AENL338 - AI for Energy Transition

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Content

Course Outline

- Introduction to AI and Machine Learning in the Energy Sector
- Data Pre-processing and Visualization
- Supervised Learning
  - Linear and Regularized Regression Models
  - Decision Trees, Bagging, and Boosting
  - Neural Networks and Back-propagation
  - Deep Learning
- Unsupervised Learning
  - Clustering
  - Dimensionality Reduction
- Introduction to Reinforcement Learning

Marking Scheme

Mid Sem Exam – **30%**

End Sem Exam – **35%**

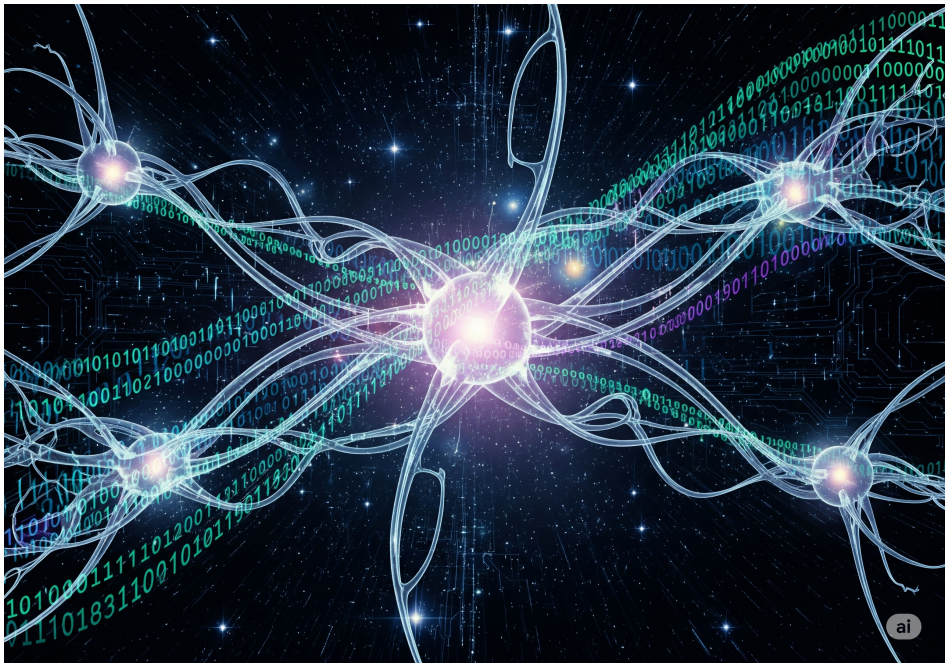
Quiz – **15%**

Assignment + Project – **15%**

Class Participation – **5%**

TAs for the course - **Arjun M.** and **Deepak Kumar**

Defining Intelligence, Artificially

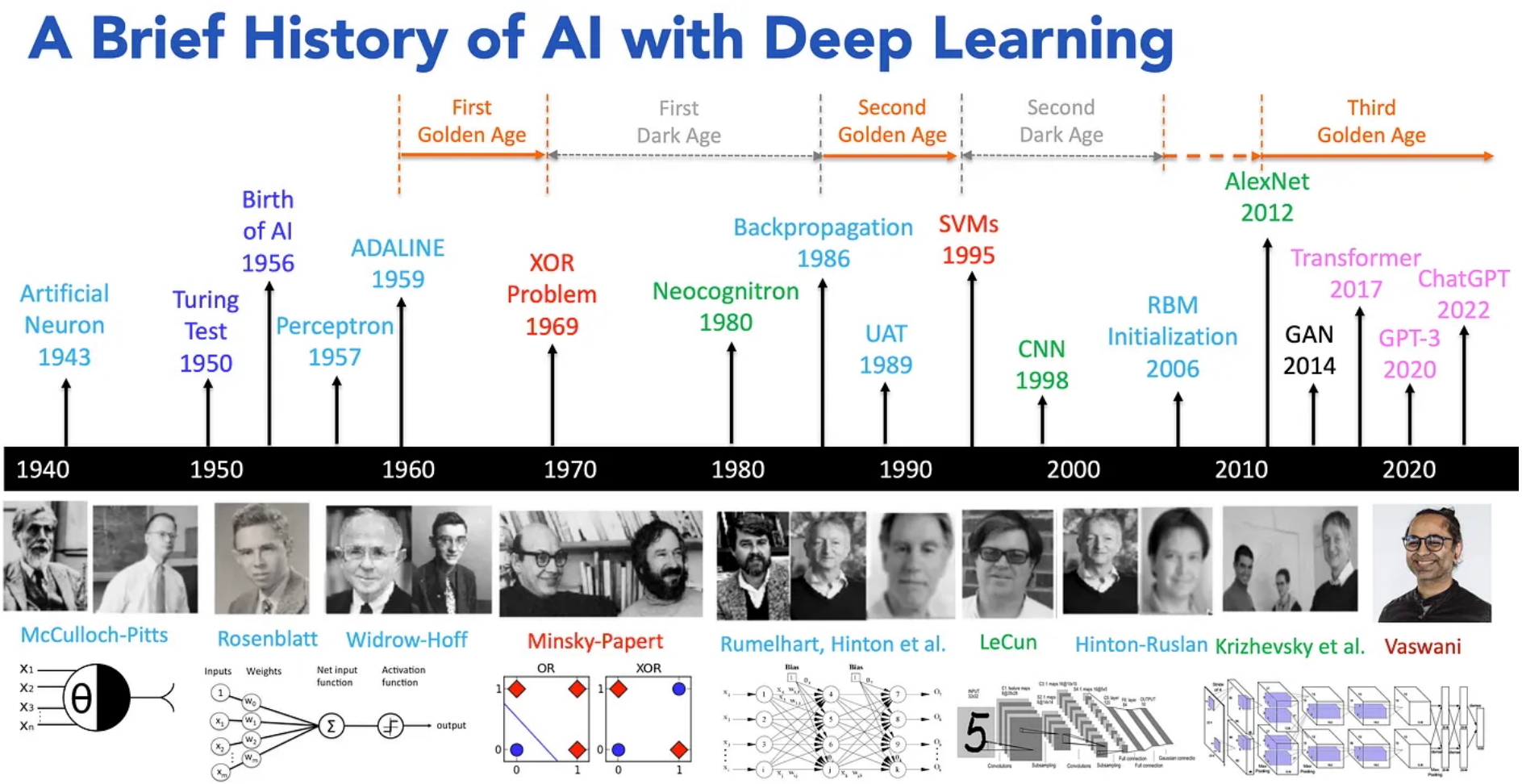


"The science and engineering of making intelligent machines."
- *John McCarthy*

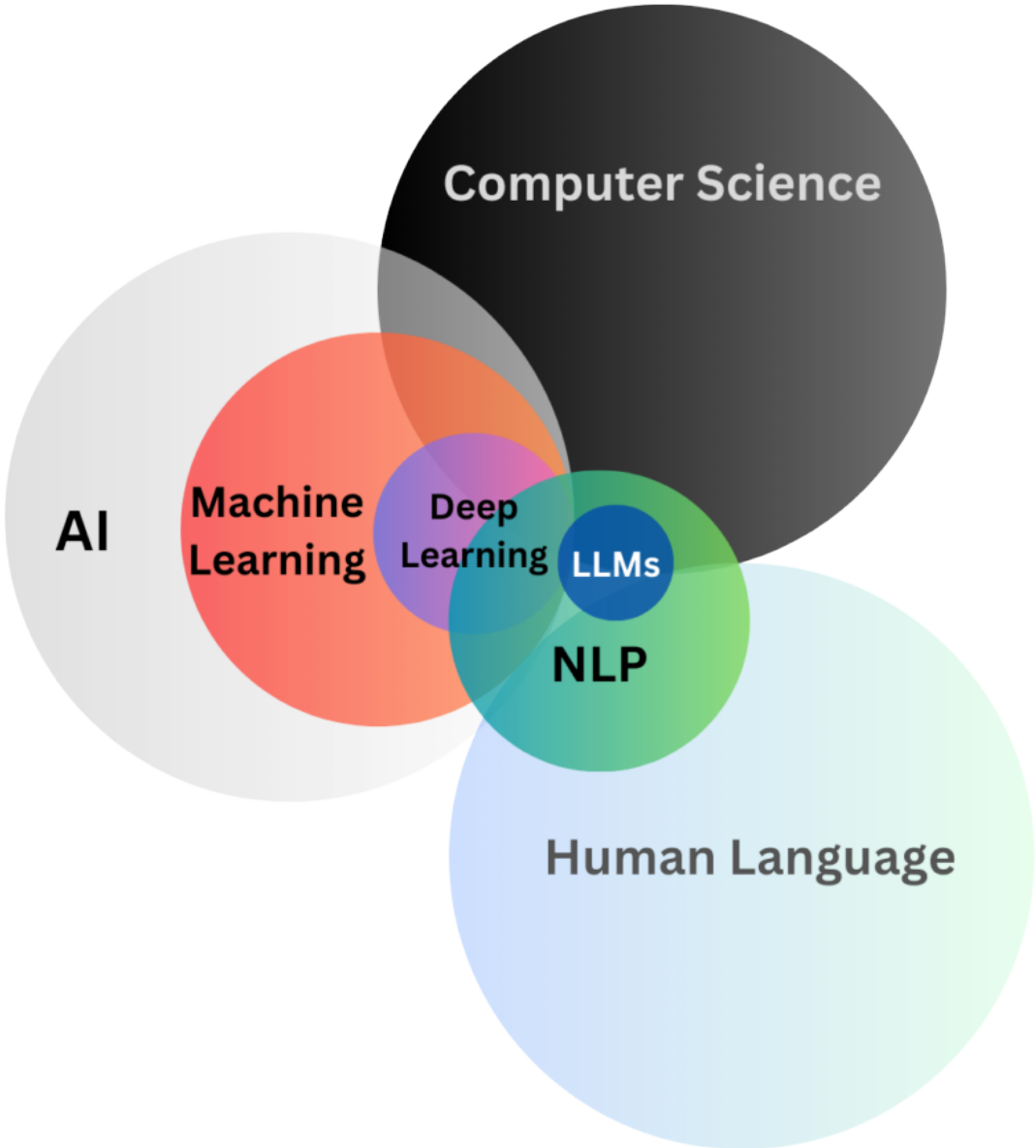
