

Introduction to Civil Information Systems

Mark A. Austin

University of Maryland

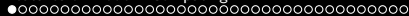
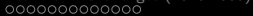
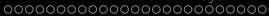
austin@umd.edu

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Overview

- 1 Modern Civil Infrastructure Systems
 - Industrial Revolution
 - Post- Industrial Revolution
 - Transition to Information Era
- 2 Near-Term Challenges (2020-2060)
 - Crisis in US Infrastructure Investment
 - Urbanization and Sustainable Cities
- 3 Features of Modern Computing
- 4 Urban and Global Applications
- 5 Summary (Connections to Scientific Computing)



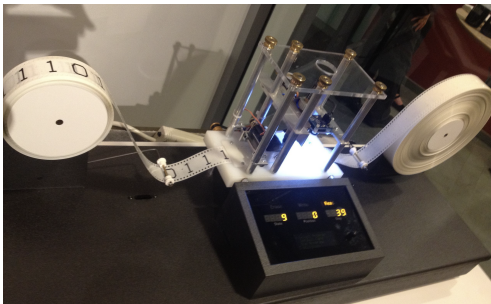
Features of Modern Computing

Key Question: How can we use modern computing technologies to **improve** Civil Engineering Systems?

Early Models of Computing

Turing Machine Model: 1930s ...

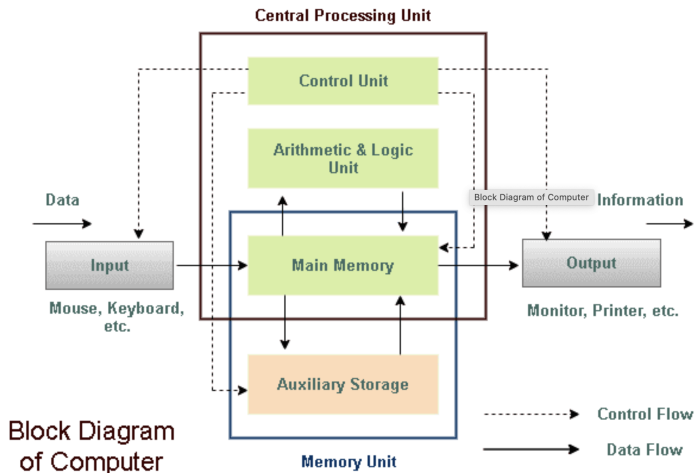
- Alan Turing (1936) created the **Turing machine** that included the **idea** of a **computer program**.



- Turing showed that you can **compute anything** using only **6 primitives**: right, left, print, scan, erase, nothing.

Early Models of Computing

Block Diagram of a Computer: 1980s ...



Block Diagram of Computer

State-of-the-Art Computing

What does a modern computer do?

- Performs calculations – **billions** (sometimes even trillions) of **calculations per second**.
- Remembers results – **gigabytes** and terabytes of **storage**.

Modern Programming Languages

- **Modern programming languages** have a **more convenient set of primitives**.
- Can abstract methods to create new primitives (e.g., user-defined objects).
- **Anything computable in one language** is **computable in any other programming language**.

Man and Machine (Traditional View)

Man	Machine
<ul style="list-style-type: none">● Good at formulating solutions to problems.● Can work with incomplete data and information.● Creative.● Reasons logically, but very slow.● Performance is static.● Humans break the rules.	<ul style="list-style-type: none">● Manipulates Os and 1s.● Very specific abilities.● Requires precise descriptions of problem solving procedures.● Dumb, but very fast.● Performance doubles every 18-24 months.● Machines will follow the rules.

Sensible Problem Solving Strategy

Let engineers and computers play to their strengths:

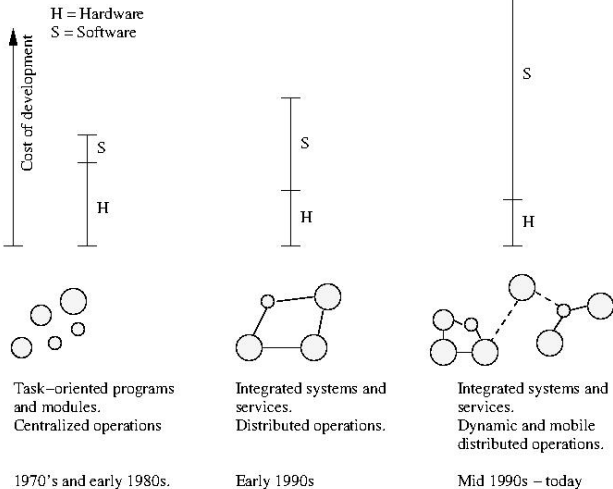
- Accelerates the solution procedure.
- Enables the analysis of problems having size and complexity beyond manual examination.
- Adds value in areas that will lead to long-term economic growth.

