INDIAN INSTITUTE OF INFORMATION TECHNOLOGY

Systems Engineering Management

Dr. Animesh Chaturvedi

Assistant Professor: IIIT Dharwad

Post Doctorate: King's College London & The Alan Turing Institute

PhD: IIT Indore MTech: IIITDM Jabalpur

Systems Engineering Management

- Complex systems,
- Interdisciplinary Science, Engineering, and Management,
- Systems theory,
- Systems thinking,
- System development life cycles,
- Synergy,
- Project management,
- Engineering Domains (Industry 4.0),
- Communities (INCOSE and IEEE SMC Society).

Systems Engineering Management

- An interdisciplinary field of engineering and management
- Focuses on System's
  - design,
  - development,
  - integrate,
  - testing,
  - maintenance, and
  - evolution
- Uses principles of
  - Systems thinking principles and
  - System life cycles.

https://en.wikipedia.org/wiki/Systems_engineering

Systems Engineering Definitions

- "… On large-scale-system problems, teams of scientists, engineers, generalists as well as specialists, expert their joint efforts to find a solution and physically realize it…" — *Harry H. Goode & Robert E. Machol, 1957.* [1]

- "… each system is an integrated whole even though composed of diverse, specialized structures and sub-functions…" — *Systems Engineering Tools by Harold Chestnut, 1965.* [2]

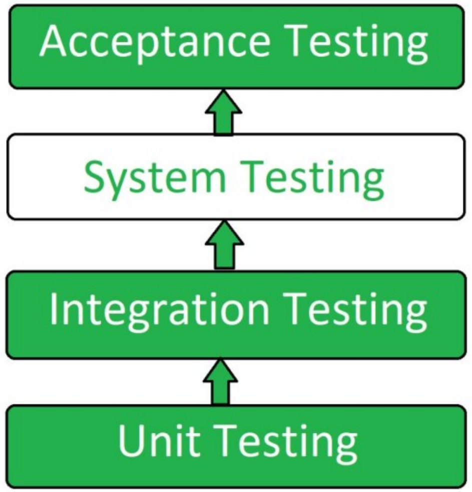
[1] Goode, Harry H.; Robert E. Machol (1957). "*System Engineering: An Introduction to the Design of Large-scale Systems*". McGraw-Hill. p. 8. LCCN 56011714.

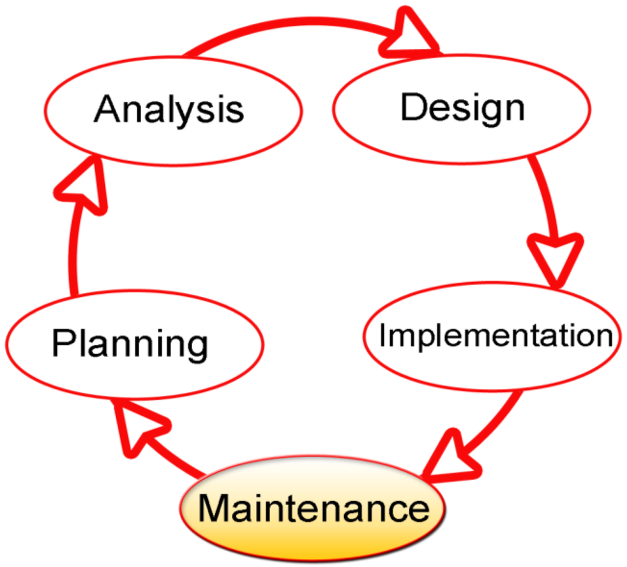
[2] Chestnut, Harold (1965). *Systems Engineering Tools*. Wiley. ISBN 978-0-471-15448-8.

https://en.wikipedia.org/wiki/Systems_engineering

Systems Engineering Definitions

- "…a robust approach to the design, creation, and operation of systems. … identification and quantification of system goals, creation of alternative system design concepts, performance of design trades, selection and implementation of the best design, verification that the design is properly built and integrated, and post-implementation assessment …" *NASA Systems Engineering Handbook, 1995.* [3]



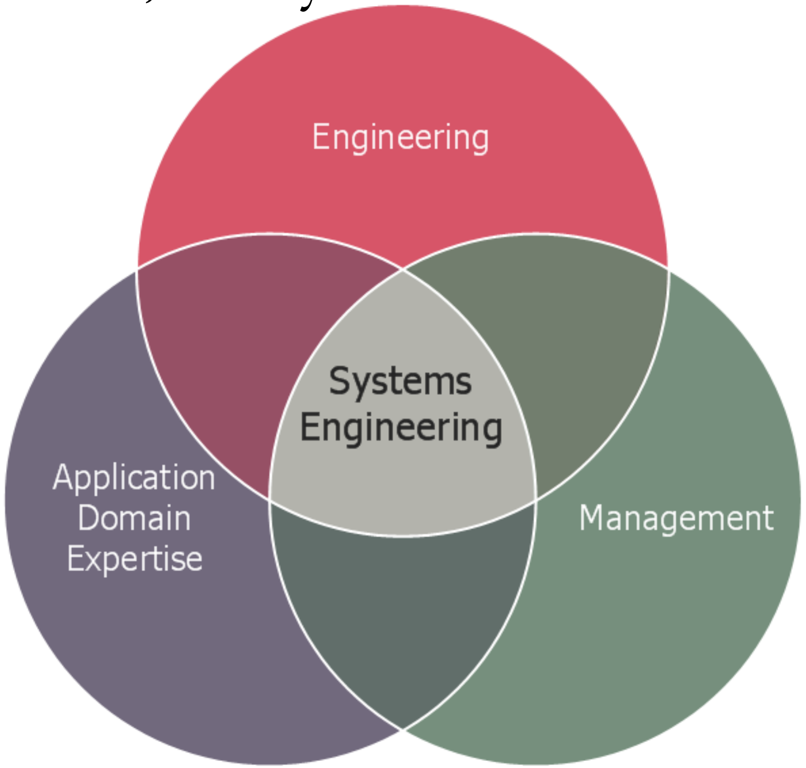


[3] *NASA Systems Engineering Handbook*. NASA. 1995. SP-610S.

https://en.wikipedia.org/wiki/Systems_engineering

Systems Engineering Definitions

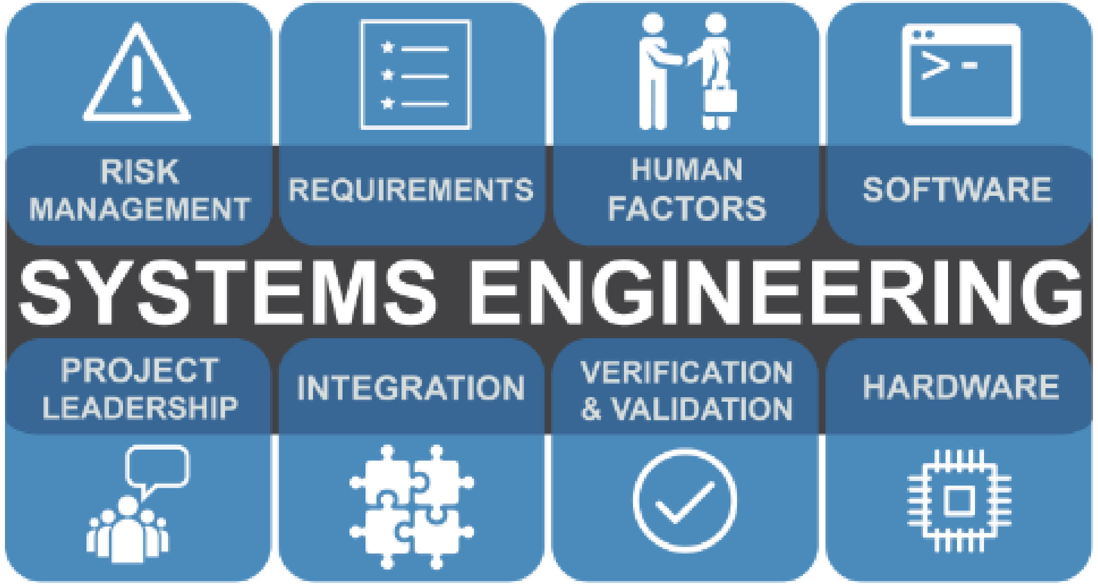
- "…a system is an integrated composite of people, products, and processes that provide a capability to satisfy a stated need or objective." [4]
- "Systems engineering consists of two significant disciplines: the technical knowledge domain in which the systems engineer operates, and systems engineering management." [4]



[4] *Systems Engineering Fundamentals.* Defense Acquisition University Press, 2001

