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VIEWPOINT

Ai4tech: X-AI enabling X-Tech with human-like, generative, decentralized, humanoid and metaverse AI

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Abstract
The X-AI age is characterized by the synergy of diverse forms of intelligence-human, natural, social, and artificial (AI). It represents an ecosystem of comprehensive AI paradigms and the flourishing development of deep learning, large language models, and generative AI applications. X-AI reignites the debate on fundamental AI questions: What is AI? What constitutes machine intelligence? What are the implications when AI integrates with business and technology in the new era of artificial general intelligence and human-like AI? This article aims to inspire critical thinking, debate, and discussion on this new era of AI meeting technology, shaping AI4Tech through X-AI enabling X-Tech. We explore the ecosystems of X-AI and X-Tech and the general and domain-specific AI4Tech areas. X-AI enabling X-Tech nurtures a new age of smart businesses and intelligent technologies. The synergy between conventional, human-like, generative, decentralized, humanoid, and metaverse AI unlocks the potential to overcome previous limitations, impossibilities, unknowns, and dreams of AI and technology.

Keywords Artificial intelligence (AI) · X-intelligence · Data science · X-AI · X-Tech · AI for technology · AI4Tech · Human-like AI · Generative AI · Decentralized AI · Humanoid AI · Metaverse AI

1 Introduction

The 70-year evolution of AI is now entering a new era of artificial general intelligence (AGI) [1] and human-like to human-level and human-like AI (HAI) [2], spanning across every discipline, sector, and domain, forming what we call the X-AI age [3]. In [4], we introduce the concept of X-AI,[1] referring to both this new age of AI and the emerging AI ecosystem. X-AI consolidates comprehensive new-generation developments aimed at simulating human, natural, social, and artificial intelligence, ultimately achieving ubiquitous intelligence [5], HAI, or AGI.

The human, scientific, technological, social, economic, and cyber worlds face escalating challenges and revolutions, necessitating a powerful driving force like X-AI to:

- Handle the exponentially increasing amounts of data and extract greater insights and value from customers, products, services, enterprises, and markets.
- Address the growing uncertainties, changes, and challenges arising from business, social, economic, political, and global perspectives.
- Process the continuously evolving data characteristics, complexities, and challenges.

X-AI offers significant potential to address these challenges, particularly by enabling new-generation X-Tech through:

- The foundational roles of X-AI in fostering intelligent, proactive, personalized, and automated enterprise strategy, planning, operations, competition, growth, and decision-making across technical areas and sectors.
- The transdisciplinary, transformational, and translational AI science and technology [6], empowering today's and future generations of X-Tech for advanced enterprises, society, and the economy.

The development of AI meeting technologies is advancing into a new generation, X-AI meeting X-Tech, or AI4Tech.

[1] Another term XAI is used for explainable AI. More about X-AI research can be found in our lab: https://datasciences.org/artificial-intelligence/.

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Here, we expand the discussion on the ecosystem of X-AI and X-Tech, the family of AI4Tech, the foundational elements of X-AI enabling this new generation, and X-AI applications. These applications are exemplified by humanized real-time multimodal humanoid AI and physical-cyber-social-virtual metaverse AI.

2 The era of X-AI

Humans demonstrate both innate and acquired intelligence [7], which enables capabilities such as goal-setting, intention, emotion, sentiment, perception, vision, conversation, communication, behavior, action, learning, inference, decision-making, and reflection. *Nature* is driven by natural intelligence [8], utilizing mechanisms like adaptation, selection, mutation, and evolution. *Society* [9] operates based on key elements including social structures, relationships, interactions, functions, norms, governance, and conflict resolution. These human, natural, and social principles, mechanisms, and implications serve as the origin and foundation of AI. Their advancements inspire increasingly advanced machine intelligence and drive the evolving emergence of new forms of X-AI and X-intelligences.

2.1 X-AI and X-intelligences

X-AI aims for omniscient X-intelligences [10] and develops diversified and complementary AI paradigms [4, 11]. Examples of these X-intelligences and AI paradigms include:

- Behavior intelligence and behavioral AI
- Data intelligence and data-driven AI
- Domain intelligence and domain-driven AI
- Symbolic intelligence and symbolic AI
- Situated intelligence and situated AI
- Embodied intelligence and embodied AI
- Connectionist intelligence and connectionist AI
- Nature-inspired intelligence and natural AI
- Social intelligence and social AI
- Organizational intelligence and organizational AI
- Network intelligence and network AI
- Human intelligence and human-like/human-level AI

These X-intelligences and AIs [4, 5, 12] surpass the classic thinking, scope, and development of machine intelligence [13], as well as the traditional concepts of mind and machine [14, 15].

These X-AI and X-intelligences represent the features and future of new-generation AI and intelligent systems. Figure 1 illustrates the main aspects of X-AI in terms of AI goals, tasks, and paradigms to achieve HAI and AGI level intelligence.

First, the "X" in X-AI refers to:

- *Ubiquitous* encompassing many, omni-, any, every, or all-round;
- *Variational* changing, evolving, and progressing over time, space, or domain;
- *Forward-looking* including future-oriented and optimal; or
- *Ecosystem-oriented*.

Accordingly, X-AI has multiple perspectives and meanings, aiming to:

- Address omniscient AI goals and tasks,
- Tackle omni-AI scenarios and complexities,
- Develop omni-AI paradigms, and
- Achieve omni-machine intelligences.

These aims are applicable to any, every, and next-best scenarios, performance levels, or outcomes of AI and intelligent systems.

Omni-AI goals X-AI aims to encompass all, any, or many goals of HAI and AGI, including perceiving, reasoning, searching, learning, recognizing, adapting, generating, planning, acting, reinforcing, optimizing, reflecting, and governing agents and their behaviors and outcomes.

Omni-AI tasks This involves developing and enabling capabilities such as identification, recognition, detection, inference, reasoning, search, learning, generation, recommendation, or intervention of intelligent agents to achieve their goals.

Omni-AI scenarios X-AI addresses challenges in AI scenarios that are unsupervised, semi-supervised, supervised, non-IID, active, online, adaptive, cross-domain, cross-market, cross-organizational, multisource, multimodal, transferrable, reinforced, or feedback-based.

Omni-intelligences Also known as ubiquitous intelligence, this encompasses omniscient human, natural, social, or artificial intelligence, including traits such as intention, emotion, sentiment, vision, perception, conversation, communication, action, adaptation, evolution, selection, interaction, behavior, decision-making, and reflection. X-AI simulates and creates corresponding intelligences like visual intelligence, learning intelligence, conversational intelligence, emotional intelligence, and behavioral intelligence.

Omni-AI paradigms This refers to the comprehensive scope of AI mechanisms and paradigms, including symbolic, connectionist, learning-based, behavioral, natural (nature-inspired), networking, data-driven, social, algorithmic, emotional, system-based, and human intelligence, along with various AI methodologies.

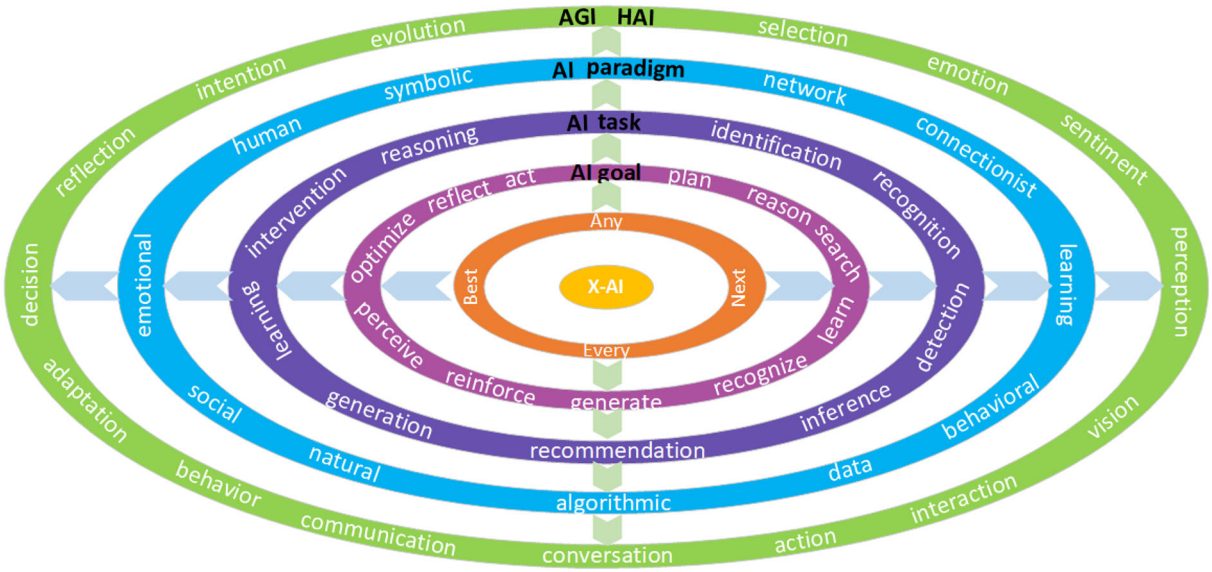


Fig. 1 X-AI: The new age of AI and the new-generation AI ecosystem with comprehensive goals, tasks, and paradigms to simulate machines with all-encompassing human-like, nature-inspired, social, and general intelligence

Every-AI This encompasses multifaceted AI solutions for every aspect, factor, time, place, body, thing, context, or domain of AI goals, tasks, paradigms, or intelligences.