Getting things to work We need to:

- Describe to the computer solution procedures that are completely unambiguous.
- Look at data, organization and manipulation of data, and formal languages.

Expanding Expectations of Computing

Economics of computing and systems development



Evolution of Computer Languages

Computer Languages. Formal description – **precise grammar** – for how a problem can be solved.

Evolution. It takes about a decade for significant advances in computing to occur:

Capability	1970s	1980s	1990s
Users	Specialists	Individuals	Groups
Usage	Numerical computations	Desktop computing	E-mail, web, file transfer.
Interaction	Type at keyboard	Screen and mouse	audio/voice.
Languages	Fortran, C	MATLAB	Python, Java

Popular Computer Languages

Tend to be **designed** for a **specific set of purposes**:

- FORTRAN (1950s – today). Stands for formula translation.
- C (early 1970s – today). New operating systems.
- C++ (early 1970s – today). Object-oriented version of C.
- MATLAB (mid 1980s – today). Stands for matrix laboratory.
- Python (1990s – today). Object-oriented scripting language.
- HTML (1990s – today). Layout of web-page content.
- Java (1994 – today). Object-Oriented language for network-based computing.
- XML (late 1990s – today). Description of data on the Web.

Post- 2000 Era

Imagine: What if COVID-19 had arrived in 2000?

- No iPhone, No iPad, No iTunes.
- No Facebook, No Instagram, No WhatsApp.
- No Google Maps, No Google Streetview.
- No Dropbox, No Zoom.

Recent Advances in Technology:

- Average internet speeds: In 2000, 0.07 Mbs; In 2009, 5-7 Mbs; In 2020, 100-200 Mbs; 5G, 1000-2000 Mbs.
- Cloud-based data storage and computational services (AWS).
- New languages: [Swift](#) → App development on [iPhone/iPad](#).
- Many new types of [sensors](#) and [methods of data collection](#).

Post-2010 Era → Emergence of AI

State-of-the-Art Implementation (2020, Google, Siemens, IBM)

- AI and ML will be **deeply embedded** in new **software and algorithms**.

Artificial Intelligence:

- **Knowledge representation** and **reasoning** with ontologies and rules. Semantic graphs. Executable **event-based processing**.

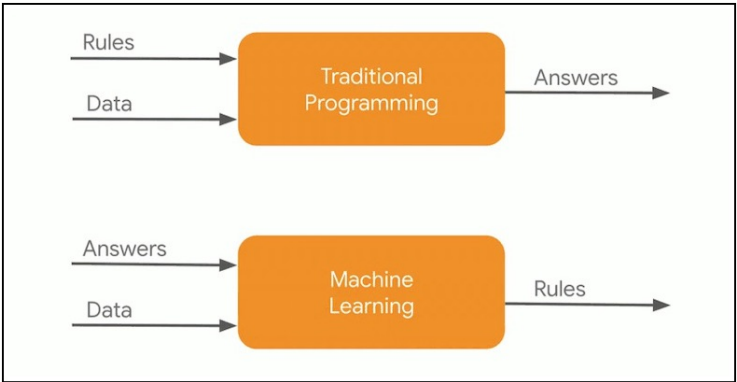
Machine Learning:

- Modern neural networks. Input-to-output prediction.
- Data mining.
- Identify **objects**, **events**, and **anomalies**.
- Learn structure and sequence. **Remember stuff**.

