major Program of National Natural Science Foundation of Zhejiang(LD24F020014), and the Zhejiang Pioneer(Jianbing) Project (2024C01032), and the Key R&D Program of Ningbo(2023Z235), and Ningbo Yongjiang Talent Programme (2023A-198-G), Beijing Life Science Academy(BLSA:2023000CB0020).

REFERENCES

[1] Zhiwen Yu, Huadong Ma, Bin Guo, and Zheng Yang. Crowdsensing 2.0. *Commun. ACM*, 64(11):76–80, oct 2021.

[2] Zhengyang Zhou, Yang Wang, Xike Xie, Lei Qiao, and Yuantao Li. Stuanet: Understanding uncertainty in spatiotemporal collective human mobility. In *Proceedings of the Web Conference 2021*, pages 1868–1879, 2021.

[3] Zhengyang Zhou, Yang Wang, Xike Xie, Lianliang Chen, and Hengchang Liu. Riskoracle: A minute-level citywide traffic accident forecasting framework. In *Proceedings of the AAAI conference on artificial intelligence*, 2020.

[4] Gang Xiong, Fenghua Zhu, Xiwei Liu, Xisong Dong, Wuling Huang, Songhang Chen, and Kai Zhao. Cyber-physical-social system in intelligent transportation. *IEEE/CAA Journal of Automatica Sinica*, 2(3):320–333, 2015.

[5] Yang Wang, Zhengyang Zhou, Kai Liu, Xike Xie, and Wenhua Li. Large-scale intelligent taxicab scheduling: A distributed and future-aware approach. *IEEE Transactions on Vehicular Technology*, 69(8):8176–8191, 2020.

[6] Constantin-Bala Zamfirescu, Bogdan-Constantin Pirvu, Dominic Gorecky, and Harish Chakravarthy. Human-centred assembly: A case study for an anthropocentric cyber-physical system. *Procedia Technology*, 2014.

[7] Feijia He, Liwei Shen, and Xin Peng. Resource choreography in cyber-physical-social systems: Representation, modeling and execution. *IEEE Transactions on Services Computing*, 2023.

[8] Alfio Costanzo, Alberto Faro, Daniela Giordano, and Concetto Spampinato. An ontological ubiquitous city information platform provided with cyber-physical-social-systems. In *2016 13th IEEE Annual Consumer Communications Networking Conference (CCNC)*, 2016.

[9] Farhan Amin and Gyu Sang Choi. Hotspots analysis using cyber-physical-social system for a smart city. *IEEE Access*, 8:122197–122209, 2020.

[10] Constantin Scheuermann, Raman Tandon, Bernd Bruegge, and Stephan Verclas. Detection of human limits in hazardous environments: A human-centric cyber-physical system. 07 2016.

[11] Yuan Fang, Yuto Lim, Sian En Ooi, Chenmian Zhou, and Yasuo Tan. Study of human thermal comfort for cyber–physical human centric system in smart homes. *Sensors*, 20(2), 2020.

[12] Wenbin Dai, Wanqi Huang, and Valeriy Vyatkin. Knowledge-driven service orchestration engine for flexible information acquisition in industrial cyber-physical systems. pages 1055–1060, 2016.