Lesson 01.2: The Foundations of AI

MSML610: Advanced Machine Learning

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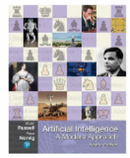

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References: - AIMA (Artificial Intelligence: a Modern Approach), Chap 1

SCIENCE ACADEMY

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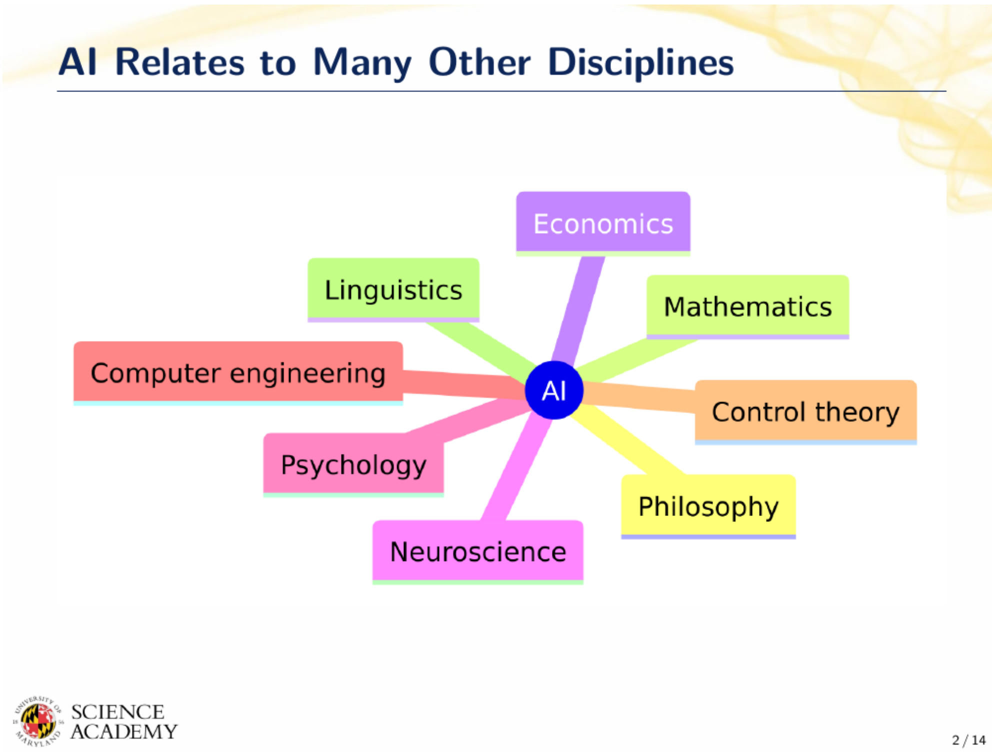
2 / 14: AI Relates to Many Other Disciplines

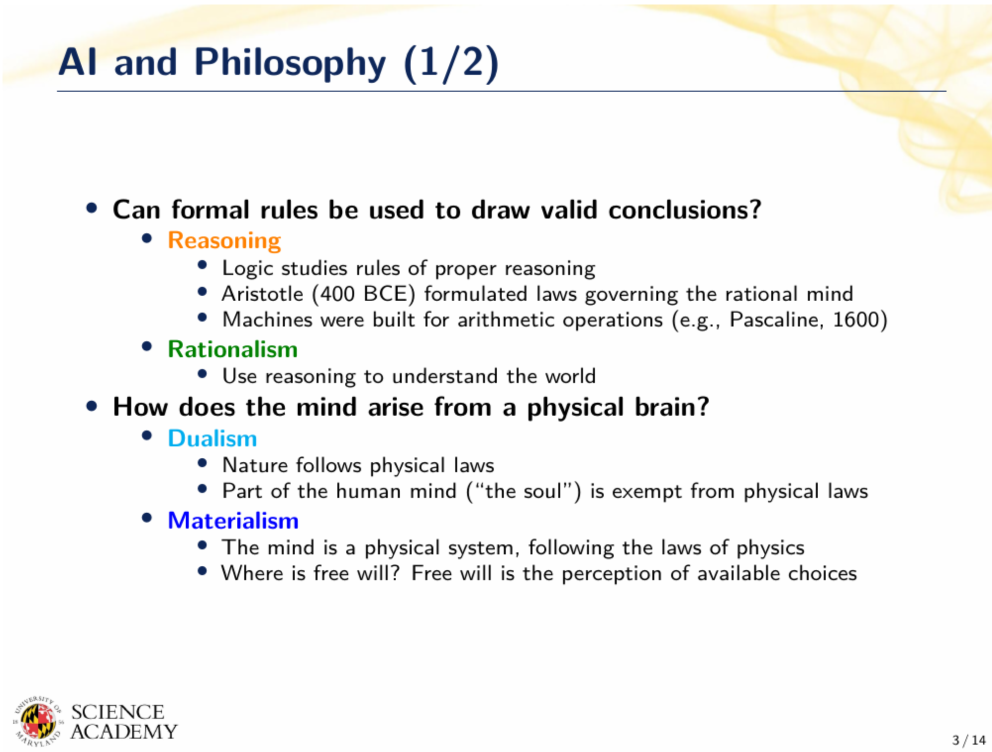


- **AI and Philosophy**: Philosophy helps us understand the ethical implications and the nature of intelligence itself. It raises questions about consciousness, free will, and the moral status of AI systems. Philosophical discussions guide the development of AI in a way that aligns with human values.
- **AI and Mathematics**: Mathematics is the backbone of AI. It provides the tools and frameworks, such as algorithms and statistical models, that are essential for developing AI systems. Concepts like probability, calculus, and linear algebra are crucial for machine learning.
- **AI and Economics**: Economics contributes to AI through decision-making models and game theory. It helps in understanding how AI can optimize resources, predict market trends, and automate economic processes.
- **AI and Neuroscience**: Neuroscience inspires AI by providing insights into how the human brain processes information. This understanding helps in developing neural networks and other AI models that mimic human cognitive processes.
- **AI and Psychology**: Psychology offers insights into human behavior and cognition, which are essential for creating AI systems that interact naturally with humans. It helps in designing user-friendly interfaces and understanding user needs.
- **AI and Computer Engineering**: Computer engineering provides the hardware and software infrastructure necessary for AI. It involves designing efficient algorithms and systems that can handle large-scale data processing and complex computations.
- **AI and Control Theory**: Control theory is used in AI for developing systems that can maintain desired outputs despite changes in the environment. It is crucial for robotics and

autonomous systems.

