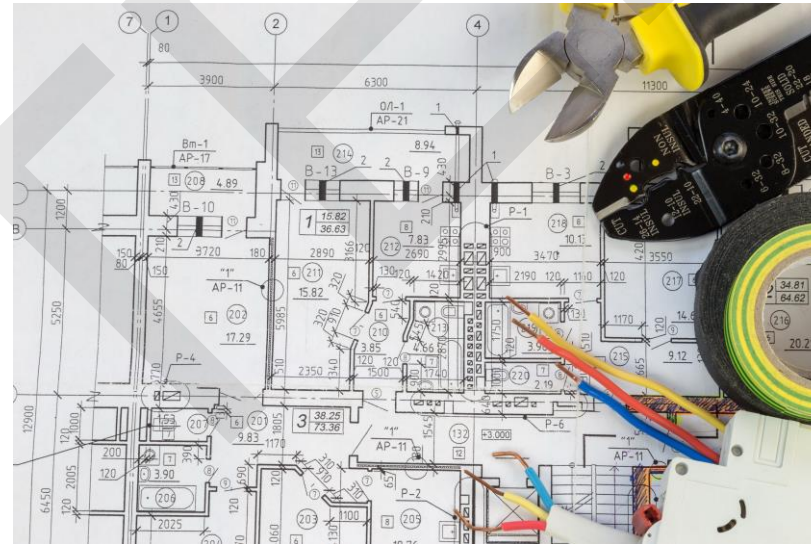
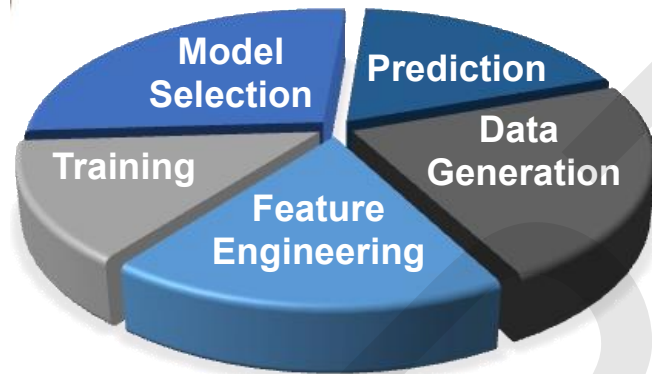


# Machine Learning for Core Engineering Disciplines



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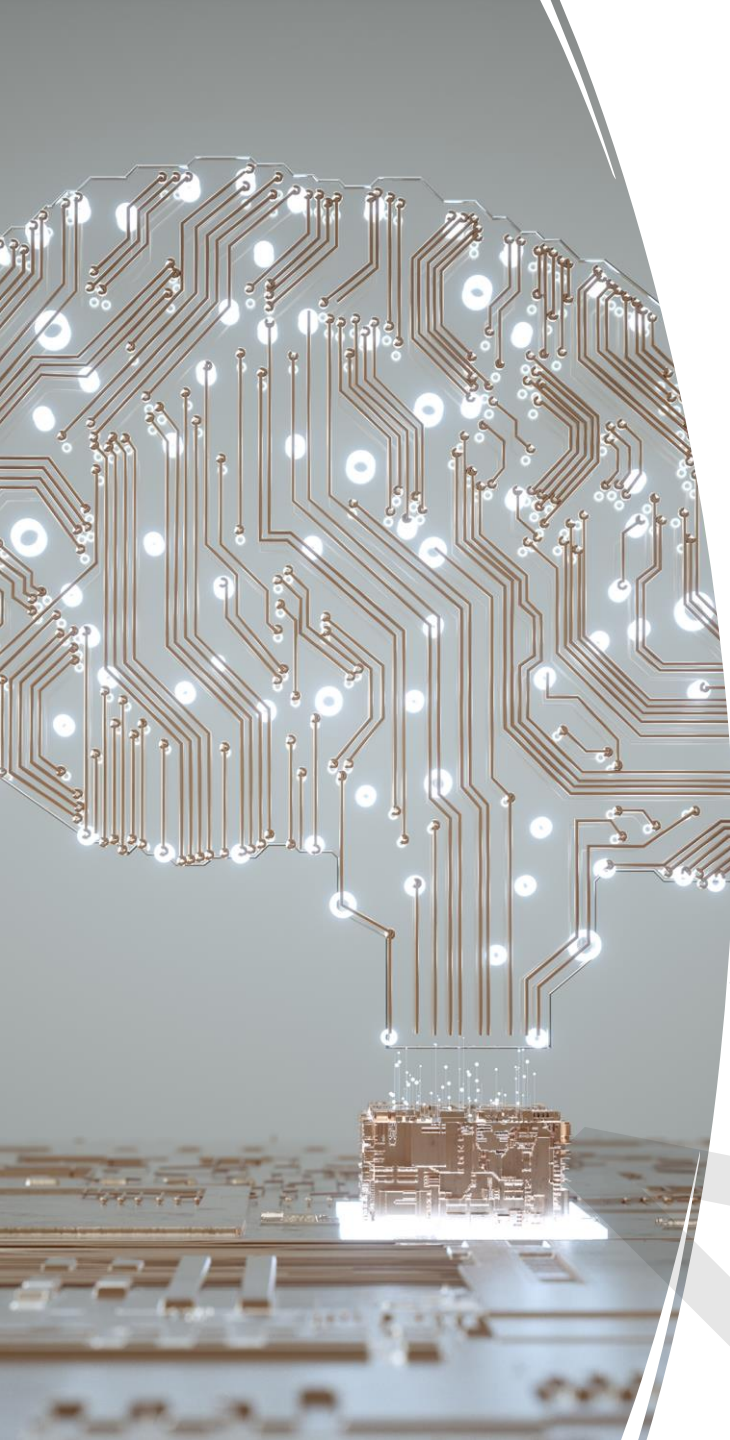
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# Introduction to data science