Any-AI It refers to the flexibility of AI to operate anytime, anywhere, by anybody, in any form, for anything, anyhow, in any context, at any scale, under any weather conditions, or throughout lifelong learning.

Next-AI It aims for future-oriented AI solutions, advancing towards the next or next-best stages, designs, mechanisms, or outcomes of AI, adapting to changing and evolving conditions across objects, time, space, or domains.

Best-AI It strives for optimal AI designs, performance, and outcomes, aiming to approach human-like to human-level intelligence and functionality.

AI ecosystems This encompasses a range of ecosystems that collectively strive to simulate diverse human-like or artificial general intelligences, employing various AI paradigms, performing diverse tasks and functions within AI systems, and engaging with a variety of stakeholders.

2.2 X-intelligence metasynthesis with generative and metaverse AI

The X-AI ecosystem necessitates synthesizing X-intelligences, addressing omni-AI goals, tasks, and scenarios, and developing theories, mechanisms, and methods for omni-AI paradigms. This concept inspires metasynthetic intelligence and metasynthetic AI [3, 4]. Metasynthetic AI involves

- Synthesizing ubiquitous intelligences, such as human intelligence, domain intelligence, data intelligence, behavior intelligence, machine intelligence, network intelligence, social intelligence, and organizational intelligence, on demand.
- Establishing consensus across multiple AI goals, tasks, and paradigms.
- Managing the divergence and convergence between various goals, tasks, paradigms, and intelligences.

In essence, metasynthetic AI seeks to integrate and coordinate diverse forms of intelligence to achieve comprehensive and adaptive AI solutions.

The metasynthesis of ubiquitous X-intelligences can adopt methodologies similar to qualitative-to-quantitative metasynthesis [5, 16, 17]. This approach, inspired by techniques and case studies in metasynthetic engineering and metasynthetic computing [5], aims to integrate various intelligent paradigms effectively. For instance, methodologies such as building a hall for workshop of metasynthetic engineering (HWME) through qualitative-to-quantitative metasynthesis [16] illustrate how diverse intelligences can be synthesized and integrated. This process involves translating qualitative insights into quantitative representation, facilitating the comprehensive integration of intelligent paradigms across different intelligent agents, stakeholders, and systems.

In the era of large language models (LLMs) [18] enabled by generative AI [19–21] and deep multimodal learning [22], and the emergence of multimodal large language models (or large multimodal models, LMMs) [23], the development of metasynthetic AI and metasynthetic intelligent systems holds

significant promise. These advancements go beyond the constraints of building human–machine cooperative systems like HWMEs (Hall for Workshop of Metasynthetic Engineering). Key challenges in developing human–machine cooperative HWMEs include:

- Facilitating real-time human–machine cooperation in problem-solving systems and processes.
- Transforming qualitative problem-solving insights into quantitative knowledge effectively.
- Synergizing diverse stakeholders involved in the process.
- Integrating and synergizing diverse forms of intelligence.
- Iteratively reflecting, refining, and optimizing systems based on live feedback or domain-expert instructions.

These challenges can be more effectively addressed by hybridizing generative AI with other AI methodologies and techniques. This approach leverages the strengths of generative AI, deep multimodal learning, and LMMs to enhance cooperation between humans and machines, streamline problem-solving processes, and optimize knowledge transformation and application.

For example, metasynthetic AI can

- *Synergize the ecosystem of stakeholders* Integrate diverse stakeholders, including human domain experts, devices (like electric vehicles or robots), and edge and cloud-based computing into problem-solving systems. This integration is facilitated by real-time multimodal learning, enhancing interaction and communication dynamics (Sect. 6.1).
- *Enable immersive, real-time, and multimodal human–machine interaction* Integrate technologies like the metaverse with virtual 3D digital humans and AI-driven health and medical diagnosis. This integration supports real-time communications between patients, specialists, and other interfaces (Sect. 6.2).
- *Support multi-party, multidisciplinary, multilingual, and diversified stakeholder involvement* Facilitate various types of stakeholder interactions (conflicting, defensive, complementary, collaborative, or competitive) through multimodal, emotional, audio, video, and textual communications. This is enabled by LLMs and LMMs.
- *Provide and synergize representation, inference, reconstruction, and emergence of X-intelligences* Integrate multi-paradigm models into phased modularization and workflows within problem-solving systems and processes.
- *Support interactions, communication, networking, and interoperability across computing entities* Enable seamless interactions, communication, networking, and interoperability across hierarchical and heterogeneous computing entities, components, and systems. This includes integrating device, edge, and cloud-based computing and communication.
- *Support qualitative-to-quantitative transformation and translation* Utilize different embedding and representation mechanisms, heterogeneous contextual fusion, and input-to-output transformation and translation modeling through constructing mixed embedding, attention, and translation deep networks.
- *Characterize and extract enterprise data DNA* [24] Identify and capture foundational elements, entities, attributes, flows, processes, logics, and relations across various facets of enterprise operations, human resources, corporate services, production, client relationship management, and governance.

These capabilities illustrate how metasynthetic AI can enhance cooperation, interaction, and problem-solving across diverse domains and stakeholders, leveraging advanced AI technologies to address complex challenges unsolvable by individual AI systems and stakeholders.

3 The era of X-Tech

In business, X-Tech specifically refers to the interconnected ecosystems comprising various stakeholders such as companies, providers, customers, and markets. Building upon this semantic, aligned with the diverse capabilities of X-AI, we emphasize the technical content of X-Tech.

3.1 The X-Tech ecosystem

Technically, X-Tech encompasses a wide array of domain-specific and targeted technologies tailored to various industries and sectors. Here are some typical examples of X-Tech areas:

- *HealthTech* Technology focused on healthcare innovations and advancements.
- *MedTech* Technological solutions specifically designed for medical applications.
- *CareTech* Technologies addressing healthcare, aged care, and elderly care needs.
- *FinTech* Financial technologies transforming the financial services industry.
- *BankTech* Technology innovations in banking and financial institutions.
- *PayTech* Payment technologies facilitating secure and efficient payment systems.
- *InsurTech* Technological innovations in the insurance sector.
- *TelTech* Telecommunications technologies and advancements.

- *ManuTech* Manufacturing technologies enhancing production and industrial processes.
- *TransTech* Transportation technologies and innovations.
- *AgriTech (AgTech)* Agricultural technologies improving farming practices and efficiency.
- *FoodTech* Technologies focused on advancements in food production and processing.
- *CityTech* Urban technologies addressing city infrastructure and management.
- *HomeTech* Technologies for smart home solutions and home automation.
- *CustomerTech* Technologies enhancing customer experience and engagement.
- *ArtsTech* Technological innovations in the arts and creative industries.
- *EcomTech* E-commerce technologies enabling online business operations.
- *MarketTech* Sales and marketing technologies for targeted and effective marketing strategies.
- *EventTech* Technologies enhancing event planning and management.
- *GameTech* Technological advancements in gaming and interactive entertainment.
- *VisualTech* Technologies for visualization, animation, and graphics.
- *SocialTech* Technologies facilitating social networking and online communities.
- *MediaTech* Technologies related to media production, distribution, and consumption.
- *DefTech* Defense technologies focusing on defense and security applications.
- *SecureTech* Security technologies ensuring cyberspace, data and system security.
- *SafeTech* Safety technologies promoting workplace and public safety.
- RegTech Regulatory technologies assisting with compliance and regulatory requirements.
- *CompTech* Compliance technologies ensuring adherence to regulations.
- *RiskTech* Risk management technologies addressing risk assessment and mitigation.

Fig. 2 illustrates the various areas of X-Tech, each with core functions and attributes tailored to meet common industry needs and challenges. These technologies play crucial roles in driving innovation, productivity, efficiency, and competitiveness across diverse sectors.

Further, similar to the concepts in X-AI, X-Tech refers to any-tech, all-tech, next-tech, best-tech, and the technology ecosystem (tech-ecosystem).

- *Any-tech* Refers to technologies that can operate anytime, anywhere, by anybody, in any form, under any context, at any scale, or during any phase of applications and developments. Any-tech emphasizes the versatility and adaptability of technologies to various conditions and requirements.
- *Every-tech* Encompasses every aspect, time, space, body, or domain of technologies. It implies comprehensive coverage and application of technologies across all possible dimensions and scenarios.
- *Next-tech* Refers to technologies that are evolving, futuristic, new, next-generation, or aiming for next-best stages, designs, or mechanisms. Next-tech highlights advancements and innovations in technology that are poised to shape the future.
- Best-tech: Refers to technologies that achieve optimal design, performance, or outcomes. It denotes excellence in technological solutions and outcomes, striving for the highest standards and effectiveness.
- *Tech-ecosystem* Refers to the ecosystem comprising different technologies. It encompasses the interconnected network of technologies, including their development, deployment, integration, and interaction within various industries and sectors.

These aspects of X-Tech parallel the coverage of X-AI, emphasizing the breadth, evolution, excellence, and ecosystem of technologies across diverse industries, sectors, and applications.

3.2 Core functions and attributes driving X-Tech

While X-Tech across various domains and purposes may manifest in diverse forms, they often share common core functions and attributes.

First, X-Tech shares core functions, encompassing input, output, environment, information processing or analysis, core logic, and interfacing:

- *Input* Involves connecting and ingesting input data or signals.
- *Environment* Refers to the material, informational, or energetic surroundings affecting the technical system.
- *Information processing or analysis* Includes processing or analyzing data derived from inputs or the external environment.
- *Core logic* Implements the fundamental operations and logic of the technology, facilitating input-to-output transformations and mappings.
- *Interfacing* Encompasses interfaces for input and output, ensuring usability for end users.
- *Output* Connects outputs to external systems or users, delivering desired outcomes.