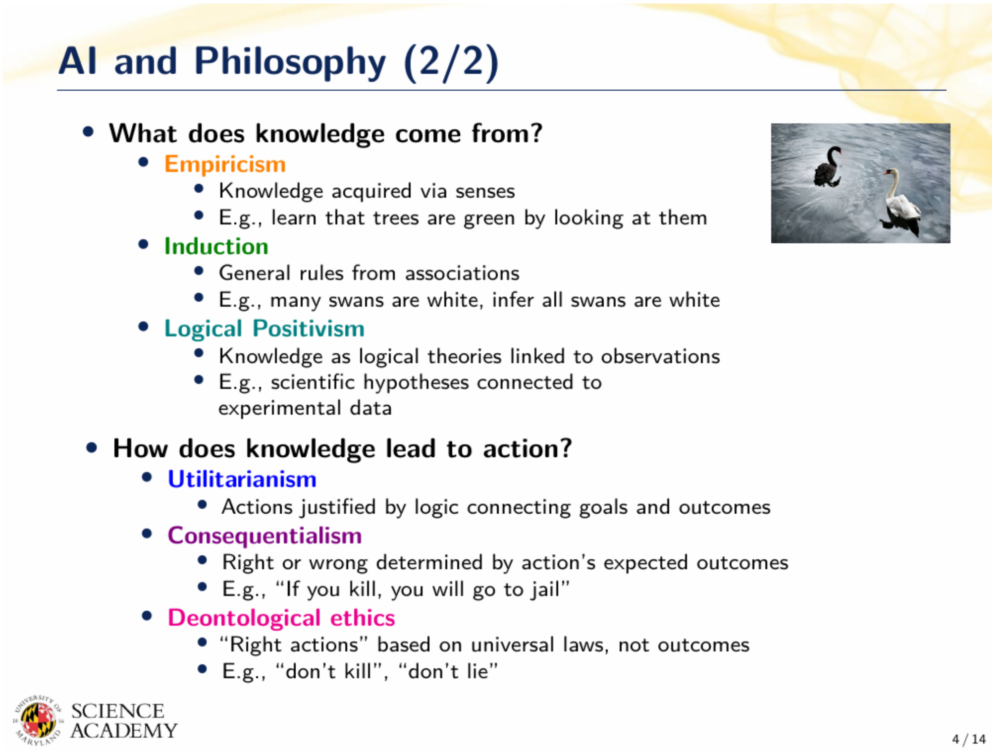
- **AI and Linguistics**: Linguistics is vital for natural language processing, enabling AI to understand and generate human language. It helps in developing systems that can communicate effectively with humans.

3 / 14: AI and Philosophy (1/2)



- **Can formal rules be used to draw valid conclusions?**
  - **Reasoning**
    - Logic is the study of how we can make correct conclusions based on given information. It helps us understand what makes an argument valid or invalid.
    - Aristotle, a philosopher from ancient Greece, was one of the first to explore how humans think logically. He created some of the earliest rules for logical reasoning, which have influenced thinking for centuries.
    - Over time, humans have built machines to help with logical tasks, like doing math. One of the earliest examples is the Pascaline, a mechanical calculator from the 1600s. This shows our long-standing interest in using machines to assist with logical processes.
  - **Rationalism**
    - Rationalism is the belief that we can understand the world by using reason and logic. It suggests that our ability to think logically is key to gaining knowledge.
- **How does the mind arise from a physical brain?**
  - **Dualism**
    - Dualism is the idea that while the physical world follows certain laws, there is a part of the human mind, often referred to as "the soul," that operates beyond these laws. This suggests a separation between the mind and the physical body.
  - **Materialism**
    - Materialism argues that the mind is not separate from the body but is instead a physical system that operates according to the laws of physics. This view raises questions about concepts like free will, suggesting that what we perceive as free will might just be our awareness of different choices we can make.

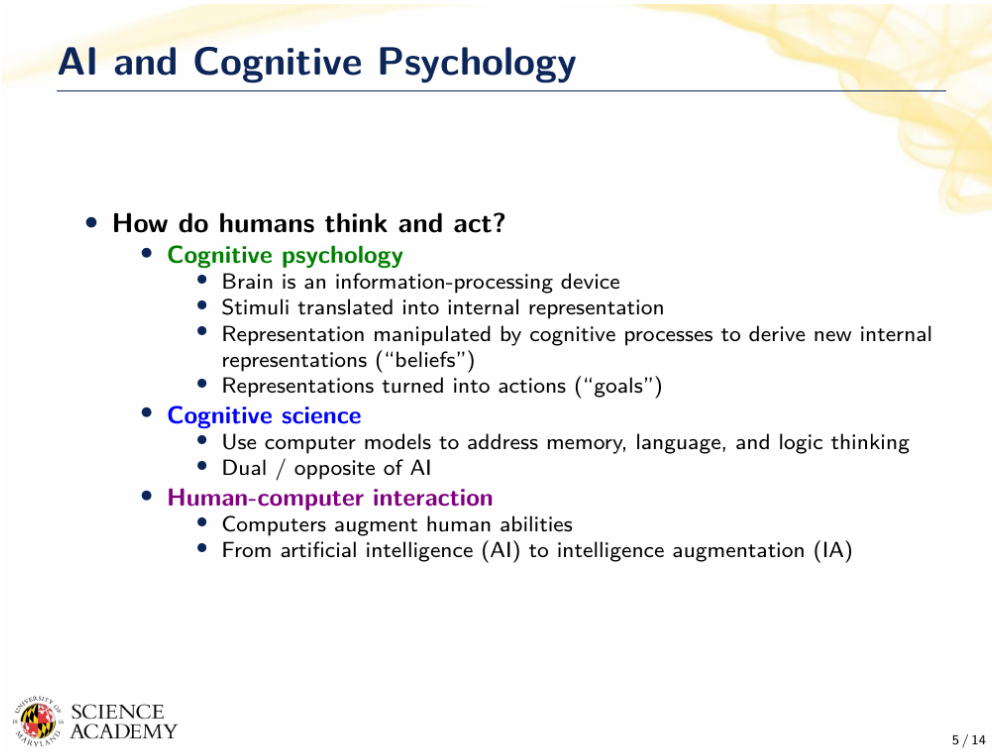
4 / 14: AI and Philosophy (2/2)



