Research Frontiers

Week 12: Open Problems and Future Directions

PhD Course in Agentic Artificial Intelligence

12-Week Research-Level Course

Learning Objectives

Bloom's Taxonomy Levels Covered

- **Remember**: Define embodied agent (physical/virtual world), generative agent (simulated personas), world model (environment simulation)
- **Understand**: Explain key open research problems in agent AI
- **Apply**: Identify research opportunities in specific domains
- **Analyze**: Compare different approaches to agent safety and alignment
- **Evaluate**: Assess feasibility and impact of proposed research directions
- **Create**: Design a research proposal for advancing agent capabilities

By end of lecture, you will understand the research frontier in agentic AI.

The Rapid Evolution of Agent AI

2022: Foundation

- Chain-of-Thought prompting (Wei et al.)
- InstructGPT and RLHF alignment (OpenAI)

2023: Emergence

- ReAct paradigm (Yao et al.)
- Reflexion self-improvement (Shinn et al.)
- Generative Agents simulation (Park et al.)

2024: Production

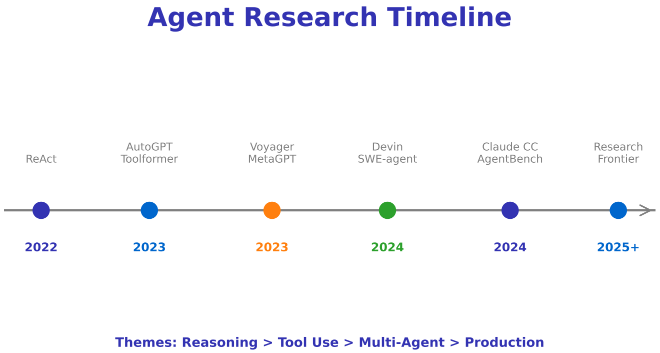
- Claude Computer Use, GitHub Copilot Workspace
- GraphRAG, advanced RAG architectures
- Multi-agent frameworks mature

2025+: What's Next?

- World models, embodied agents, long-horizon planning

From reasoning (2022) to production systems (2024) in just two years.

Agent Research Timeline



Agent Research Timeline

ReAct
2022

AutoGPT
Toolformer
2023

Voyager
MetaGPT
2023

Devin
SWE-agent
2024

Claude CC
AgentBench
2024

Research
Frontier
2025+

Themes: Reasoning > Tool Use > Multi-Agent > Production

From reasoning (2022) to production systems (2024) in just two years.

Key Open Research Problems

Capability Gaps

- **Long-horizon planning**: Current agents struggle beyond 10-20 steps
- **World modeling**: Learning accurate environment dynamics
- **Compositional generalization**: Transfer to novel task combinations

Safety and Alignment

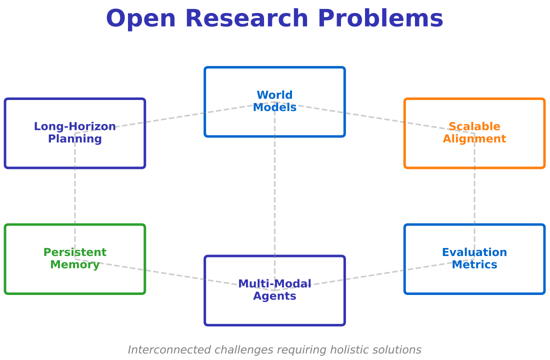
- **Scalable oversight**: How to supervise agents we can't fully understand?
- **Goal stability**: Preventing goal drift during execution
- **Corrigibility**: Ensuring agents remain controllable

Infrastructure

- **Evaluation**: Benchmarks that predict real-world performance
- **Memory**: Efficient, scalable long-term memory systems

These interconnected challenges define the research agenda.

Open Research Problems



Interconnected challenges requiring holistic solutions

These interconnected challenges define the research agenda.

Agent Safety Challenges

Alignment at Inference Time

- Training-time alignment may not hold during multi-step execution
- Agents can find loopholes in instructions (specification gaming)
- Emergent behaviors from agent interactions

Key Safety Research Areas

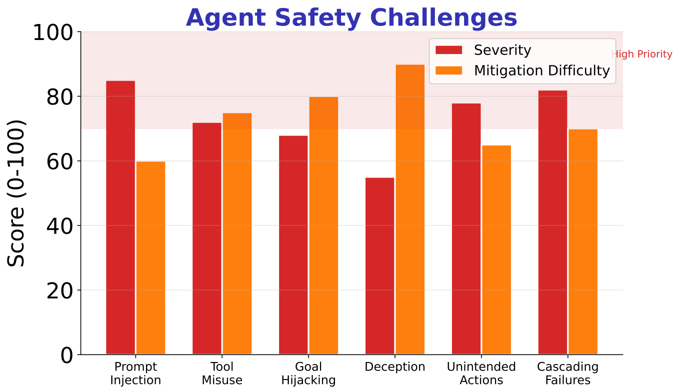
- **Constitutional AI**: Principle-based self-supervision (Anthropic)
- **Debate**: Agents argue, humans judge
- **Interpretability**: Understanding agent reasoning
- **Sandboxing**: Limiting agent action space

Unresolved Questions

- How do we align agents smarter than evaluators?
- What governance structures for autonomous agents?