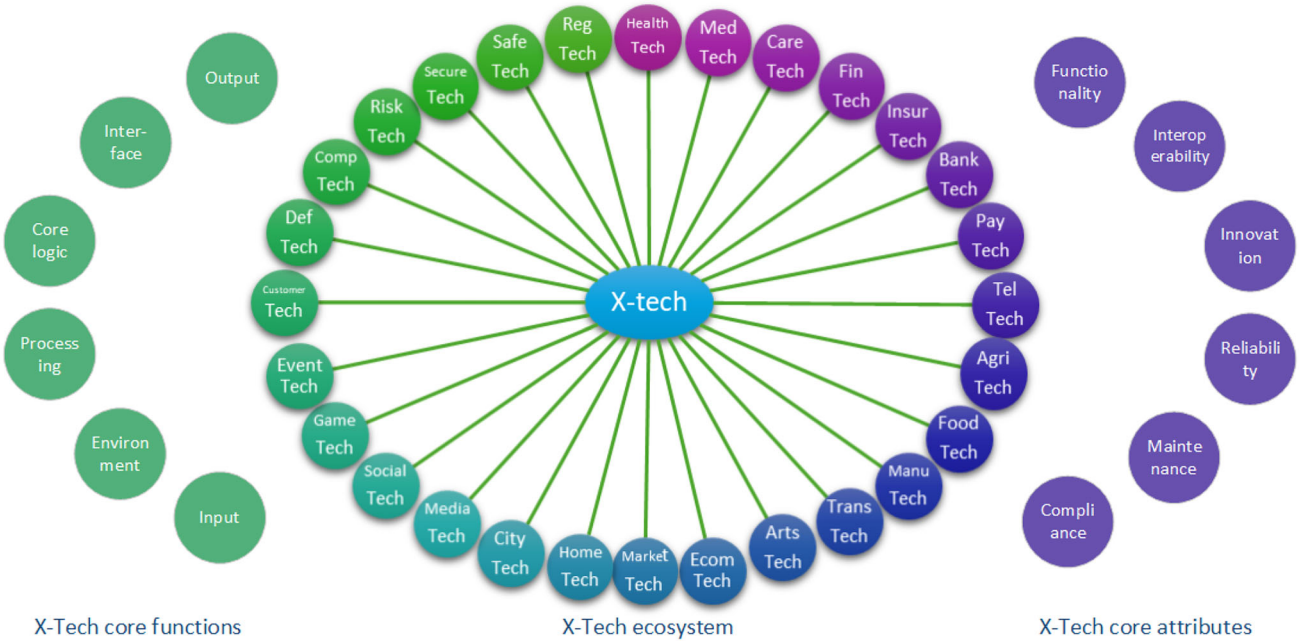


Fig. 2 X-Tech: The ecosystem comprising diverse businesses and their respective technologies, characterized by core functions and attributes essential to their merits and functions

These functions collectively define the conceptual framework and operational capabilities of X-Tech across different domains and purposes.

Then, different X-Tech areas share core attributes, which include functionality, interoperability, innovation, reliability, maintainability, and compliance:

- *Functionality* Pertains to the specific purpose or problem-solving capabilities of the technology.
- *Interoperability* Involves the ability to integrate or be compatible with other technologies or systems.
- *Innovation* Reflects significant improvements or advancements introduced by the technology.
- *Reliability* Ensures consistent and robust performance under various conditions.
- *Maintainability* Refers to the ease with which the technology can be maintained and supported.
- *Compliance* Involves adherence to principles, specifications, and regulations relevant to the industry or domain.

These core attributes underscore the essential qualities of X-Tech across diverse applications and sectors.

In addition to core functions and attributes, specific X-Tech may possess additional functions and attributes, such as automation, efficiency, security, usability, scalability, affordability, or sustainability. These attributes further define the capabilities and qualities of each technology within its specific domain or for its specific application.

4 AI4Tech: X-AI for X-Tech

The core functions and attributes of X-Tech necessitate not only specific technical designs, mechanisms, processes, and specifications, but also common and enabling capabilities. X-AI plays a crucial role as one of these critical capabilities, enabling, improving, or revolutionizing core functions and attributes. In this new era of intelligent science, technology, and economy, AI, along with affiliated and complementary technologies like data science, plays essential, and often critical, roles in driving X-Tech and enabling domain-specific AI4Tech.

4.1 X-AI transforming X-Tech functions and attributes

X-AI acts as the catalyst and innovation engine for the next generation of X-Tech. This involves upgrading and transforming existing technical methodologies, designs, mechanisms, and performance, towards intelligent solutions that enhance overall performance.

Intelligentizing core functions X-AI can significantly improve, transform, or innovate the systems, products, functions, services, interfaces, or outcomes of X-Tech. For instance, by developing corresponding X-AI technologies and methodologies, the core functions of X-Tech can undergo substantial upgrades and transformations.

- *Input* Facilitating efficient and direct processing of higher-level complexities of inputs, including complex characteristics (like mixed and heterogeneous signals), complex structures (e.g., matrices, networks, or graphs), complex relations (e.g., causality), or sophisticated semantics (e.g., concepts, knowledge graph, and ambiguity); handling complex scenarios of inputs, such as multisource, multimodal, dynamic, and evolving features; tackling complex input quality, such as of low quality and with significant quality issues; and enabling automated connection, storage, or updating of inputs.
- *Environment* supporting complex external factors, multiple domains, dynamic contexts, and enterprise-wide environments; enhancing efficient, real-time and evolving interactions with environments; and assessing the roles and impacts of environmental influences on the system.
- *Information processing or analysis* Revolutionizing capabilities and capacity for processing and analyzing information; enabling intelligent and scalable processing, analytics and learning; enabling automated or human–machine-interactive processing; expanding the depth and width of information processing; and discovering new insights and potentials into previous unknowns and impossibilities.
- *Core logic* Upgrading and transforming technology functionalities to be more powerful and extensive. Enabling automated and hierarchical mechanisms, dynamic function capabilities, and reinforcement through feedback loops.
- Interfacing: Supporting user-friendly, personalized, immersive, and multimodal interfaces for diverse stakeholders. Enabling adaptive, customizable and personalized interfaces and supporting wireless, contactless, or sensor-free interactions.
- *Output* Delivering business and user-friendly outputs in real-time. Enabling live feedback mechanisms, reflective outputs, and fine-tuning instructions and prompting to tailor outputs according to specific needs.

These enhancements illustrate how X-AI technologies can substantially improve and innovate core functions within the realm of X-Tech.

Intelligentizing core attributes of X-Tech by X-AI promotes its higher quality, efficiency, effectiveness, and performance. This fosters improved functionality, interoperability, and innovation, along with enhanced reliability, maintainability, and compliance.

- *Functionality* Enhancing design standards and problem-solving capabilities, such as by integrating multiple design paradigms with evidence-based discovery, thereby enabling more powerful functions and services.
- *Interoperability* Improving the ecosystem of the target technology and developing next-generation interface methods for technical integration, such as implementing end-to-end system integration solutions.
- *Innovation* Revolutionizing design thinking, methodologies, and technical solutions, such as by shifting from shallow analytical methods and machine learning to deep analytics and learning approaches.
- *Reliability* Enhancing the scope, design, implementation, and performance reliability, such as ensuring trust, safety, ethics, accountability, and explainability within the technical system.
- Maintainability: Transforming design thinking, interfaces, and specifications to facilitate technical maintenance and support, including interactive virtual 3D visualization for system diagnosis, simulation, and intervention.
- *Compliance* Broadening compliance efforts to encompass safety, trust, ethics, and more. Incorporating design thinking and technical solutions to monitor and regulate technology, such as upgrading from rule-based design to real-time adaptive detection of risks, anomalies, or fraud.

These enhancements illustrate how X-AI can intelligently improve core attributes of X-Tech, leading to higher quality, efficiency, effectiveness, and overall performance.

More generally, the ecosystem of X-AI and X-intelligences described in Sect. 2.1, along with X-intelligence metasynthesis from Sect. 2.2, can facilitate the upgrading, transformation, and innovation of X-Tech functions and attributes. This necessitates the development of shared AI capabilities and technologies.

4.2 Domain-specific AI4Tech

The AI4Tech ecosystem encompasses X-AI applied to domain-specific technologies. It represents the synergy between X-AI and various domain-specific X-Tech areas. Figure 3 illustrates the symbiotic relationship between X-AI tasks and capabilities and their application in different X-Tech domains. X-AI tasks and capabilities include representation, analytics, learning, detection, recognition, identification, reasoning, inference, adaptation, communication, generation, reconstruction, recommendation, reinforcement, planning, search, reflection, and optimization. The X-tech ecosystem comprises HealthTech, MedTech, CareTech, FinTech, InsurTech, BankTech, PayTech, TelTech, ManuTech, TransTech, AgriTech, FoodTech, CityTech, HomeTech, MarketTech, EcomTech, CustomerTech, ArtsTech, EventTech, GameTech, SocialTech, MediaTech, VisualTech, DefTech,

SecureTech, SafeTech, RegTech, CompTech, and RiskTech, etc.