- **What does knowledge come from?**
  - **Empiricism**
    - This is the idea that knowledge is gained through our senses. For example, we understand that trees are green because we see them with our eyes. This approach emphasizes observation and experience as the primary sources of knowledge.
  - **Induction**
    - Induction involves forming general rules based on specific observations. For instance, if you see many swans and they are all white, you might conclude that all swans are white. This method is about making broader generalizations from specific instances.
  - **Logical Positivism**
    - This philosophy suggests that knowledge should be based on logical theories that are closely tied to observations. For example, scientific hypotheses are considered valid when they can be tested and confirmed through experiments and data.
- **How does knowledge lead to action?**
  - **Utilitarianism**
    - Utilitarianism is about making decisions based on the logic that connects goals with outcomes. It suggests that actions are justified if they lead to the greatest good for the greatest number of people.
  - **Consequentialism**
    - This ethical theory determines the rightness or wrongness of actions based on their outcomes. For example, the statement "If you kill, you will go to jail" reflects the idea that the consequences of an action determine its moral value.
  - **Deontological ethics**
    - Deontological ethics focuses on the morality of actions themselves, rather than their

outcomes. It is based on following universal laws or rules, such as “don’t kill” or “don’t lie,” regardless of the consequences.

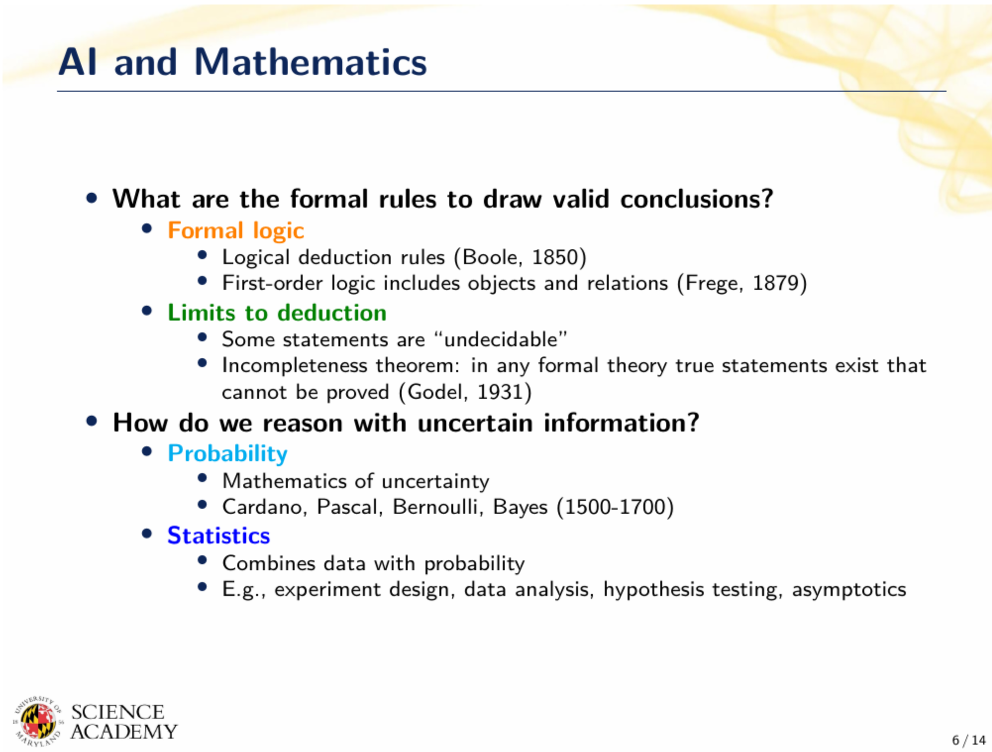
5 / 14: AI and Cognitive Psychology



- **How do humans think and act?**
  - **Cognitive psychology**
    - Cognitive psychology views the brain as an *information-processing device*. This means that just like a computer processes data, our brain processes information from the world around us.
    - When we encounter stimuli, such as sights or sounds, our brain translates these into *internal representations*. These are mental images or concepts that help us understand and interact with the world.
    - These internal representations are then manipulated by cognitive processes. This means our brain uses these representations to form new ideas or *beliefs* about the world.
    - Finally, these representations can lead to actions, which are our *goals*. For example, if you believe it's going to rain, your goal might be to carry an umbrella.
  - **Cognitive science**
    - Cognitive science uses computer models to explore complex human abilities like memory, language, and logical thinking. These models help us understand how these processes work in the brain.
    - It is often seen as the *dual* or *opposite* of AI because while AI focuses on creating intelligent machines, cognitive science focuses on understanding human intelligence.
  - **Human-computer interaction**
    - This field studies how computers can *augment* or enhance human abilities, making tasks easier or more efficient.
    - The shift from artificial intelligence (AI) to intelligence augmentation (IA) highlights the focus on using technology to support and enhance human capabilities, rather

than just replicating them.