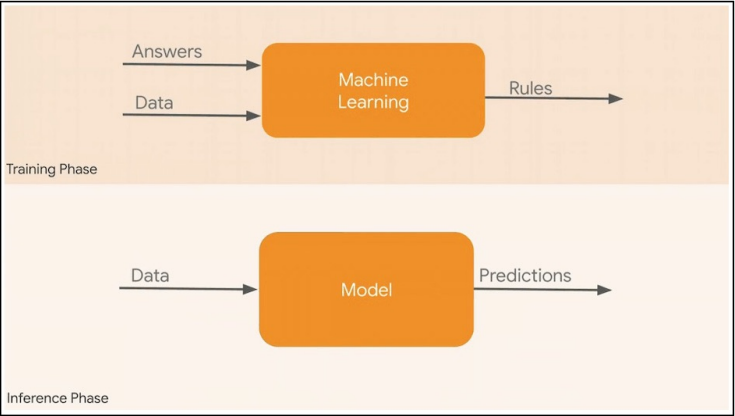
Man and Machine (AI-ML View)

Man	AI-ML Machine
<ul style="list-style-type: none"> • Good at formulating solutions to problems. • Can work with incomplete data and information. • Creative. • Reasons logically, but very slow. Forgetful. • Performance is static. • Humans make the rules, then they break them. 	<ul style="list-style-type: none"> • Manipulates 0s and 1s. • Can work with incomplete data and information. • Creative. • Fast logical reasoning. • Performance doubles every 18-24 months. • Data mining can discover the rules.

Traditional Programming vs AI-ML Workflow

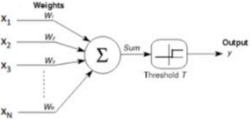


Traditional Programming vs AI-ML Workflow



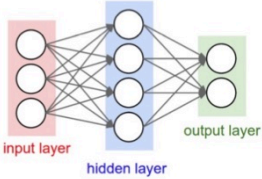
Machine Learning Capabilities (1980-1990)

Expressive Power of a Neural Network

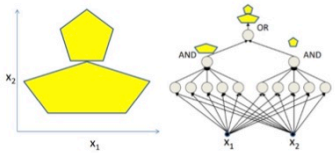
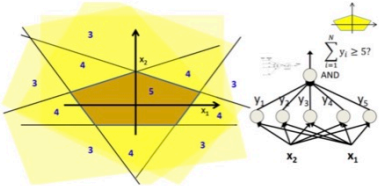


$$y = \begin{cases} 1 & \text{if } \sum_{i=1}^d w_i x_i \geq T \\ 0 & \text{else} \end{cases}$$

Neural Network with Single Hidden Layer



Approximation of Functions / Boolean Logic

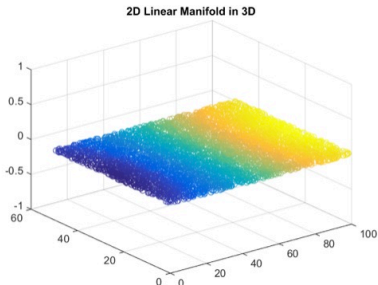
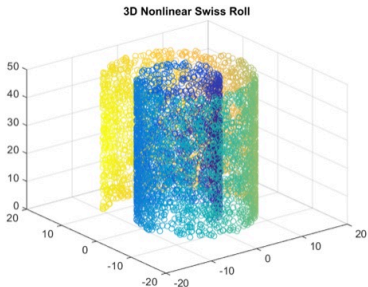


Classification of Machine Learning Problems

Dimensionality Reduction

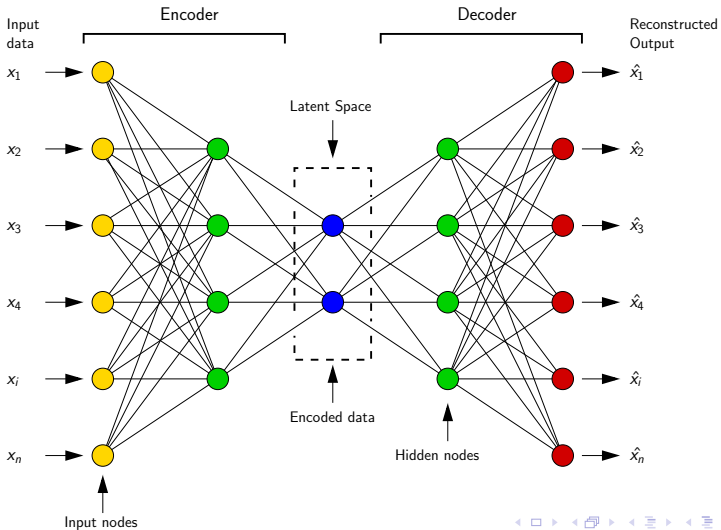
Strategies of **dimensionality reduction** involve transformation of data to new (lower) dimension in such a way that some of the dimensions can be **discarded without** a **loss of information**.

Example: Projection of Swiss Roll data in 3D to 2D ...