Systems Engineering Definitions

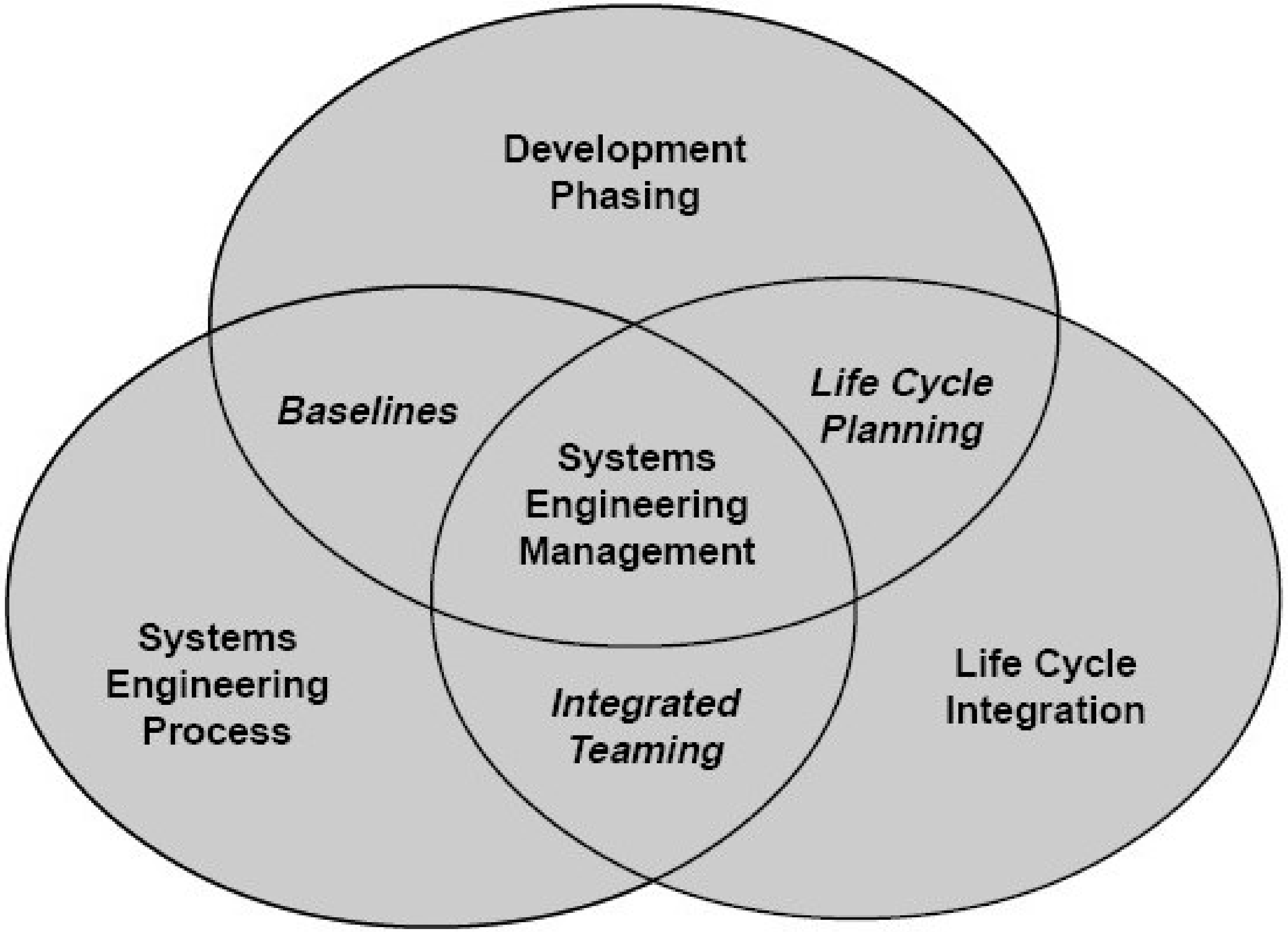
- "An interdisciplinary approach and means to enable the realization of successful systems" *INCOSE handbook, 2004.* [5]
- "…a branch of engineering which concentrates on the design and application of the whole as distinct from the parts, looking at a problem in its entirety, taking account of all the facets and all the variables and linking the social to the technological." *Conquering Complexity, 2005.* [6]



[5] *Systems Engineering Handbook*, version 2a. INCOSE. 2004.

[6] *Conquering Complexity: lessons in defence systems acquisition*, The Defence Engineering Group. University College London. 2005.

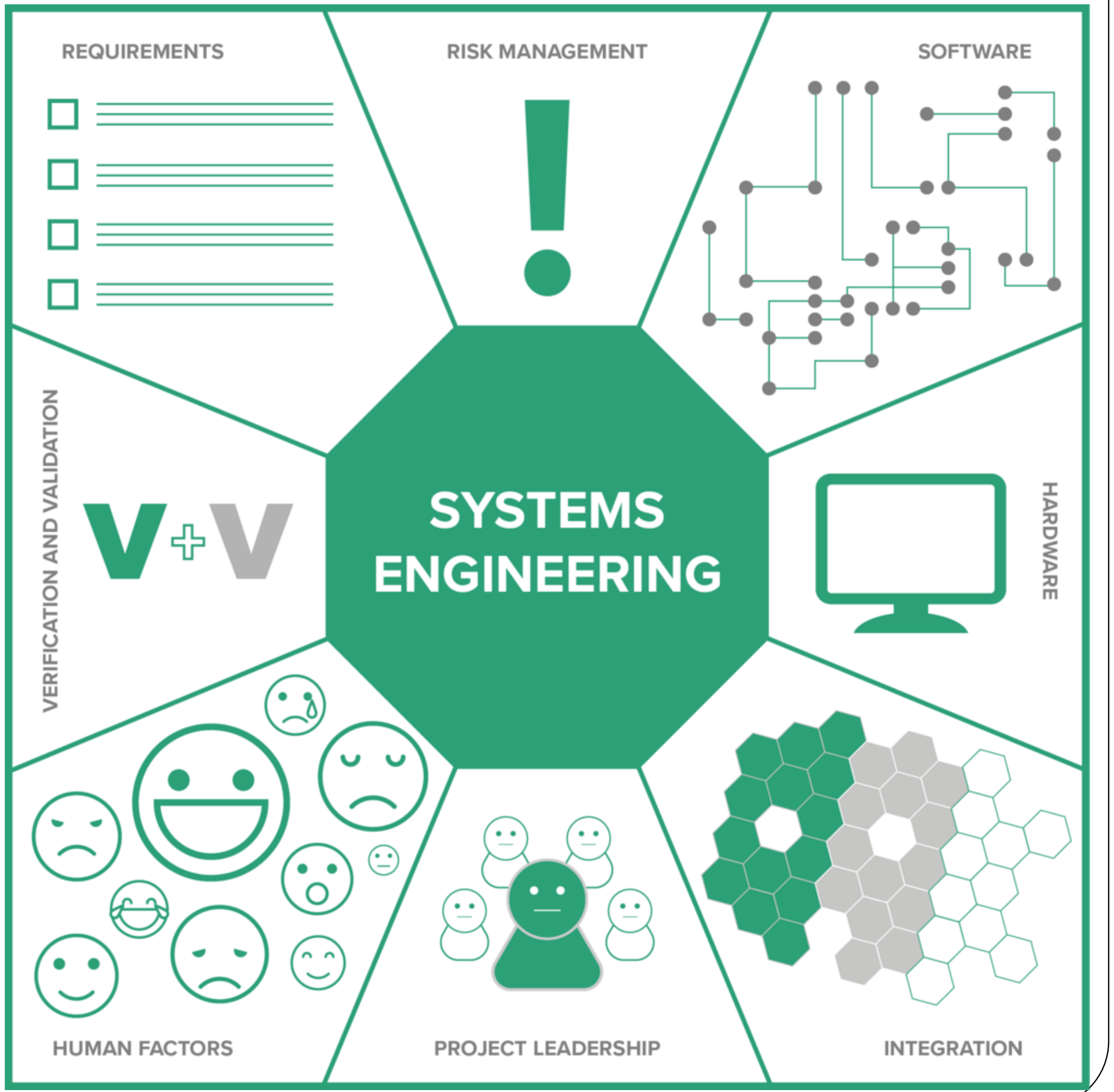
Systems Engineering Management Activities



[4] *Systems Engineering Fundamentals.* Defense Acquisition University Press, 2001

Systems Engineering Activities

- Use of tools to validate assumptions or theories on systems and its internal interactions between components
  - System architecture,
  - System model, Modeling, and Simulation,
  - Optimization,
  - System dynamics,
  - Systems analysis,
  - Statistical analysis,
  - Reliability analysis, and
  - Decision making



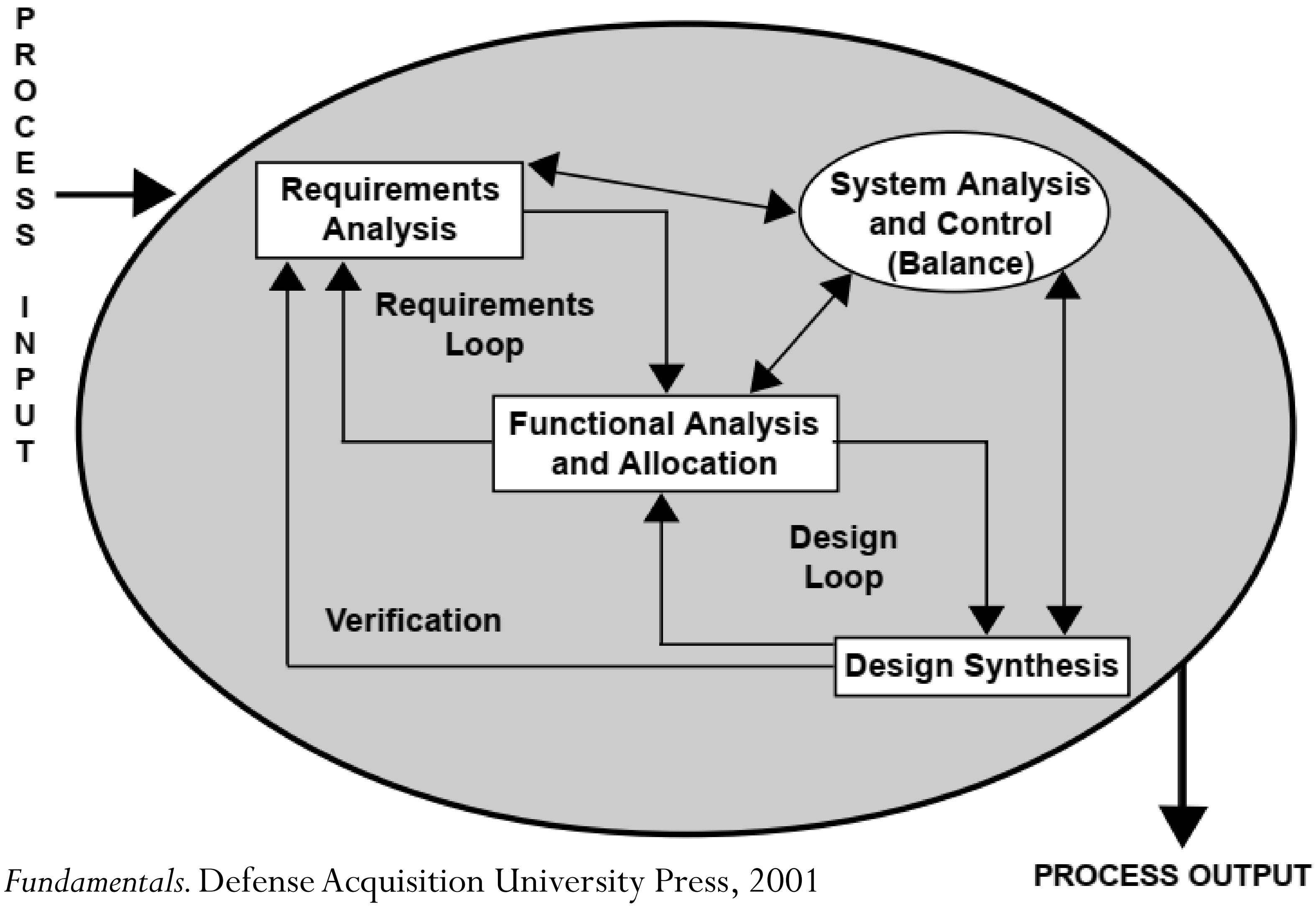
[4] *Systems Engineering Fundamentals.* Defense Acquisition University Press, 2001