6 / 14: AI and Mathematics

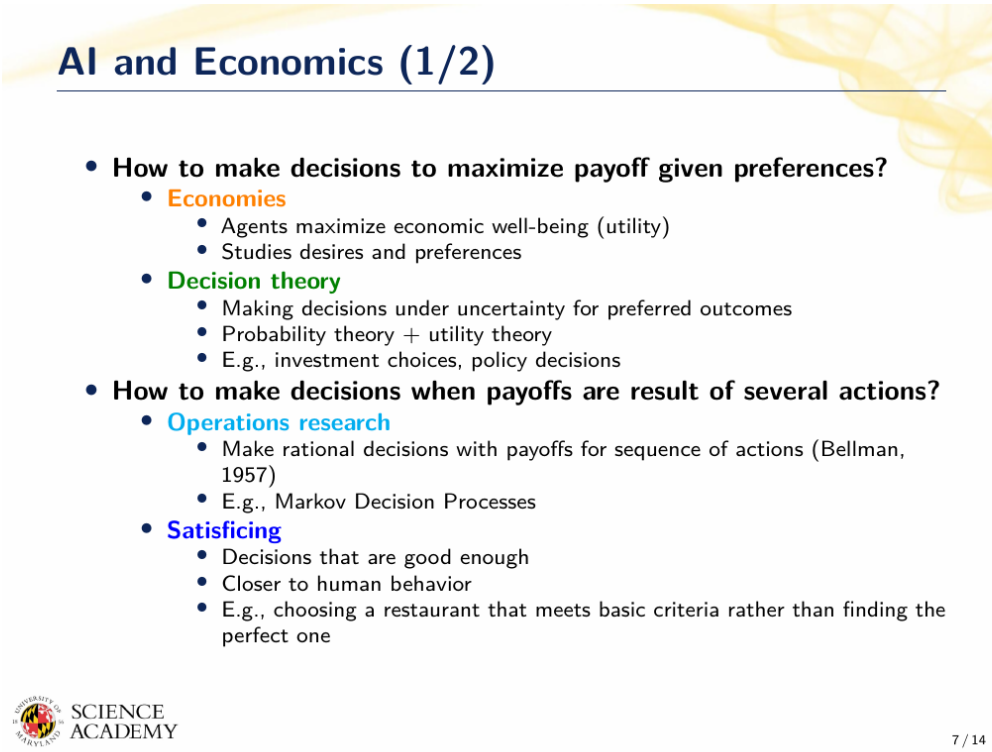


- **What are the formal rules to draw valid conclusions?**
  - **Formal logic**
    - *Logical deduction rules* are the foundation of formal logic, which was significantly developed by George Boole in the mid-19th century. These rules help us derive conclusions from given premises in a structured way.
    - *First-order logic* expands on basic logic by including objects and their relationships, a concept introduced by Gottlob Frege in 1879. This allows for more complex reasoning about the world.
  - **Limits to deduction**
    - Not all statements can be resolved through deduction; some are “undecidable,” meaning we can’t determine their truth or falsehood using existing rules.
    - Gödel’s *Incompleteness Theorem* tells us that in any sufficiently complex formal system, there are true statements that cannot be proven within the system. This was a groundbreaking discovery by Kurt Gödel in 1931, showing the inherent limitations of formal logic.
- **How do we reason with uncertain information?**
  - **Probability**
    - Probability is the branch of mathematics that deals with uncertainty. It provides a framework for quantifying and reasoning about the likelihood of different outcomes.
    - The development of probability theory involved contributions from several mathematicians, including Cardano, Pascal, Bernoulli, and Bayes, between the 1500s and 1700s.
  - **Statistics**
    - Statistics combines data with probability to make informed decisions and predic-

tions. It involves designing experiments, analyzing data, testing hypotheses, and understanding long-term trends (asymptotics).

* This field is crucial for interpreting data and drawing conclusions in the presence of uncertainty, making it a key tool in both scientific research and practical applications.

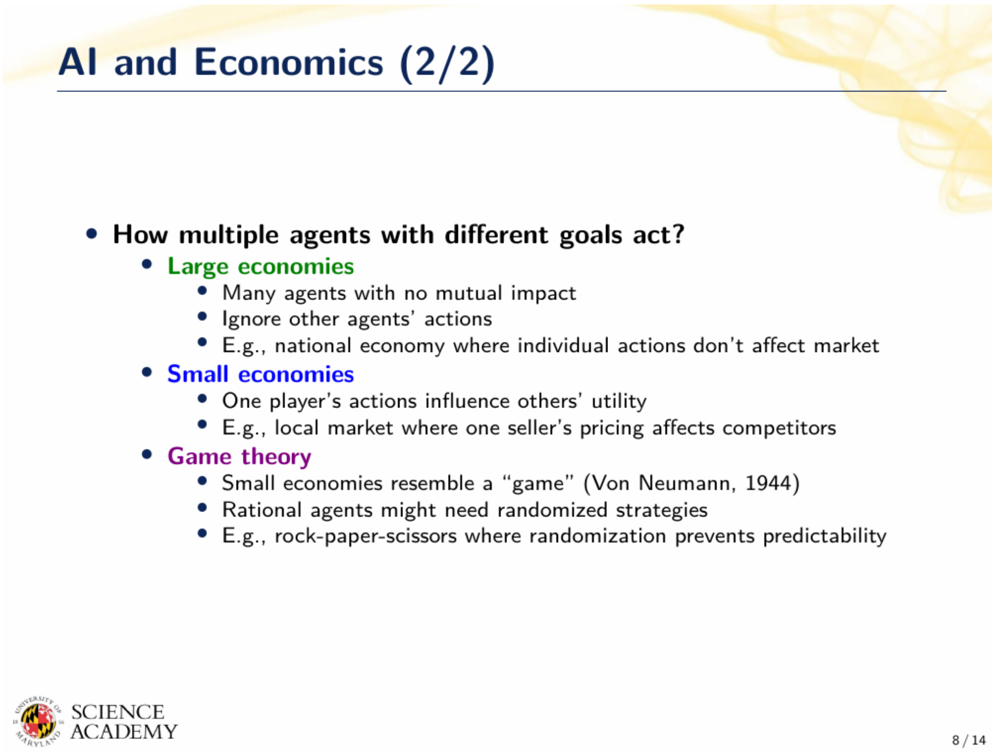
7 / 14: AI and Economics (1/2)