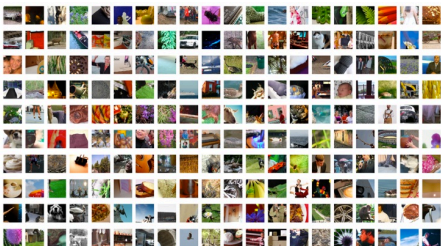
Classification of Machine Learning Problems

AutoEncoder (Encoder-Decoder-Reconstruction)



Classification of Machine Learning Problems

ImageNet and Deep Learning (2009-present)



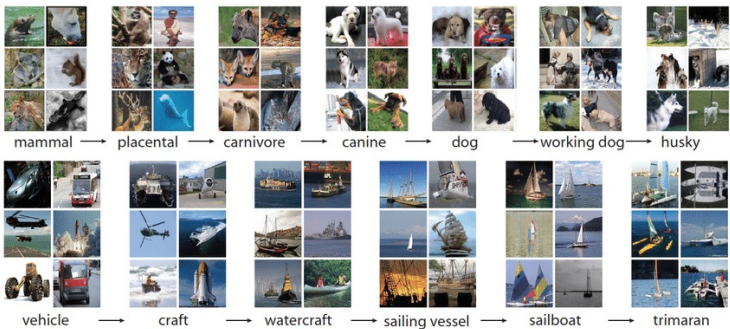
Indexed Database of 14.2 million Images

- Project initiated by Fei Fei Li in 2006
- Image annotation process crowd sourced via Amazon's Mechanical Turk. Categories derived from WordNet.
- Well organized → supervised machine learning.

Classification of Machine Learning Problems

ImageNet and Deep Learning Capabilities:

- Identify objects in an image.
- 27 high-level categories; 21,800 sub-categories.



ImageNet and Deep Learning

Capabilities (2018):

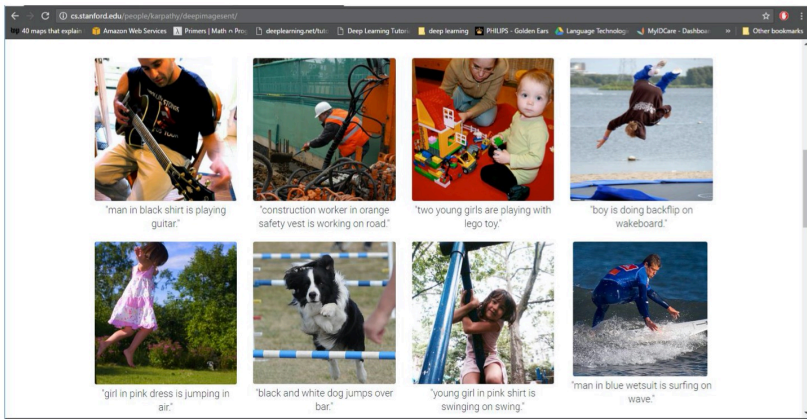
- Identify relationship among multiple objects in a image.

Example. Dog riding skateboard



ImageNet and Deep Learning

Captions generated by a neural network:



The screenshot shows a web browser window with the URL `cs.stanford.edu/people/karpathy/deepimagesent/`. The browser's address bar and tabs are visible at the top. Below the browser window, eight images are displayed in a 2x4 grid, each with a caption generated by a neural network. The captions are:

- "man in black shirt is playing guitar."
- "construction worker in orange safety vest is working on road."
- "two young girls are playing with lego toy."
- "boy is doing backflip on wakeboard."
- "girl in pink dress is jumping in air."
- "black and white dog jumps over bar."
- "young girl in pink shirt is swinging on swing."
- "man in blue wetsuit is surfing on wave."

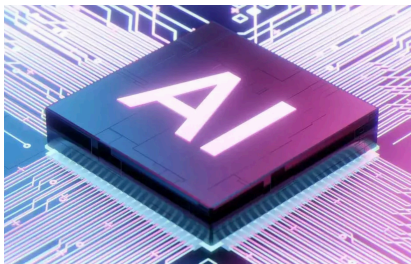
Machine Learning at Scale

Object-recognition module:

- 24 million nodes; 140 million parameters; 15 billion connections.

Source: Fei Fei Li, TEDTalk, YouTube 2015.

AI Chips: Nvidia, Google TPUs, etc ...