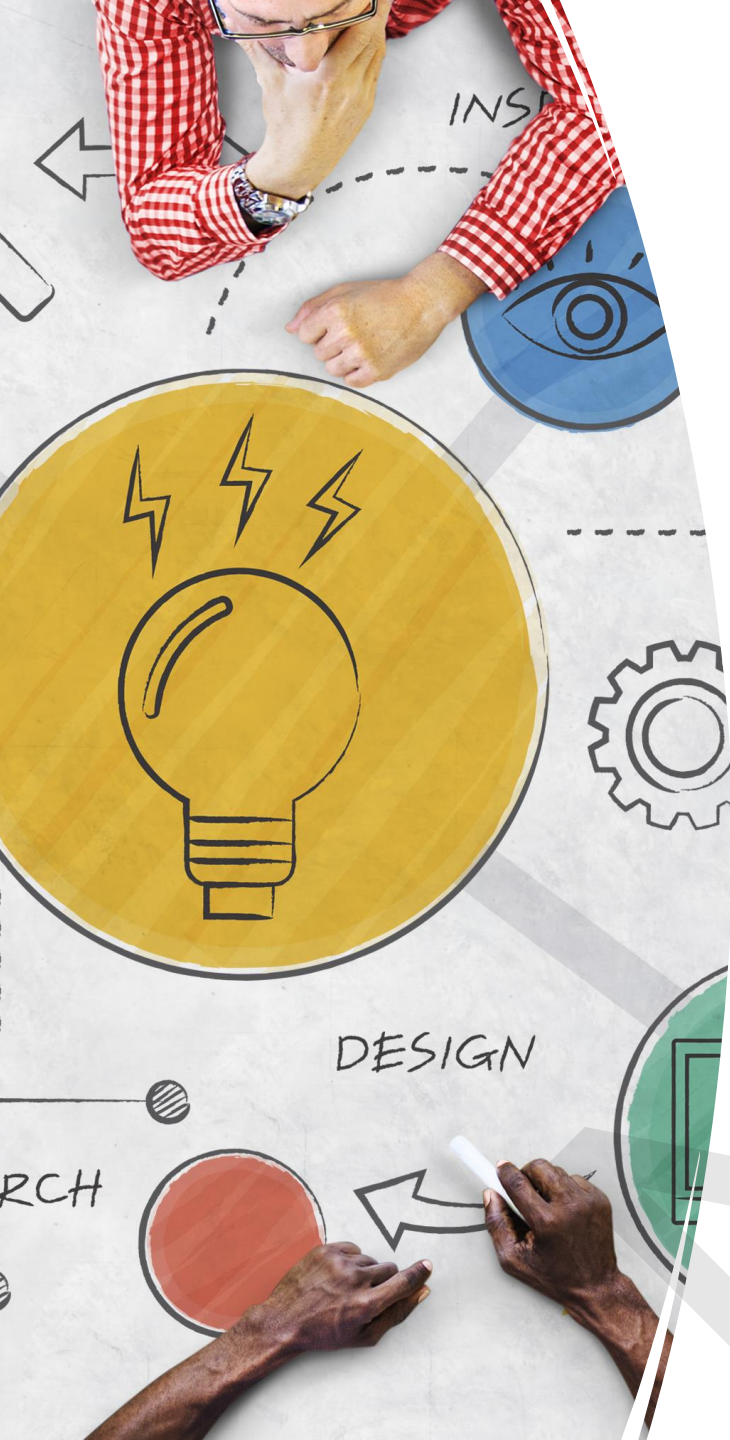
- **Data science** is the application of statistical and mathematical principles to analyze and understand data
- **Probability and statistics** play a major role in data science owing to the probabilistic (stochastic) nature of many physical, chemical, and biological processes around us



