Peijun YE, Xiao WANG, Wenbo ZHENG, Qinglai WEI, Fei-Yue WANG, 2022. Parallel cognition: hybrid intelligence for human-machine interaction and management. *Frontiers of Information Technology & Electronic Engineering*, 23(12):1765-1779. https://doi.org/10.1631/FITEE.2100335

Parallel cognition: hybrid intelligence for human-machine interaction and management

Key words: Cognitive learning; Artificial intelligence; Behavioral prescription

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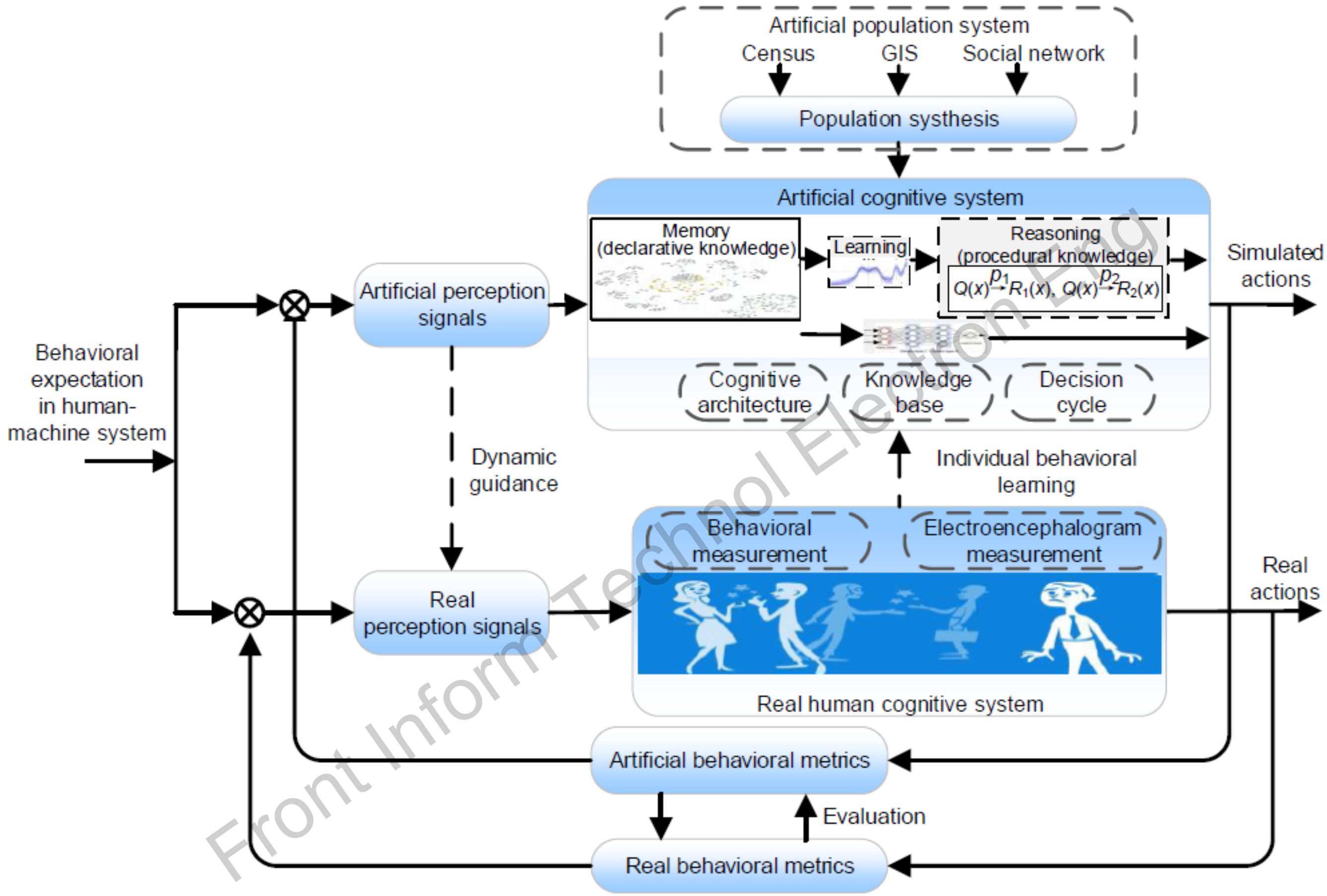
Motivation