Systems Engineering Processes

- Encompasses manual and technical activities to define the product and which need to be carried out to convert a system definition to a sufficiently detailed system design specification for product manufacture and deployment.
- Design and development of a system can be divided into four stages, each with different definitions:
  - task definition (informative definition),
  - conceptual stage (cardinal definition),
  - design stage (formative definition), and
  - implementation stage (manufacturing definition).

https://en.wikipedia.org/wiki/Systems_engineering

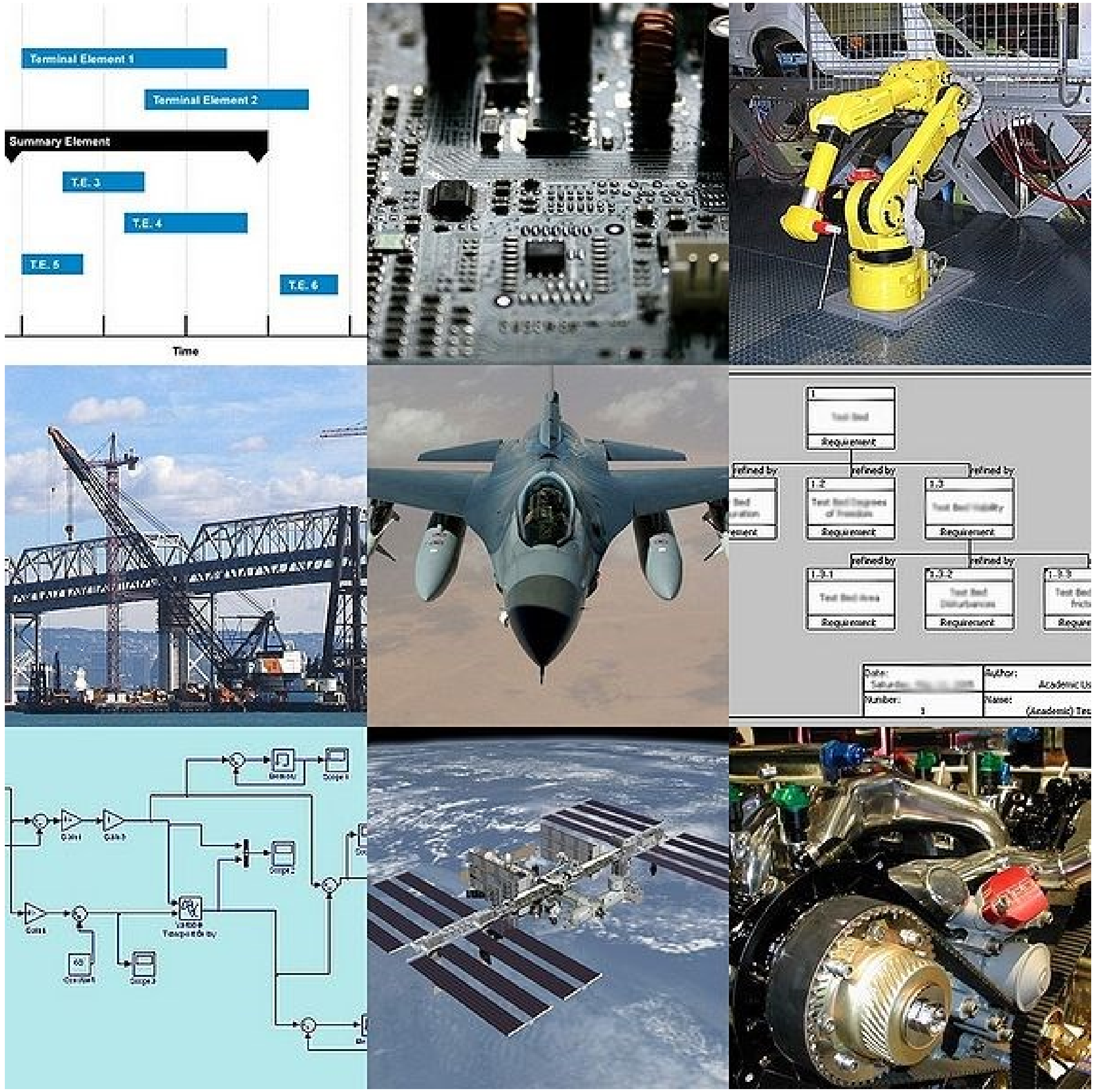
Systems Engineering Processes



[4] *Systems Engineering Fundamentals*. Defense Acquisition University Press, 2001

Systems Engineering Examples

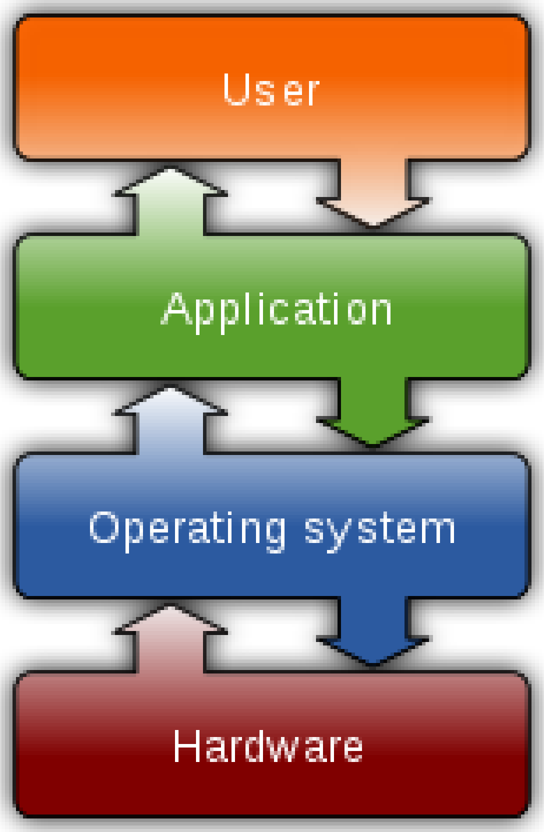
- Systems engineering helps in complex projects: spacecraft design, computer chip design, robotics, software integration, and bridge building.
  - Modeling,
  - Simulation,
  - Requirements analysis,
  - Scheduling,
  - Manage complexity

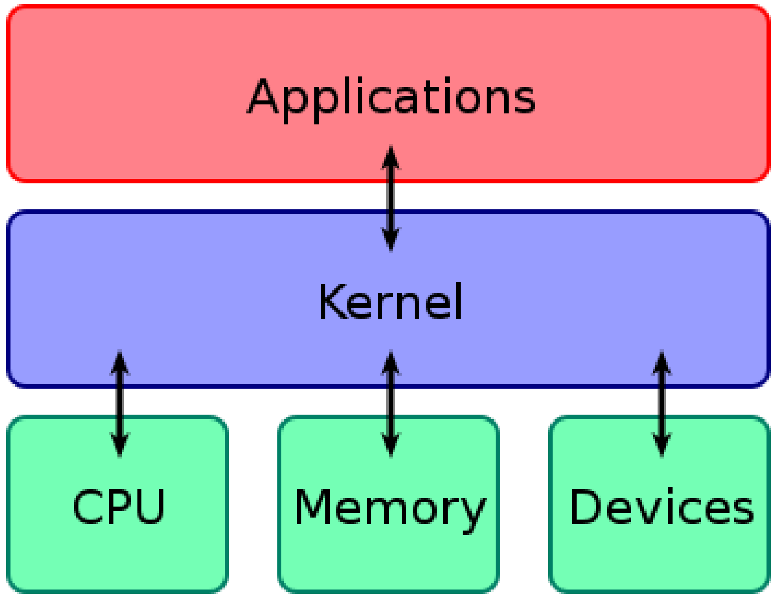


https://en.wikipedia.org/wiki/Systems_engineering

SysEng: Operating system

- Kernel manages the connection between application software with the hardware of a computing machine.

