Introduction to Artificial Intelligence and its Impact on Sustainable Development

Joe Tekli, Ph.D.
My Area of Expertise

- Web-based **semi-structured data** processing & applications
  - XML, RDF, & OWL are at the center stage of data engineering
    - Main building block toward **Intelligent Web Data Processing**

**DataBases**
Handling structured data and complex queries (e.g., SQL, grammars)

**Information Retrieval**
Handling flat data & ranked queries (e.g., keyword search)

**Data Mining**
Discovering & inferring hidden data patterns (e.g., clustering, classification)
Let’s try to look at the future…

Modern times (1936)

People are expected to spend less time on daily routines!
Content

- Introduction
- Definition of AI
- Fields of Study in AI
- Impact on Sustainable Development
- Wrapping up
Definition of AI

- We are called *Homo Sapiens* = the Wise Man
  - *Intelligence*: distinctive characteristic of the human race

- **What is Intelligence?**
  - Question with different perspectives: philosophical, scientific and moral
  - Intelligence characterizes the way we:
    - Think
    - Behave
    - Perceive things
    - Manipulate objects
    - Predict events
    - Interact with our environment
    - Communicate with other intelligent entities

- **Artificial Intelligence (AI):** field of study bridging *computer science* and *computer engineering*, aiming to create intelligent entities
There are different views of AI, aiming to simulate/create:

<table>
<thead>
<tr>
<th>Reasoning</th>
<th>Consistency with human performance</th>
<th>Consistency with ideal performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human Reasoning</td>
<td></td>
<td>Rational Reasoning</td>
</tr>
<tr>
<td>Human Behavior</td>
<td></td>
<td>Rational Behavior</td>
</tr>
</tbody>
</table>

**Definition of AI**

- There are different views of AI, aiming to simulate/create:
  - Human Reasoning
  - Rational Reasoning
  - Human Behavior
  - Rational Behavior
Definition of AI

In this context, we can redefine AI:
- Creation of rational (intelligent) agents capable of:
  - Perceiving their environment
  - Making decisions
  - To maximize their chances of achieving the desired goal
  - Given time constraints and restrictions in processing resources
  - While resisting noise/uncertainty, making decisions based on:
    - Incomplete
    - Inaccurate
    - Partially incorrect data

Deep blue vs. Kasparov, 1997
PackBot (US Army)
ASIMO (Hoda)
DART (US Army)
Content

- Introduction
- Definition of AI
- Fields of Study in AI
- Impact on Sustainable Development
- Wrapping up
Content

- Introduction
- Definition of AI
- Fields of Study in AI
  - Search Agents
  - Knowledge Representation
  - Natural Language Processing
  - Approximate Reasoning
  - Machine Learning
  - Social Intelligence
  - Evolutionary Computation
- Impact on Sustainable Development
- Wrapping up
1. Search Agents

- **Main Premise:** Solving a problem intelligently by searching for the best solution in a space of many possible solutions.

- **Problem definition:**
  1. Producing abstract mathematical representation of the environment - Called the state space: $S$, set of states an agent can find itself in.
  2. Identifying the set of actions an agent can undertake to change states - Called the transition model.
  3. Identifying the agent’s goal, i.e., the state(s) the agent needs to reach - Representing the solution(s) to the problem being formulated.
  4. Identifying the agent’s utility function, i.e., a cost function evaluating the quality of a given solution.

The agent is supposed to reach the optimal solution, i.e., the most cost effective solution.
1. Search Agents: Applications

Fields of Study in AI

GPS systems
Intelligent navigation & transportation systems
1. **Search Agents**: Applications

**Planning & Scheduling**

- 63 states

**Problem solving**

- 64 states

**Gaming & Simulation**

...
Content

- Introduction
- Definition of AI
- Fields of Study in AI
  - Search Agents
  - Knowledge Representation
  - Natural Language Processing
  - Approximate Reasoning
  - Machine Learning
  - Social Intelligence
  - Evolutionary Computation
- Applications of AI in Astronomy
- Wrapping up
2. Knowledge Representation

- Many of the problems machines are expected to solve will require extensive knowledge about the world

- **Main Premise**: Assigning information well defined meaning, to be automatically understood and processed by machines