- In complex human-in-loop systems, human operators have different physiological and psychological capacities such as cognitive load, distraction, and knowledge level. Learning the operator’s physiological as well as mental states (like the fatigue or risk preference) and further intervening/prescribing operator actions is vital to reduce unconscious human errors.
- In complex social systems, learning individual’s cognitive features and prescribing one’s behavior can elevate the system’s overall utility, since users are usually self-interested and have access to only local information.
- Virtual reality (VR), augmented reality (AR), artificial intelligence (AI), and other emerging technologies provide potential paths to prescribe human behaviors nowadays.

Main idea

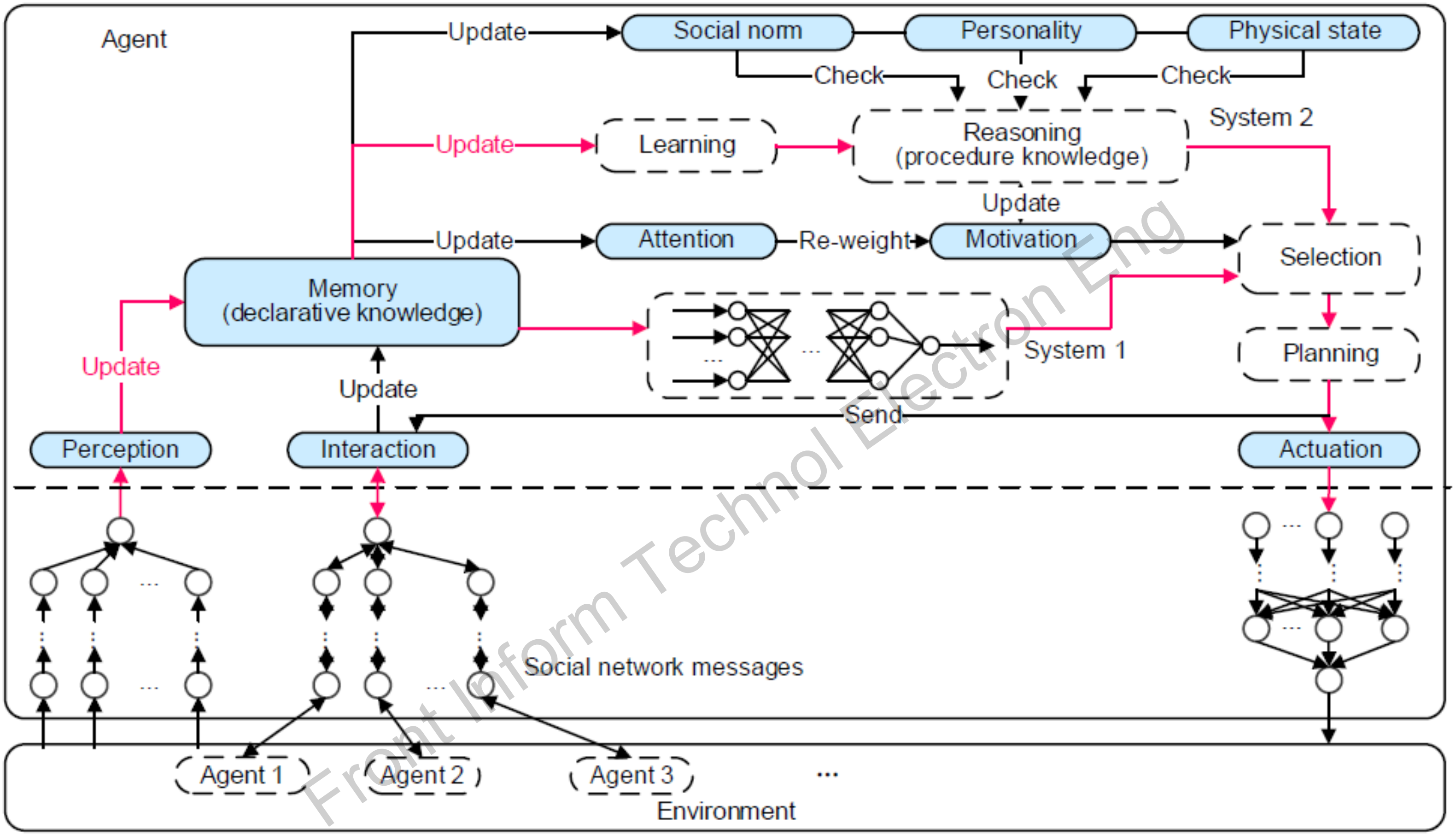
- We propose a new research paradigm—parallel cognition—to computationally interpret, learn, predict, and prescribe individual behaviors in complex systems.
- In the descriptive cognition, a learning agent adaptively extracts new cognitive knowledge from one's environment-action data flow to adjust his/her customized cognitive model.
- In the predictive cognition, the virtual agent computationally searches numerous deliberative paths to investigate one's probable decisions in different situations.
- In the prescriptive cognition, the agent selects the most appropriate environmental signals to prescribe the individual's action in the expected way.