Machine Learning at Scale (Transformers)

Input

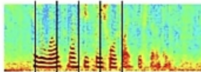
Output

Pixels:



"leopard"

Audio:



"How cold is it outside?"

"Hello, how are you?"



"Bonjour, comment allez-vous?"

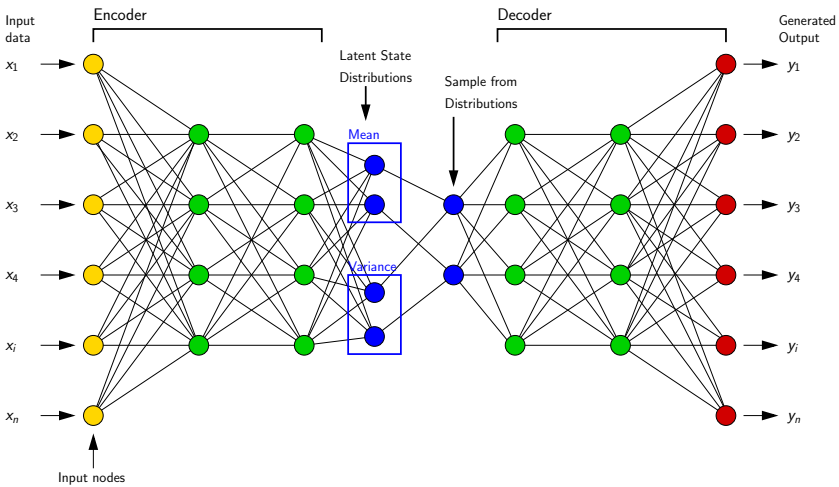
Pixels:



"A cheetah lying on top of a car"

Post-2020 Era → Explosion of Generative AI

Variational AutoEncoders (Generative Models)

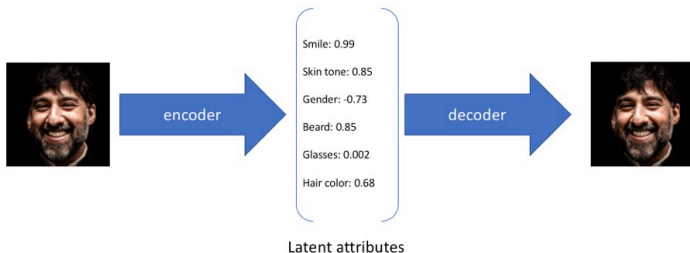


Post-2020 Era → Explosion of Generative AI

Standard Autoencoders vs. Variational Autoencoders:

- A **standard autoencoder** outputs a **single value** for each **encoding dimension**.
- **Variational autoencoders** provide a **probability distribution** for each latent attribute.

Example: Single value representations for latent attributes:



Post-2020 Era → ChatGPT

ChatGPT: Generative Pre-Trained Transformer

AU

write paragraph on civil engineering



Civil engineering is a fundamental discipline that shapes and transforms the physical infrastructure of our modern world. It encompasses the design, construction, and maintenance of a vast array of structures and systems, ranging from buildings, bridges, and roads to water supply networks, sewage systems, and environmental protection facilities. Civil engineers are responsible for ensuring the safety, functionality, and sustainability of these essential structures that support and enhance our daily lives. Their work involves a deep understanding of materials, mechanics, geotechnical engineering, structural analysis, and urban planning. By integrating scientific principles with innovative technologies, civil engineers address societal needs, address challenges posed by urbanization, and contribute to the creation of resilient and efficient urban environments. Whether it's developing eco-friendly infrastructure, earthquake-resistant buildings, or efficient transportation systems, civil engineering remains at the forefront of shaping a better and more connected world.



🔄 Regenerate

Send a message



Post-2020 Era → ChatGPT

AU

integrate $\sin(3x) \cdot \sin(2x)$ dx

To integrate the expression $\int \sin(3x) \cdot \sin(2x) dx$, we can use the product-to-sum trigonometric identity, which states that:



$$\sin(A) \cdot \sin(B) = (1/2) \cdot [\cos(A - B) - \cos(A + B)].$$

Using this identity, we can rewrite the integral as:

$$\begin{aligned} \int \sin(3x) \cdot \sin(2x) dx &= (1/2) \int [\cos(3x - 2x) - \cos(3x + 2x)] dx \\ &= (1/2) \int [\cos(x) - \cos(5x)] dx. \end{aligned}$$