- **How to make decisions to maximize payoff given preferences?**
  - **Economies**
    - In economics, agents (like individuals or companies) aim to maximize their economic well-being, which is often referred to as *utility*. This means they make choices that they believe will give them the most satisfaction or benefit.
    - Economists study what people want and how they make choices based on these desires and preferences. This helps in understanding consumer behavior and market dynamics.
  - **Decision theory**
    - Decision theory is about making choices, especially when there is uncertainty involved. It combines probability theory (which deals with the likelihood of events) and utility theory (which deals with the satisfaction or benefit from outcomes).
    - This theory is applied in various fields, such as choosing where to invest money or deciding on government policies, where the outcomes are uncertain but preferences are clear.
- **How to make decisions when payoffs are result of several actions?**
  - **Operations research**
    - Operations research involves making rational decisions where the payoff depends on a sequence of actions. This concept was notably developed by Bellman in 1957 and is used to optimize complex processes.
    - An example is Markov Decision Processes, which help in planning and decision-making where outcomes are partly random and partly under the control of a decision-maker.
  - **Satisficing**

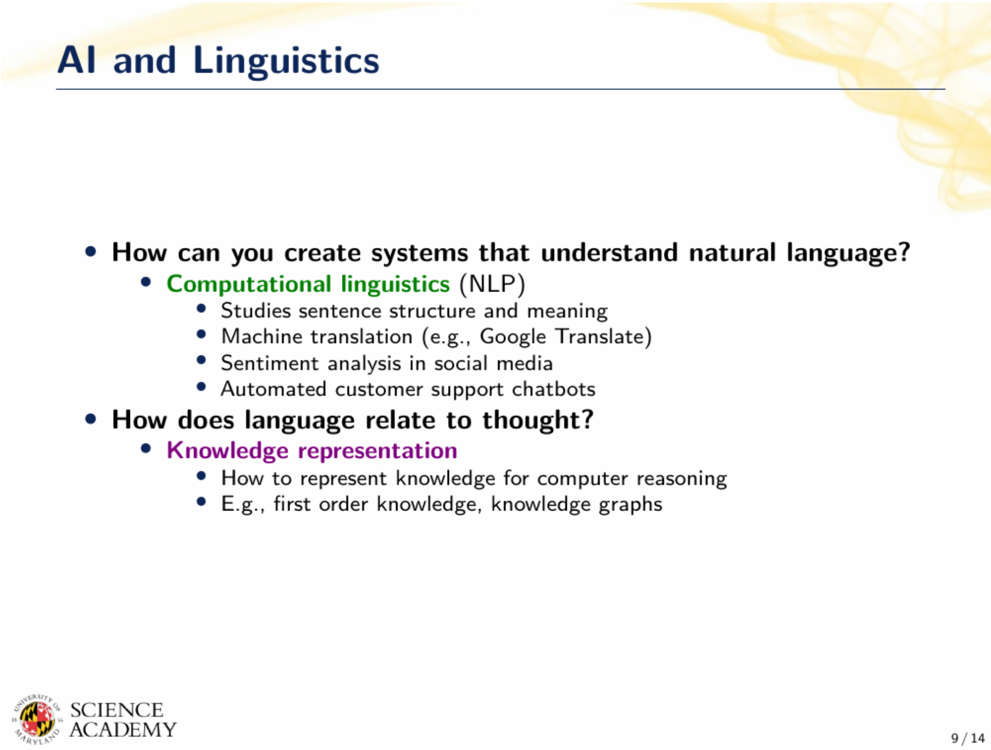
* Satisficing is about making decisions that are “good enough” rather than perfect. This approach is more aligned with how humans often make decisions in real life.
* For instance, when choosing a restaurant, instead of searching for the absolute best option, a person might pick one that meets their basic criteria, like being nearby and affordable. This reflects a practical approach to decision-making.

8 / 14: AI and Economics (2/2)



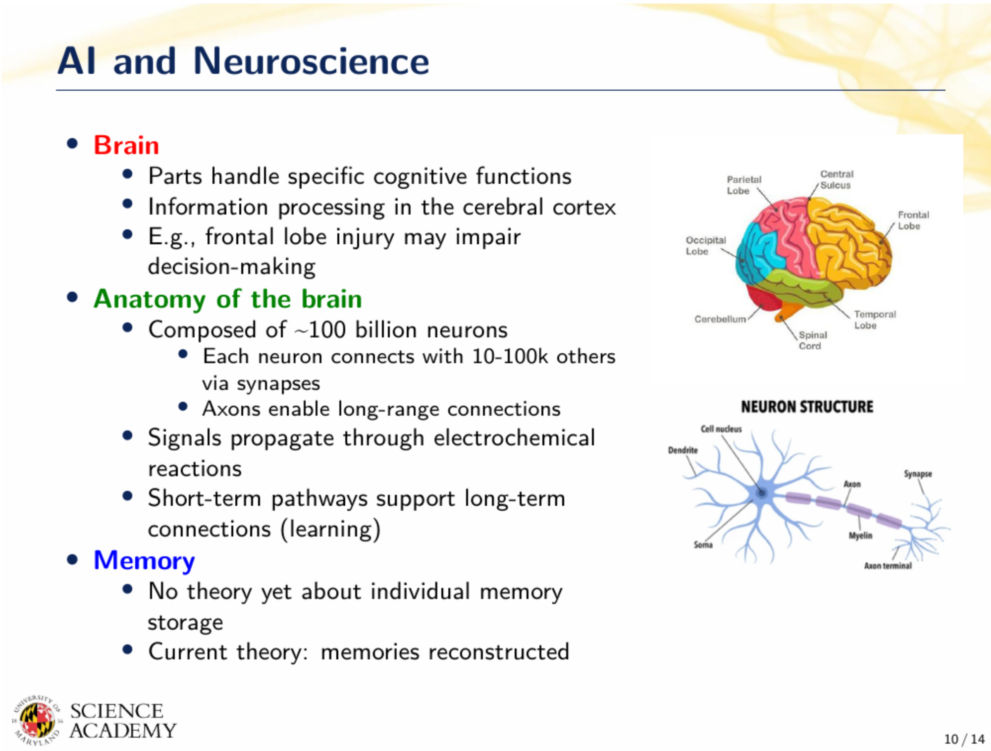
- **How multiple agents with different goals act?**
  - **Large economies**
    - In large economies, there are many agents, such as individuals or companies, each acting independently. Because there are so many participants, the actions of one agent typically do not have a noticeable impact on the overall market. This means that each agent can make decisions without needing to consider how others will react. For example, in a national economy, a single person's decision to buy or not buy a product is unlikely to affect the market price of that product.
  - **Small economies**
    - In contrast, small economies are characterized by fewer agents, where the actions of one can significantly influence the outcomes for others. Here, each player's decisions can affect the utility or satisfaction of others. For instance, in a local market, if one seller decides to lower their prices, it can directly impact the sales and pricing strategies of other sellers in the same market.
  - **Game theory**
    - Game theory is a framework for understanding strategic interactions in small economies, where the actions of one agent can affect others. It was formalized by John Von Neumann in 1944. In these scenarios, agents are considered rational and may need to use randomized strategies to avoid being predictable. A classic example is the game of rock-paper-scissors, where players use random choices to prevent their opponents from anticipating their next move. This concept helps in analyzing competitive situations where the outcome depends on the actions of multiple decision-makers.