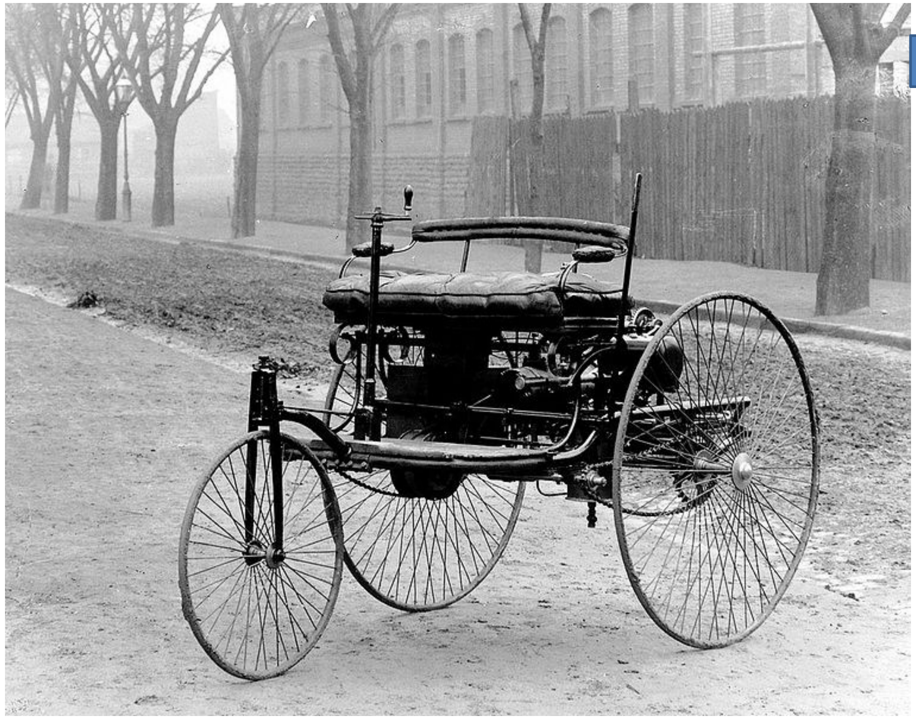


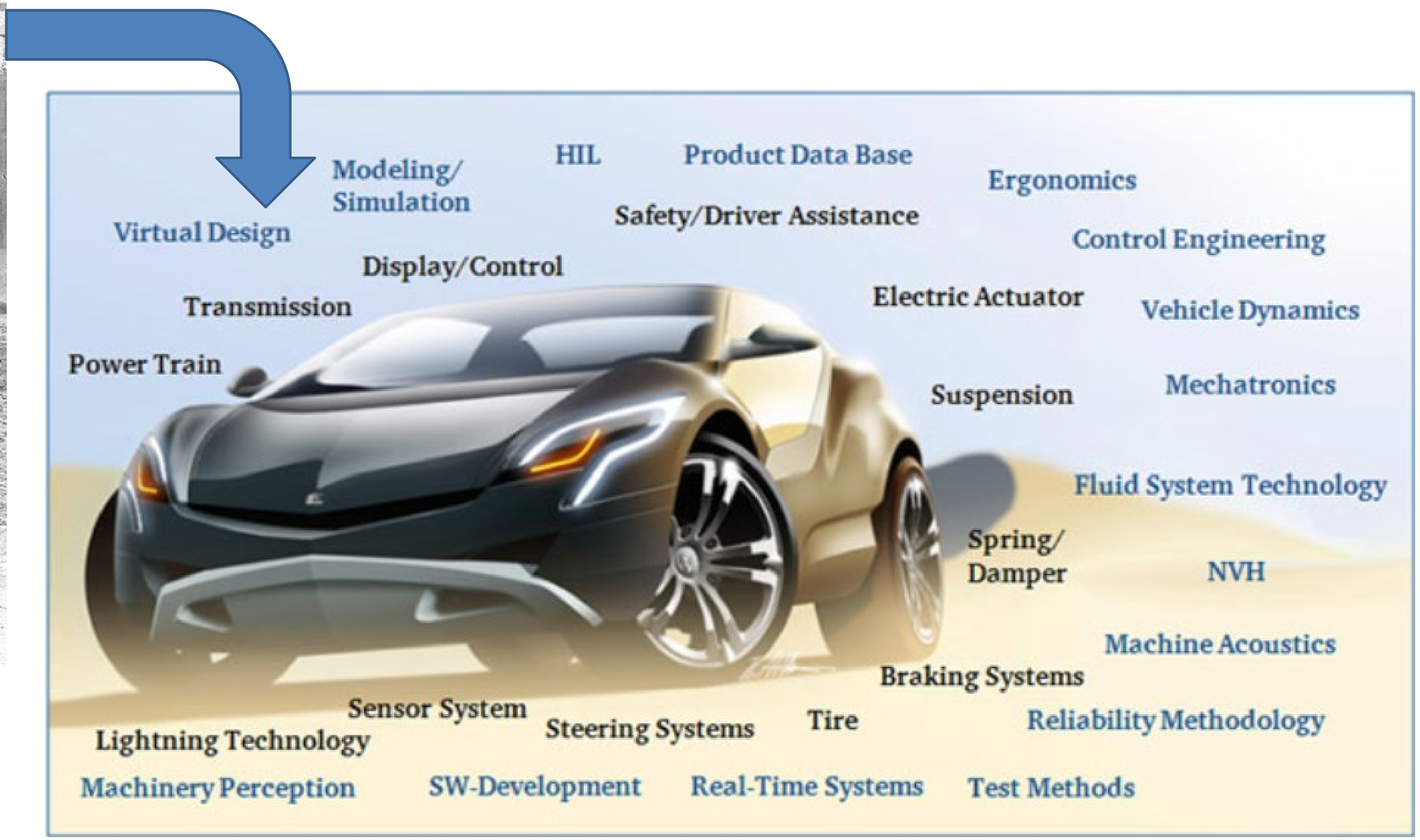


https://en.wikipedia.org/wiki/Operating_system

SysEng: Automobile systems

- Automobile systems from 1 engineer to 1000s of engineer working to built modern automobile





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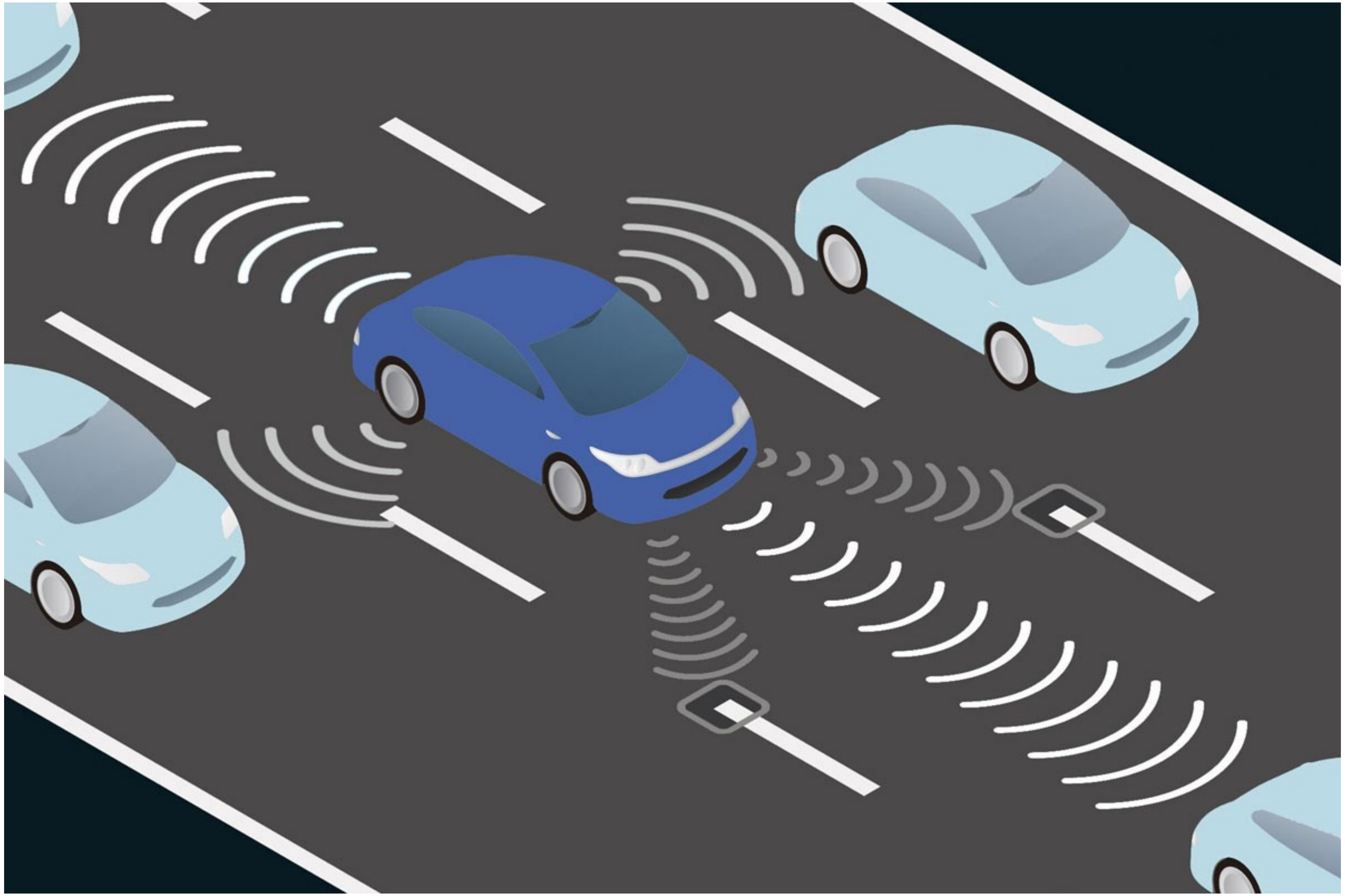
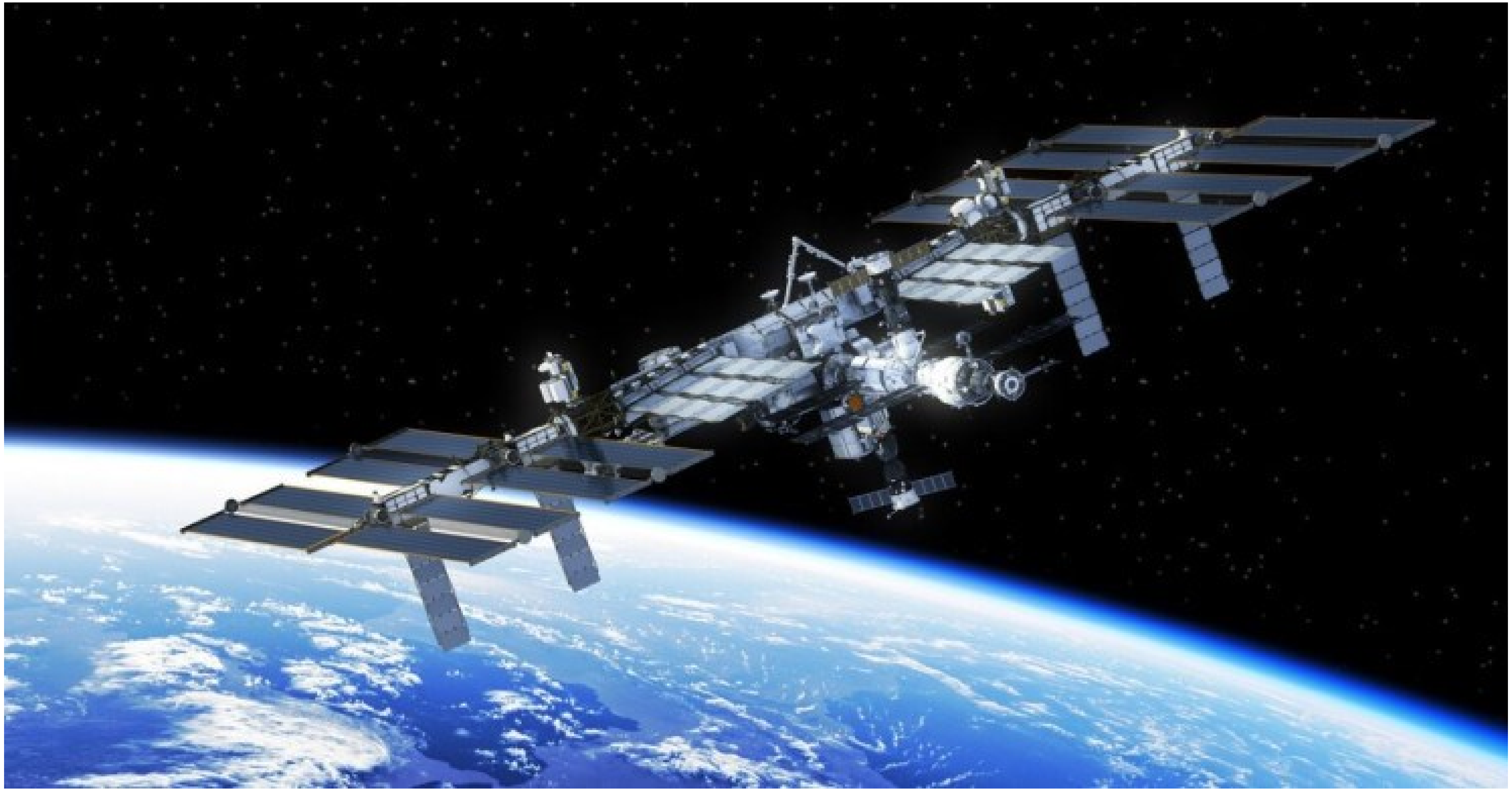
Autonomous Automobile Systems