- **Basic constructs:**
  - **Controlled vocabulary** (e.g., machine-readable dictionary)
    - A list of ordered words with explicit semantic meanings
  - **Thesaurus** (e.g., lexicon)
    - A dictionary enriched with semantic relations
      - Is-A, Related-To, Attribute-Of, See-Also, etc.
  - **Ontology** (e.g., knowledge base)
    - Thesaurus with an explicit formalization of relations
      - Using dedicated grammar rules
2. Knowledge Representation

- **Knowledge base** (e.g., ontology)
  - Modeled as a **Semantic Network**
    - Concepts connected via (hierarchical) relations

![Semantic Network Diagram]

- **Car**
  - A motor vehicle with four wheels

- **Cab**
  - A car driven by a person whose job is to take passengers where they want to go in exchange for money

- **Engine**
  - The machine that propels an automobile
2. Knowledge Representation

- **Knowledge processing**: evaluating relatedness between concepts

\[
\text{Dist}(c_1, c_2, SN) = \sum_{c \in \text{MinPath}(c_1, c_2, SN)} \text{Weight}(c_1, c, SN)
\]

\[
\text{Weight}(c_1, c_2, SN) = \left( \beta + (1-\beta) \times \frac{\text{Child}(SN)}{\text{Child}(c_2)} \right) \times \left( \frac{\text{Depth}(c_2) + 1}{\text{Depth}(c_2)} \right)^\alpha \times \text{Type}(c_1, c_2)
\]
Content

- Introduction
- Definition of AI
- Fields of Study in AI
  - Search Agents
  - Knowledge Representation
  - Natural Language Processing
  - Approximate Reasoning
  - Machine Learning
  - Social Intelligence
  - Evolutionary Computation
- Impact on Sustainable Development
- Wrapping up
3. Natural Language Processing

- **Speech Recognition:**
  - A traveler calling United Airlines can communicate and book tickets, using:
    - A system of automatic speech recognition and a dialogue management system
  - **SIRI:** mobile application using voice commands to manipulate mobile phone

“Hello World”
3. Natural Language Processing

- **Machine Translation:**
  - Hot research area, requiring combination of various NLP techniques including: semantic analysis, WSD, and DM,
    - **PanDoRa:** machine translation system for hand-held equipment (Carnegie Mellon)

- **Information Retrieval**
  - Core NLP components in state-of-the-art search engines

- **Information Extraction & Content Analysis**
  - Central in DM applications: Part-of-Speech tagging & Text categorization

- **Lexicography**
  - Creating domain specific dictionaries
3. Natural Language Processing

- Useful in many application scenarios:
  - Serving disabled people
    - Special aids for the blind
  - Telephony and related domains
    - Automated call management systems
  - Military
    - High-performance fighter aircrafts
    - Helicopters
    - Battle management
  - Medical field
    - Digital doctors and digital clinics
  - Home automation
Content

- Introduction
- Definition of AI
- Fields of Study in AI
  - Search Agents
  - Knowledge Representation
  - Natural Language Processing
  - Approximate Reasoning
  - Machine Learning
  - Social Intelligence
  - Evolutionary Computation
- Impact on Sustainable Development
- Wrapping up
4. Approximate Reasoning

- **Main premise:** The world is *imperfect, inaccurate, and full of uncertainty*
  - Need to add a **truth scale** between *true* and *false*
  - Pioneered in **Fuzzy Logic** (L. Zadeh)

- **Specifications:**
  1. Data: **Boolean Logic:** False (0) – True (1)
     **Fuzzy Logic:** 0 → 1
  2. Reasoning: **Boolean Logic:** Hypothesis ⇒ Conclusion
     **Fuzzy Logic:** Hypothesis ⇒ Conclusion with a degree of truth

- **Origins:** Eastern Reasoning originated with **Buddha** around 600 B.C.
  - Each and every entity contains a little of its inverse, $A$ and $\overline{A}$
  - E.g., *A person is partly good and partly bad* (Yang Yin)
4. Approximate Reasoning

Glimpse on Mathematical Constructs:

Ordered referential set

\[ A = \{0, 1, 2, 3\} \quad \text{and} \quad \overline{A} = \{4, \ldots, 8\} \]

\[ f^S_A(0) = 1 \quad \Rightarrow \text{Element } 0 \in A \text{ with } 100\% \text{ precision, i.e., } 0 \in 100\% \text{ in } A \]

\[ f^S_A(1) = 0.95 \quad \Rightarrow \text{Element } 1 \in A \text{ with } 80\% \text{ precision, i.e., } 1 \in 95\% \text{ in } A \]

\[ f^S_A(2) = 0.65 \quad \Rightarrow \text{Element } 2 \in A \text{ with } 65\% \text{ precision, i.e., } 2 \in 65\% \text{ in } A \]
4. Approximate Reasoning