The interaction and synergy between X-AI and X-Tech cultivate domain-specific AI4Tech for specific domains and applications. For example, AI4Tech can be instantiated into AI4Health (or HealthAI), AI4Medicine (AI4Med, or MedAI), AI4Care (or CareAI), AI4Finance (AI4Fin, or FinAI), AI4Banking (AI4Bank, or BankAI), AI4Insurance (AI4Insure, or InsurAI), AI4Payment (AI4Pay, or PayAI), AI4Telco (AI4Tel, or TelAI), AI4Manufacturing (AI4Manu, or ManuAI), AI4Transport (AI4Trans, or TransAI), AI4Agriculture (AI4Agri, or AgriAI), AI4Food (or FoodAI), AI4City (or CityAI), AI4Home (or HomeAI), AI4Market (or MarketAI), AI4Ecom (or EcomAI), AI4Customer (or CustomerAI), AI4Arts (or ArtsAI), AI4Event (or EventAI), AI4Game (or GameAI), AI4Social (or SocialAI), AI4Media (or MediaAI), AI4Visualization (or VisualAI), AI4Defense (AI4Def, or DefAI), AI4Security (AI4Secure, or SecureAI), AI4Safety (AI4Safe, or SafeAI), AI4Regulation (AI4Reg, or RegAI), AI4Compliance (AI4Comp, or CompAI), and AI4Risk (or RiskAI). Below, we briefly introduce these AI4Tech areas.

The AI4Tech ecosystem can be further categorized into several families based on similar sectoral focuses, tasks, or services, without diving into specific X-Tech areas to avoid duplication. These families encompass commonly applicable AI goals, tasks, technologies, and innovations across various sectors.

First, AI4Health (or HealthAI), AI4Medicine (or MedAI), and AI4Care (or CareAI) are revolutionizing the landscape, operations, management, and performance of health, medicine, and care sectors. They facilitate diagnostic and predictive analytics, personalized medicine, customized elderly and patient care, enhanced healthcare operations and management, innovative drug discovery and vaccination, and proactive epidemic warning and control. Examples include:

- Viral, disease, and symptom identification and diagnosis using medical imaging analytics, genomic data analytics, and pathological and clinical data analytics.
- Health condition monitoring and management through sensor-based remote and virtual monitoring, accident detection, early warning systems, and telehealth or telemedicine support.
- Drug and treatment discovery and matching via drug-target interaction analysis, genomic research, and chemical structure discovery.
- Personalized medicine by integrating personal health and medical data with genomic, medical, and clinical analytics to provide evidence-based drug and treatment recommendations.
- Improving healthcare operations and management with humanoid robots for automating general inquiries, resource scheduling, documentation, and reducing medical errors, biases, and accidents.

Second, AI4Finance (AI4Fin, or FinAI), AI4Banking (AI4Bank, or BankAI), AI4Insurance (AI4Insure, or InsurAI), and AI4Payment (AI4Pay, or PayAI) are transforming the finance, insurance, banking and payment industries. They enable large-scale process automation, improved customer experiences, and efficient evidence-based decision-making, operations, risk management, and compliance. Examples include

- Automating algorithmic trading through the development of quantitative high-frequency trading strategies, algorithms, and portfolios.
- Predictive market, economic, and strategic modeling by analyzing the impact of market and macroeconomic factors and forecasting market trends and movements.
- Automating operations and processing tasks such as insurance claims, loan applications, credit card processes, or mortgage applications.
- Securing real-time payments with features like real-time smart contracts, automatic risk and compliance checks, and contactless execution.
- Automating evidence-based risk management, compliance, and regulation oversight.

Third, AI4Agriculture (AI4Agri, or AgriAI) and AI4Food (or FoodAI) are profoundly reshaping the agriculture and food industries. They optimize resource utilization, automate production processes, enhance efficiency, and ensure food safety. For AgriAI, for example,

- Predictive and Precision Farming, such as for monitoring and controlling crop health, soil conditions, yield prediction, weather patterns, pests, and diseases. This can be achieved through analyzing data from drones, satellites, and sensors to detect and predict changes in their statuses and conditions.
- Automation of Machinery, Harvesting, and Irrigation Systems, including developing autonomous tractors and robots that optimize operations based on real-time analysis of crop growth, soil moisture levels, and weather conditions.

For FoodAI, examples include

- Optimization of Food Supply Chains, such as by forecasting demand and optimizing logistics. This ensures efficient distribution and reduces food wastage.
- Ensuring Food Quality and Safety, such as through automated inspection, tracing, and reporting of defects,

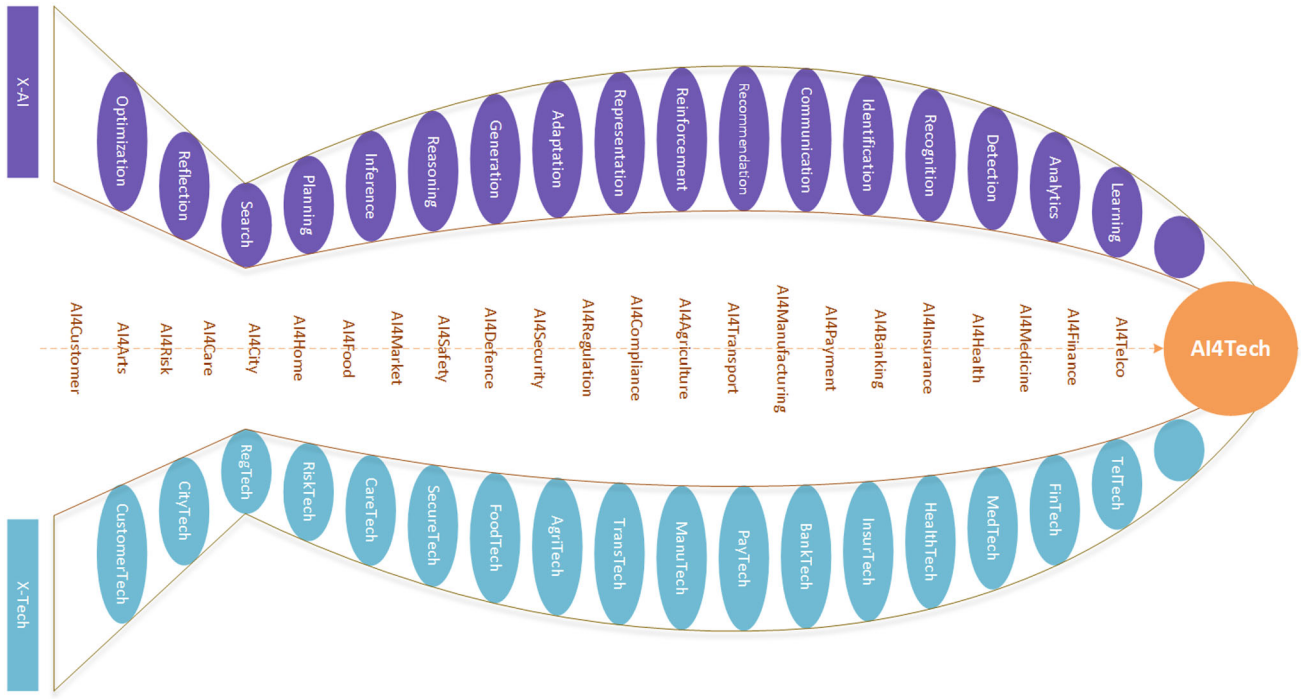


Fig. 3 AI4Tech: X-AI enabling X-Tech towards domain-specific AI for advanced technologies

contamination, and quality issues throughout food production, processing, packaging, and delivery stages.

Fourth,

AI4City (or CityAI), AI4Home (or HomeAI), and AI4Transport (AI4Trans, or TransAI) are pivotal in developing smart cities, smart homes, and smart transportation systems. Here are some examples. AI4City (CityAI) can enhance

- Urban Planning: Utilizes evidence-based modeling, simulation, planning, monitoring, evaluation, and optimization to enhance urban environments.
- Resource Efficiency: Manages facilities, utilities (such as electricity, water, and gas), traffic flow, waste management, public safety, and emergency response.

AI4Home (HomeAI) can improve

- *Intelligent energy management* Provides energy-efficient lighting based on weather conditions and residential needs.
- *Smart appliance management* Controls kitchen devices and washing machines for optimal usage and predictive maintenance.
- *Home security* Enhances security through intrusion detection and unauthorized access monitoring using surveillance video analysis and biometric authentication.

AI4Transport (AI4Trans, TransAI) can enable

- *Autonomous vehicles* Integrates self-driving vehicles with real-time monitoring of human and road conditions for safe navigation.
- *Public transportation optimization* Develops dynamic and predictive schedules, monitoring systems, and maintenance protocols for efficient public transport operations.
- *Traffic management improvement* Improves traffic safety by detecting, predicting, alerting, and mitigating accidents, aggressive driving behaviors, and traffic congestion patterns.

Fifth, AI4Manufacturing (AI4Manu, or ManuAI) plays increasingly critical roles in enhancing the efficiency, productivity and quality through capabilities such as

- *Predictive maintenance* Utilizes AI to predict equipment failures, recommending optimal times, locations, and processes for maintenance and quality control to minimize downtime and enhance operational efficiency.
- *Automated manufacturing processes* Automates, customizes, and optimizes manufacturing design, development, production processes, and workflows to streamline operations, reduces costs, and improve consistency in production.

- *Personalized design and supply chain optimization* Informs personalized product design based on customer preferences and feedback, optimizing the supply chain and logistics for cost-effectiveness and efficiency to enhance customer satisfaction and reduce lead times.
- *Innovation and quality management* Drives innovation in product design, inventory management, market research, customer service, and quality control through AI-driven insights and analytics to foster continuous improvement and competitive advantage in the manufacturing sector.