# What is artificial intelligence (AI)?

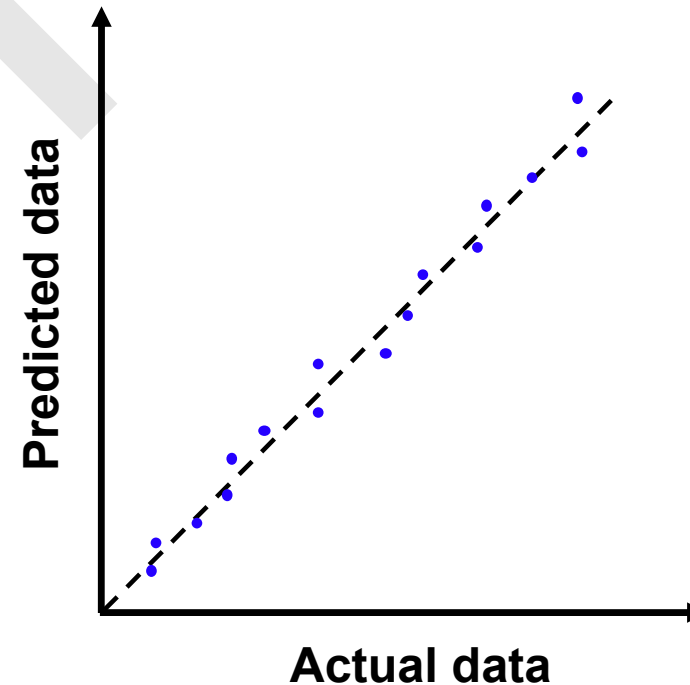
- **Artificial intelligence (AI)** involves imparting human-like cognitive functions to machines so that they can make inferences and decisions based on input data
- Given a certain situation/data, an AI can take an informed decision and perform some action based on that
- **Examples:** chatbots, self-driving cars, speech recognition, computer vision, etc.



