SCIENCE CHINA
Information Sciences

• PERSPECTIVE •

January 2026, Vol. 69, Iss. 1, 116101:1–116101:3
https://doi.org/10.1007/s11432-025-4589-x

Towards cobodied/symbodied AI: concept and eight scientific and technical problems

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Received 24 February 2025/Accepted 7 September 2025/Published online 4 January 2026

Citation Lu F, Zhao Q P. Towards cobodied/symbodied AI: concept and eight scientific and technical problems. Sci China Inf Sci, 2026, 69(1): 116101, https://doi.org/10.1007/s11432-025-4589-x

Over the past decade, artificial intelligence (AI) has achieved remarkable progress, largely driven by the widespread adoption of deep learning techniques. These advances have driven breakthroughs in multiple fields, such as computer vision and natural language processing. Nevertheless, despite these successes, current AI systems still face fundamental challenges. Large-scale pretrained models such as GPT-4 [1] represent disembodied AI systems, lacking physical embodiment and operating solely via software for data processing, learning, and decision-making [2]. As a result, despite their widespread acclaim in academia and industry, such models continue to encounter substantial barriers in real-world deployment scenarios requiring physical interaction with the environment.

In contrast, embodied AI has emerged as a key research frontier. Unlike disembodied AI, it leverages robotic platforms as physically embodied agents to interact with the environment. By integrating AI's computational and learning capabilities with robots' embodied interaction capacities, it aims to overcome the limitations in real-world environmental engagement [3]. Embodied AI not only provides critical sensory-perceptual feedback loops for learning and evolution of AI [4], but also enables tangible pathways for deploying AI in the physical world. Nevertheless, embodied AI confronts three major challenges: (1) enabling efficient autonomous perception and continual learning; (2) enhancing robotic mobility and manipulation capabilities; and (3) ensuring safe and ethically compliant behavior.

Notably, both disembodied and robot-based embodied AI treat humans as external entities. This implies that they operate independently of human perspectives, delivering solutions solely from an AI-centered viewpoint. However, fully autonomous decision-making and execution remain technically immature, with legal and ethical frameworks still underdeveloped. More critically, deploying these systems will inevitably reshape existing social patterns by competing with humans in both production and daily life, leading to public distrust and societal resistance.

To address this, we propose a new technological paradigm that re-centers human agency: the collaborative embodiment of a unified cognitive entity formed by human intelligence (HI) and AI. To ground it, we introduce two core technical components: (1) dual-brain integration, referring to the deep and bidirectional alignment of human and AI cognitive processes to establish semantic consensus; and (2) physical co-embodiment, denoting the tight coupling of the human body and AI-driven hardware as a unified agent for shared environmental interaction. Together, these mechanisms form the foundation of the new paradigm.

Definition 1 (Cobodied intelligence)**.** Cobodied intelligence is one that emerges from the dynamic coupling of human-AI brains (dual-brain integration), human-AI co-embodied hardware (physical co-embodiment), and the shared environment, enabling human-perspective-grounded human-AI collaborative perception, decision, execution, and learning—thereby forming a co-evolving agent adaptive to dynamic environments.

Definition 2 (Cobodied AI)**.** Cobodied AI is the AI component within cobodied intelligence, designed to sense, respond to, and learn from both environmental interactions and human-AI collaborative dynamics.

For simplicity, we recommend using "cobodied AI" to represent both terms, unless otherwise specified.

This new paradigm re-examines human-AI relations. As shown in Figure 1, it preserves human primacy as the perspective anchor while integrating both agents' capabilities, enabling human-AI mutual assistance and co-learning over time. Without replacing human agency, cobodied AI enhances human perception and adaptability, actualizes human intent, and yields AI systems that are more controllable, deployable, and ethically trustworthy.

The concept of cobodied AI fundamentally differs from existing paradigms such as augmented intelligence and hybrid intelligence [5]. While these theories also focus on human-AI collaboration, they primarily rely on task partitioning to exploit complementary strengths toward achieving specific goals. Typically, they coordinate human and AI as separate agents in a task pipeline through predefined interaction protocols to achieve intelligent complementarity. In some cases, AI systems are expected to surpass human performance through autonomous decision-making and execution. Clearly, these paradigms do not require deep alignment between human and artificial intelligences from a human-centered perspective; nor do they require physical co-embodiment during task execution.