Framework



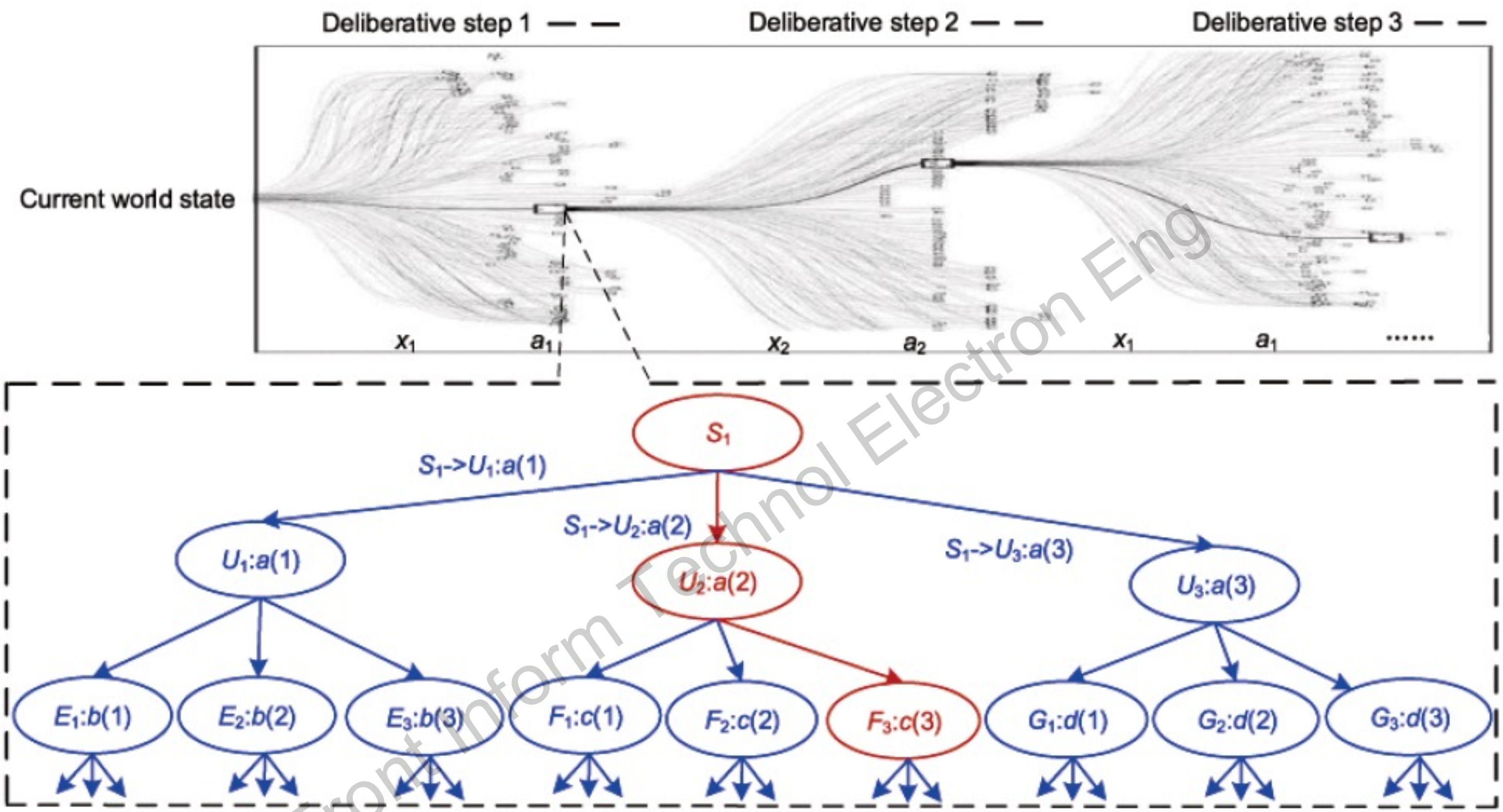
- The parallel cognition framework is composed of two peer systems—artificial and real human cognitive systems.
- These two cognitive systems keep their independent running loops throughout the task, but perform interactions with each other.