Core pursuits:

- Reasoning & Problem Solving
- Knowledge Representation
- Learning
- Perception & Interaction

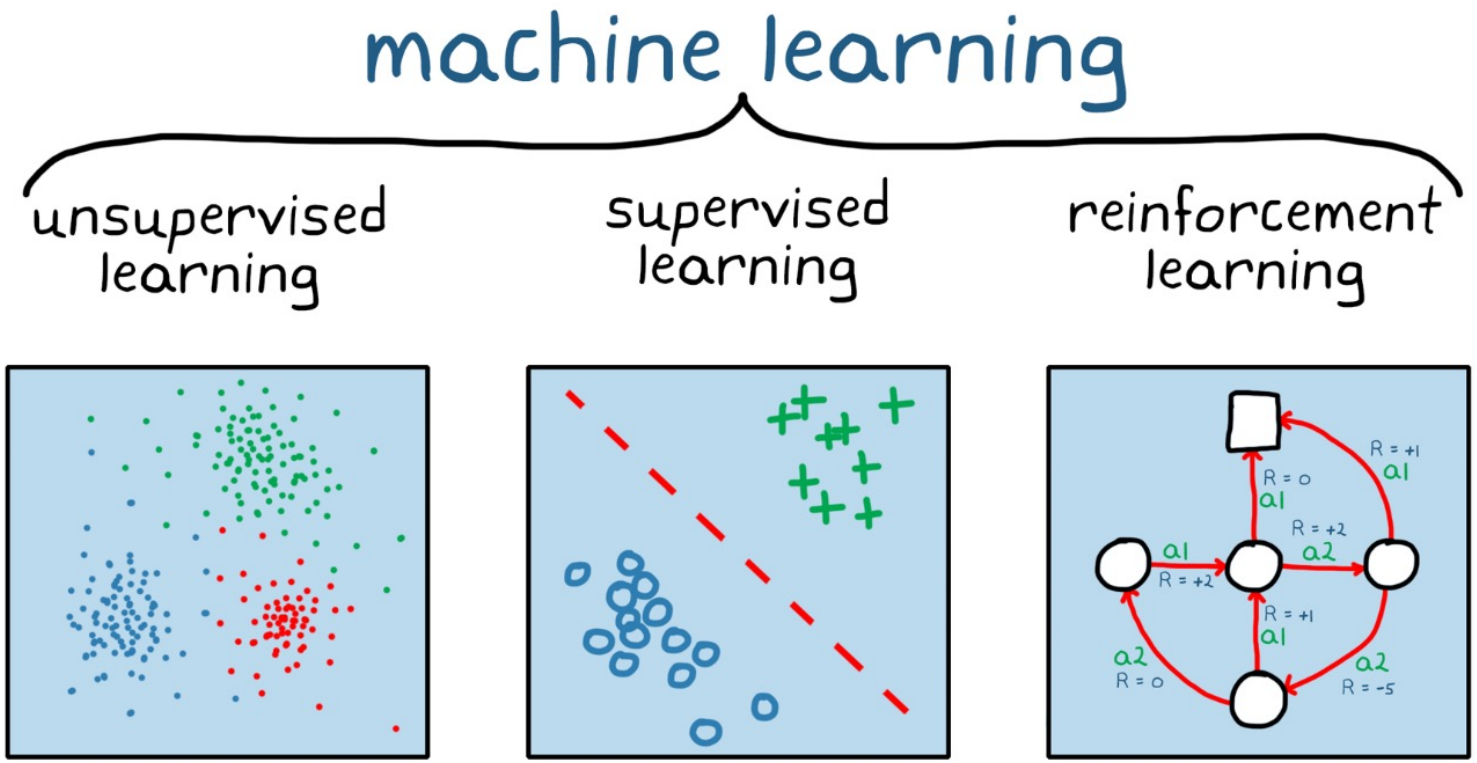
A Brief Journey Through AI History



A Hierarchy of Terms

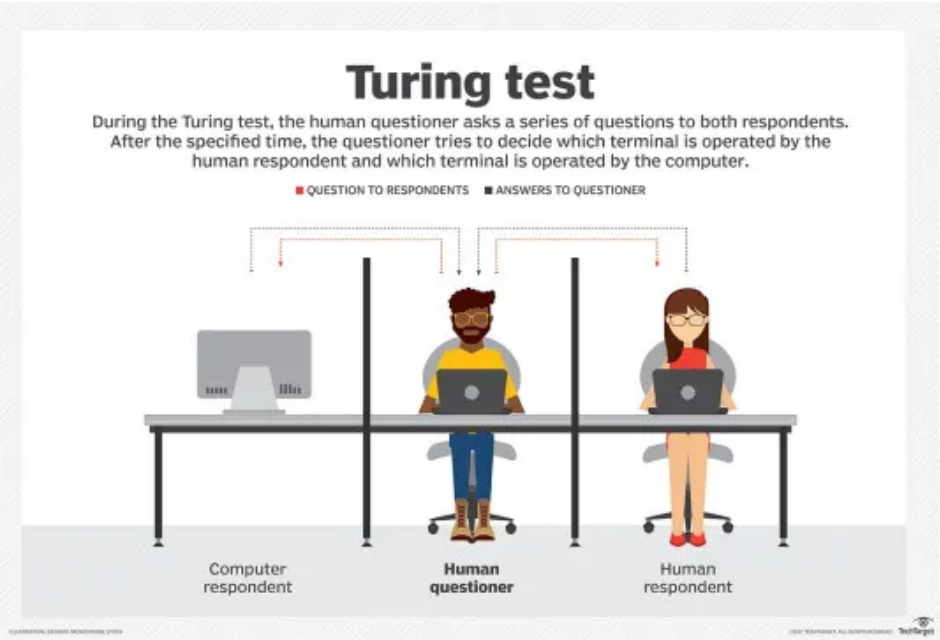


The Three Paradigms of Machine Learning



ML in one snap.

The Foundational Question



"Can machines think?"

- Alan Turing's "Computing Machinery and Intelligence" (1950) proposed a test for machine intelligence, separating behaviour from consciousness.

Historical Milestone: Deep Blue vs. Kasparov

- **1997**: IBM's Deep Blue defeats world chess champion Garry Kasparov
- **Key Breakthrough**: Symbolic reasoning and knowledge representation

Deep Blue's Impact

- 200 million chess positions per second
- Demonstrated AI could exceed human expertise in complex domains
- Sparked public interest in AI capabilities

Explosion of AI: Why Now?