In contrast, cobodied AI focuses not just on task comple-

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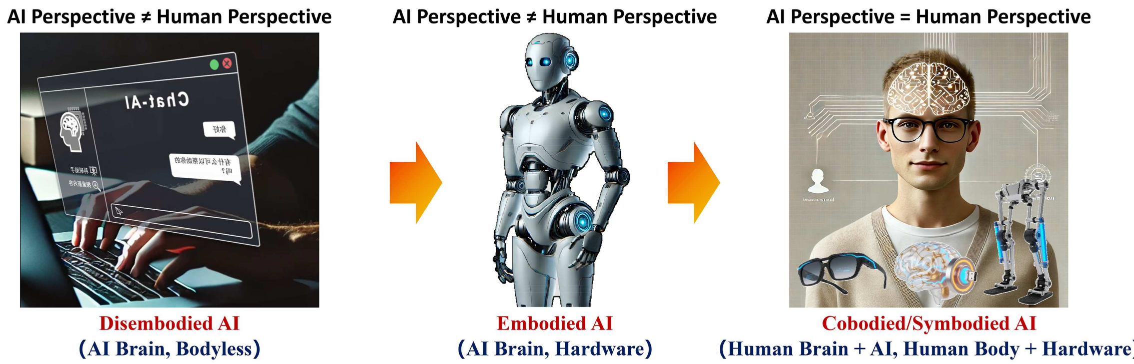

Figure 1 (Color online) Illustration and comparison of technical concepts: disembodied AI, embodied AI, and cobodied/symbodied AI.

tion, but on offering a distinct pathway toward generalized AI embodiment in real-world contexts. Its core innovation lies in fusing human and AI into a unified, human-centered cognitive-physical entity through “dual-brain integration” and “physical co-embodiment”. Thus, cobodied AI unites human and AI into a single interactive agent for real-world engagement; it cares for human needs and seeks to co-evolve with them rather than task completion.

Compared with embodied AI, cobodied AI also engages in environmental perception, decision-making, execution, and learning. However, they differ fundamentally in how they interact with and learn from the environment. Embodied AI interacts with the environment directly and autonomously through robotic bodies, utilizing environmental feedback to drive AI learning and task execution. In contrast, cobodied AI interacts through the human body, augmented by AI-enabled hardware. It uses bilateral feedback (both human physiological signals and environmental stimuli) for AI learning, ultimately enabling dual-brain collaborative decision-making and human-initiated task execution.

The development of cobodied AI can be conceptually divided into two stages. In the early technical phase, the goal is to realize the foundational form of dual-brain integration and physical co-embodiment, with an emphasis on information-level alignment and intelligent interplay. The mature phase, however, remains beyond current technological horizons and thus resists precise definition. Nevertheless, this study identifies eight foundational challenges (detailed later) whose resolution is essential for its eventual realization. At that stage, with emotional, mnemonic, cognitive, and physical dimensions holistically integrated, this paradigm can also be termed symbodied AI, reflecting the evolution from co-embodiment to true symbiosis.

Overall, developing cobodied/symbodied AI involves unique scientific and technical challenges, along with the need for new implementation roadmaps. This requires addressing the inherently interdisciplinary nature of the field, which spans neuroscience, cognitive science, neurobiology, life sciences, human-computer interaction, virtual reality, robotics, and control engineering. Managing this cross-disciplinary complexity calls for addressing eight foundational challenges in the early stages of development. These challenges cover the core dimensions of cobodied/symbodied AI: foundational theory, cognitive and intelligence architectures, hardware and software implementation, and practical impacts and applications. Below, we introduce these eight scientific and technical challenges.

(1) Foundational theories and research roadmaps. Given the technical features of “dual-brain integration” and “physical co-embodiment” in cobodied AI, it is essential to study the conceptual boundaries of key elements like the human brain, AI systems, human body, and environmental contexts. Their interaction mechanisms should also be systematically studied and clarified. All potential technical challenges in biological/neural, computational, and physical domains must be identified. A phased implementation plan should be developed to address short-term, mid-term, and long-term goals.

Furthermore, a comprehensive theoretical model and research methodology for cobodied AI must be established. This framework should cover key stages, from perception to decision-making, decision-making to execution, execution to feedback, and feedback to evolution. It should also integrate theories from cognitive psychology and related disciplines in planning the roadmap for research and technological development.

(2) Theories and methods of “dual-brain integration”. To build the dual-brain integration theory, breakthroughs are needed in two areas: cognitive neuroscience and AI algorithms [6]. For cognitive neuroscience, the primary focus is to address questions such as: What is the process of human cognitive decision-making? What are its key steps? And how can observable, computable models be developed through direct or indirect interventions?

For AI algorithm design, relevant frameworks covering perception, understanding, and decision-making must be studied. Multimodal data channels (vision, hearing, language, force, touch) should be integrated to ensure algorithms align with human cognitive processes. Additionally, cobodied AI requires AI computation from the human first-person perspective, necessitating new computational and interaction paradigms.