Descriptive cognition



- The artificial cognitive system (ACS) is built on a universal architecture that contains a deliberative cycle and an intuitive cycle.
- The deliberative cycle is based on the fuzzy logic reasoning while the intuitive cycle exploits artificial neural networks.

Predictive cognition

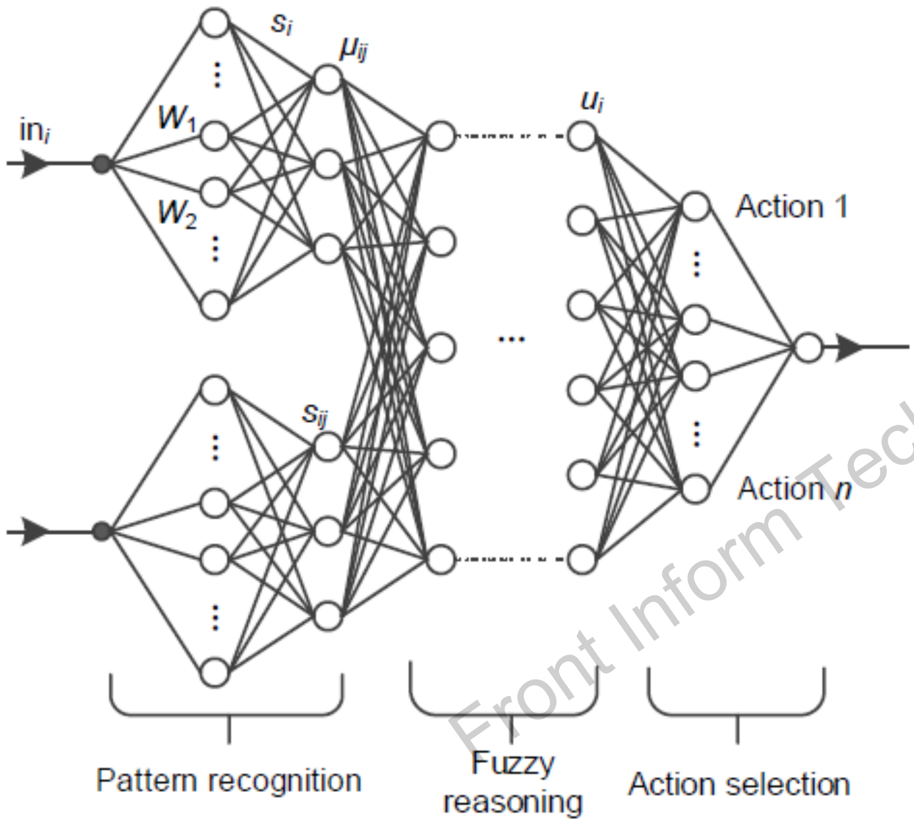


- The fuzzy logic based reasoning creates a reasoning tree with the current world state as its root and final achievable states as leaves.
- By introducing an appropriate intervention, the reasoning tree can be expanded to cover comprehensive deliberative trajectories.

Prescriptive cognition

- Using a broad search of computational deliberation experiments, the ACS will find expected sequential states (of both machines and humans) as time goes on in the future via human-machine interaction.
- The optimal interaction pattern will determine the optimal perception signals that are returned to the individual to prescribe his/her appropriate actions.
- Basic perception signals contain visual image/video, audio instruction/warning, olfactory stimuli, tactile sense, and so on.
- The bidirectional interactions between two cognitive systems are iteratively running, with the ACS and its human counterparts co-evolving in synergy.

Adaptive deliberation learning



- The adaptive learning neural network is composed of three subnetworks, the pattern recognition, fuzzy reasoning, and action selection networks.
- The perception world states are the inputs while the user's final action is the output.
- After training by prior psychological decisions, the learning network can extract a decision rule chain from each record in a data stream scenario.