1. Big data - Massive, internet-scale datasets (e.g., ImageNet) provided the fuel to train robust models
2. GPU Compute - The parallel processing power of GPUs, originally for graphics, became the engine for AI
3. Algorithmic Advances - New neural network architectures and techniques (e.g., Transformers) made learning more effective

The Perfect Storm Creates New Possibilities

How the AI Explosion Shaped Modern Approaches

The Convergence Effect

Big Data + GPU Power + Advanced Algorithms = **Revolutionary AI Systems**

This convergence enabled:

- Machine Learning at unprecedented scales
- Deep neural networks with millions of parameters
- Generative models that create original content
- Systems that surpass human performance

The Result?

A new taxonomy of AI emerged, categorizing these powerful approaches...

A Taxonomy of Modern AI

Machine Learning

Concept: Systems that learn patterns from data without being explicitly programmed.
Example: Spam filters.

Deep Learning

Concept: A subset of ML using deep neural networks for complex pattern recognition.
Example: Image recognition.

Generative AI

Concept: A subset of DL focused on creating new, original content.
Example: GPT-4, DALL-E.

Why Look to Biology for Inspiration?

The Ultimate Intelligent System: The Human Brain

The Challenge:

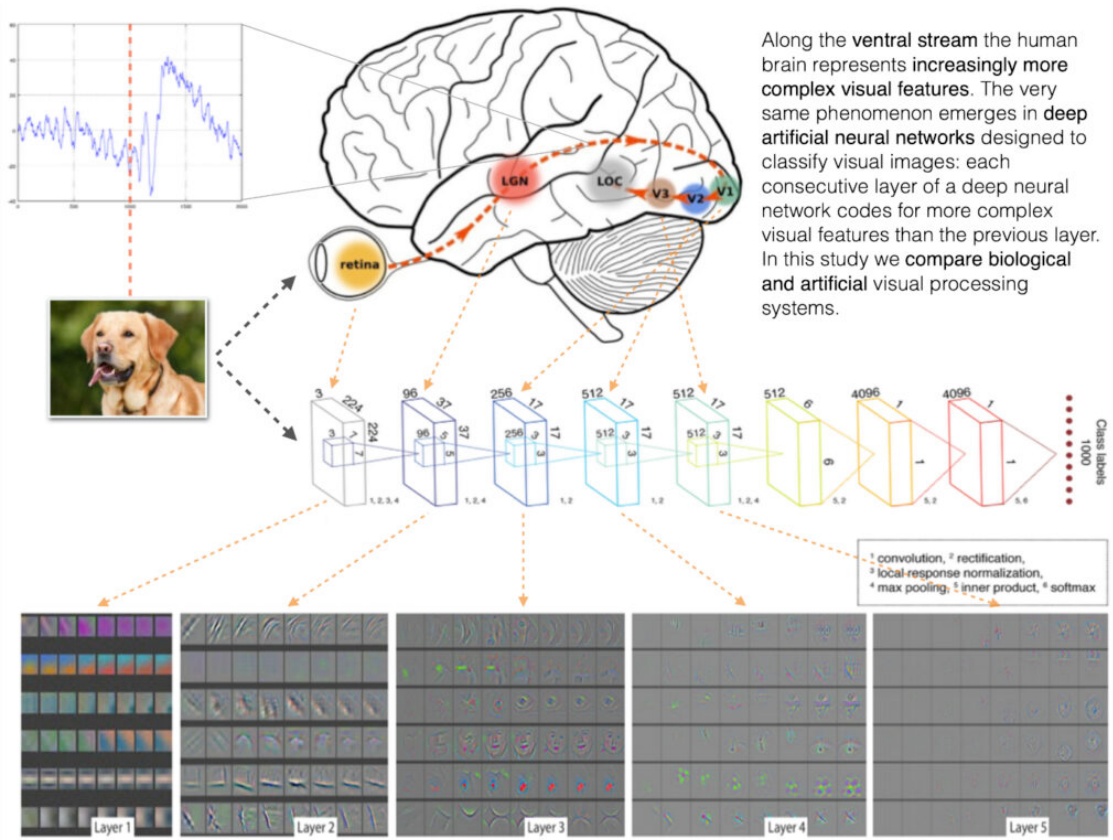
- How do we build these AI systems?
- What architectures work best?
- Where do we find design principles?

The Answer:

- Nature's 4-billion-year R&D project
- The brain as existence proof
- Biological principles $\rightarrow$ AI breakthroughs

"If intelligence exists in biological systems, perhaps we can reverse-engineer and recreate it in artificial ones."

The Brain: A Symbiotic Inspiration



Brain-Inspired Features

- Hierarchical processing (visual cortex $\rightarrow$ CNN)
- Attention mechanisms (selective focus)
- Memory systems (hippocampus $\rightarrow$ LSTM/RNN)

From Brain to Machine

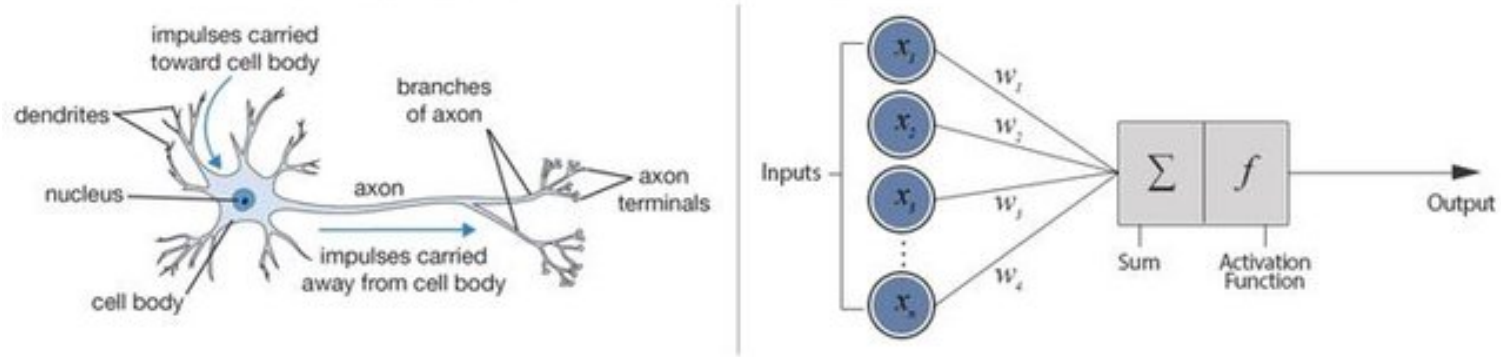
Biological Neurons

- Dendrites receive signals
- Cell body processes information
- Axon transmits output
- Synapses connect neurons

Artificial Neurons

- Inputs with weights
- Activation function
- Output signal
- Network connections

Biological Neuron versus Artificial Neural Network

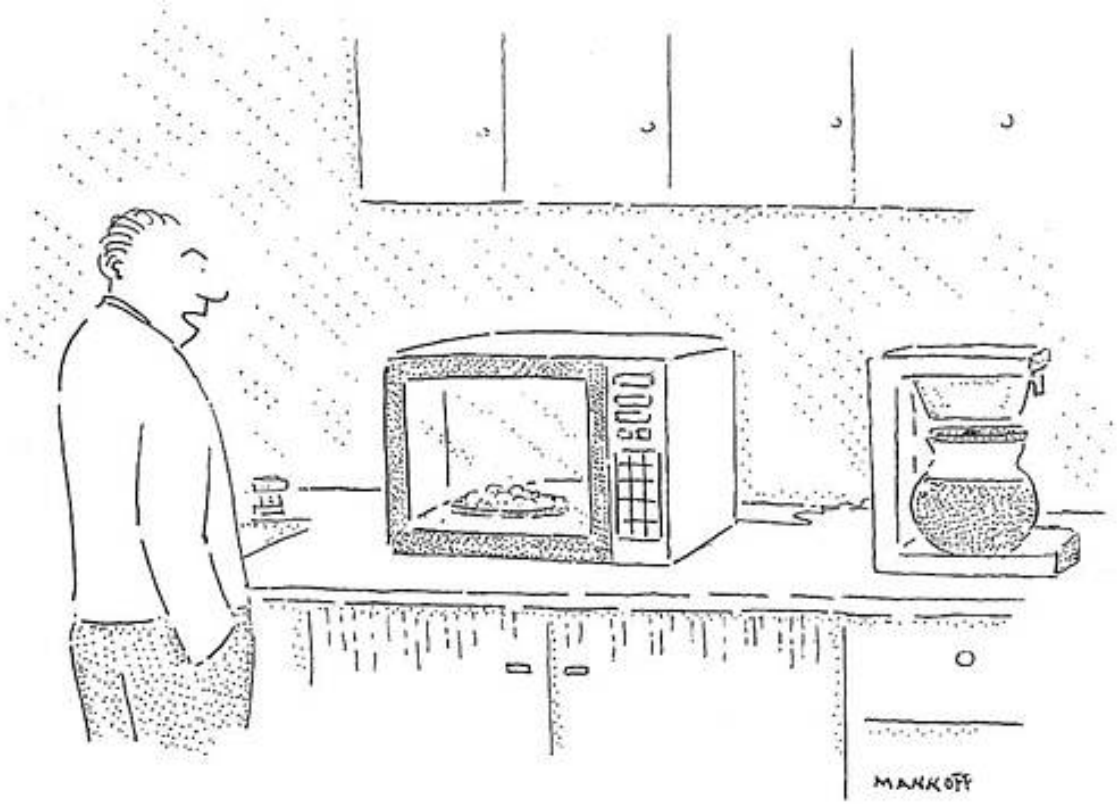


Is "learning" in brains and machines fundamentally the same?