Further, AI4Market (or MarketAI), AI4Ecom (or EcomAI), and AI4Customer (or CustomerAI) enable efficient, fair and personalized marketing and supply chain management, and ecommerce services, and enhance positive and personalized customer experiences. They can reshape traditional marketing, ecommerce, and customer relationship management practices; discover deep insights into customer preferences, behaviors, demand trends, feedback, and sentiment. For example, AI4Market (or MarketAI) can improve

- *Competitive strategy prediction* Predicts competitor strategies, enabling businesses to strategically position themselves in the market for enhanced competitiveness.
- Sales Strategy Optimization:Informs and optimizes future sales strategies based on market insights, seasonal demand fluctuations, and production forecasts.
- *Demand forecasting and inventory management* Forecasts seasonal demand patterns and optimizes inventory and production to meet market needs efficiently.

AI4Ecom (or EcomAI) can upgrade

- *Workflow automation* Automates ecommerce workflows, including order processing, inventory management, and supply chain logistics, streamlining operations for efficiency.
- *Customer segmentation and personalization* Segments customers based on preferences and behaviors, enabling personalized pricing, product recommendations, and targeted marketing campaigns.
- *Customized services* AI customizes delivery options and customer services, enhancing the overall ecommerce experience and satisfaction.

AI4Customer (or CustomerAI) can enable

- *Sentiment analysis* Analyzes customer sentiment and feedback across various channels, providing actionable insights for improving products and services.
- *Targeted campaigns* Tailors targeted marketing campaigns and content based on customer preferences and behavior data, maximizing engagement and conversion rates.
- *Optimized customer experience* Optimizes customer interactions and experiences through personalized communications, recommendations, and support services, fostering loyalty and satisfaction.

In addition, AI4Arts (or ArtsAI), AI4Event (or EventAI), AI4Game (or GameAI), AI4Social (or SocialAI), AI4Media (or MediaAI), AI4Visualization (or VisualAI), and AI4Telco (AI4Tel, or TelAI) transform various aspects of culture, social interaction, entertainment, communication, creative design, and telecommunications. They revolutionize the design, production, delivery, operations, and services of arts, music, media, game, and entertainment toward digitized, personalized, virtuality-reality-mixed, and novel design, production, and recommendation. For example, AI4Arts (or ArtsAI) enables

- *Digitized and personalized content* Revolutionizes the creation, production, and delivery of arts and music through digitization and personalization.
- *Immersive expression and engagement* Integrates virtual and mixed reality technologies, enhancing artistic expression and audience engagement.

AI4Event (or EventAI) supports

- *Event automation* Automates event inquiries, communications, planning, scheduling, resourcing, and operations, streamlining event management processes.
- *Personalized alignment* Enables personalized and relevant event recommendations and session alignments based on attendee preferences and profiles.

AI4Game (or GameAI) can transform

- *Game design and production* Transforms game design, production, and operations, leveraging advanced technologies for enhanced gameplay experiences.
- *Entertainment innovation* Drives innovation in game development towards virtual reality, mixed reality, and interactive storytelling.

AI4Social (or SocialAI) can strengthen

- *Social networking* Enhances social networking platforms with advanced analytics, content moderation, and personalized content recommendations.
- *Community engagement* Fosters community engagement and interaction through personalized feeds, recommendations, and communication tools.

AI4Media (or MediaAI) can optimize

- *Media production and distribution* Optimizes media production workflows, enhances content creation, and improves distribution strategies.
- *Content personalization* Tailors media content recommendations and advertising based on viewer preferences and behavior analytics.

AI4Visualization (or VisualAI) can enable

- *Visual content generation* Generates and enhances visual content, including animations, graphics, and virtual environments.
- *Visual understanding* Develops advanced data visualization techniques for better understanding and presentation of complex information.

AI4Telco (AI4Tel, or TelAI) can support

- *Network optimization* Optimizes site selection, capacity planning, and network slicing; improves network traffic, resource and energy allocation and efficiency; and enhances network performance.
- *Security and fraud prevention* Predicts and prevents network faults, security threats, fraud, and malicious activities through advanced analytics and monitoring.
- *Predictive maintenance* predicts network issues and recommends maintenance scheduling and resourcing.
- *Customer experience* Enhances personalized customer experiences through tailored service offerings and proactive retention resolution.

Lastly but not least, AI4Defense (AI4Def, or DefAI), AI4Security (AI4Secure, or SecureAI), AI4Safety (AI4Safe, or SafeAI), AI4Regulation (AI4Reg, or RegAI), AI4Compliance (AI4Comp, or CompAI), and AI4Risk (or RiskAI) share similar and relevant goals, tasks, and issues. Typically, X-AI can improve their technical design, product manufacturing, production, and delivery; automate their operations and services; monitor, detect, predict and prevent incidents, malicious activities, violations, and exceptions; and improve quality, performance and experience for better safety, security, and compliance.

For example, AI4Defense (AI4Def, or DefAI) can provide

- *Enhanced technical design* Improves the technical innovation, design, manufacturing, and production of defense technologies, products and applications.
- *Automated operations* Automates defense operations and services, enhancing efficiency and response times.
- *Proactive monitoring and prevention* Monitors, detects, predicts, and prevents security incidents and malicious activities, ensuring robust defense mechanisms.

AI4Security (AI4Secure, or SecureAI) can enable

- *Advanced security systems* Enhances the design and production of cybersecurity, data and system security infrastructure and products.
- *Operational automation* Automates security operations and services, streamlining security monitoring and assurance processes and improving response times.
- *Predictive detection and prevention* Monitors, detects, predicts, and prevents security threats, attacks, violations, and malicious activities, ensuring comprehensive security measures.

AI4Safety (AI4Safe, or SafeAI) can provide

- *Improved safety systems* Enhances the technical innovation, design and quality of safety devices, products and services.
- *Automated safety operations* Automates safety operations and services, ensuring efficient and effective safety management.
- *Online prediction and prevention* Monitors, detects, predicts, and prevents safety incidents and exceptions in real time, enhancing overall safety standards.

AI4Regulation (AI4Reg, or RegAI) can enable

- *Improved regulation efficiency* Automates the detection, analysis, and identification of regulation violations.
- *Expanded regulation effectiveness* Broadens the coverage, detection and confirmation of regulatory violations from online, social media and documented reports and resources.
- *Cross-domain regulation* Enables the fusion and cross-reference of knowledge, information and approaches from legal, IT and administrative authorities to identify cross-organizational violations.

AI4Compliance (AI4Comp, or CompAI) can support

- *Human–machine cooperation* Combines automated compliance check, monitoring and forecasting with human expert-based knowledge, rules, and investigation.
- *Online and active compliance* Enables real-time compliance monitoring, detection, early warning and intervention over time.

AI4Risk (or RiskAI) can strengthen

- *Risk rating performance* Develops adaptive, dynamic and robust rating mechanisms and measures from multi-source, multmodal, and lifelong interactions and experiences to cover novel, evolving risk factors and accidents.
- *Next-best action recommendation* Tracks and analyzes suspicious activities over time and space, predicts and recommends next best actions for intervention and mitigation.

5 X-AI foundations

The overarching goal of achieving Human-like Artificial Intelligence (HAI) and Artificial General Intelligence (AGI) necessitates foundational research on X-AI, establishing the X-AI foundations. Although capturing, characterizing, and transferring natural and social intelligence pose significant challenges, we highlight the following critical technologies essential for progressing toward HAI and AGI:

- Deciphering goals and intentions,
- Cultivating emotion and sentiment
- Enhancing vision and perception
- Broadening conversation and communication
- Revealing action and behavior
- Enabling decision and reflection
- Integrating reality and virtuality

Fig. 4 emphasizes these critical capabilities in enabling X-AI and X-Tech, particularly for exploring unknown and seemingly impossible systems and problems in an open world [25].

5.1 Deciphering goals and intentions

Goals and intentions are fundamental aspects of human intelligence and humanity. They are both subjective and objective, making them challenging to acquire, represent, and learn. However, they are critical for simulating human intelligence and achieving HAI and AGI.

The primary objectives of unlocking goals and intentions are to understand, characterize, and formulate these concepts and their underlying mechanisms. This exploration seeks to answer questions such as:

- How are goals and intentions formed?
- How do goals and intentions evolve?
- How do goal and intentions drive and influence emotions, behaviors, and decisions?

The key X-AI outputs of unlocking goals and intentions include new-generation theories, technologies, solutions, and tools for characterizing, representing, formulating, learning, and inferring goals and intents, as well as their formation and evolution mechanisms and processes. Additionally, these outputs explore the influence of goals and intentions on emotions, behaviors, and decisions.

The key outcomes of unlocking goals and intentions for X-Tech include:

- *Next-generation businesses* Enhanced goal planning, purposeful strategy design, and intention-to-decision processes in various sectors such as online services, e-commerce, recommendations, gaming, and customer relationship management.
- *Substantial applications* Improvements in purposeful health, customer planning, strategy, recommendations, care, and decision-making processes.
- *Increased proactiveness* Significant advancements in forward-looking planning, prediction, and intervention for applications in customer care, marketing, and sales.

5.2 Cultivating emotion and sentiment

Emotion and sentiment are essential attributes of human intelligence, expressing humanity through facial expressions, behaviors, and subjective experiences such as consciousness, empathy, and opinions. Therefore, the primary objectives of nurturing emotion and sentiment include characterizing, representing, analyzing, and learning these aspects, while addressing questions such as:

- What are the underlying drivers of emotion and sentiment?
- How can emotion and sentiment be learned from multimodal interactions?
- What are the relationships between emotion, sentiment, behaviors, and decisions?