9 / 14: AI and Linguistics



- AI and Linguistics
- **How can you create systems that understand natural language?**
  - **Computational linguistics** (NLP)
    - This field focuses on how computers can be programmed to process and analyze large amounts of natural language data. It involves understanding both the structure (syntax) and meaning (semantics) of sentences.
    - *Machine translation* is a key application, where systems like Google Translate convert text from one language to another. This requires understanding the nuances of both languages to provide accurate translations.
    - *Sentiment analysis* is used to determine the emotional tone behind words, often applied to social media to gauge public opinion or customer feedback.
    - *Automated customer support chatbots* use NLP to understand and respond to customer inquiries, providing quick and efficient service without human intervention.
- **How does language relate to thought?**
  - **Knowledge representation**
    - This concept deals with how information and relationships are structured so that computers can use them to simulate human reasoning and decision-making.
    - Examples include *first order knowledge*, which involves logical statements that can be used to infer new information, and *knowledge graphs*, which visually represent relationships between different pieces of information, helping systems understand context and make connections.

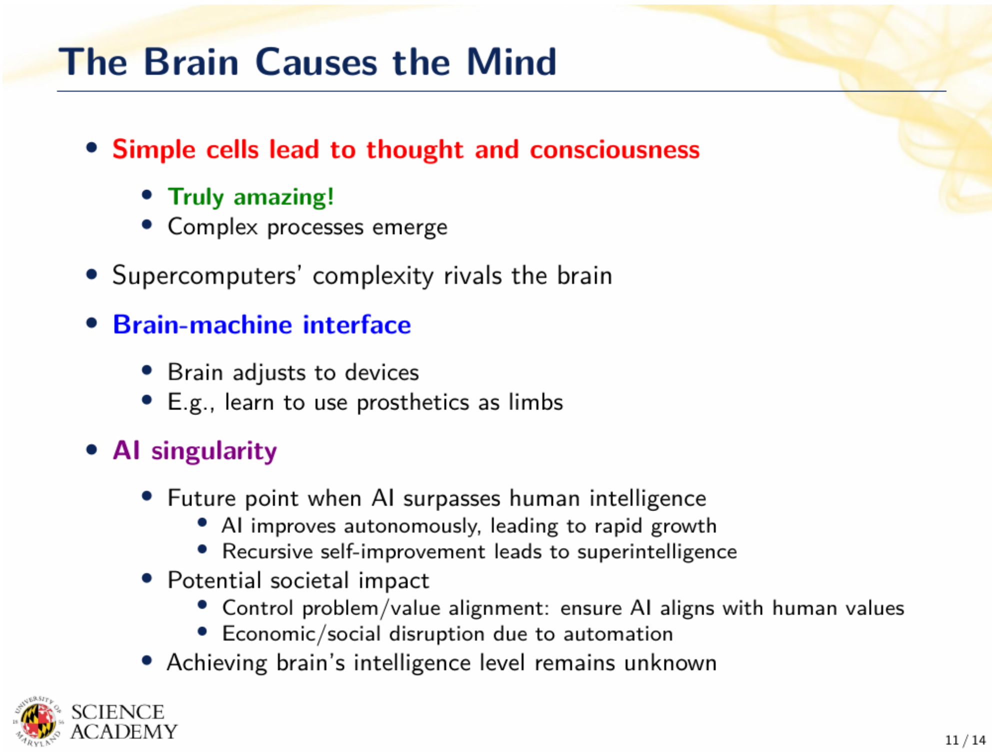
10 / 14: AI and Neuroscience



- **Brain**
  - The brain is a complex organ where different parts are responsible for specific cognitive functions. This means that certain areas of the brain are specialized for tasks like thinking, memory, and movement.
  - The cerebral cortex is a key area for processing information. It plays a crucial role in higher brain functions such as perception, reasoning, and decision-making.
  - For example, if someone suffers an injury to the frontal lobe, which is part of the cerebral cortex, they might have trouble making decisions or controlling their behavior.
- **Anatomy of the brain**
  - The brain is made up of approximately 100 billion neurons. Neurons are the basic building blocks of the brain and nervous system.
    * Each neuron can connect with between 10,000 to 100,000 other neurons through structures called synapses. This vast network allows for complex communication within the brain.
    * Axons are long, thread-like parts of a neuron that carry signals over long distances within the brain, facilitating communication between different brain regions.
  - Neurons communicate through electrochemical reactions, which are essential for transmitting signals throughout the brain.
  - Short-term pathways in the brain can develop into long-term connections, which is a fundamental process for learning and memory formation.
- **Memory**
  - Scientists have not yet developed a comprehensive theory about how individual memories are stored in the brain.
  - The prevailing theory suggests that memories are not stored as exact replicas but are

reconstructed from various pieces of information when needed. This means that our recollection of events can be influenced by various factors and may not always be entirely accurate.