(3) Conflict handling in “dual-brain integration”. The fundamental differences between human brains and AI systems naturally lead to different decision-making processes when they collaborate. Effective strategies for resolving such conflicts may rely on step-by-step interpretable AI algorithms that treat the human brain as the ultimate decision authority [7]. This can enable deep alignment and mutual understanding between humans and artificial intelligence through real-time synchronization across multiple interaction modes.

Given different types of tasks, appropriate collaboration patterns and opinion weighting mechanisms between humans and AI systems must be explored to leverage their respective strengths. Developing methods to refine decision strategies based on auditable, reversible records of historical human-AI decision-making processes is also a key research area. Additionally, effective mechanisms for handling emergency scenarios must be established.

In the long term, as AI technology advances and ethical/regulatory frameworks mature, it will be critical to investigate whether the “human-centered” dual-brain integration model can evolve into true symbiosis, where human brains no longer serve as the sole decision-making authority.

(4) AI-environmental interaction through human body.

How dual-brain intelligence physically interacts with the environment through the human body is the fundamental question of cobodied AI. This involves two key aspects: how their cognitive decisions are externally expressed through the human body, and how environmental stimuli generate feedback signals to both brains through the human body. Compared with highly controllable robotic execution and sensing, integrating human body-based interaction and perception with AI remains underexplored.

Safety is the top priority. Specifically, to prevent accidents, dual-brain decisions must not allow human bodies to perform actions that exceed physiological limits or physical tolerance thresholds. Restricting decision boundaries with real-time monitoring is essential for safety.

Additionally, broader cobodied AI configurations may include exoskeletons, human-vehicle co-piloting, and robotic assistants. Research into these implementations can further improve human adaptability and environmental manipulation capabilities.

(5) Key equipment and interaction technologies. Research on hardware and software integration for cobodied AI is essential. This includes developing human-centric wearable devices [8] (e.g., smart glasses, bracelets, and exoskeletons), virtual reality equipment [9] (e.g., immersive helmets and mixed reality glasses), and neural implantable BCIs [10] (e.g., cortical electrodes and neural chips). Non-wearable systems such as robotic arms and mobile robots also require seamless integration. Cobodied AI devices must support multiple channels for information acquisition, perception, interaction, and presentation to interact with users and external environments.

For different scenarios and requirements, suitable hardware and software solutions must be provided. Evaluating and ensuring device usability, effectiveness, and safety is thus essential.

(6) AI-side learning and evolution. By integrating AI with the human body, cobodied AI creates special physical feedback loops for AI learning. Unlike embodied AI, which relies solely on robotic bodies, cobodied AI features dual-brain coexistence and human body participation. This significantly increases the environmental interaction complexity and learning difficulty.

To implement AI learning in cobodied AI, research is needed on collecting and modeling multisource feedback data during human-AI-environment interactions. It also requires capturing dual-brain cognitive decision-making processes to provide data for AI learning. For AI model training, optimization methods should be designed to efficiently use dual-channel feedback from both human and environmental inputs.

(7) Impact of cobodied AI experiences on human intelligence. The application of cobodied AI technologies will revolutionize user experiences through unprecedented AI symbiosis. For instance, in individuals with visual impairments, long-term use of real-time eye tracking-driven audio descriptions may offer a visual-like experience, potentially supporting the brain's formation of compensatory visual pathways. This can create new research directions for neuroscience and cognitive science.

Conversely, accumulating cobodied AI experiences may introduce uncertainties in long-term human cognitive development and habit formation, presenting both positive prospects and safety risks.

(8) Integration between cobodied AI and embodied AI. Compared with robot-centered embodied AI, cobodied AI represents a distinct physical manifestation paradigm. As related technologies mature, these two paradigms will increasingly converge in practical applications.

For example, human-centered cobodied AI and robot-centered embodied AI can collaborate to complete physical-world tasks through "dual-brain" and "multi-body" integration. Under this framework, it is essential to re-examine the technical challenges, identify potential risks, and explore new possibilities for enhancing human capabilities.

Conclusion. This study formally defines the concept of cobodied AI, differentiates it from related technologies, and identifies eight foundational scientific and technical challenges for its realization. By re-centering human agency through dual-brain integration and physical co-embodiment, cobodied AI offers a viable pathway toward generalized AI embodiment in real-world contexts.

As an emerging paradigm, cobodied AI confronts multiple challenges, spanning usability, scalability, and cost-effectiveness, ethical and legal governance, privacy and security, as well as sociocultural adaptation. Crucially, new ethical frameworks are required to address not just data privacy, but the potential for cognitive manipulation and the redefinition of human agency itself. Tackling these challenges demands close, sustained collaboration across academia, industry, and government. Concerted efforts by researchers, engineers, policymakers, and ethicists must accelerate the safe, efficient, and sustainable development of cobodied AI technologies for the benefit of humanity.

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