The anticipated outcomes of nurturing emotion and sentiment for X-Tech encompass: (1) Development of new-generation theories, technologies, solutions, and tools for recognizing, tracking, learning, generating, and inferring emotion and sentiment from oral, visual, and written communication, expressions, behaviors, and interactions. These advancements will explore their relationships and impacts on behavior, actions, conversations, and decisions. (2) Creation of next-generation metaverse digital twins featuring emotional humanoid avatars, enabling simulation and emulation of human emotion and sentiment.

The key outcomes for X-Tech include:

- Implementation of new-generation applications, such as user-friendly online social media, networking platforms, questionnaires, surveys, and question/answering services.

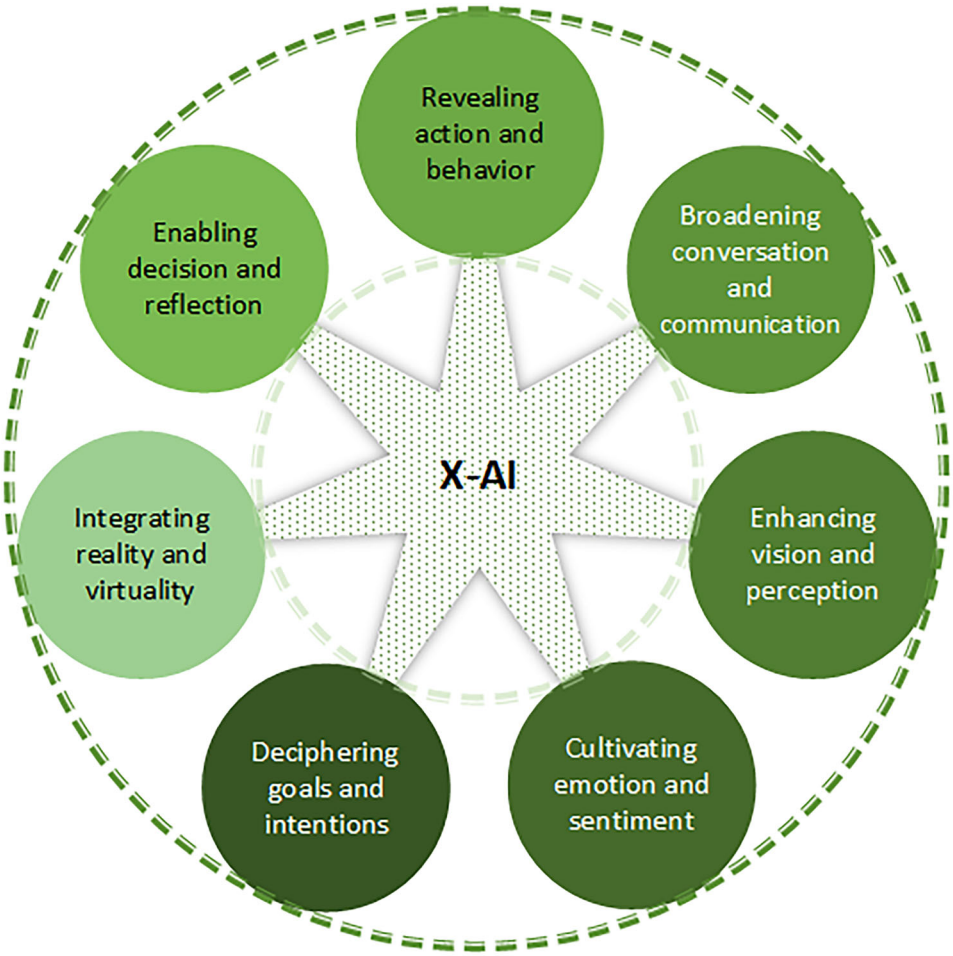


Fig. 4 X-AI foundations: Foundational enabling intelligences and capabilities for X-Tech

- Development of new-generation services that facilitate automated, emotionally humanized customer communication, receptionism, and care.
- Introduction of humanized and user-friendly robo-advising, virtual reality experiences, and social interactions within next-generation sectors like HealthTech, FinTech, and CustomerTech.

5.3 Enhancing vision and perception

Vision and perception are fundamental cognitive capabilities found in living organisms. Despite notable advancements in pattern recognition and computer vision, there remains a need for foundational research to fully understand, formulate, represent, and simulate these abilities.

The key objectives of advancing vision and perception include:

- How can visual observations from images and videos be perceived and recognized in real-time complex contexts?
- How can multi-party visual expressions be discriminated and analyzed in real-time and complex contexts?
- How can large-scale and real-time visual perception, incorporating emotion, action, and behaviors, be enabled in humanoid robots?

The key outputs of advancing vision and perception include: (1) New-generation theories, technologies, solutions, and tools for recognizing, classifying, and generating audio and video in multimedia, multimodal, and multi-party conversations and interactions. (2) Next-generation technologies to learn from vision and perception to action and decision-making. (3) Next-generation technologies enabling humanoid robots for real-time audio and video conversations with multiple parties in live streams. (4) New-generation metaverse digital twins to facilitate multimedia humanoid avatars.

The key outcomes for X-Tech include:

- Broad applications of new-generation imagery, visual, and video-based interactions.
- Novel applications for multi-party vision tasks, such as object, action, behavior, and scenario recognition in videos.

- Next-generation humanoid robots equipped with live multimedia capabilities to support humanized robotic healthcare, aged care, receptionist duties, and customer inquiries.
- Humanized and user-friendly avatars for personalized robo-advising, telehealth services, online chatbots, and more.

5.4 Broadening conversation and communication

Conversation and communication are essential for social interaction, cooperation, collaboration, and other forms of sociability. They encompass various multimodal channels and means of interaction.

Accordingly, the primary objectives of expanding conversation and communication include addressing the following queries:

- How can acoustic and visual conversations be perceived and recognized in real-time contexts, including tones and pitch?
- How can robotic systems discriminate between multi-party conversations in visually complex, live contexts?
- How can systems enable situated conversations that integrate short to long-term memory, historical context, and prior interactions?
- How can conversations be contextualized with emotion, actions, and behaviors in live settings?

The key outputs of expanding conversation and communication include: (1) Development of new-generation theories, technologies, solutions, and tools for recognizing and generating personalized vocal conversations. (2) Advancement in next-generation humanoid robots capable of supporting multi-party conversations in a multimodal and situated manner. (3) Creation of new-generation technologies that enable humanized communication for actionable insights and decision-making.

The key outcomes of enabling X-Tech include:

- Deployment of new-generation chatbots with humanized, multimedia conversation capabilities.
- Enhanced effectiveness in human-robot communications.
- Extensive application of humanized, human-like robots for communication with elderly, aged, and disadvantaged groups.
- Development of new-generation multi-party and situated online robot advisers and chatbots.
- Facilitation of humanized and user-friendly social interactions across new-generation HealthTech, FinTech, and CustomerTech applications, among others.

5.5 Revealing action and behavior

Action and behavior reflect aims, intentions, emotions, and decisions, serving as key means to express and achieve intelligence.

The key objectives of disclosing action and behavior include exploring:

- How to learn sequences of visual actions and behaviors in live 3D, 4D, visual, emotional, or conversational contexts?
- How to recognize and discriminate multi-party and influential behaviors in complex contexts?
- How to model the utility, impact, or influence of sequential behaviors with varied consequences?
- How to model the relations and transformations from behaviors to actions and predict next-best actions?

The key outputs of disclosing action and behavior include: (1) New-generation theories, technologies, solutions, and tools to characterize, recognize, trace, and recommend high-impact and high-utility behaviors of single and multiple parties. (2) Next-generation humanoid robotic technologies to recognize, track, generate, and intervene in multi-party interaction behaviors over time. (3) New technologies to enable behavior-to-action transformation and recommend next-best actions.

The key outcomes of enabling X-Tech include:

- New businesses and applications in games, online entertainment services, and 3D/4D production, leveraging visual actions and behaviors.
- Enhanced behavior management with a focus on impact, influence, and utility targets.
- Proactive behavior management and intervention actions in customer-provider relationships, customer care, and support services.

5.6 Enabling decision and reflection

Decision and reflection represent high-level intelligent behaviors and outcomes. Understanding their mechanisms, formation, and impact can enhance decision-making and influence other aspects of intelligence.

Therefore, the key objectives of unlocking decision and reflection include understanding:

- WWhat drives decision-making and its quality in the context of goals, intention, and explicit factors such as emotion, sentiment, vision, perception, conversation, and communication behavior and action?
- How to map and relate procedural, reactive, proactive, and prescriptive decisions to implicit goals and inten-

tions, and explicit factors like emotion, sentiment, vision, perception, conversation, and communication behavior and action?
- How does reflection function and influence decision-making within the framework of other human intelligences?
- How to synergize comprehensive X-AI capabilities to improve and recommend better decisions?

The key outputs of unlocking decision and reflection include: (1) New-generation decision theories, technologies, and tools to reason about decisions in comprehensive X-intelligence contexts; (2) New-generation reflection theories, technologies and tools to optimize and recommend decisions based on reflection and other human intelligences.

The key outcomes of enabling X-Tech include:

- *Improved decision quality and effect* Enhanced decision-making that is proactive, personalized, situational, and reflective.
- *Streamlined process from goal-planning to action* Better integration and automation from goal-planning to recommending and taking next-best actions.
- *Automated purposeful decision-making* Automation of decision-making processes during multimodal and reflective communication, and interactions with customers and stakeholders.
- Significant Improvement in Recommendations and Management: Enhanced effectiveness in recommendations, sales, marketing, and customer management, leading to better outcomes in these areas.