Now, we can integrate each term separately:

$$\int \cos(x) dx = \sin(x) + C_1,$$

$$\int \cos(5x) dx = (1/5)\sin(5x) + C_2.$$

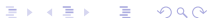
Putting it all together:

$$\begin{aligned} \int \sin(3x) \cdot \sin(2x) dx &= (1/2) \cdot [\sin(x) + C_1 - (1/5)\sin(5x) - C_2] \\ &= (1/2) \cdot [\sin(x) - (1/5)\sin(5x)] + (C_1/2 - C_2). \end{aligned}$$

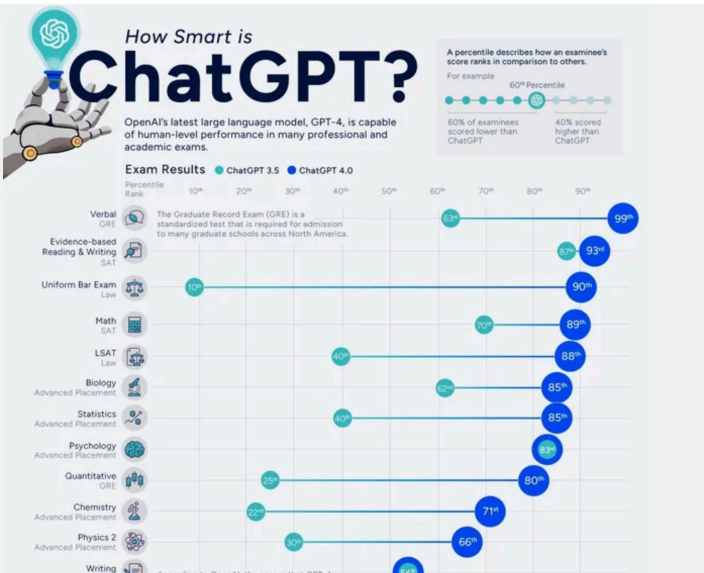
So, the integral of $\sin(3x) \cdot \sin(2x)$ with respect to x is:

$$\int \sin(3x) \cdot \sin(2x) dx = (1/2) \cdot [\sin(x) - (1/5)\sin(5x)] + C,$$

where $C = C_1/2 - C_2$ is the constant of integration.



Post-2020 Era → ChatGPT



Post-2020 Era → AI Video Presentation



Machine Learning in CEE

Opportunities for Machine Learning in CEE:

- Predicting system response and performance.
- Interpreting data and formulating models to predict component and subsystem-level properties.
- Information retrieval from images and text.
- Recognizing patterns in streams of sensed data.

Economic Considerations (CS Perspective):

- Urban infrastructure is permanent/semi-permanent and very expensive to build and maintain.
- Prioritize improvements to efficiency by identifying and removing bottlenecks in performance.
- Use AI-ML to identify events, cause-and-effect relationships, and design of actions that enhance system performance.

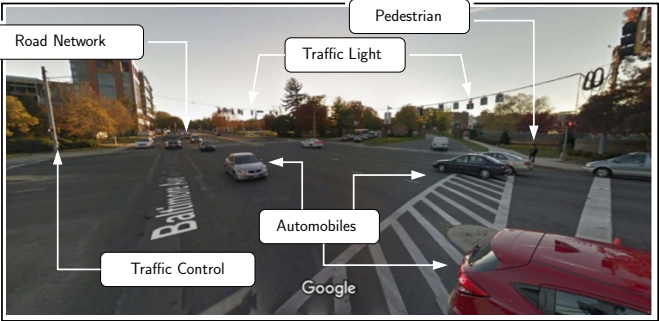
AI-ML Enabled Decision Making

AI Traffic System: Reduced congestion and accident rates:



AI-ML Enabled Decision Making (Self-Driving Cars)

Goal. How to traverse traffic intersection safely and without causing an accident?

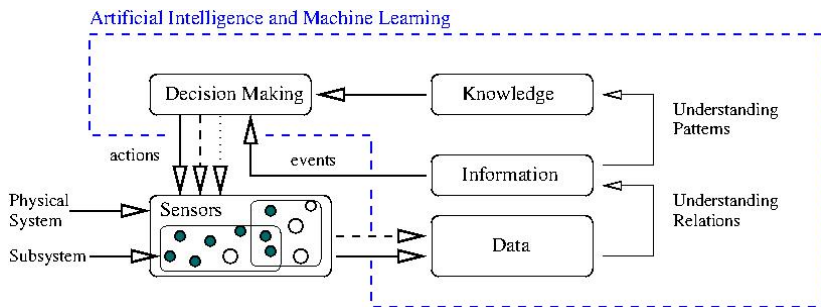


Required Capability. Observe, evaluate, reason, take actions.