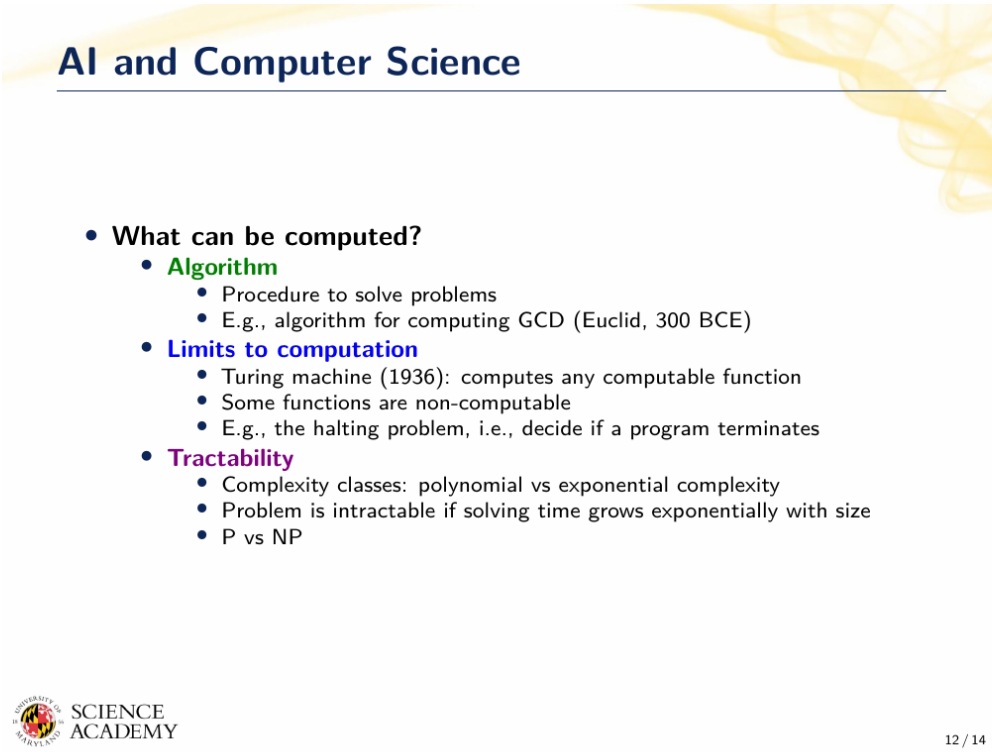
11 / 14: The Brain Causes the Mind



- **The Brain Causes the Mind**
  - **Simple cells lead to thought and consciousness**
    - The brain is made up of billions of simple cells called neurons. These neurons connect and communicate with each other, creating complex networks that give rise to thought and consciousness. This is truly amazing because it shows how simple building blocks can lead to incredibly complex processes.
    - These complex processes are what allow us to think, feel, and be aware of our surroundings. It's a reminder of how intricate and powerful the human brain is.
- **Supercomputers' complexity rivals the brain**
  - Modern supercomputers are incredibly complex and can perform calculations at speeds that rival the processing power of the human brain. However, while they can process data quickly, they don't yet replicate the nuanced and adaptable nature of human thought.
- **Brain-machine interface**
  - This technology allows the brain to communicate directly with external devices. Over time, the brain can adapt to these devices, allowing people to learn to use prosthetics as if they were natural limbs. This shows the brain's incredible ability to adjust and integrate new tools into its functioning.
- **AI singularity**
  - The AI singularity is a theoretical future point where artificial intelligence surpasses human intelligence. At this point, AI could potentially improve itself autonomously, leading to rapid advancements and the emergence of superintelligence.
    - This raises important questions about the societal impact of such a development. Ensuring that AI aligns with human values (known as the control problem or value alignment) is crucial to prevent unintended consequences.

    * Additionally, there could be significant economic and social disruptions due to increased automation, affecting jobs and industries.
  - Despite these discussions, achieving a level of intelligence comparable to the human brain remains a significant challenge and is still unknown.