Autonomous Automobile Systems

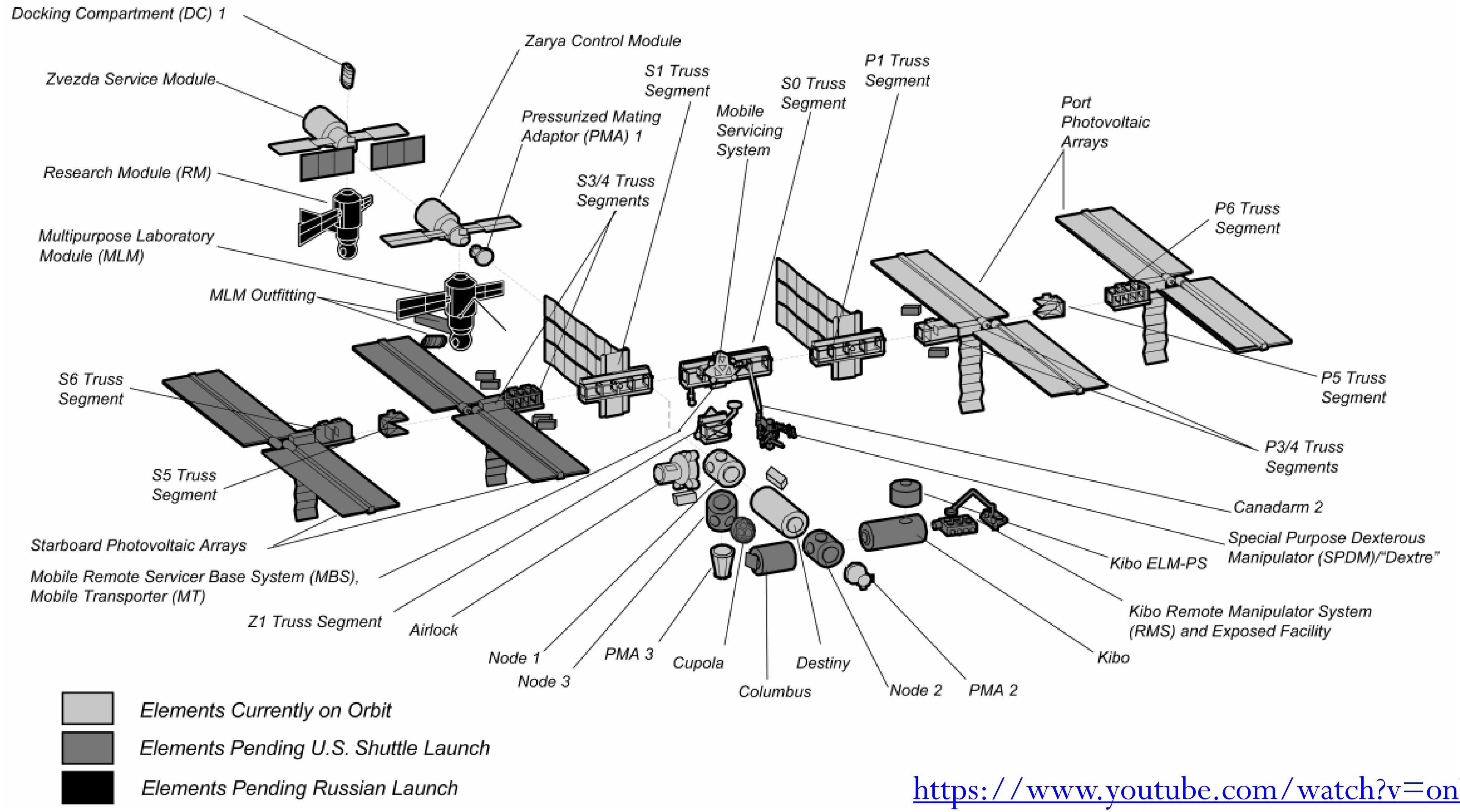


International Space Station (ISS)



https://en.wikipedia.org/wiki/Systems_engineering

ISS Components



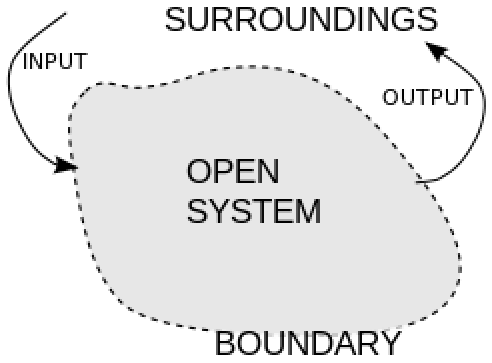
https://www.youtube.com/watch?v=onVhbeY7nLM

[7] *International Space Station Basics*, National Aeronautics and Space Administration (NASA).

Complex systems

Complex system

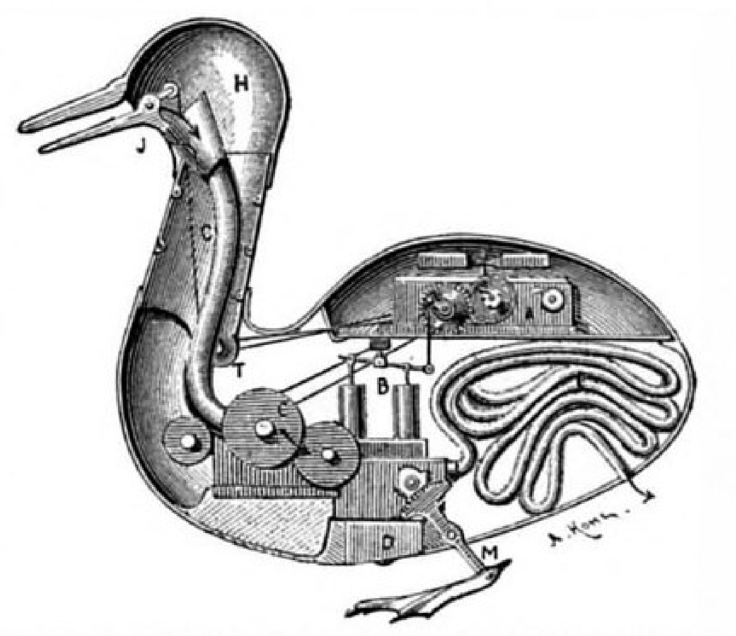
- An interdisciplinary domain
- Composed of many components (or entities) interacting with each other.
  - power grid, transportation or communication systems,
  - social and economic organizations (like cities),
  - organisms, a living cell, the human brain, and
  - an ecosystem, climate, entire universe.
- Behavior is hard to model with dependencies, relationships,
  - interactions between their components or
  - interactions between system and its environment



https://en.wikipedia.org/wiki/Complex_system

Complex system and Reductionism

- Reductionism is old domain since 16th century
- explains system in terms of parts and their interactions
  - Define a domain of possible parts
  - Generate inputs over the interaction between parts
  - Perform a deterministic computation on the input data
  - Aggregate the results
- interprets a complex system as the sum of its parts

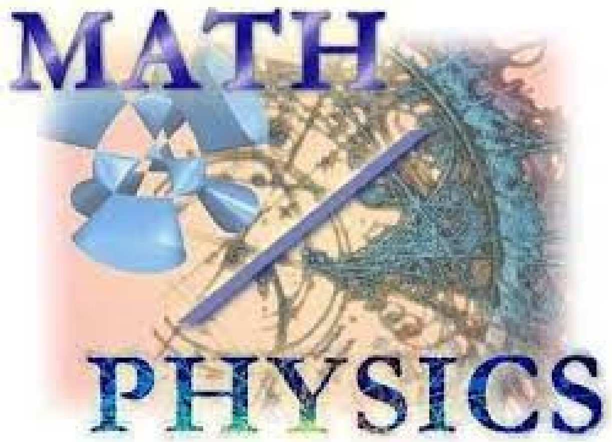


Complex system properties

- **Nonlinearity:** a set of simultaneous equations with the variables of a polynomial degree higher than one
- **Emergence:** entities have properties emerging only when the they interact together
- **Spontaneous order** arises from interactions between component of disordered system
- **Adaptation:** behavior of mutation and self-organization for the changes
- **Feedback loops:** outputs are routed back as inputs as part of a chain of cause-and-effect that forms a circuit or loop

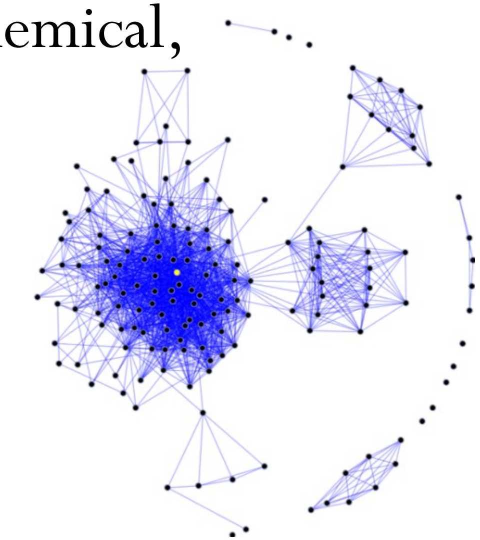
Complex system and Disciplines

- **Statistical physics:** methods of probability theory and statistics, and mathematical tools
  - deals with large populations and approximations,
- **Information theory:** quantification, storage, and communication of information (e.g. signals)
  - Subfield of Communication, Electronics, and Computer Science
- **Nonlinear dynamics:** the change of the output is not proportional to the change of the input.
  - Changes in variables over time, or, space etc.
  - Measures chaotic, unpredictable, or counterintuitive