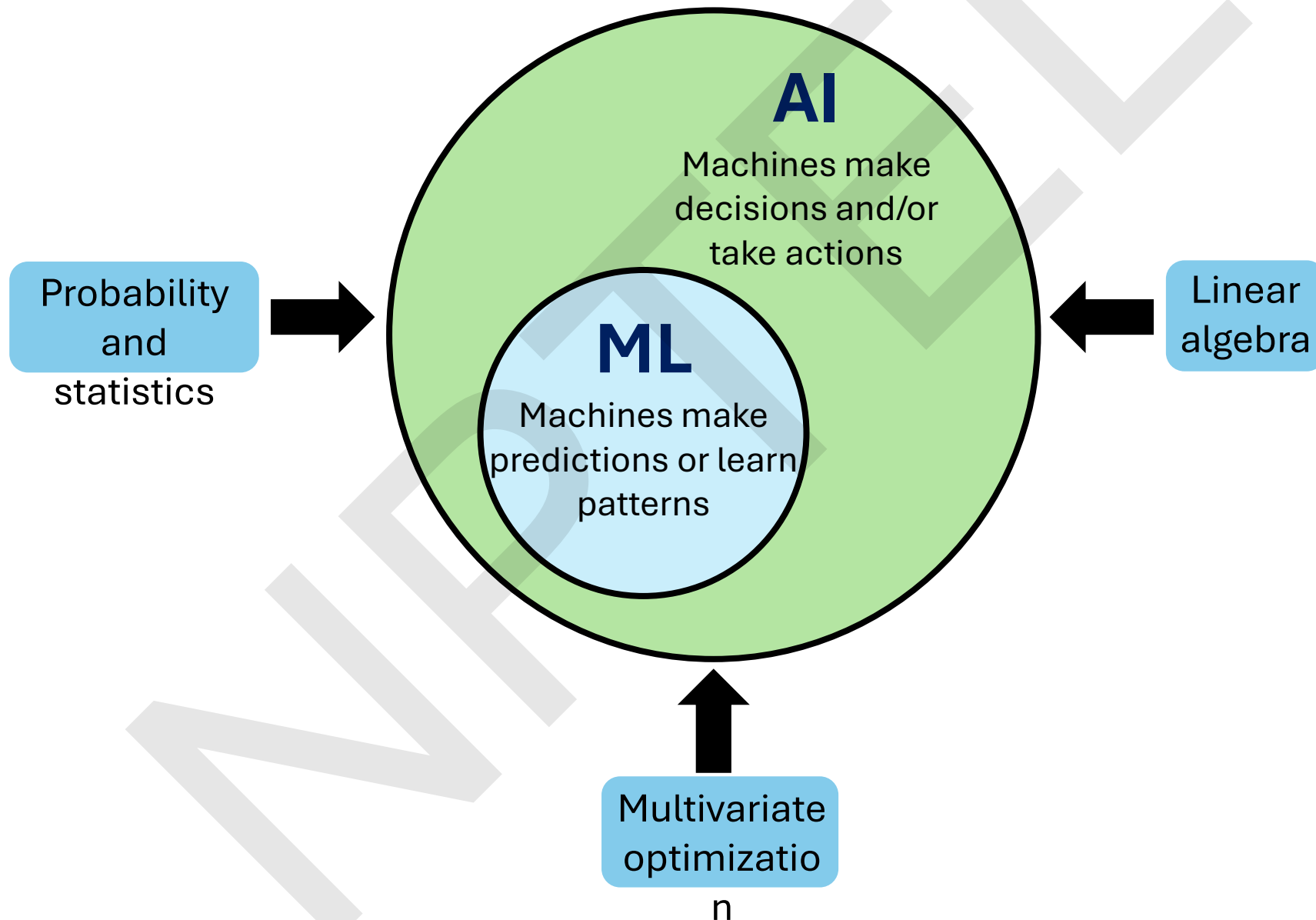


# What is machine learning (ML)?

- **Machine learning (ML)** is the use of computers to learn (rather than memorize) datasets involving a number of variables, so that they can make predictions corresponding to unseen data points.



# Relationship between AI and ML





# A very brief history of AI/ML

- **1950s-1970s: Birth of AI**

- **1950:** Alan Turing proposed the Turing Test
- **1956:** Dartmouth workshop led by Claude Shannon, John McCarthy, Nathaniel Rochester, and Marvin Minsky coined the term AI
- **1959:** Arthur Samuel defined ML as the ability of a computer to learn without being explicitly programmed
- Focus on symbolic AI: rule-based reasoning, problem-solving



# A very brief history of AI/ML

- **1980s-1990s: Rise of ML**
  - Shift from rules to data-driven learning
  - Rediscovery of backpropagation enabled training of ANNs
  - Resurgence of recurrent neural networks: Hopfield networks and long short-term memory
  - Rise of statistical methods (e.g., classification and regression trees, SVMs, gradient-boosted trees, etc.)



# A very brief history of AI/ML

- **2000s-2020s: Deep learning revolution**
  - Explosion of big data and GPU computing
  - Breakthroughs in vision (ImageNet) and natural language processing (gated recurrent units, transformers, attention)
  - Applications to healthcare, self-driving cars, and virtual assistants
  - 2024 Nobel Prize in Physics to John Hopfield and Geoffrey Hinton for foundational work in ML and ANNs