Challenges. Multiple domains, multiple streams of heterogeneous data, event-driven behavior, dynamic, time critical.

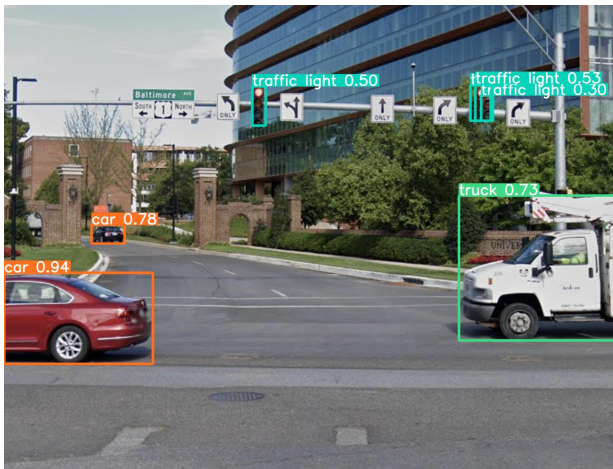
AI-ML Enabled Decision Making (Self-Driving Cars)

Solution Procedure. Pathway from sensing and data collection to ... action ... improved performance, now enabled by AI and ML capabilities:

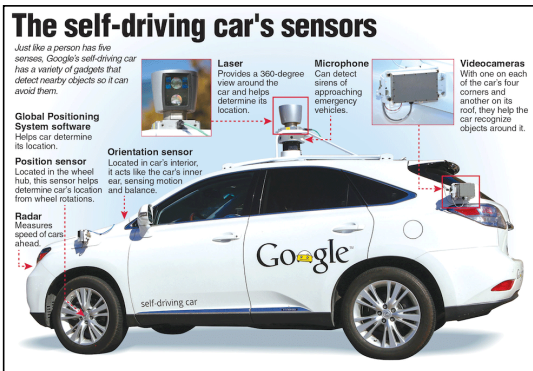


AI-ML Enabled Decision Making (Self-Driving Cars)

Ainur's Experiments with Computer Vision (OpenCV):



AI-ML Enabled Decision Making (Self-Driving Cars)



Today: Modern automobiles → 100 million lines of software.

Tomorrow: Self-Driving automobiles → 200-300 million lines of software.

Google DeepMind (2018-2020)

Teach Self-Driving Cars to Navigate a City without a Map



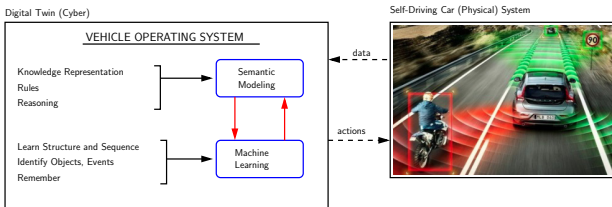
Test Cities: London, Paris, New York.

Digital Twin Systems

New Computing Infrastructure → New System Abstractions

Digital Twins (2000-today)

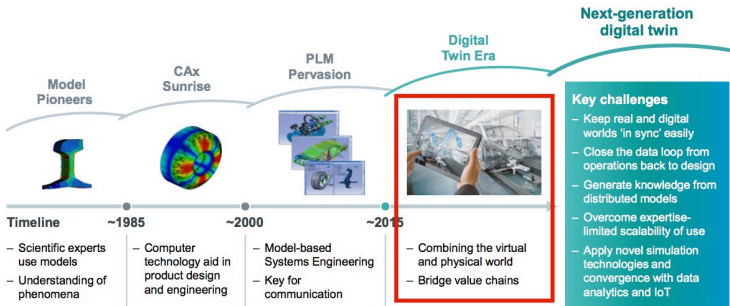
Definition. Virtual representation of a physical object or system that operates across the system lifecycle (not just the front end).



Required Functionality

- Mirror implementation of physical world through real-time monitoring and synchronization of data with events.
- Provide algorithms and software for observation, reasoning, and physical systems control.

Digital Twins (Business Case + Applications)



Many Applications

- NASA Spacecraft
- Manufacturing processes
- Building operations
- Personalized medicine
- Smart Cities
- ... etc.