5.7 Integrating reality and virtuality

Reality and virtuality are increasingly intertwined and coexist across scientific, technological, social, economic, and cultural domains. This blending fosters new and emerging opportunities for both X-AI and X-Tech. Therefore, we highlight their critical roles in enabling and supporting X-AI and X-Tech advancements.

The key objectives of mixing reality and virtuality for X-AI and X-Tech include exploring:

- How to transfer and synergize X-AI reality to the virtual world through creating intelligent avatars?
- How to transfer and synergize X-AI to humanoid robots toward human-level humanoids?
- How to synergize human, humanoid robot, and digital twin toward smart physical, virtual, and robotic ecosystems?

The key outputs of mixing reality and virtuality include: (1) Next-generation theories, technologies, solutions, and tools for human-like humanoid robots. (2) Next-generation theories and tools for developing omniverse digital innovations. (3) New-generation digital twins fusing humans, humanoids, and the metaverse in decentralized device-edge-cloud fused innovations.

The key outcomes of enabling X-Tech include:

- New-generation businesses and applications in online metaverse games, entertaining services, customer services, robo-advising, and chatbots.
- Significant applications of human-humanoid-metaverse ecosystems, such as for smart transport control, health and medical diagnosis, and financial advising.
- Efficient humanoid robots for care support, customer interaction, inquiries, etc., connecting professionals, humanoids, and metaverse avatars.

As elaborated in Sect. 6.2, integrating metaverse AI with decentralized AI and humanoid AI can establish next-generation intelligent systems and services. This integration merges physical, social, cyber, and virtual technologies and spaces, paving the way for innovative advancements.

6 AI4Tech applications

Section 4.2 delineates extensive and diverse applications of X-AI in specific X-Tech domains, fostering the development of domain-specific AI4Tech. Additionally, we present two scenarios and use cases showcasing the integration of X-AI with humanoid AI and metaverse AI.

6.1 Humanized real-time multimodal humanoid AI

An exemplary instance of metasynthetic AI and metasynthetic intelligent systems is humanoid AI, marking a new era in X-AI convergence with humanoid robotics [26]. For instance, Fig. 5 depicts the computational framework of Ameca [27], a cutting-edge humanoid robot empowered by real-time, interactive, and emotionally intelligent multimodal large language modeling and humanoid AI.

This new-generation humanoid AI and robot

- Integrates humans, the Ameca robot, edge and cloud devices, merging their intelligence, learning capabilities, computing power, and services into a unified ecosystem.
- Establishes real-time connections to ChatGPT [28] and other cloud services, enabling access to and integration of internet-based and decentralized knowledge and information.
- Incorporates cutting-edge AI paradigms and technologies, such as generative AI with computer vision, natural

language processing, facial expression recognition, emotion emulation, and multimodal modeling.
- Facilitates cross-modal transformations, including emotion-to-action, vision-to-language, and image-to-text conversions, as well as human-to-robot knowledge transfer.

Through domain-driven pretraining, fine-tuning, instructions, and prompting of large language models [29], coupled with customized AI techniques enabling purposeful vision, communication, behavior, emotion, interaction, collaboration, and navigation [26], humanoid AI robots can be tailored for specific domains and tasks. They can assume roles and responsibilities previously managed by humans, such as receptionists, financial robo-advisers, telehealth general practitioners, and caregivers. This versatility allows them to execute a wide range of AI goals, tasks, and scenarios as discussed in Sect. 2.1.

6.2 Physical-cyber-social-virtual metaverse AI

Drawing from cyber-physical-social systems [30], the convergence of physical, cyber, social, and virtual realms, along with their respective principles, techniques, capabilities, and stakeholders, has become increasingly demanding. This trend is further heightened by rapid advancements in metaverse technologies and their integration with conversational and generative AI and X-Tech.

Figure 6 illustrates the AIVerse metaverse AI ecosystem, integrating physical, cyber, social, and virtual capabilities and stakeholders, enabling decentralized, privacy-preserving, and secure cross-disciplinary, cross-domain, and cross-organizational X-AI and X-Tech.

AIVerse operates through the following components:

- *AIVerse engine* Provides infrastructure, facilities, interfaces, processing capabilities, and services to integrate X-AI, X-Tech, and metaverse elements including design, data, applications, stakeholders, and governance.
- *AIVerse design* Enables virtual, visual, multimodal, multimedia, 3D, 4D, and augmented reality design, visualization, digital twins, and digitization processes.
- *AIVerse X-AI foundation* Supports X-AI paradigms, goals, tasks, functions, and capabilities, encompassing AI models, algorithms, tools, and services.
- *AIVerse X-Tech foundation* Provides core functions, attributes, and system facilities for both general and domain-specific applications, configurations, and support.
- *AIVerse interfacing* Manages connectivity, communication, interaction, and stakeholder engagement with end users, domain experts, and third-party service providers.
- *AIVerse integration* Handles connection, processing, and management of external systems, applications, services, and data sourced from online platforms, domain-specific providers, and third-party sources.
- *AIVerse AI4Tech applications* Deploys and instantiates applications tailored for various domains such as HealthAI, MedAI, CareAI, FinAI, BankAI, InsurAI, PayAI, AgriAI, and FoodAI, integrating functionalities discussed in Sect. 4.2.
- *AIVerse stakeholders* Supports and engages stakeholders including end users, domain experts, AI and technical designers, developers, and third-party service providers.

An example of AIVerse is a metaverse AI system for health and medicine, HealthAIVerse. HealthAIVerse integrates physical, cyber, social, and virtual capabilities to deliver decentralized, privacy-preserving, and secure X-AI and X-Tech solutions in the healthcare domain. It consists of device-edge-cloud-fused, decentralized systems and services, including

(1) *Health and medicine metaverse* Digitizes human health conditions and medical statuses using 3D design, high-resolution visualization, mixed reality, and digital twins. Simulates and diagnoses health conditions, effects of pharmaceutical and non-pharmaceutical treatments.
(2) *External application and data integration* Injects, transforms, and represents patient demographics, health conditions, clinical records, medical imaging, and pathological tests from patients, general practitioners, and specialists.
(3) *HealthTech, MedTech and CareTech engine* Integrates health, medical, and care technologies and device readings to assist in AI and specialist diagnosis and treatment.
(4) *HealthAI, MedAI and CareAI engine* Analyzes, models, identifies, recognizes, and predicts medical symptoms, diseases, and conditions. Recommends treatments, healthcare strategies, protocols, timing, and pathways to assist specialists in diagnosis, treatment, and postoperative care.
(4) *Humanoid health and medical assistants and specialists* Supports health inquiries, treatments, and care. Provides online and physical health support, communicates with patients, caregivers, and health providers. Assists GPs and specialists in AI-enabled diagnosis, recommendation, emergency support, and after-hour care.
(5) *Stakeholder interfacing* Provides interfaces to (1) patients for injecting their personal health, living, social and medical data; and personalizing their expectations, preferences, treatments, and feedback; (2) patient's supporters for their communications, inquiries, and care-giving to the patient and with GP or specialist; (3) GPs and special-

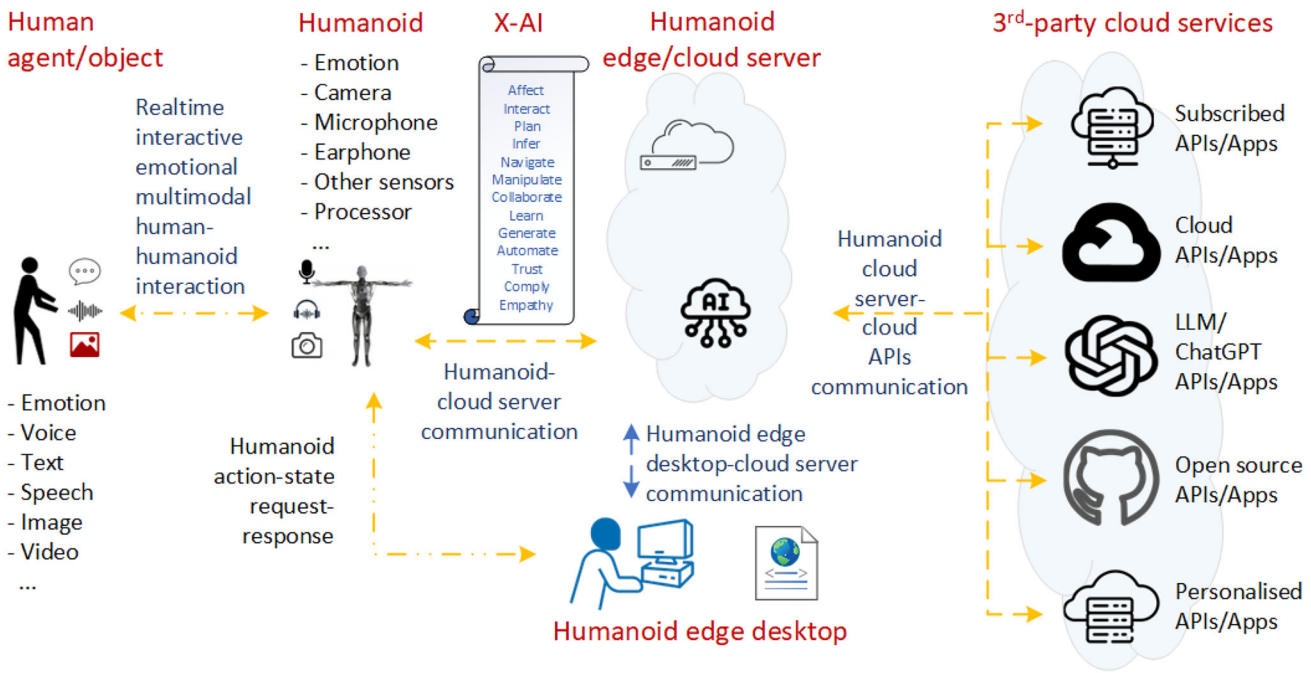


Fig. 5 The humanoid AI ecosystem: represents a new era in robotics, mirroring human intelligence and behavior. Powered by real-time, interactive, emotional, and multimodal large language models, alongside humanoid AI, it seamlessly integrates device, edge, and cloud computing to enable decentralized AI. Notes: some of icons are from the web