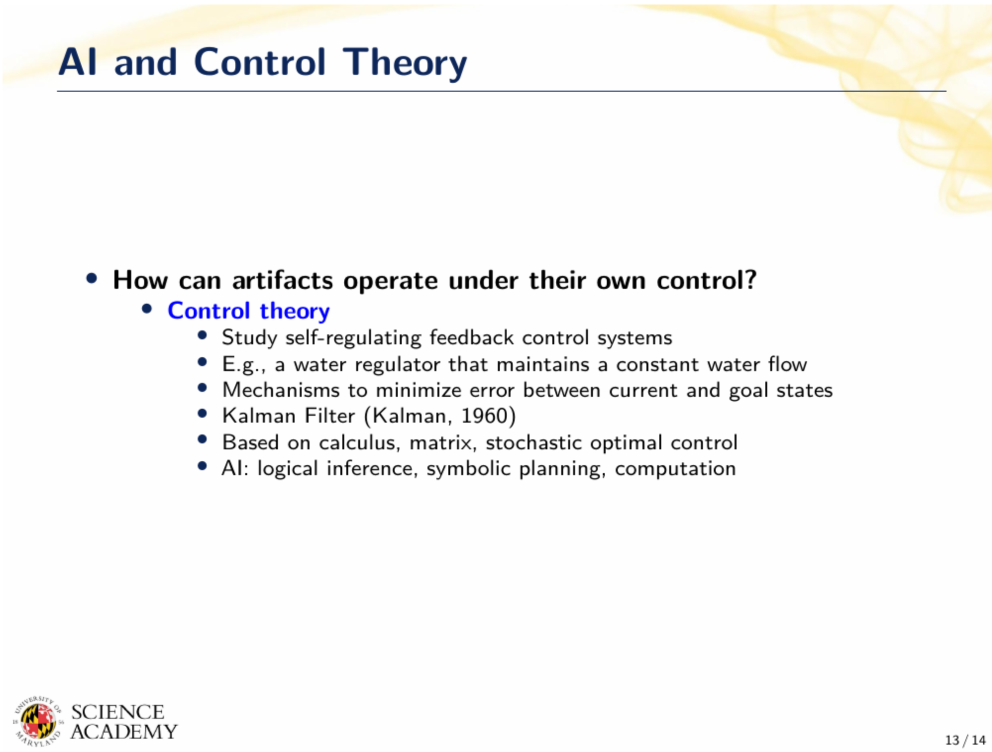
12 / 14: AI and Computer Science



- **What can be computed?**
  - **Algorithm**
    - An *algorithm* is essentially a step-by-step procedure or formula for solving a problem. Think of it as a recipe that tells you exactly what steps to take to achieve a desired outcome. For example, the algorithm for computing the Greatest Common Divisor (GCD) was devised by Euclid around 300 BCE. This ancient algorithm is still used today to find the largest number that divides two numbers without leaving a remainder.
  - **Limits to computation**
    - The concept of a *Turing machine*, introduced by Alan Turing in 1936, is a foundational idea in computer science. It is a theoretical device that can simulate any algorithm's logic. However, not all problems can be solved by a Turing machine. Some functions are inherently non-computable, meaning no algorithm can solve them. A classic example is the *halting problem*, which asks whether a given program will eventually stop running or continue indefinitely. This problem is proven to be unsolvable by any algorithm.
  - **Tractability**
    - Tractability refers to how feasible it is to solve a problem within a reasonable amount of time. Problems are categorized into complexity classes based on how their solving time increases with input size. Polynomial complexity problems are generally considered tractable, as their solving time grows at a manageable rate. In contrast, problems with exponential complexity are often intractable, as their solving time increases rapidly with input size. The famous *P vs NP* question asks whether every problem whose solution can be quickly verified (NP) can also be quickly solved (P).

This is one of the most important open questions in computer science.

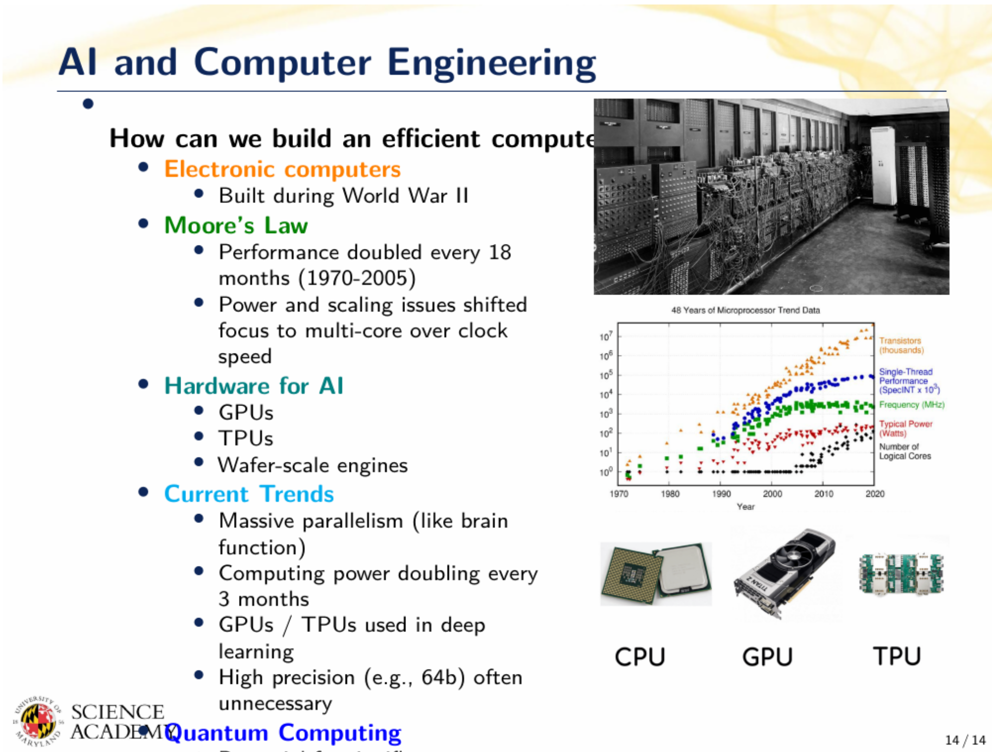
13 / 14: AI and Control Theory



- AI and Control Theory
- **How can artifacts operate under their own control?**
  - **Control theory**
    - **Study self-regulating feedback control systems**
      - Control theory is all about understanding how systems can manage themselves without constant human intervention. It focuses on creating systems that can adjust their behavior based on feedback to maintain a desired state.
    - **E.g., a water regulator that maintains a constant water flow**
      - A simple example is a water regulator, which adjusts the flow of water to keep it steady, even if the pressure changes. This is a practical application of control theory in everyday life.
    - **Mechanisms to minimize error between current and goal states**
      - The goal of control systems is to reduce the difference between where the system is and where it should be. This involves continuously measuring performance and making adjustments.
    - **Kalman Filter (Kalman, 1960)**
      - The Kalman Filter is a mathematical tool used in control theory to predict and correct the state of a system. It helps in making accurate estimations by considering uncertainties and noise in the data.
    - **Based on calculus, matrix, stochastic optimal control**
      - Control theory uses advanced mathematics like calculus and matrices to model and solve problems. Stochastic optimal control deals with making the best decisions under uncertainty.

* **AI: logical inference, symbolic planning, computation**
  - In AI, control theory principles are applied to enable machines to make decisions and plan actions logically. This involves using algorithms to simulate human-like reasoning and problem-solving.

14 / 14: AI and Computer Engineering



- **How can we build an efficient computer?**
  - **Electronic computers**
    - These were first developed during World War II, marking the beginning of modern computing. They were large, room-sized machines that laid the groundwork for today's technology.
  - **Moore's Law**
    - This is an observation that the number of transistors on a microchip doubles approximately every 18 months, leading to a doubling of performance. This trend was consistent from 1970 to 2005. However, as chips became more densely packed, issues like heat and power consumption arose, prompting a shift from increasing clock speeds to developing multi-core processors.
  - **Hardware for AI**
    - *GPUs* (Graphics Processing Units) and *TPUs* (Tensor Processing Units) are specialized hardware designed to handle the massive computations required by AI applications. Wafer-scale engines are another innovation, providing even more computational power by integrating many processors on a single wafer.
  - **Current Trends**
    - Modern computing is moving towards massive parallelism, which mimics how the human brain processes information. This approach allows for more efficient processing of complex tasks. The pace of computing power advancement has accelerated, with significant improvements occurring every three months. In AI, GPUs and TPUs are crucial for deep learning tasks, and it has been found that high precision, such as 64-bit calculations, is often unnecessary for many AI applications.
  - **Quantum Computing**

* This emerging technology holds the promise of dramatically speeding up certain types of computations. For example, Shor's algorithm, which is used for factoring large numbers, could be significantly accelerated by quantum computers, potentially impacting fields like cryptography.