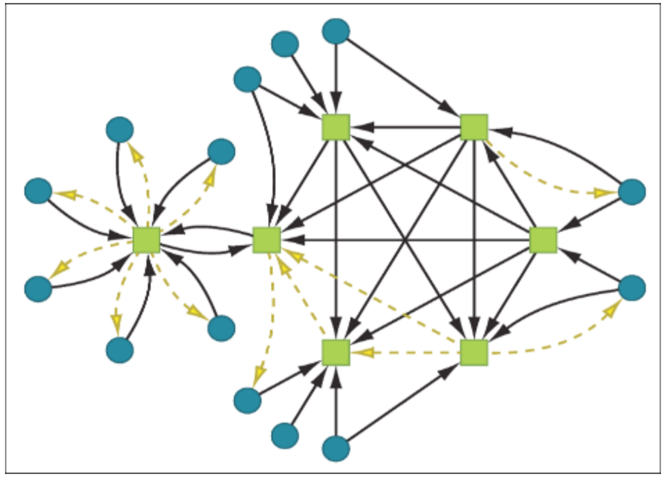


Complex system and Disciplines

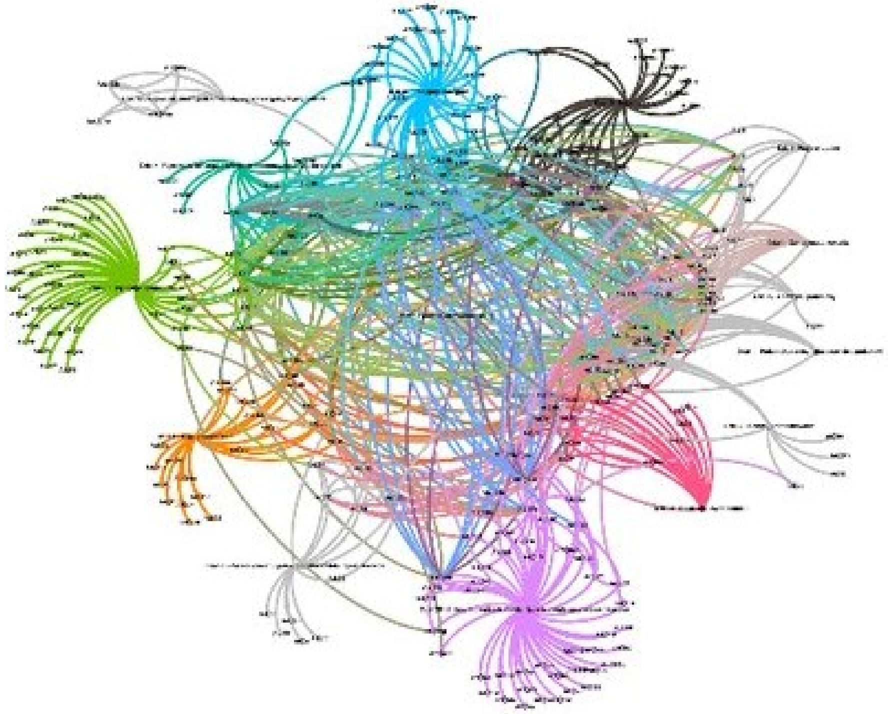
- **Computer science:** programming creates complex systems, and application involving complex real-world data,
- **Sociology:** studies human behaviour, social behavior, society, patterns of social relationships, social interaction, and culture
- **Social network analysis:** investigate social structures with networks and graph theory
- **Biology:** studies life and living organisms, physical structures of chemical, molecular interactions



Complex system and Graph Theory

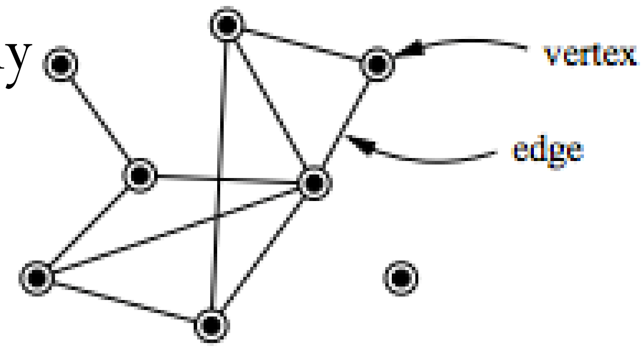


- Represented with a network (graph)
  - nodes represent the components (or entities) and
  - edges (or links) represents entities' interactions.
- Depicts collection of discrete objects and relationships between them
  - persons within an organization,
  - logic gates in a circuit,
  - genes in gene regulatory networks, or
  - between any other set of related entities



Graph Theory

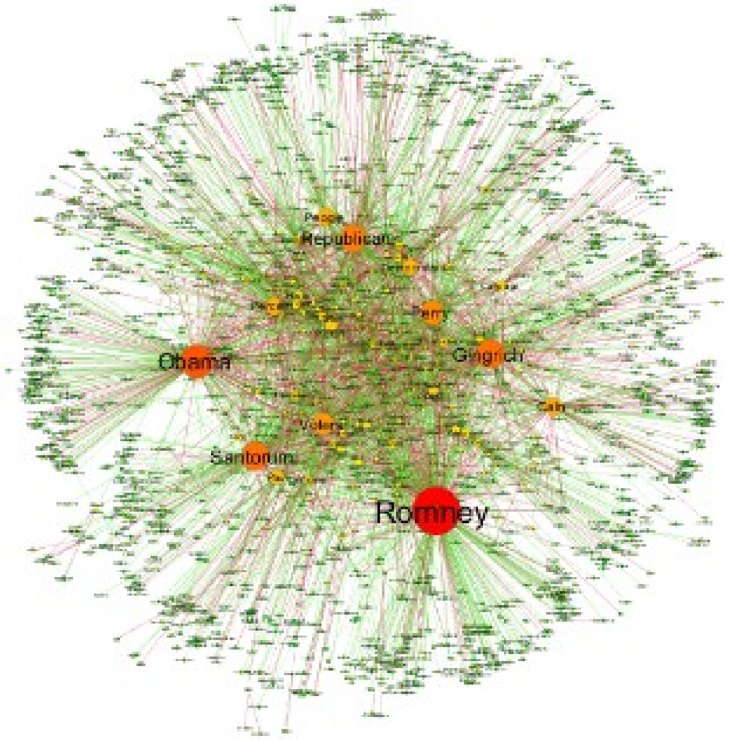
- Study of mathematical structures used to model relationship between discrete elements of a set
- Vertices (or nodes) are connected by edges (or links)
- Undirected graphs, where edges link two vertices symmetrically
- Directed graphs, where edges link two vertices asymmetrically
- Graph is an ordered triple $G = (V, E, \emptyset)$
  - V is a set of vertices (or nodes)
  - E is a set of edges (or links)
  - $\emptyset: E \rightarrow \{\{x, y\} \mid x, y \in V \text{ and } x \neq y\}$ an incidence function mapping every edge to an unordered pair of vertices



Network Theory

- Graph representing symmetric or asymmetric relations between discrete objects
- Graph with nodes and/or edges have attributes (e.g. names)
- Network theory is a subdomain of Graph theory
- Network theory is applied graph theory

Graph or Network Theories



- **Graph colouring:** e.g. coloring a graph so that
  - no two adjacent vertices have the same color, or
  - no two coincident edges are the same color
- **Matching** is a set of edges without common vertices
- **Route problems:** e.g. shortest path problem
  - minimum spanning tree (MST): a subset of the connected edges that connects all the vertices together, without any cycles, and with minimum possible total edge weight.
  - traveling salesman problem (TSP): "Given a list of cities and the distances between each pair of cities, what is the shortest possible route that visits each city exactly once and returns to the origin city?"

Graph or Network Theories

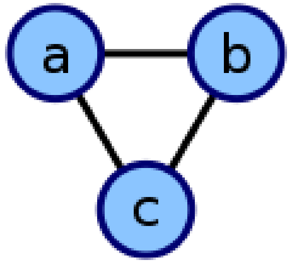
- **Network flow:** "Directed graph where each edge has a capacity and each edge receives a flow, where the amount of flow on an edge cannot exceed the capacity of the edge"
- **Transport problem:** study of optimal transportation and allocation of resources.
- **Trans-shipment problem:** a subgroup of transportation problems, where, transportation may or must go through intermediate nodes, possibly changing modes of transport
- **Critical path analysis:** identifying the longest dependent activities and measuring the time required to complete a project
- **PERT** to analyze and represent the tasks involved in completing a given project

Complex systems Representation

- Complex systems can be represented by Complex networks
- Complex networks can represent connections between component (or entities)
- Complex network can be represented as a graph with
  - vertices (or nodes) representing entities and
  - edges (or links, or connections) representing the relationship between components.

Complex systems Representation

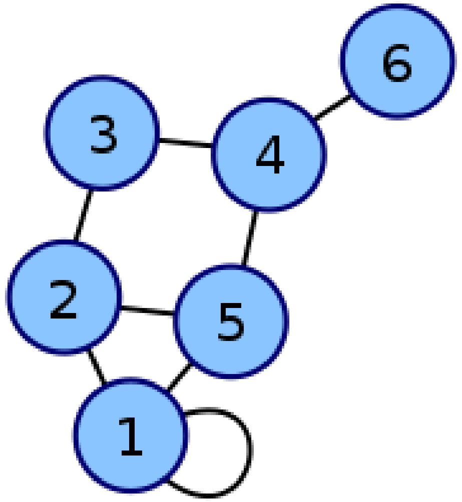
- Adjacency list is a collection of unordered lists used to represent a finite graph.
- List contains the set of neighbors of a vertex in the graph.
- Undirected graphs:
  - data structure two different linked list nodes for each edge



Adjacency list representation	
a	b
a	c
b	a
b	c
c	a
c	b

Complex systems Representation

- Adjacency matrix is a square matrix used to represent a finite graph.
- Matrix with rows and columns are indexed by vertices
- an adjacency list is more space-efficient than an adjacency matrix (stored as a two-dimensional array)
- adjacency list is as simple
- Matrix are 2-Dimensional representation.