Useful in many scenarios:

- Creating control systems based on the “human common sense”
  - Creating intelligent agents simulating human reasoning/behavior

- Used when it is difficult to utilize traditional mathematical methods
  - E.g., human reasoning is often non-deterministic or stochastic

- Creating reflex-based systems using condition-action rules

Some practical applications:

- **Autofocus** and **auto-tuning** in sensors (e.g., digital cameras)
- **Braking** and **handling** (gear change, acceleration) **systems in automobiles**
- **Speech recognition** in Natural Language Processing (NLP)
- **Robotic systems** simulating human (or animal) walk and/or behavior
Content

- Introduction
- Definition of AI
- Fields of Study in AI
  - Search Agents
  - Knowledge Representation
  - Natural Language Processing
  - Approximate Reasoning
  - Machine Learning
  - Social Intelligence
  - Evolutionary Computation
- Impact on Sustainable Development
- Wrapping up
5. Machine Learning

- **Machine learning** is the science of getting computers to act without being explicitly programmed.

- In the couple of years decade, *machine learning* has given us:
  - Self-driving cars, practical speech recognition, effective web search, among other applications, as well as a vastly improved understanding of the human genome…

  ![Key to make progress towards human-level AI](image)

- Machine learning techniques fall within two main categories:
  - *Supervised* learning
  - *Unsupervised* learning
5. Machine Learning

5.1. Supervised Learning:

- **Main premise:** Identifying an output measure based on input data
  - By mapping inputs to desired output
    - Using sample input/output data provided by experts: \textit{training data}

- Training data provided in the form of examples $(X_1, y_1), \ldots, (X_m, y_m)$
  - where $X$ is a vector of $x_1, \ldots, x_k$ input values
  - And $y$ is the output generated by unknown/desired activation function $f$

Discover a function $h$ that approximates the desired activation function $f$

- Approach known as \textit{classification}
5. Machine Learning

5.1. Supervised Learning:

- Cat. 1
- Cat. 2
- Cat. 3
- Cat. 4
- Cat. 5
5. Machine Learning

5.1. Supervised Learning:

- Different classification algorithms exist in the literature
  - E.g., Instance-based, Support Vector Machines, and Artificial Neural Networks

Inspired by biological brain: ideal learning/recognition system
5. Machine Learning

5.1. Supervised Learning:

- When the output of classifier is a numerical value (e.g., temperature degree)
  - The learning problem is called **regression analysis**

- We can approximate $f$ with different hypotheses, e.g., $h_\alpha, h_\beta,$ and $h_\gamma$
  
  $\Rightarrow$ We usually choose the **simplest** (following **Ockham’s razor**)

Major category of techniques allowing **predictability**
5. Machine Learning

5.2. Unsupervised Learning:

- **Main premise:** Finding a *hidden pattern*/structure in unlabeled data
  - Absence of an expert/knowledge about expected outputs for inputs
    ⇒ *Lack of training* data
    
    ![Learning without external intervention]

- **Typical approach:** *clustering*
  - Organizing/*grouping* related input data into *similar categories*
    - Based on the input data relatedness/*similarity* following certain features
      ⇒ Without any expert knowledge or training data
        - Sample clustering approaches:
          - Hierarchical agglomerative/divisive, partitional, spectral, etc.
5. Machine Learning

- Essential in many applications requiring:
  - Pattern learning
  - Pattern detection
  - Pattern recognition
  - Pattern discovery

- A pattern can be:
  - An audio signal
  - A still image
  - A moving image
  - A radio-wave
  - A sound-wave
  - A part of speech
  - …

Supervised learning

Unsupervised learning

Hand writing patterns

Ratio wave patterns

Star configuration patterns
Fields of Study in AI

Machine learning is useful as pre-processing
  - Preparing for other AI techniques
    - Search, knowledge representation, NLP, Reasoning, etc.
    - E.g., deciphering **alien alphabet**
Content

- Introduction
- Definition of AI
- Fields of Study in AI
  - Search Agents
  - Knowledge Representation
  - Natural Language Processing
  - Approximate Reasoning
  - Machine Learning
  - Social Intelligence
  - Evolutionary Computation
- Impact on Sustainable Development
- Wrapping up
6. Social Intelligence

- **Main premise**: Understanding human emotions and intentions, and reacting accordingly.