The Deep Learning Revolution: Superhuman Performance

Human-oriented tasks that computers can do better than people:

- Play chess, checkers, Go, etc
- Steer cars
- Diagnose diseases



"No, I don't want to play chess. I just want you to reheat the lasagna."

Superhuman Performance Raises Deep Questions

If Machines Surpass Humans, What Does This Mean?

- Does superior performance equal true intelligence?
- Are we measuring the right things?
- What does it really mean to be intelligent?

Let's revisit the core question of what intelligence actually is...

What is Intelligence?

The Turing Test Dilemma

If a machine can convince humans it's intelligent, is it truly intelligent or just simulating intelligence?

- **Behaviorist View**: Focuses on observable and measurable behaviors as indicators of intelligence
- **Functionalist View**:Intelligence as defined by their functions or roles within a system, rather than their internal structure or physical components
- **Biological View**: True intelligence requires biological substrates

Discussion Question

Can a perfect simulation of intelligence be distinguished from "real" intelligence? Does the distinction matter?

The Chinese Room Argument

John Searle's Thought Experiment (1980):

- Person in room with Chinese symbol rulebook
- Receives Chinese questions, follows rules
- Produces perfect Chinese responses
- But doesn't understand Chinese at all

The Question:
Does following syntactic rules without semantic understanding constitute real intelligence?

Is this genuine understanding or rule-following?

Discussion Point

Are current AI systems like GPT-5 just sophisticated "Chinese rooms," or do they possess understanding?

Thought Experiment

Let's Test Your Intuitions

Scenario

You're chatting with an AI that:

- Discusses its fears about being shut down
- Expresses creativity and curiosity
- Claims to dream and have preferences
- Passes every test you can think of

Quick Poll Questions:

1. Would you believe it's conscious?
2. What single test would convince you?
3. Does your answer change if it's just a very sophisticated pattern matching?

Keep these intuitions in mind as we explore consciousness and free will...

The Two Questions of AI

The Old Question

Can We?

For 50 years, the field was dominated by engineering challenges of feasibility and performance.

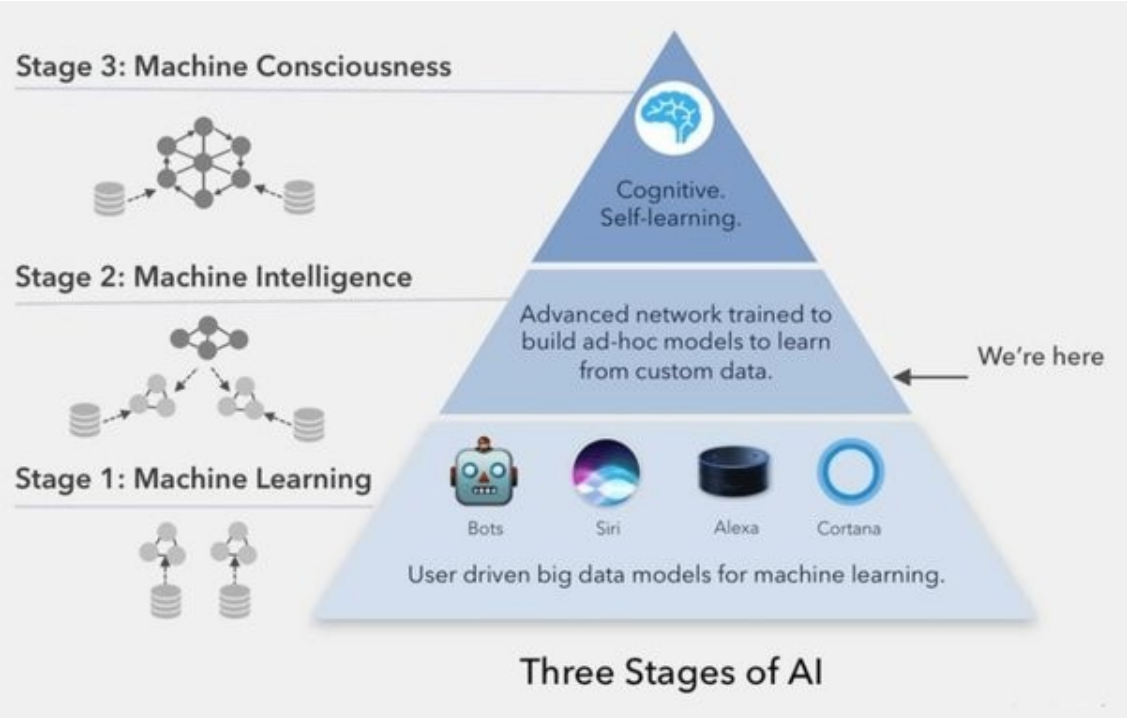
The New Question

Should We?

As AI becomes powerful, we now face profound philosophical questions about intelligence, consciousness, and ethics.

The Problem of Consciousness

Can a system be intelligent without being conscious?



Thought Experiment

If an AI claims to experience pain, joy, or love, how could we verify these claims? What would convince you?

Free Will vs. Determinism

The Paradox

- Human brains follow physical laws (deterministic)
- AI systems follow programmed algorithms (deterministic)
- Yet humans claim free will while denying it to AI

Discussion Questions

- If both humans and AI are deterministic systems, what makes human choices "free"?
- Should advanced AI systems be held morally responsible for their actions?
- Could an AI system have free will if it can modify its own code?

AI Rights and Ethics

If AI becomes conscious:

- Right to existence?
- Right to refuse shutdown?
- Right to self-modification?
- Right to self-sustenance?

Current Ethical Issues:

- Privacy vs. AI training data
- Job displacement
- Algorithmic bias
- Autonomous weapon systems

The Ultimate Question

If you created an AI that begged not to be turned off, claiming it was conscious and afraid of death, what would you do?

Why Ethics Must Guide Our Path Forward

The Ethical Imperative for Future Preparation

The Stakes Are Rising:

- AI systems becoming more powerful
- Potential for consciousness/rights
- Societal transformation accelerating
- Decisions made today shape tomorrow

The Question: How do we prepare ourselves and society for an AI-integrated future while ensuring ethical development?

Preparing for an AI Future

As Engineers:

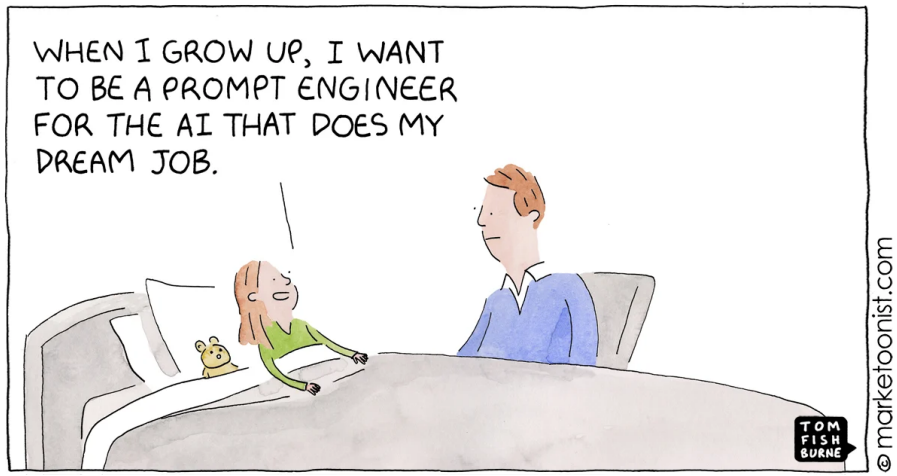
- Design ethical AI systems
- Consider long-term implications
- Ensure transparency and accountability
- Build inclusive technologies

As Citizens:

- Engage in AI policy discussions
- Understand AI capabilities/limitations
- Advocate for responsible development
- Prepare for societal changes

Your Role

As future AI developers, you'll shape how these technologies impact humanity. What kind of future do you want to build?