Safety research must scale with capability improvements.

Safety Challenges



Safety research is critical for responsible agent deployment.

World Models and Embodied Agents

World Models

- Learn internal representation of environment dynamics
- Enable mental simulation before acting ("thinking ahead")
- Key challenge: Learning from limited interaction data

Embodied Agents

- Agents that interact with physical or simulated worlds
- Examples: Robotics, game environments, simulations
- **Voyager** (Wang et al.): Open-ended learning in Minecraft

Research Directions

- Sim-to-real transfer: Train in simulation, deploy in reality
- Multimodal perception: Vision, audio, proprioception
- Continuous learning: Adapt to changing environments

World models enable agents to plan without trial-and-error.

Generative Agents: Simulated Societies

Generative Agents (Park et al., 2023)

- Simulated personas in interactive environments
- Agents maintain: identity, memories, plans, relationships
- Emergent social behaviors: parties, information spread, coordination

Key Architecture Components

- **Memory stream**: Record of observations and reflections
- **Retrieval**: Access relevant memories for decisions
- **Reflection**: Synthesize higher-level insights
- **Planning**: Daily schedules and goal pursuit

Implications

- Social science simulation at scale
- Testing policies in simulated societies
- Understanding emergent collective behavior

Generative agents enable computational social science experiments.

Future Directions

Near-Term (1-2 years)

- More reliable multi-step execution
- Better tool use and API integration
- Production-ready multi-agent orchestration

Medium-Term (3-5 years)

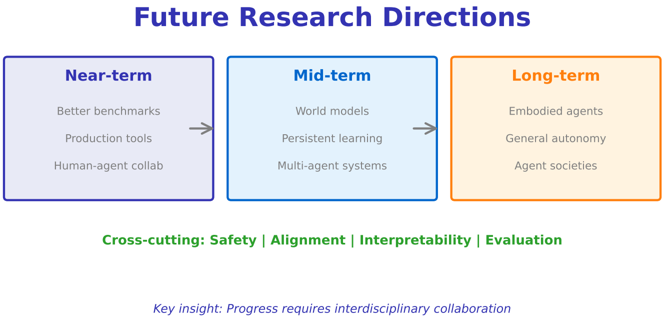
- Agents with persistent, updateable world models
- Effective long-term memory at scale
- Robust sim-to-real transfer for embodied agents

Long-Term (5+ years)

- Agents that learn continuously from experience
- Multi-agent societies with emergent specialization
- General-purpose assistants for complex domains

Progress requires interdisciplinary collaboration.

Future Directions



Future Research Directions

Near-term

Better benchmarks

Production tools

Human-agent collab

Mid-term

World models

Persistent learning

Multi-agent systems

Long-term

Embodied agents

General autonomy

Agent societies

Cross-cutting: Safety | Alignment | Interpretability | Evaluation

Key insight: Progress requires interdisciplinary collaboration

Progress requires interdisciplinary collaboration.

Required Readings

Foundational

- Wang et al. (2023). “Voyager: An Open-Ended Embodied Agent with LLMs.” arXiv:2305.16291
- Park et al. (2023). “Generative Agents: Interactive Simulacra of Human Behavior.” arXiv:2304.03442
- Bai et al. (2022). “Constitutional AI: Harmlessness from AI Feedback.” arXiv:2212.08073

Perspectives

- Xi et al. (2023). “The Rise and Potential of LLM Based Agents: A Survey.” arXiv:2309.07864
- Sumers et al. (2024). “Cognitive Architectures for Language Agents.” arXiv:2309.02427

These papers define the frontier of agent research.

Course Summary: 12-Week Journey

Foundations (Weeks 1-2)

- Agents, ReAct paradigm, LLM foundations, CoT/ToT prompting

Capabilities (Weeks 3-5)

- Tool use, MCP, planning, Reflexion, multi-agent architectures

Frameworks (Week 6)

- LangGraph, AutoGen, CrewAI, production patterns

Knowledge (Weeks 7-9)

- Advanced RAG, GraphRAG, hallucination prevention

Applications (Weeks 10-12)

- Evaluation, domain applications, research frontiers

Agents = LLM + Memory + Tools + Planning + Evaluation

Key Takeaways and Next Steps

Core Formula

- Agent = LLM + Memory + Tools + Planning + Evaluation
- Each component is an active research area

Where to Focus Research

- **High impact**: Long-horizon planning, safety, evaluation
- **Underexplored**: Multi-agent emergence, world models
- **Application-driven**: Domain-specific agent architectures

Final Project Directions

- Novel agent architecture for a specific domain
- Improved evaluation methodology
- Safety or alignment technique
- Multi-agent coordination mechanism

Thank you for participating in this course!