Case study: travel behavioral prescription

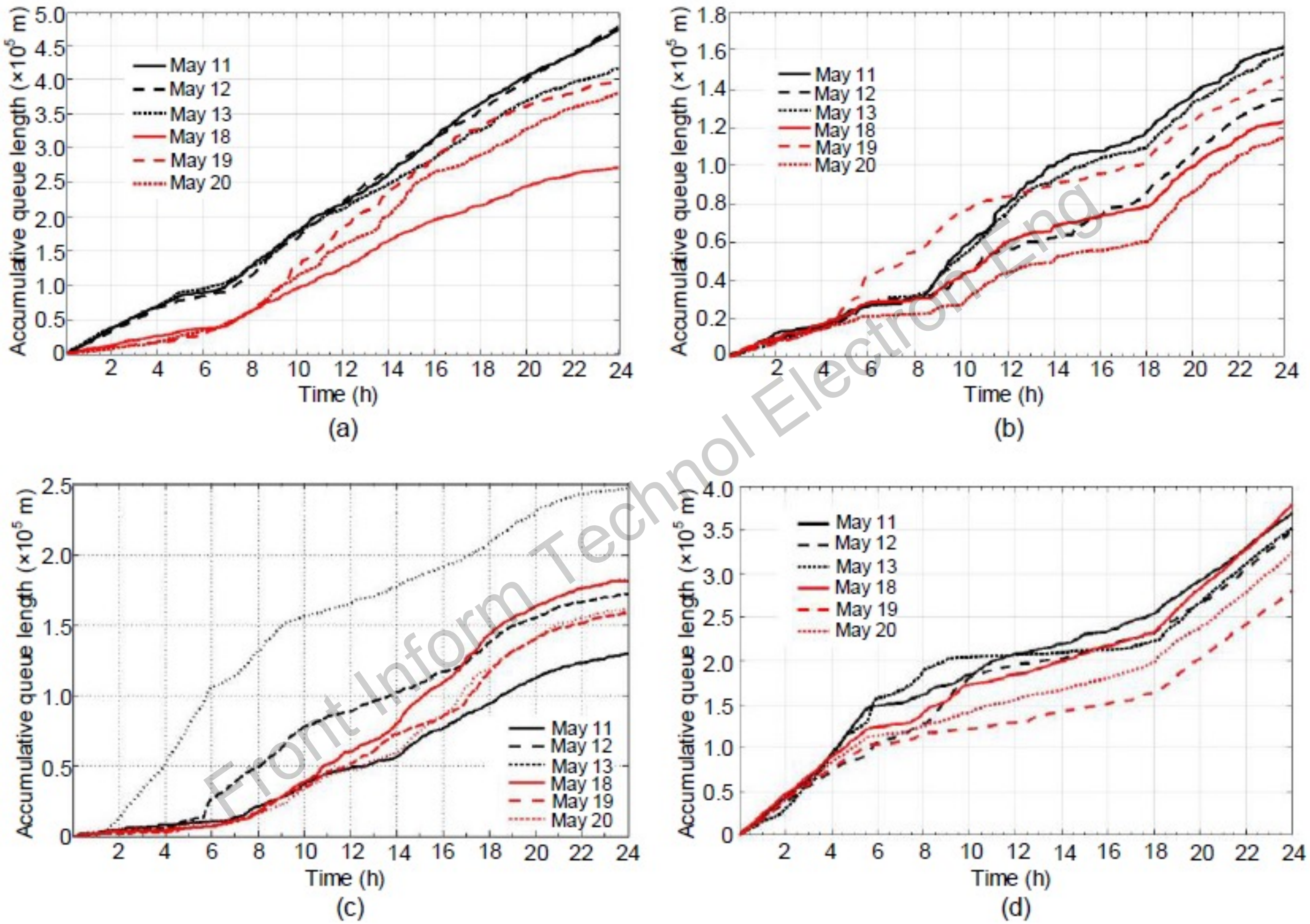


Fig. 9 Comparison of queue length before and after the travel behavioral prescription in the east (a), south (b), west (c), and north (d) directions (References to color refer to the online version of this figure)

- Behavioral prescription helps reduce the queue length in the intersections.