- **Reaction** depends on the goal of the intelligent agent being developed:
  - Conducted based on input from sentiment analysis.
Terms highlighting similar emotions usually show

- Similar syntactic distributions in a corpus

Lexical Context

W1 = \{2, 1, \ldots, 4\}

Context feature vector

- Co-occurrence
- Contextual
- Sentiment patterns

Sentiment Mining

- Decision trees
- Bayesian networks
- Support vector machines

Machine Learning

- Variance
- Correlation
- Regression analysis

Statistical Analysis
Fields of Study in AI

- Using **reference knowledge bases** describing affect sentiments
  - E.g., **WordNet Affect** and **SentiWordNet**
6. Social Intelligence

Assigning **sentiment scores** to data
- Text, images, audio, graph, etc.
  - Matched with input data to identify closest sentiment scores
6. Social Intelligence

- Central in many application scenarios:
  - Enhancing **social media** apps
    - With human like suggestions
  - **Customers reviews** on products
  - Information and **tutoring tools**
    - Digital instructors
  - **Elections** and **voting** stat analysis
    - Analyzing population mood
  - **Computational humor** systems
  - **Human-Computer interaction**
    - Human like robotics
What is Sustainable Development?

“Development that meets the needs of the present, without compromising on the ability for future generations to meet their needs”
Impact on Sustainable Development

AI can impact the 5 dimensions of sustainability

- Legal frameworks
- Organizational structures
- Emotional well-being
- Elderly care
- Work efficiency

- Fraud detection
- Connection & interactions
- Liability concerns
- Digital storytelling
- Health
- Trustworthiness
- Privacy concerns
- Knowledge management
- Planned obsolescence

- Organizational structures
- Further globalization
- Competitive investment
- Trade linkages
- Fiscal challenges
- Speech recognition
- Engineering ethics

- Social
- Economic
- Environmental
- Technical
- Individual

- Rise in unemployment
- Speech recognition
- Ethics
- Deep learning
- AI coding AI
- Visual object detection
- Responsibility
- Waste management
- Increase of gadgets
- Pollution reduction

- Education

Impact on Sustainable Development

1. Economic Dimension

- **Trend**: 40% of customer-facing employees will consult with AI for decision making and daily tasks
  - It will mainly happen in developed countries
    - CERN initiative to create European AI hub
    - French and German funding for AI

- **Upside**: Cheaper services in developed countries
  - Creation of high-end jobs back in-house

- **Downside**: Limited outsourcing to developing countries
  - Decreasing need for low-skilled workers
Impact on Sustainable Development

2. Technical Dimension

- **Trend**: Advances in ML and increase in computational power
  - Ushering in a whole bunch of practical applications

- **Upside**: Benevolent applications
  - Driverless cars, assistive agents (supporting elderly or disabled people), medical diagnosis through deep learning

- **Downside**: Warfare
  - Autonomous killer drones, swarm bots
3. Environmental Dimension

- **Upside:** Lots of potential
  - *Pattern recognition:* support waste and pollution management
    - Analyze state of animals and trees through imagery, *enhancing local biosphere*
    - Autonomous vehicles: eco-driving and faster routes, leading to *less pollution*
  - *Regression analysis:* predictive systems
    - Weather forecasting, environmental crises, likelihood of extreme events: *early warning*
3. Environmental Dimension

- **Downside:** Many dangers
  - **Planned obsolescence:** limited functional life of electronics, design for fashion
    - Competitive pressure
    - Lack of customer concern
  
- **Use of natural resources:** mining bots to extract rare earth materials like gold, silver, led, zinc, etc.
Impact on Sustainable Development

4. Individual Dimension

- **Upside:**
  - Can help reduce work hours
    - *Digital assistants, chat bots, analytical tools* can take over some of the simpler tasks
  - Medical and health informatics: from improved and *early diagnosis*, to *preventive care*, and *robotic surgery*