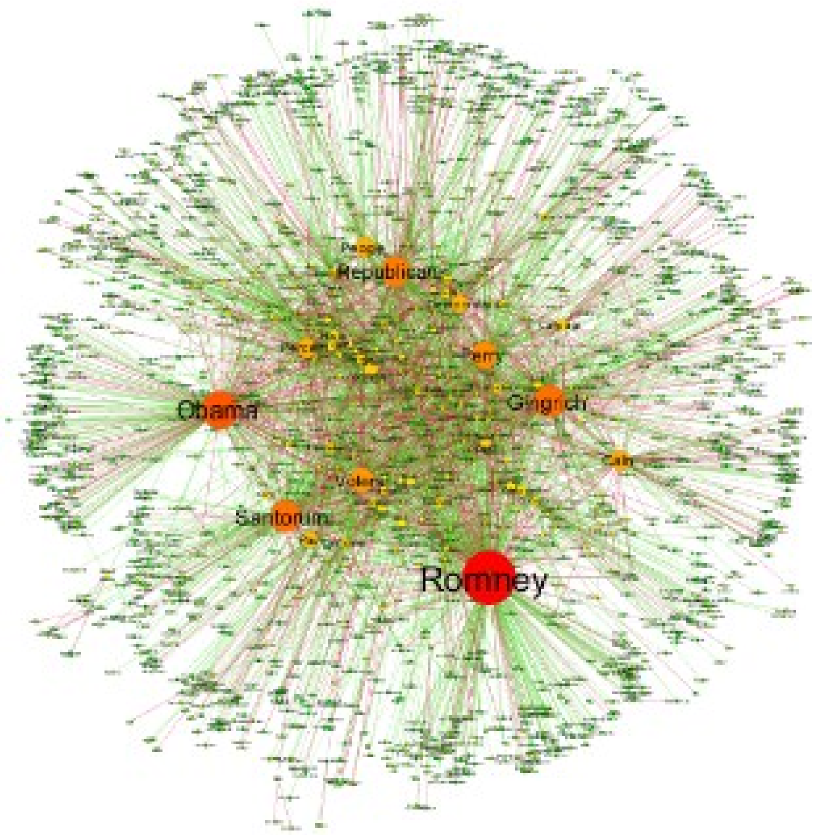
$$\begin{pmatrix} 2 & 1 & 0 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \end{pmatrix}$$

Complex systems Representation

- Multilayer Network representation:
- Complex systems can be described by representing many interacting entities in
  - a Single network or
  - Multilayer networks
- Examples social networks, neural networks
- Co-occurring network structure made by links, activity as the nodes (e.g. community structure between multi-links).
- Dynamic entity relationships can be represented with multilayer networks, multiplex networks, and network of networks.

Complex Networks

- Non-trivial topological features in networks representing real systems
- e.g. theories: Network motifs are small subgraphs that are over-represented in the network
- Examples of Complex networks are
  - computer networks,
  - biological networks,
  - technological networks,
  - brain networks,
  - climate networks and
  - social networks.



https://en.wikipedia.org/wiki/Complex_network

Complex Network analysis

- **Electric power systems analysis:**
  - a graph consists from representing electric power aspects (e.g., transmission line impedances)
- **Biological network analysis:**
  - analysis of molecular networks
  - visualize the nature and strength of interactions between species
  - Gene Regulatory Networks (GRN), Metabolic networks, Protein-Protein Interaction, molecular interactions
- **Operations research:** logistical networks, social networks, epistemological networks

Complex Network analysis

- **Computer science:** graphs are used to represent networks of communication, data organization, computational devices, the flow of computation, etc.
  - **Link analysis:** the link structure of a World Wide Web, Internet, Computer Network
  - website can be represented by a directed graph,
  - the vertices represent web pages and directed edges represent links from one page to another
- **Social network analysis:**
  - graph with the structure of relationships between social entities.
  - entities are persons, groups, organizations, nation states, web sites, or scholarly publications

Interdisciplinary Science, Engineering, and Management

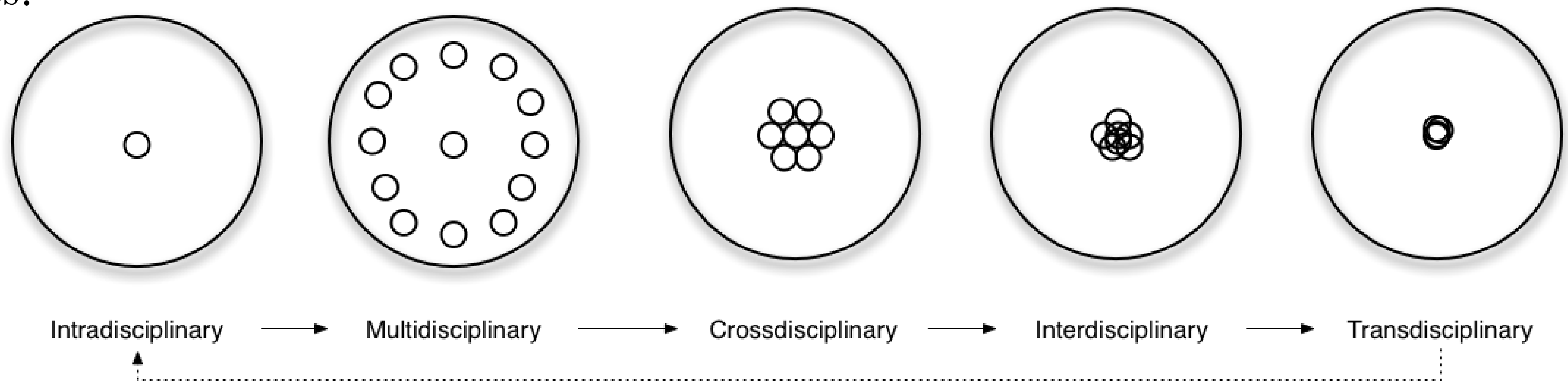
Interdisciplinary

- An organizational unit involving two or more academic disciplines,
- Dedicated journals, conferences and university departments.
- Three levels of cross-disciplinary research:
  - **Multidisciplinarity:** Pluridisciplinary level draws knowledge from different disciplines but stays within their boundaries.
  - **Interdisciplinarity:** Cross-disciplinary level analyzes, synthesizes and harmonizes links between disciplines.
  - **Transdisciplinarity:** Discipline-forming level integrates and transcends traditional boundaries.

[8] Choi BC, Pak AW. Multidisciplinarity, interdisciplinarity and transdisciplinarity in health research, services, education and policy: 1. Definitions, objectives, and evidence of effectiveness. Clin Invest Med. 2006 Dec; 29(6):351-64. PMID: 17330451.
https://en.wikipedia.org/wiki/Interdiscipline

Disciplinarities:
intra, cross, multi, inter, trans

- Intradisciplinary: working within a single discipline.
- Crossdisciplinary: viewing one discipline from the perspective of another.
- Multidisciplinary: people from different disciplines working together, each drawing on their disciplinary knowledge.
- Interdisciplinary: integrating knowledge and methods from different disciplines, using a real synthesis of approaches.
- Transdisciplinary: creating a unity of intellectual frameworks beyond the disciplinary perspectives.



https://www.arj.no/2012/03/12/disciplinarities-2/

Interdisciplinary in System Engineering

- Interdisciplinary is an adjective
- "An interdisciplinary approach that encompasses the entire technical effort, and evolves into and verifies an integrated and life cycle balanced set of system people, products, and process solutions that satisfy customer needs. (EIA Standard IS-632, *Systems Engineering*, December 1994.)"
- "An interdisciplinary, collaborative approach that derives, evolves, and verifies a life-cycle balanced system solution which satisfies customer expectations and meets public acceptability. (IEEE P1220, *Standard for Application and Management of the Systems Engineering Process*, [Final Draft], 26 September 1994.)"
- "Systems engineering is an interdisciplinary engineering management process that evolves and verifies an integrated, life cycle balanced set of system solutions that satisfy customer needs."

[4] *Systems Engineering Fundamentals.* Defense Acquisition University Press, 2001

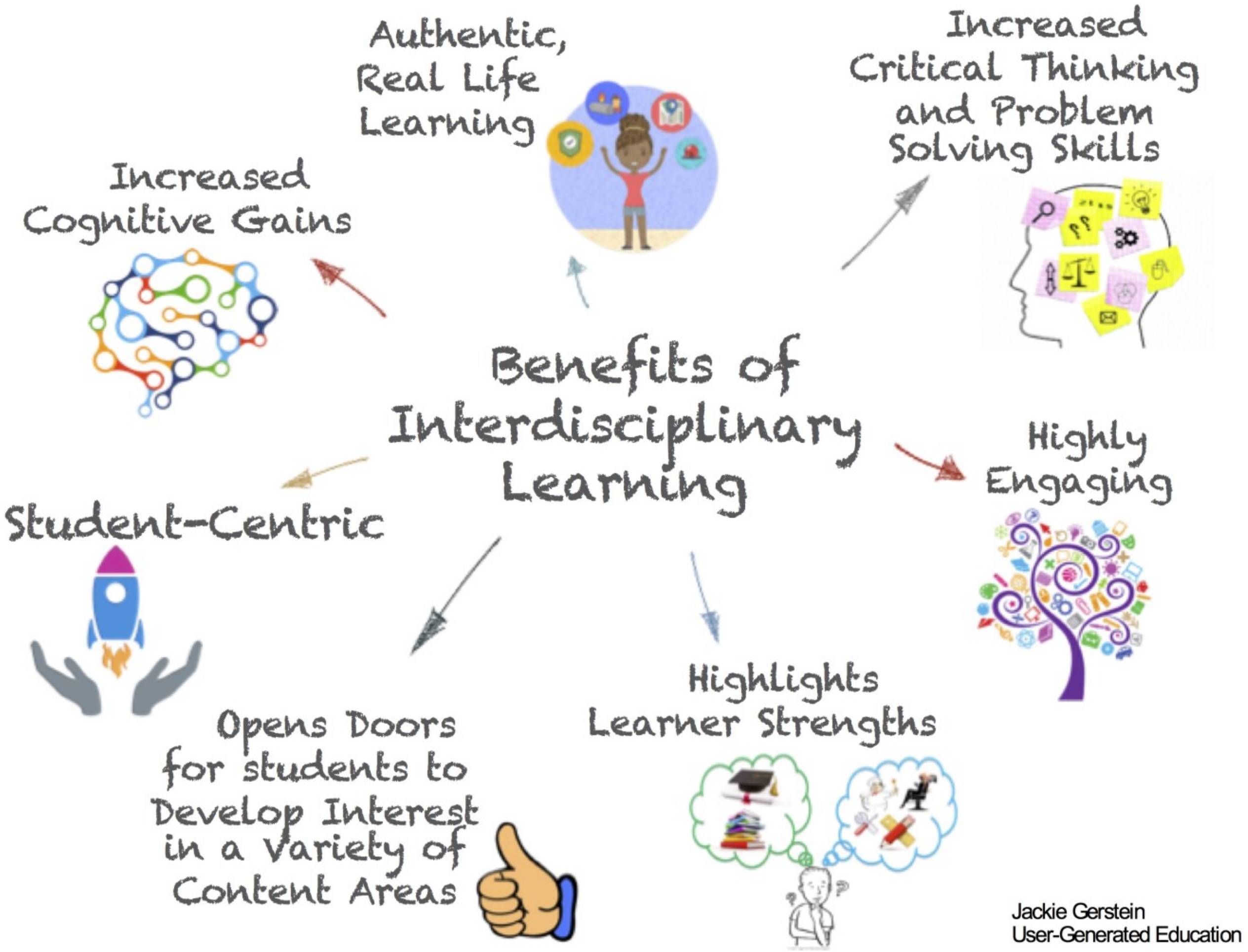
Interdisciplinary

- aka. Interdisciplinary studies
- combination of two or more academic disciplines into one activity (e.g., a research project).
- Disciplines could be like
  - social science,
  - mechanical engineering,
  - electrical engineering,
  - computer science and engineering, etc.
- Inter-discipline examples Electromechanics, Mechatronics, Bioinformatics, Biomedical Engineering, Data Science/Analytics, Computational Social Systems etc.