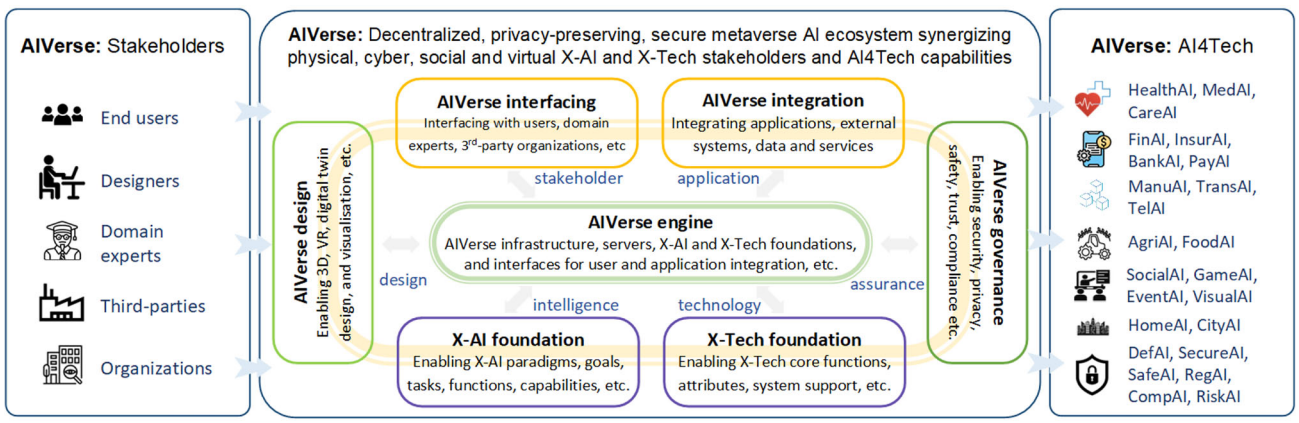


Fig. 6 Metaverse AI ecosystem: Integrating physical, cyber, social, and virtual capabilities and stakeholders to enable decentralized, privacy-preserving, and secure cross-disciplinary, cross-domain, and cross-organizational X-AI and X-Tech. Notes: some of icons are from the web

ists for their immersive communications, monitoring, and diagnosis of the patient, and providing explanation, education and simulation of treatment pathways and effects over time and condition to the patient or her/his caregivers.

(6) *The HealthAIVerse engine* Provides computing, analytics and learning infrastructure for large-scale multimodal modeling; real-time connections to online LLMs such as ChatGPT, and third-party services such as Google and AWS cloud; links to real-time web and cloud services such as humanoid servers, GP and specialist's systems and applications, and health, medical and care support systems; and connections to processing and management facilities for external applications, data, and resources.

(7) *The HealthAIVerse governance* Ensures security, safety, trust, and privacy protection during communication, sharing, storage, and AI operations. Monitors and audits operations for ethics, risk, and regulatory compliance.

Figure 7 illustrates the HealthAIVerse system framework for visualizing, analyzing, simulating, treating, and managing heart atherosclerosis. This framework involves

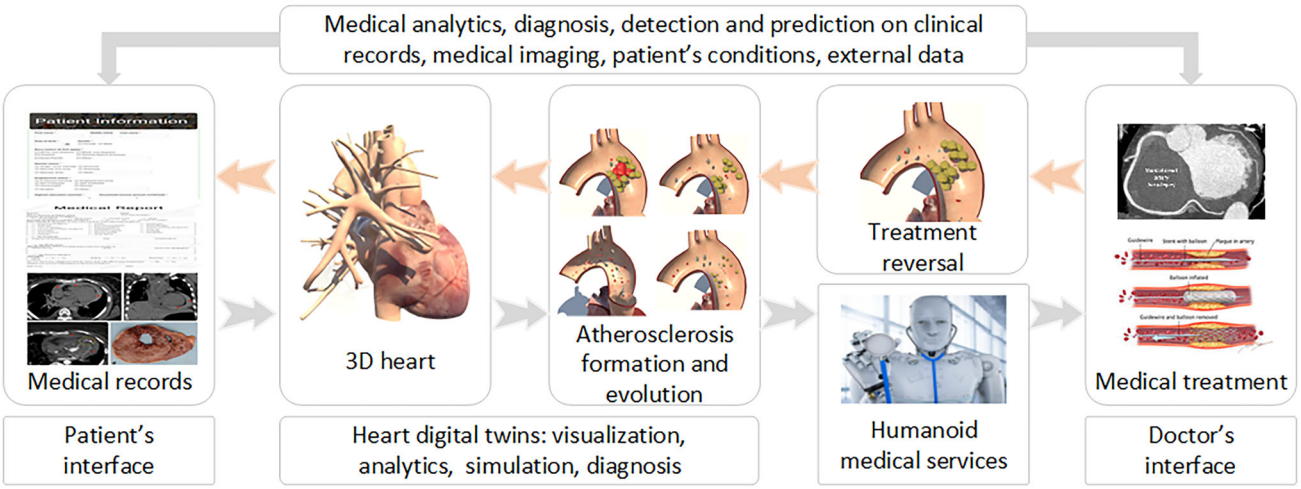


Fig. 7 A HealthAIVerse framework: integrating stakeholders with digital twins, medical systems, patient data, and humanoid medical services. Notes: some of icons are from the web

stakeholders such as patients, doctors, humanoid medical assistants, health and medical AI scientists, and metaverse developers. It

- Injects a patient's health conditions, clinical records, and medical imaging related to their heart, transferring the heart-related health conditions to the 3D heart model.
- Visualizes the heart conditions and the formation and reversal of heart atherosclerosis based on the patient's data.
- Assists general practitioners (GPs) and specialists in their diagnosis and treatment by analyzing the injected patient's data.
- Provides interfaces for patients and doctors to interact with the digital twins, allowing them to simulate and manipulate the heart conditions.
- Visualizes the progression of heart conditions over time and treatment.
- Incorporates HealthAI, MedAI, and CareAI techniques to understand the patient's conditions and data, support doctors' diagnoses and treatments, and educate patients about healthcare.
- Integrates humanoid doctors and medical assistants to assist patients and medical professionals.

Likewise, the principles of AIVerse can be extended to other X-Tech domains to establish tailored AIVerse ecosystems specific to each field.

7 Rethinking basic AI questions

The significant achievements and applications of deep learning [31], LLMs, and LMMs have sparked debates surrounding narrow AI, general AI, and superintelligent AI [32]. Developments in X-AI, HAI, and AGI further reinvigorate ongoing debates on fundamental questions within AI disciplines. These debates encompass AI definitions, methodologies, the intersection of mind and machine, machine intelligence, superintelligence, the roles and relationships between humans and AI, and the future trajectory of AI.

- *Regarding mind and machine* When integrating human brain, cognition, neurology, biology, and biomedicine into AI thinking, design, and applications for achieving human–machine parity, what defines AI? What are the different types of AI? What does the future hold for AI?
- *Regarding what is AI and how AI works* As natural, social, and artificial intelligence intersect with human intelligence, is human intelligence still the ultimate goal of machine intelligence? What are the boundaries and potential of intelligence? Will AI surpass human capabilities?
- *Regarding human-centered systems* As LLMs and LMMs increasingly exceed human capacities and capabilities at a rapid pace, are human-centered computing and systems still indispensable?
- *Regarding superintelligence* As AI advancements such as LLMs and LMMs surpass human abilities in large-scale learning, inference, and computing, does superintelligence still aim to exceed the capabilities of the most talented human minds? How do we define, evaluate, and regulate the quality, performance, trustworthiness, and safety of AI systems?
- *Regardinghuman and AI roles* With automated machines and humanoid robots increasingly replacing routine human roles and responsibilities, how can we ensure that AI systems align with human values and objectives? Will

AI systems replace humans? Will robots dominate the human domain? Can AI address global challenges that humans find unsolvable?

These fundamental issues are integral to the development of disciplines, shaping the vision and mission of next-generation AI and technology, and influencing the strategic futures of scientific, technological, economic, and social systems.

8 Concluding remarks

Generative AI, marked by advancements like large language models and large multimodal models, is reshaping the AI and technology ecosystem. Their integration with traditional AI and technical advancements is fostering the emergence of a new era in X-AI and X-Tech ecosystems. Many previously perceived imperfections, unknowns, and dreams are becoming feasible or partially implementable. This article aims to inspire critical thinking, debate, and discussion on AI's new era intersecting with technology, forging AI4Tech through X-AI enabling X-Tech. The AI4Tech ecosystem will revolutionize existing AI and technology, fostering new methodologies, principles, designs, and applications in both general and domain-specific domains such as FinAI, HealthAI, and SocialAI. Achieving these advancements will rely on conventional AI, human-like AI, generative AI, humanoid AI, decentralized AI, and metaverse AI, each playing crucial roles in refining the fields of AI, technology, and business.

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