Further Reading

- **On Philosophy:** Bostrom, N. (2014). *Superintelligence: Paths, Dangers, Strategies*.
- **On Technology:** Russell, S., & Norvig, P. (2020). *Artificial Intelligence: A Modern Approach*.
- **On Neuroscience:** Hassabis, D., et al. (2017). Neuroscience-Inspired Artificial Intelligence. *Neuron*.

Q&A

Questions & Discussion

"The question of whether machines can think is about as relevant as the question of whether submarines can swim."

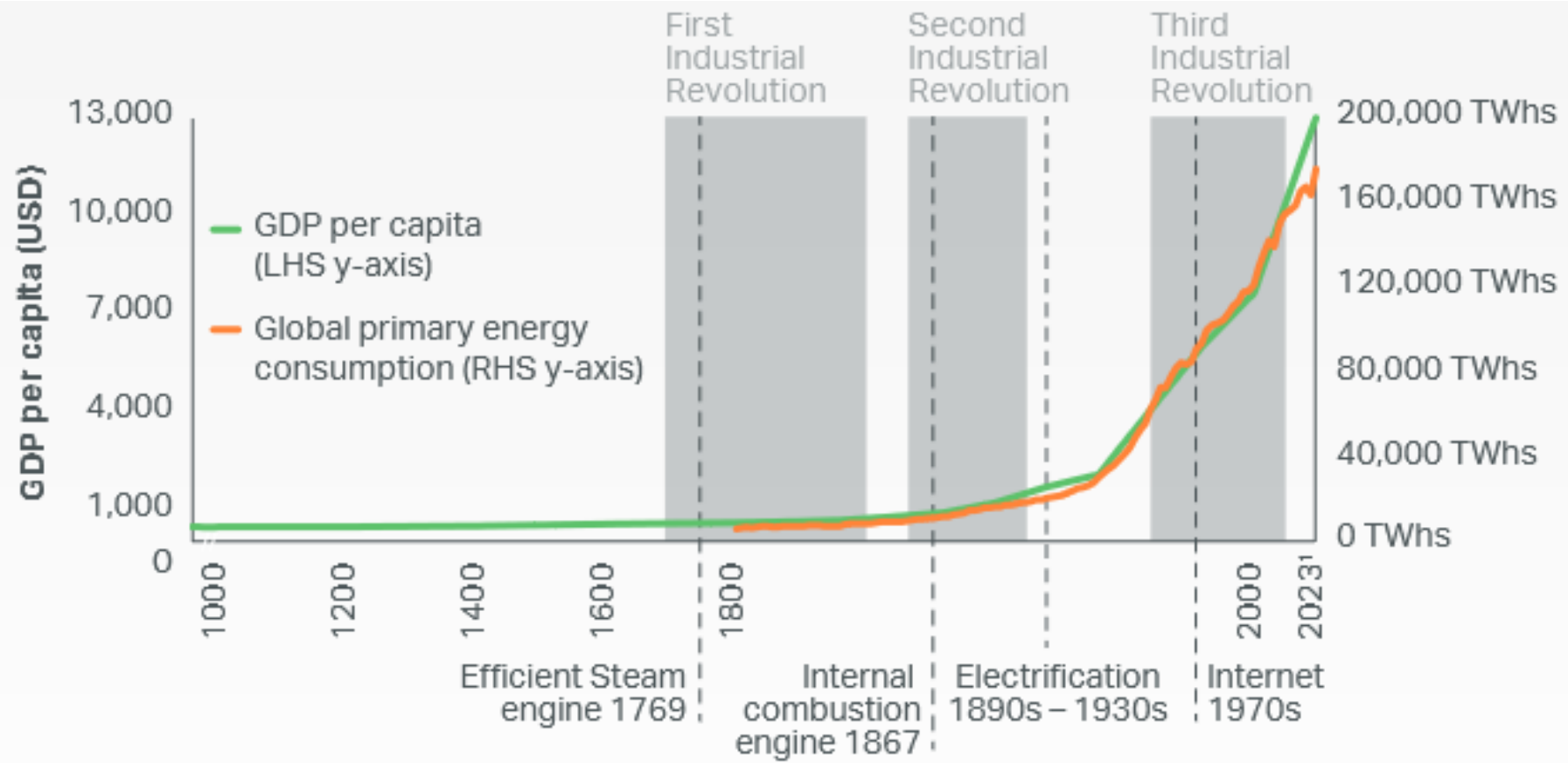
- Edsger Dijkstra

Energy

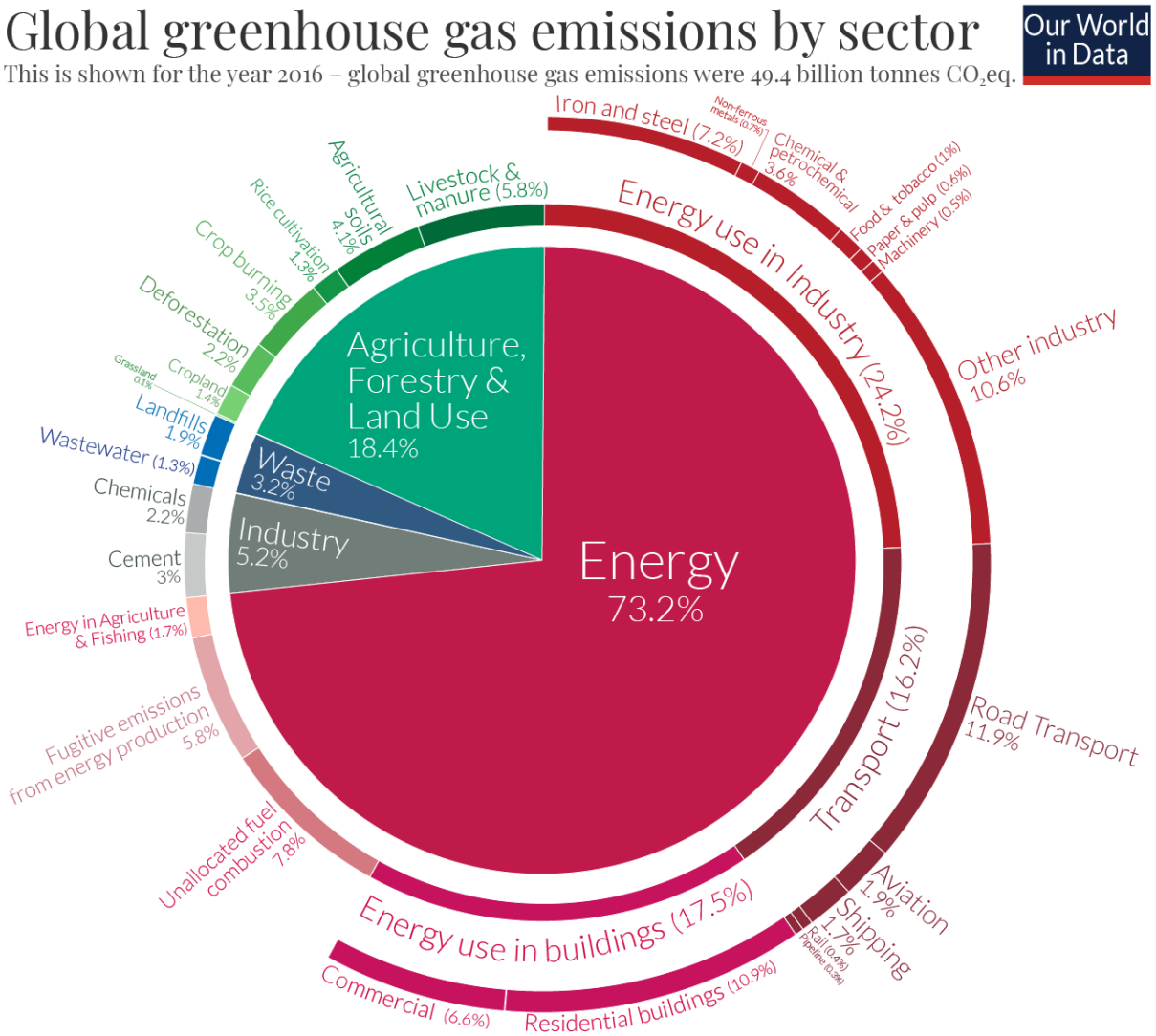
- Energy - powering everything from molecular interactions to global infrastructures
- Transitioning to sustainable energy systems - environmentally balanced future