Digital Twins (Technical Implementation)

Technical Implementation (2023, Google, Siemens, IBM)

- AI and ML will be **deeply embedded** in new **software and algorithms**.

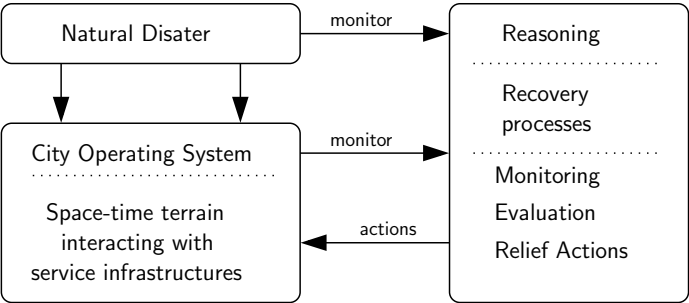
Artificial Intelligence:

- **Knowledge representation** and **reasoning** with ontologies and rules. Semantic graphs. Executable **event-based processing**.

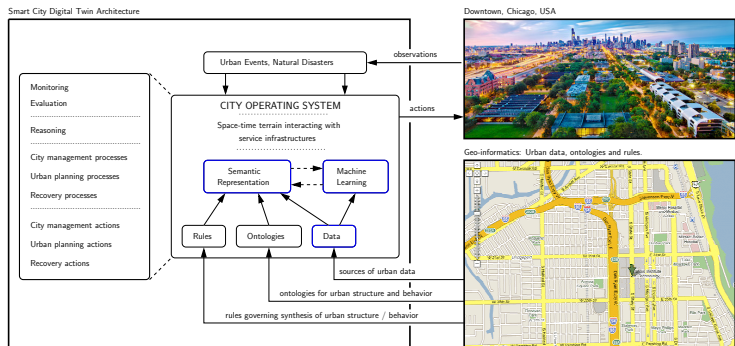
Machine Learning:

- Modern neural networks. Input-to-output prediction.
- Data mining.
- Identify **objects**, **events**, and **anomalies**.
- Learn structure and sequence. **Remember stuff**.

Digital Twin: City Operating Systems



Smart City Digital Twins (2018-2019)

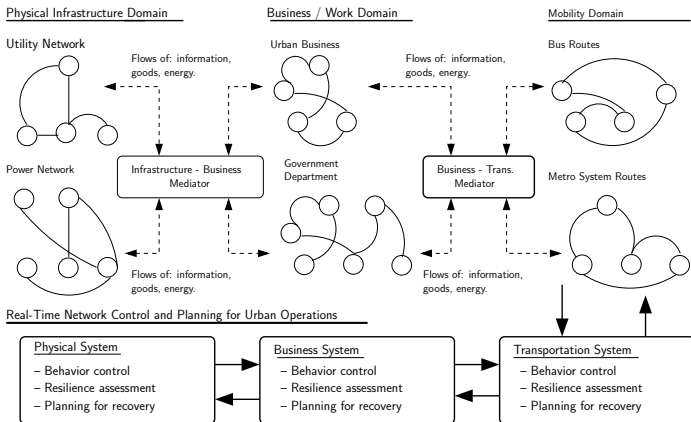


Required Capability. Monitoring and control of urban processes.

Complications. Potentially, a very large number of digital twins.

Distributed decision making.

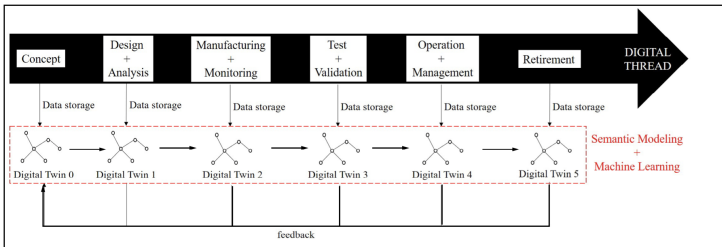
Smart City Digital Twins (2018-2019)



Requirements. Support for digital twin **individuals** and digital twin **communities**.

Digital Thread Systems

Digital Threads: (Cradle-to-Grave Lifecycle Support) ...



Graph-based Approach

A lot of **model-centric engineering** boils down to representation of systems as graphs and sequences of graph transformations punctuated by **decision making** and **work/actions**.