- Elderly care: *smart homes and robot nannies*
4. Individual Dimension

- **Downside:** Work overload
  - **Working more:** fast pace due to fast pace of technology and need to keep up
    - Less sleep and less exercise, leading to health and psychological problems
  - **Decreased human-human interaction:** due to work, social media, and digital games
    - Change in human behavior: becoming more isolated
      - Can lead to functional decline
  - **Reduced privacy:** social media and corporate hunger for data
    - Required to train more sophisticated AI systems
Impact on Sustainable Development

5. Social Dimension

◆ **Upside:**

◆ **Strengthen communities:** improve information and communication technologies
  - Development and maintenance of networks

◆ **E-Learning, E-shopping, E-business:** more efficient
  - Give you more time to socialize

Mail courier (1980s)

Instantaneous
Reliable
Global

In 30 years
Impact on Sustainable Development

5. Social Dimension

- **Upside:**
  - *AI promoting social wellbeing:* creating social campaigns (cleanliness on the road, stopping shisha smoking, building properly, anti-corruption campaigns)
    - Could be as simple as reminder of family birthdays: long time you haven't seen family, etc.

- **Downside:**
  - *Data privacy*
  - *Data or service provide trustworthiness*
  - *Increased reliance on AI:* if AI becomes increasingly used for social interactions: what if it forgets to remind us of a birthday?
  - What if AI results in injury or harm: whose to blame?
    - AI designer, data provider, or used interacting with the AI agent?
Wrapping up

AI can affect the 5 dimensions of sustainability

Legal frameworks  |  Organizational structures
---|---
Fraud detection  |  Further globalization
Connection & interactions  |  Rise in unemployment
Liability concerns  |  Competitive investment
Digital storytelling  |  Fiscal challenges
Reverse trend to outsourcing  |  Trade linkages
Emotional well-being  |  Speech recognition
Trustworthiness  |  Engineering ethics
Health  |  Ethics
Elderly care  |  Deep learning
Privacy concerns  |  AI coding AI
Work efficiency  |  Visual object detection
Education  |  Responsibility
Knowledge management  |  Planned obsolescence
Pollution reduction  |  Increase of gadgets
Waste management
Wrapping up

Recommendations to move in the right direction

- **Economic dimension:**
  - Workers need to be properly and continuously trained to become highly-skilled
    - Early retirement and frequent change of jobs…

- **Technical dimension:**
  - Revising technical code of ethics (e.g., ACM)
    - What AI should and should not do, liability, responsibility, etc.

- **Environmental dimension**
  - Corporate strategies needs to change: encouraging upgradeables/add-ons to the existing systems and re-use/re-cycling of existing ones
  - Increase consumer awareness: to reuse and follow functionality rather than fashion
Wrapping up

Recommendations to move in the right direction

- **Individual dimension**
  - *Adapting education:* need skills in mathematics, information technology, and scientific methodology: necessary to adapt to different jobs and tackling different problems
  - Education about dangers of technology and security risks, to avoid them

- **Social dimension:**
  - *Aligning the values* of all stakeholders, especially data producers and consumers
    - Citizens, civil society groups, news media, corporations, and governments
    - E.g., German government: *declaration on cooperation on AI*
  - *Refining legal framework* to handle AI related cases
17th century Amsterdam Town Hall
Wrapping up

“The unrestrained pursuit of profit poses serious threats to the soul of the nation”
Thank you!

The unrestrained pursuit of Data and AI poses serious threats to the soul of Humanity

joe.tekli@lau.edu.lb
Definition of AI

1. Simulating Human Reasoning

• Creating a system that thinks like a human being

• This requires further study and understanding of the inner-workings of the human mind, which researchers are trying to achieve by:

  • **Introspection**: The subject examines her own method of analysis (we ask questions like: "How do I form ideas", "how do I create logical connections", etc.).

  • **Experimental Psychology**: Observing other subjects in action, their behavior, their reactions to different cognitive stimuli, etc.