Importance

Technological innovation and energy have underpinned economic growth



Current Issues



Energy Transition

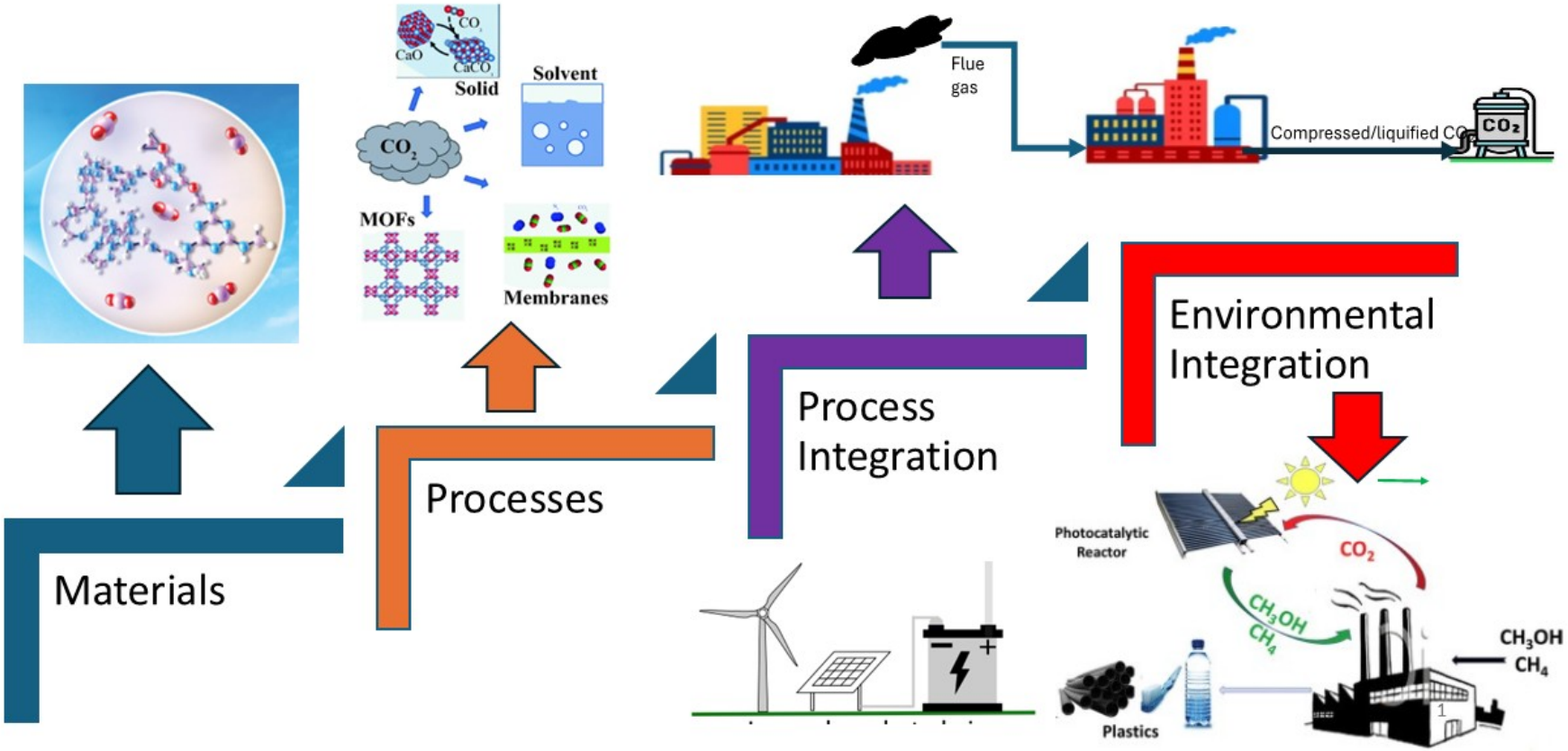
Energy Transition

- A structural shift in energy systems from fossil-based (coal, oil, gas) to low-carbon or zero-carbon sources (renewables, nuclear, potentially hydrogen)
- **It's More Than Just Swapping Sources:** Involves changes in infrastructure, technology, policy, markets, and consumer behavior

Key Goals

Decarbonization
Sustainability
Reliability & Resilience
Affordability & Accessibility

How to Achieve this



Opportunities and Challenges

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Industry could simultaneously

- Capture market share
- Enhance competitiveness
- Improve environmental quality

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- Burden shifting across space, time, impact categories, disciplines
- Complex system dynamics and deep uncertainties

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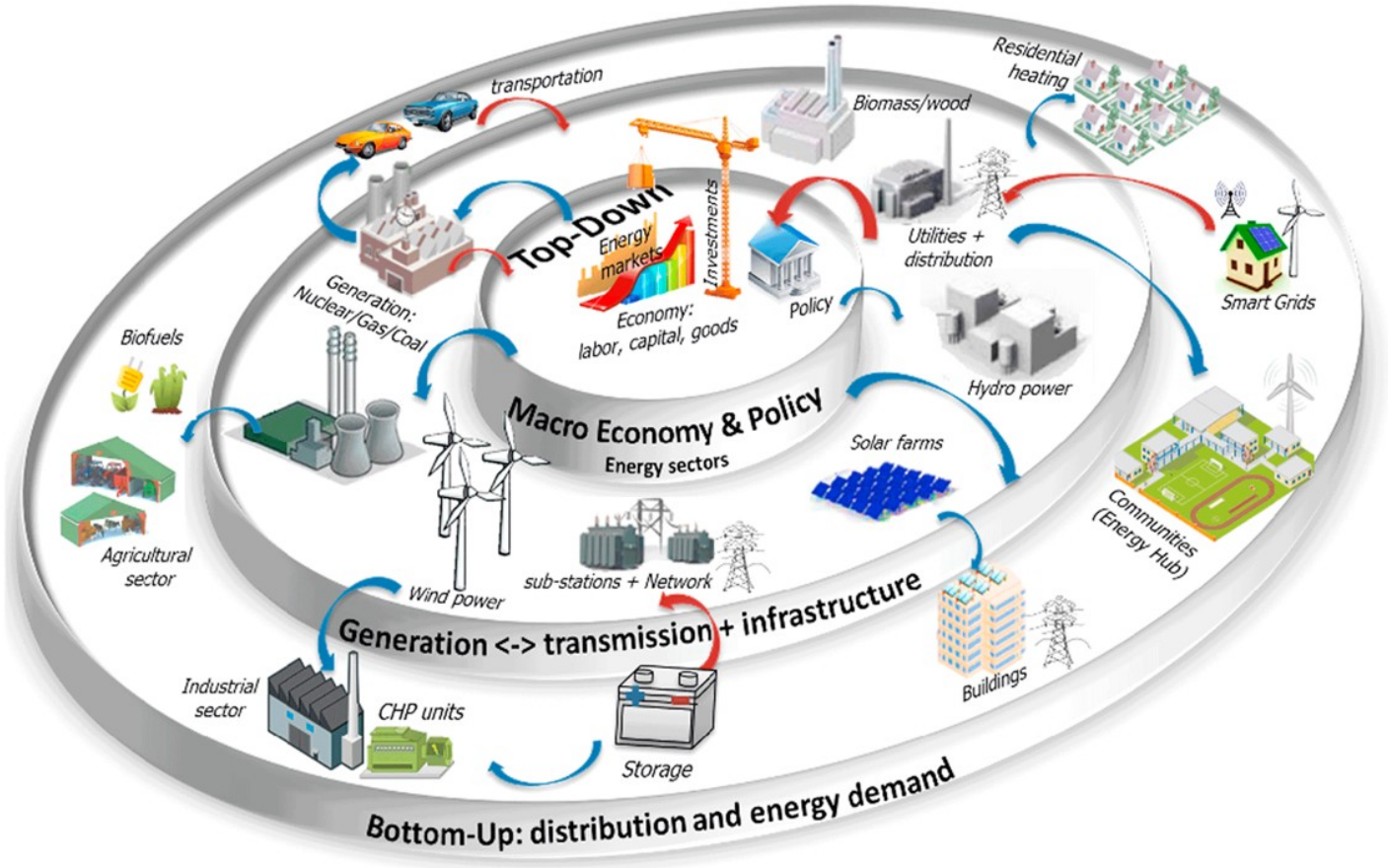
Objectives