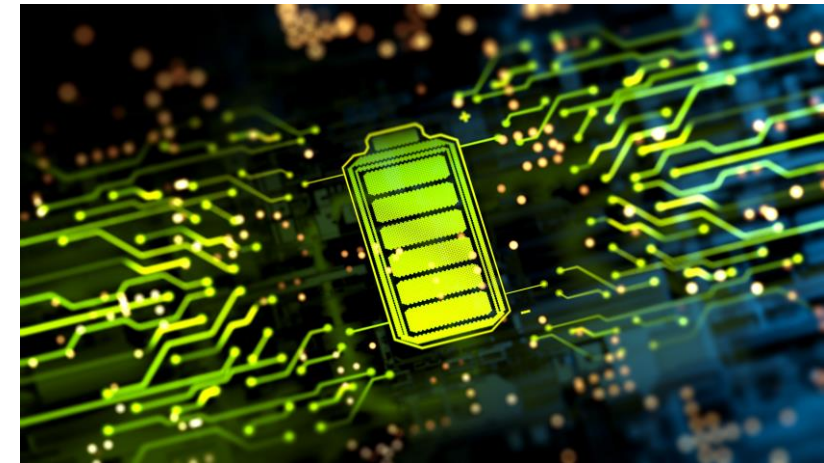
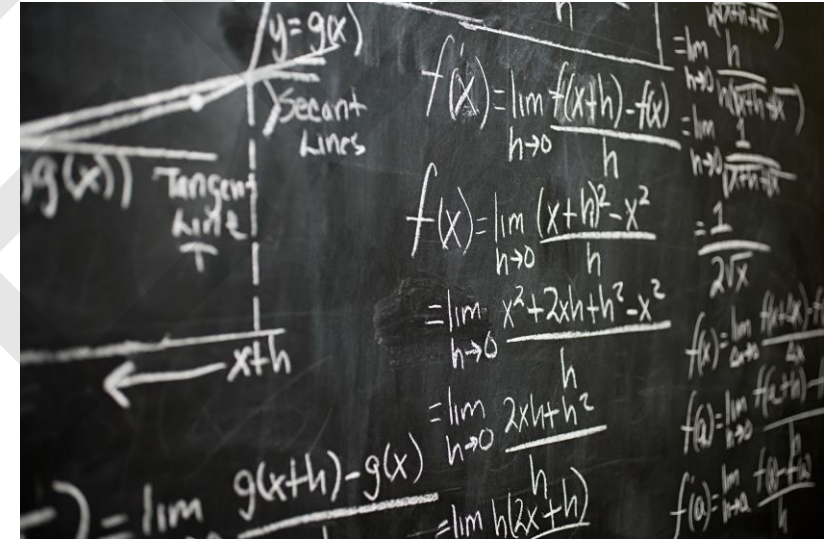
# Why are AI and ML gaining popularity?



- In recent years, **artificial intelligence (AI)** and **machine learning (ML)** have gained immense popularity in various core branches of engineering due to
  - Availability of large amounts of data (albeit of variable quality)
  - Development of new and advanced algorithms related to understanding and predicting data
  - Ability to automate experiments and simulations
  - Rise of field-specific large-language models

# Advantages of ML

- Mitigates challenges associated with a **lack of closed form expressions or theories**
- Helps **demystify datasets with a high degree of dimensionality**, i.e., with a large number of independent variables, where each one's effect is unclear
- Once trained, the model can **reduce computational cost of making predictions** by several orders of magnitude



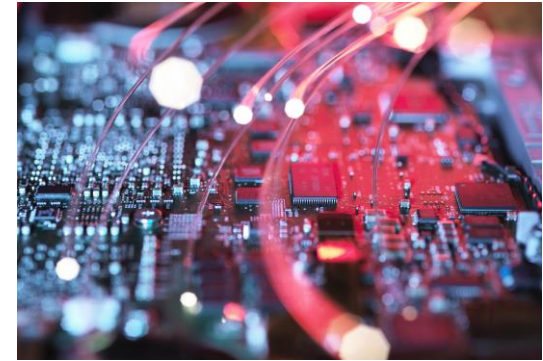
# Disadvantages of ML

- Models typically **require a large amount of data to train** which may not always be available or may be of poor quality
  - Mitigated recently by the introduction of foundation models and fine-tuning strategies
- May **obscure the physics or chemistry or biology of the problem** in some cases, since all the focus is on data
  - Physics-informed or physics-inspired ML has become popular recently



# Examples of ML applied to engineering problems

- **Chemical:** Optimization of operating conditions for a chemical plant to increase process efficiency
- **Materials:** Discovery of new electrocatalysts for green hydrogen production
- **Electrical:** Circuit design for reducing power consumption in processors
- **Civil:** Optimizing structural layouts of skyscrapers for earthquake resistance
- **Mechanical/Aerospace:** Automobile or aeroplane design for increased fuel efficiency





# Learning outcomes of the course

- **Aim:** To enable students and practitioners of core engineering disciplines to understand and deploy machine learning for various applications

- **Reference books:**

- Trevor Hastie, Robert Tibshirani, and Jerome Friedman, “***The Elements of Statistical Learning: Data Mining, Inference, and Prediction***,” Springer
- Christopher M. Bishop, “***Pattern Recognition and Machine Learning***,” Springer
- Ian Goodfellow, Yoshua Bengio, and Aaron Courville, “***Deep Learning***,” MIT Press