Case study: cognitive visual reasoning

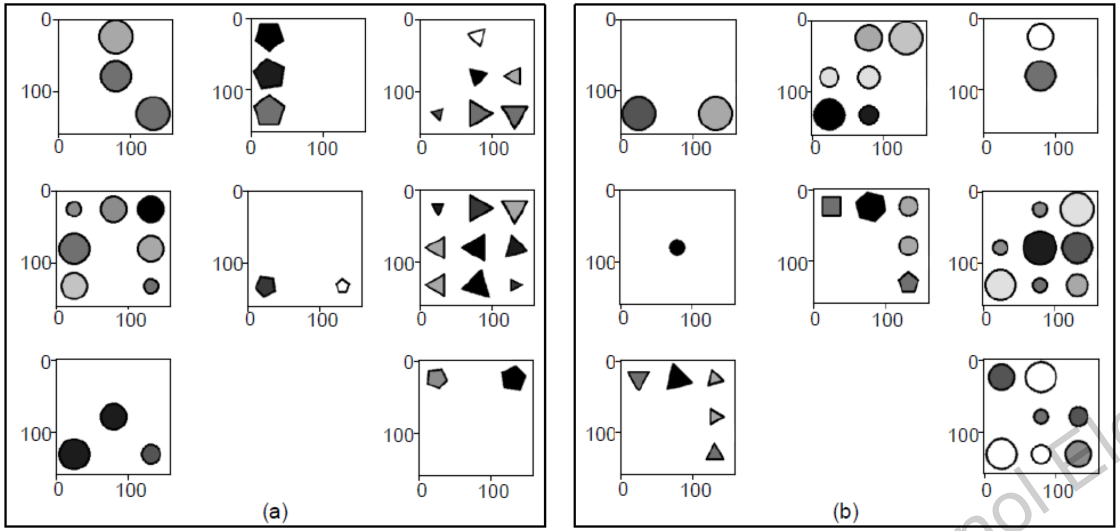
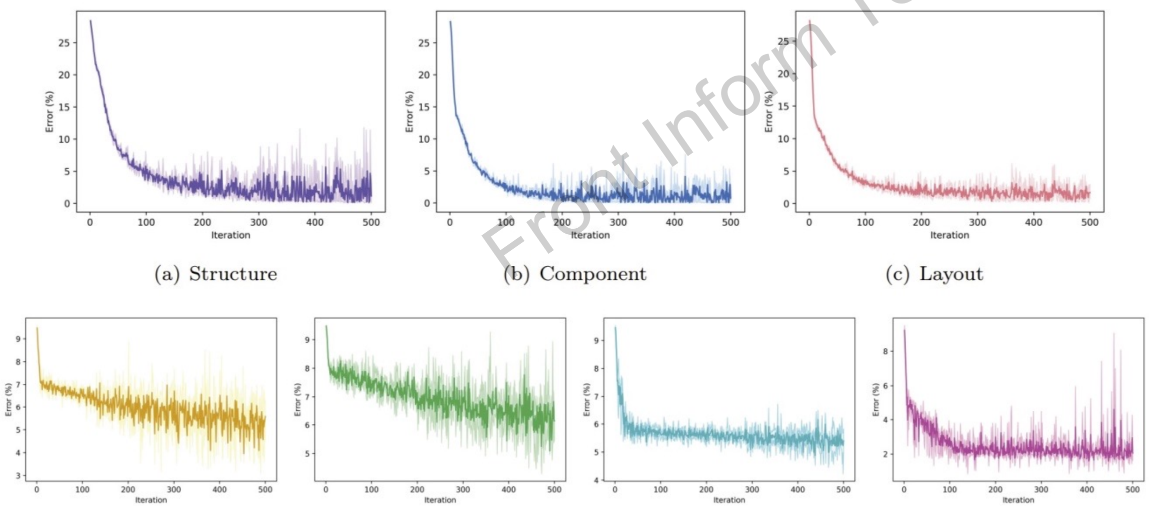


Fig. 10 An example of cognitive visual reasoning for a given problem (a) and candidates (b)



(a) Structure (b) Component (c) Layout

(d) Type (e) Size (f) Color (g) Angle

Fig. 12 Recognition errors of human participants

- The experiment scenario was generated on the RAVEN dataset, which provides synthetic tasks for relational and analogical visual reasoning.
- Recognition errors of human participants reduced after the ACS learning and problem selection.

Conclusions

- This paper proposes a new parallel cognition research paradigm with a hybrid learning method for individual cognitive knowledge.
- The paradigm contains three stages, descriptive cognition, predictive cognition, and predictive cognition, to computationally interpret, learn, predict, and prescribe individual behaviors in complex systems.
- The method was preliminarily tested and validated in urban travel behavioral prescription, a scenario of social group decision management, and cognitive visual reasoning, a scenario of individual operation prescription.

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Fei-Yue WANG received his PhD degree in computer and systems engineering from Rensselaer Polytechnic Institute, Troy, New York, in 1990. He joined the University of Arizona in 1990 and became a professor and the director of the Robotics and Automation Lab (RAL) and the Program in Advanced Research for Complex Systems (PARCS). In 1999, he founded the Intelligent Control and Systems Engineering Center at the Institute of Automation, Chinese Academy of Sciences (CAS), Beijing, China, under the support of the Outstanding Overseas Chinese Talents Program from the State Planning Council. In 2002, he was appointed as the director of the Key Lab of Complex Systems and Intelligence Science, CAS. From 2006 to 2010, he was Vice President for Research, Education, and Academic Exchanges at the Institute of Automation, CAS. In 2011, he became the State Specially Appointed Expert and the director of the State Key Laboratory for Management and Control of Complex Systems. His current research focuses on methods and applications for parallel systems, social computing, and knowledge automation.