  • **Study of the human brain**: through enhanced brain imaging and analysis techniques, allowing to identify and study neural activity, changes in synaptic performance, etc.
2. Simulating **Rational Reasoning**

- Creating a system that **thinks correctly**: *ideal thought*
- Aristotle (384-322 BC) was the first to codify **correct reasoning**
  - He introduced *syllogism*: a logical reasoning method, defining the formal structure of an argument
    - Based on two premises, and leading to a conclusion
    - Example: All men are mortal, Aristotle is a man, therefore Aristotle is mortal

  ![Foundations of modern day Logic](image)

- **Obstacles to rational thinking:**
  - Difficulty in dealing with uncertain information
  - Theoretical problem solving is not always practical (time limits & computing resources)
3. Simulating Human Behavior

- Creating a system that behaves like a human being
  - The Turing test, proposed by Alan Turing in 1950, designed to test the ability of a machine to mimic human conversation
    - A machine passes the Turing test if, after a number of questions, the human tester (asking questions) cannot know if the answers come from a human or a machine
  - To pass the test, a machine must be able to perform:
    - Natural language processing in order to communicate with the human partner
    - Knowledge representation, knowledge to effectively store and handle information
    - Automatic reasoning, in order to use the stored information to answer questions
    - Machine learning, to evolve and adapt its behavior according to the constraints at hand (e.g., adapting to the tester’s questions).
Definition of AI

4. Simulating **Rational Behavior**

- Creating a system that **behaves correctly**
  ⇒ Creating **rational agents**:  
    - A rational agent is a computer system assumed to function autonomously, with the capacity of:  
      - Perceiving its environment  
      - Adapting to changes  
      - Creating and pursuing its own goals

  **Persisting without (human) assistance**, for a long time!

- Which brings us to **cybernetic systems**:  
  - Acting on their environment, considering changes in the environment in order to control/adapt their behaviors accordingly
Content

- Introduction
- Definition of AI
- Fields of Study in AI
  - Search Agents
  - Knowledge Representation
  - Natural Language Processing
  - Approximate Reasoning
  - Machine Learning
  - Social Intelligence
  - Evolutionary Computation
- Impact on Sustainable Development
- Wrapping up
7. Evolutionary Computation

- **Main premise**: The AI system should be able to **create** and **pursue its own goals**
  - To **persist without** (human) **assistance**, for a long time
  - To **expand its knowledge** beyond predefined constraints
  - **To take the initiative: to **evolve**!**

- **Evolutionary computation**
  - Inspired by the **Darwinian Theory of Evolution**
    - **Genetic algorithms**
      - Mimicking genetic processes nature uses
7. Evolutionary Computation

- **Background in genetics:**
  - Every *organism* has a set of rules
  - Rules are encoded in the *genes*
  - Genes are connected together to form *chromosomes*
  - Each gene specifies a certain *trait*
    - Hair Color, Eye Color, etc.
  - Each gene can have different *settings*
    - Blue, Brown, etc.
  - Organisms mate: *crossover of genes* to produce *offspring*
  - Genes can *mutate* over time, result in new unexpected genes
  - Only the genes producing the *fittest* organisms survive
7. Evolutionary Computation

- **Background in genetics:**
  - **Reproduction** (crossover)
  - **Diversification** (mutation)
  - **Natural selection** (survival of fittest)
7. Evolutionary Computation

- Each node represents a **city**
- Each edge represents a **route**
- Objective: identify most effective Hamiltonian path

- **Example:**

  **Travelling Salesman Problem**

  - Sample start chromosome: \(ABCDEF\)
  - Single gene mutation: \(ABCDEF \Rightarrow ABCCBA\) ✗ Non-fit
  - Gene swapping: \(ABCDEF \Rightarrow ABDECF\)
  - Crossover: \(ABCDEF + FEDCBA = ABCCBA\) ✗ Non-fit
  - Crossover: \(ABCDEF + FEDCBA = ABCFED\) ✓ Fit
7. Evolutionary Computation

- **Same process mimicked in GA:**
  - An *organism* represents a solution to a problem
  - A *gene* represents a sequence of symbols
  - Simulating *crossover* and *mutation* functions
  - **Fitness** is evaluated using a *performance function*
    - To be maximized/minimized
  - Multiple *generations* are created
    - Until reaching the fittest

Reaching *unexpected/new* results
7. Evolutionary Computation

- Applications scenarios
  - Antenna design
  - Drug design
  - Electronic circuits design (e.g., Koza)
  - Turbine engine design (e.g., GE)
  - Auto design (e.g., GM/Red Cedar)
  - Network design
  - Control systems design
  - Satellite design
  - Stock/commodity analysis/trading
  - Factory floor scheduling (e.g., Volvo, Deere)
  - Mission analysis and planning (e.g., NASA, US military)