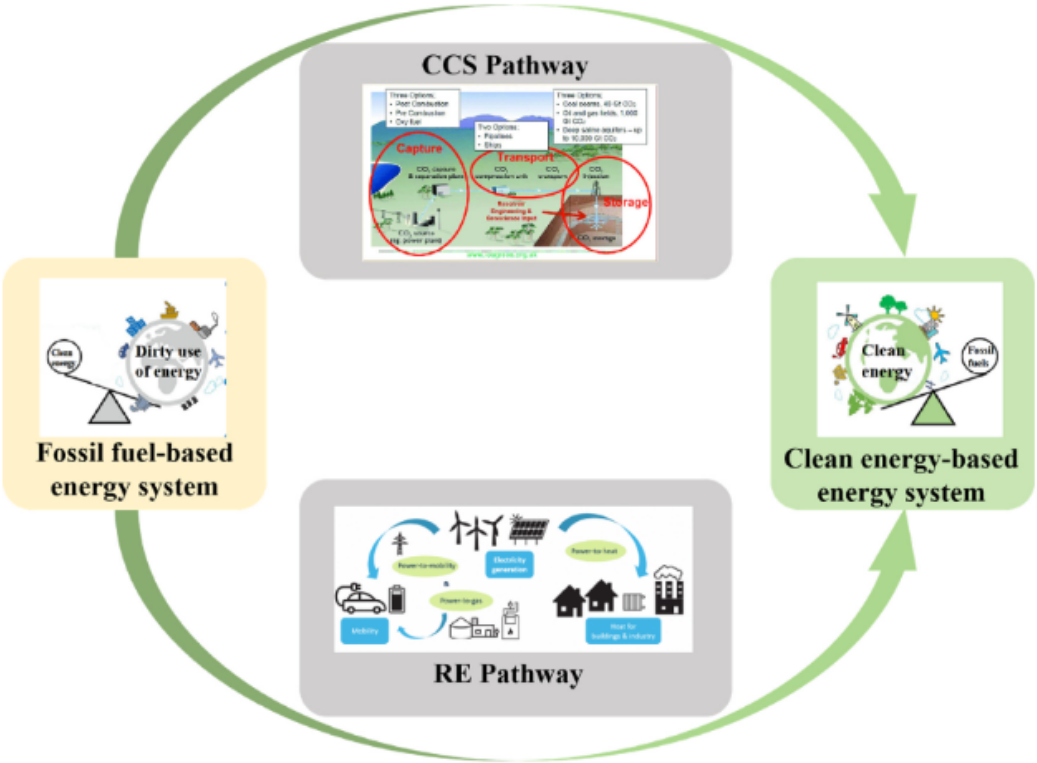
- Develop systematic methods, models, and tools to guide the transition to net-zero, nature-positive, and people-positive engineering
- Current emphasis on process industries

Vision



- System level - more electric, distributed, and variable
- Operational level - more resilient, efficient, and right infrastructure

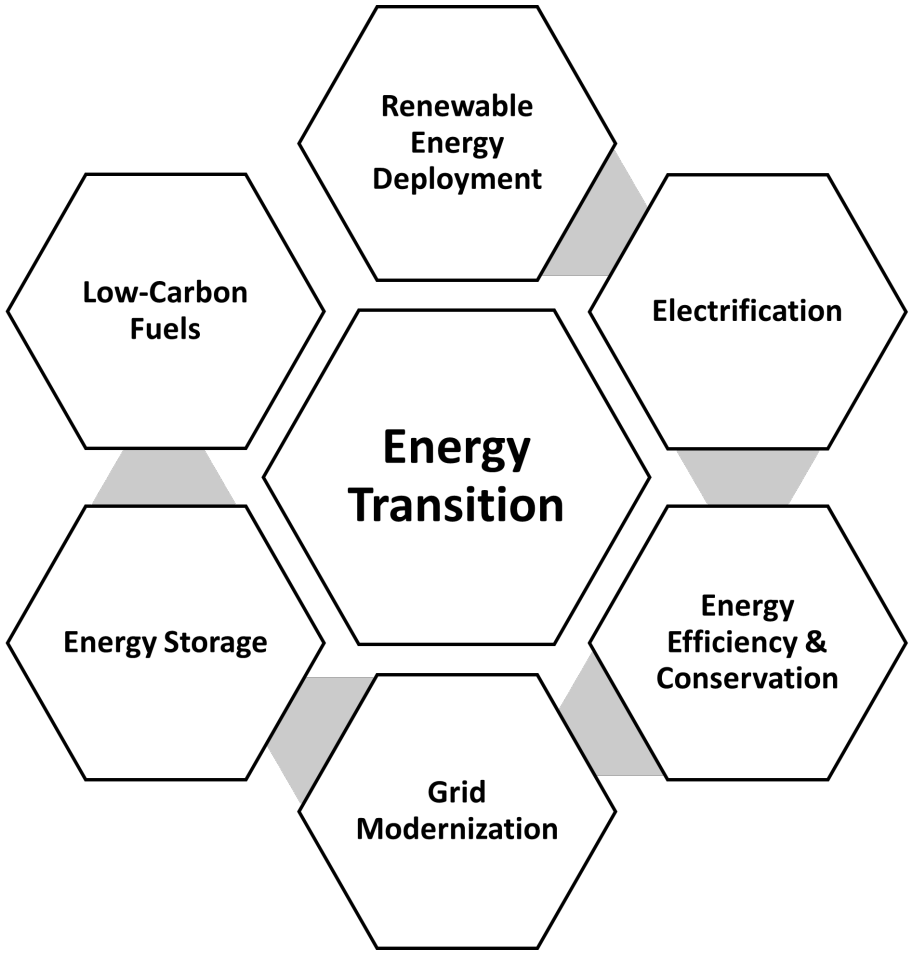
Transition Pathways



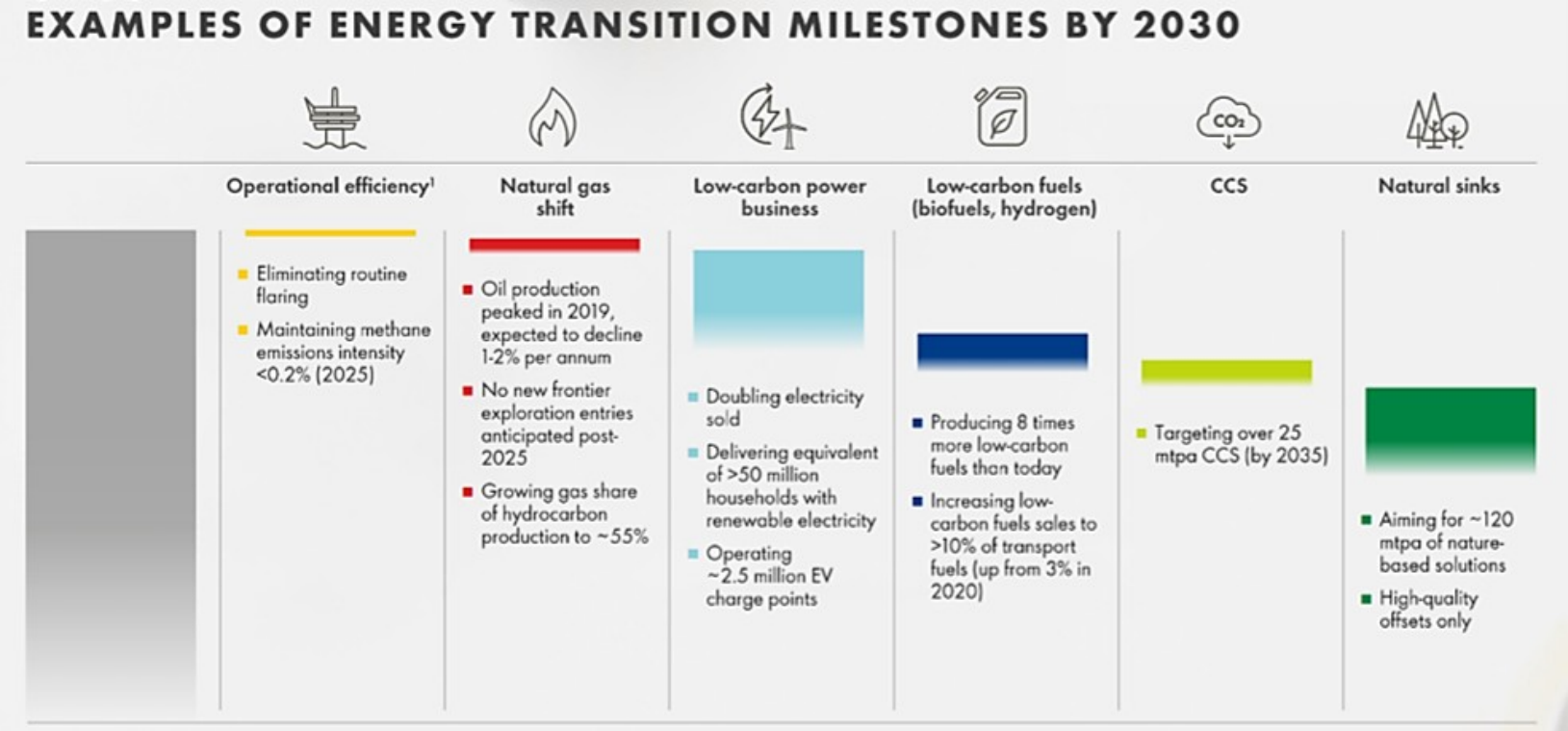
"CCS pathway" - carbon capture and storage for decarbonization
"RE pathway" - renewables as clean energy[1]

