Course: Agent-Based Modeling and Agentic Technology

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(7 weeks)

As AI rapidly evolves, the integration of Large Language Models (LLMs) is transforming agent-based modeling, creating agents with logical reasoning, behavior modeling, contextual adaptation, and real-time information retrieval. Recognized by analysts and venture capital firms as a key technology trend, *Agentic AI* enables autonomous systems to manage workflows and support strategic decision-making across industries, reshaping single-agent and multi-agent systems.

This course on *Agent-Based Modeling and Agentic Technologies* offers an in-depth exploration of systems thinking, simulation techniques, and LLM-powered agents. Students will develop foundational knowledge in agent-based modeling and progressively engage with LLM-driven agents, capable of complex interactions and adaptive responses. Applications span fields such as scientific research, policy simulations, and industrial automation, enabling students to deploy autonomous, reasoning-enabled agents in diverse scenarios.

Blending theoretical insights with hands-on applications, this course prepares students to apply agentic AI in domains like business process management, healthcare, and environmental science, where adaptability and strategic decision-making are essential. Through industry scenarios, case studies, and guest lectures, students will discover how agentic technologies enhance workflows and decision-making, empowering them to lead AI-driven innovations in their fields.

Key components of the course include:

- **Systems Thinking and Simulation Foundations**: Introduce systems thinking through Monte Carlo, discrete event, and agent-based simulations, providing foundational skills in modeling complex systems.
- **Fundamentals of Agent-Based Modeling**: Build expertise in agent-based models (ABMs), focusing on agent-environment dynamics and utilizing tools like NetLogo for practical model-building.
- **Introduction to Large Language Models (LLMs)**: Establish core knowledge of LLM architectures and applications in agentic technology, emphasizing the evolution and structure of these models.
- **LLM-Based Agent Architectures and Capabilities**: Explore memory, planning, and action modules in LLM-based agents, integrating prompt engineering to enhance interaction within multi-agent contexts.
- **Agent Frameworks and Toolkits**: Gain hands-on experience with frameworks like LangChain, LlamaIndex, and AutoGen, using these to design interactive agents through data retrieval and prompt chaining.
- **Taxonomy of LLM-Based Agents**: Categorize agent types by roles, analyzing reasoning, decision-making, and learning behaviors to match agent functions to specific applications.
- **Applications of Agent-Based and LLM-Based Agents**: Examine diverse applications across sectors, showcasing how agents transform workflows, strategic decision-making, and adaptability in industry contexts.

- **Multi-Agent System Design and Management**: Investigate multi-agent communication, coordination, and management, with case studies on areas like disaster response and energy grids.
- **Advanced Agent-Specific Retrieval-Augmented Generation (RAG) Techniques**: Learn advanced RAG methods for real-time, context-specific retrieval, enhancing agent performance in multi-agent environments.
- **Fine-Tuning, Validation, and Evaluation for Multi-Agent Systems**: Refine and evaluate agent performance, focusing on role-specific tuning, collaborative robustness, and ethical considerations.
- **Deployment and Optimization of LLM-Based Agents**: Master strategies for deploying and optimizing LLM-based agents at scale, with an emphasis on governance, ethics, and performance monitoring.
- **Exploring the Future of Agentic Technologies**: Discuss emerging trends and challenges, such as autonomous decision-making and System 2 reasoning, exploring agentic AI's potential to reshape industries.

To ensure a holistic learning experience, the course provides hands-on exposure to a suite of tools, both open-source and proprietary. Students will familiarize themselves with some of the platforms like Netlogo, AnyLogic, GPTs, and Microsoft's AutoGen. Industry scenarios and guest lectures will bring the real-world application of these technologies to the students. By the end of this journey, students will be equipped with the knowledge and skills to lead innovations in agent-based modeling and digital twin technologies, ready to make impactful contributions to their respective fields.

Learning Objectives:

Upon completion of this course, students will be able to:

- **Understand and apply systems thinking principles** to model complex systems using agent-based and other simulation methodologies (e.g., Monte Carlo, discrete event simulations).
- **Analyze and construct foundational agent-based models (ABMs)** that incorporate agent interactions and environmental dynamics.
- **Explain the architecture, capabilities, and applications of Large Language Models (LLMs)** in the context of agentic technologies and their role in enhancing agent behaviors.
- **Design and deploy LLM-based agents** using core frameworks (e.g., LangChain, AutoGen), implementing advanced data retrieval, prompt engineering, and agent interaction strategies.
- **Differentiate between various types of LLM-based agents**, such as reasoning, decision-making, and experiential learning agents, and select appropriate types for specific applications.
- **Evaluate the real-world applications of agent-based and LLM-based agents** across diverse sectors, including strategic decision-making, autonomous robotics, and infrastructure management.
- **Develop fine-tuning and validation strategies** for multi-agent systems, ensuring robust, role-specific performance and inter-agent coordination.
- **Assess deployment, optimization, and governance challenges** associated with scaling LLM-based agents, focusing on performance, ethics, and industry best practices.

This course is designed for graduate-level students who are familiar with the basics of data science and machine learning. The course will be offered in a dual-mode where students can either use low code/no code agent frameworks or use Python programming to work with LLM-based agents.

The evaluation for the course will be as follows: (a) Two class quizzes for 30%; (b) One team assignment 20%; (c) One Team Project 40% and (d) Class participation of 10%. An average student is likely to spend 6-8 hours per week.

Learning Resources

The following textbooks will be used as reference for the topics covered. Each topic will also have selected reading materials.

1. Chip Huyen, AI Engineering: Building Applications with Foundational Models, O'Reilly, 2024.
2. Louis-Francois Bouchard, Louie Peters, Building LLMs for Production. Towards AI, 2024.
3. Richmond, Barry. *An introduction to systems thinking*. High performance systems, 2001.
4. Gilbert, Nigel. *Agent-Based Models*. *SAGE Publications, Inc. eBooks*, 2008.

Course Relevance

- **Strategic Decision-Making Skills**: Understanding agent-based and LLM-driven models equips students with tools to simulate and analyze complex systems, essential for strategic decision-making in corporate and public sectors.
- **High-Impact Applications**: Agentic AI is transforming fields like business operations, policy development, and infrastructure planning, making this course valuable for students aiming to drive data-informed decisions across diverse industries.
- **Adaptability in Dynamic Environments**: This course prepares students to design adaptive AI agents capable of handling dynamic workflows, enhancing efficiency in environments where responsiveness and real-time insights are critical.
- **Industry-Relevant Expertise**: With hands-on experience in leading frameworks and tools, students gain practical knowledge directly applicable to roles in strategic analysis, governance, and decision support in today's AI-powered economy.

Course Goals

- **Equip Students for Strategic AI Applications**: Provide students with the knowledge and skills to design and deploy agent-based and LLM-powered AI systems for impactful decision-making in corporate and public sector environments.
- **Develop Proficiency in Agentic AI for Complex Analysis**: Enable students to utilize agentic AI for simulating, analyzing, and responding to complex systems, enhancing strategic insights across various industries.
- **Foster Industry-Relevant, Practical Expertise**: Prepare students to apply industry-standard frameworks and tools in real-world scenarios, making them adept in strategic analysis, adaptive workflows, and ethical AI deployment.