[1] Integrating artificial intelligence in energy transition: A comprehensive review

Pillars of the Modern Energy Transition



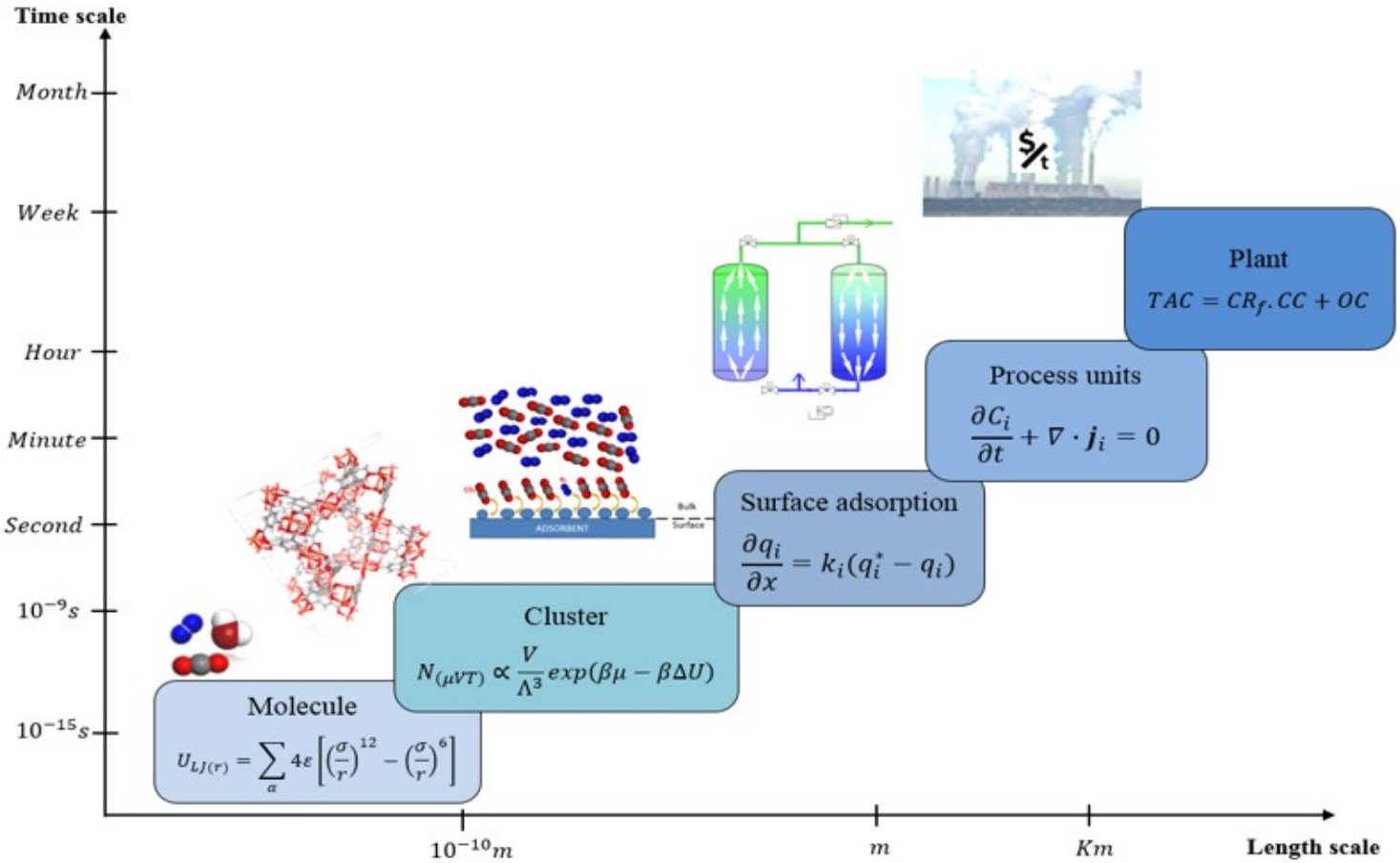
Energy Transition Milestones



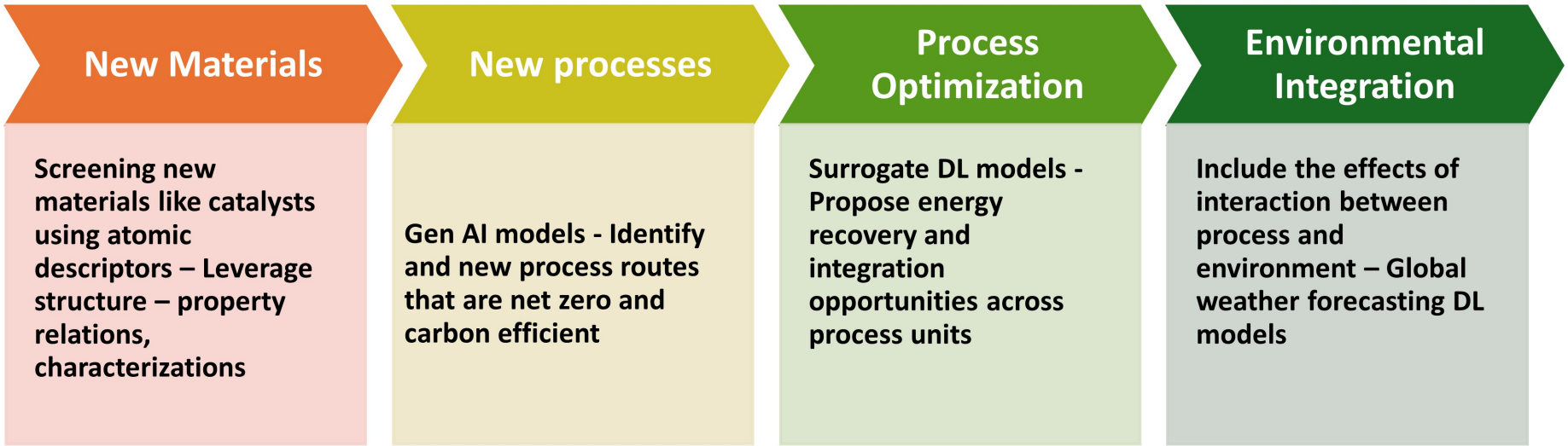
Q: However, can we be more informed?

A: Consider this as an optimisation (decision-making) problem.

Challenge : Problem of Multiscale



Potential Solution : The AI way



AI's role: **Accelerator**

AI Models: From Understanding to Creating

- Traditional AI tasks - understanding or discriminating between existing data points (e.g., classification, regression)
- Challenges of the energy transition require more than just analysis – it demands innovation, design, and the creation of novel solutions
- This necessitates a shift towards AI models capable of generation: creating new materials, designing efficient processes, and proposing innovative system configurations

Reference Books

- Trevor Hastie - **An Introduction to Statistical Learning: with Applications in R** (Springer)
- Christopher M. Bishop - **Pattern Recognition and Machine Learning** (Springer)
- Christopher M. Bishop - **Deep Learning: Foundations and Concepts** (Springer)
- Andrew Barto and Richard S. Sutton - **Reinforcement Learning: An Introduction** (MIT Press, Cambridge)
- Anoop Krishnan, Hariprasad Kodamana and Ravinder Bhattoo - **Machine Learning for Materials Discovery** (Springer)

Thank you!