https://en.wikipedia.org/wiki/Interdisciplinarity

Interdisciplinary Examples

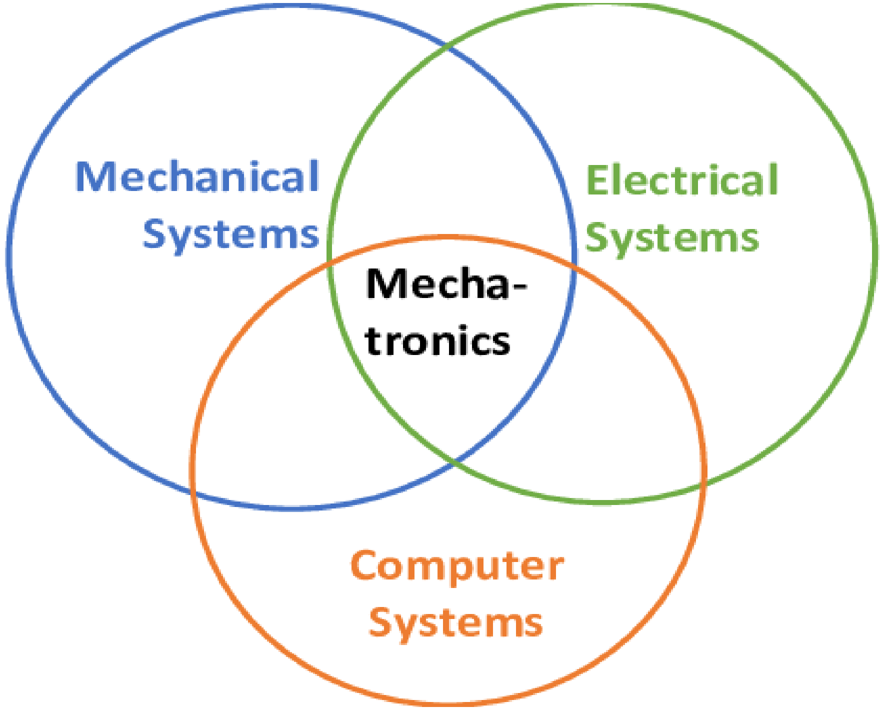
- Electromechanics focuses on the interaction of electrical and mechanical systems as a whole and how the two systems interact with each other.
- Mechatronics focuses on the engineering of electronic, electrical and mechanical engineering systems, and also includes a combination of robotics, electronics, computer, telecommunications, systems, control, and product engineering.



https://en.wikipedia.org/wiki/Electromechanics
https://en.wikipedia.org/wiki/Mechatronics

Electromechanics and Mechatronics

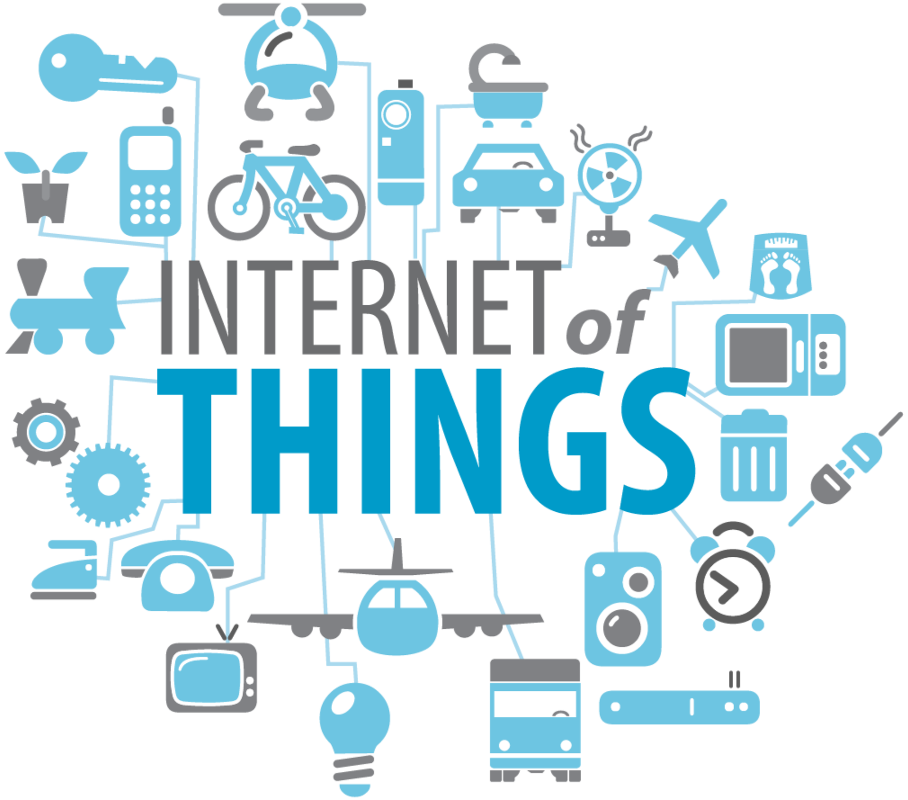
- An actuator is a component of a machine that is responsible for moving and controlling a mechanism or system, for example by opening a valve. In simple terms, it is a "mover".
- An actuator requires a control signal and a source of energy.
- A sensor is a device, module, machine, or subsystem whose purpose is to detect events or changes in its environment and send the information to other electronics, frequently a computer processor. A sensor is always used with other electronics.



https://en.wikipedia.org/wiki/Electromechanics
https://en.wikipedia.org/wiki/Mechatronics
https://en.wikipedia.org/wiki/Actuator

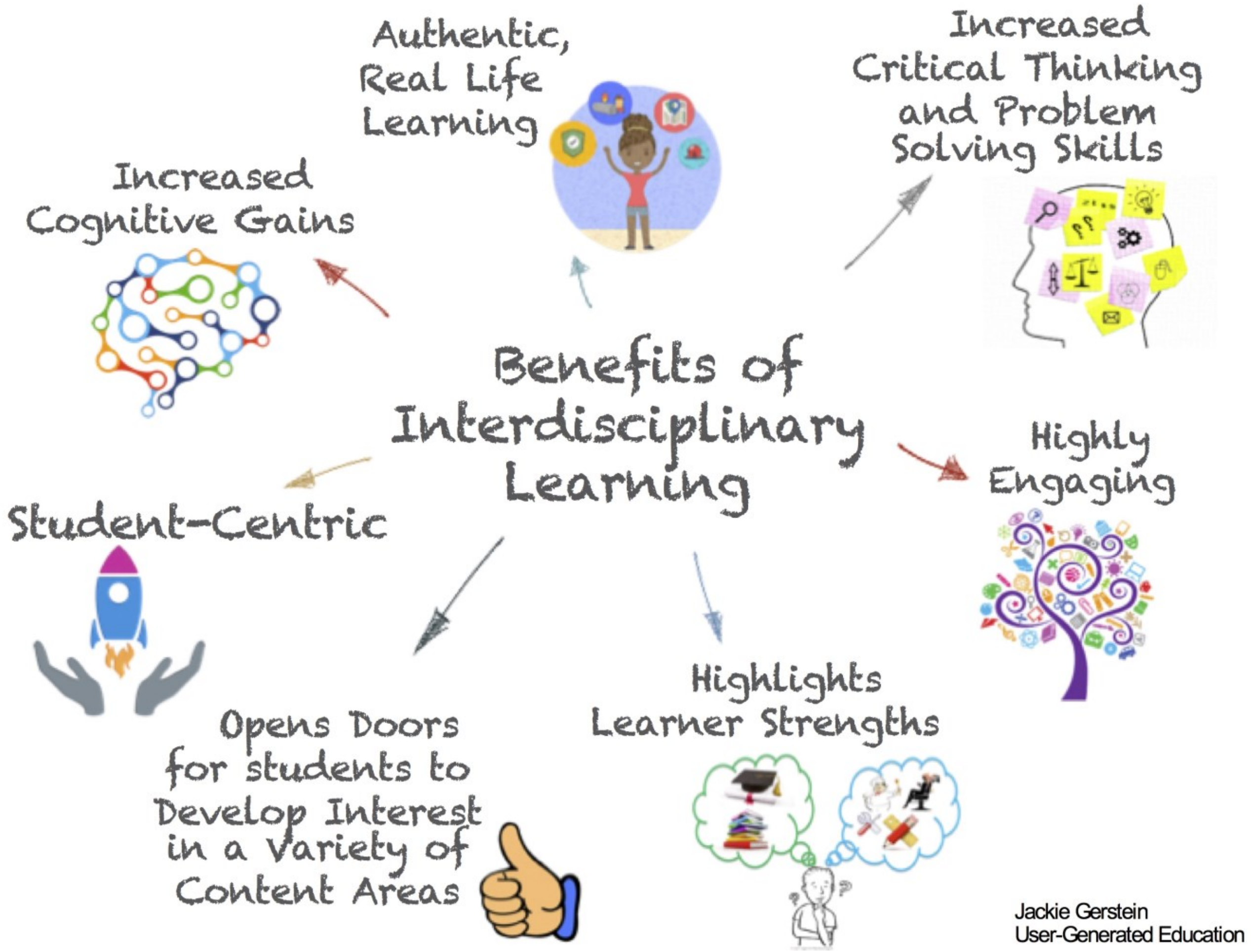
Internet of things (IoT)

- The Internet of things (IoT) is the inter-networking of physical devices, embedded with **electronics, software, sensors, actuators, and network connectivity** which enable these objects to collect and exchange data.



Interdisciplinary Examples

- Biomedical engineering (BME) is the application of engineering principles and design concepts to medicine and biology for healthcare purposes (e.g., diagnostic or therapeutic).
- Bioinformatics develops methods and software tools for understanding biological data, in particular when the data sets are large and complex.



https://en.wikipedia.org/wiki/Biomedical_engineering
https://en.wikipedia.org/wiki/Bioinformatics

Bio-Medical Engineering (BME)

- Bioinformatics
- Biomechanics
- Biomaterials science or engineering
- Biomedical optics
- Tissue engineering
- Genetic engineering
- Neural engineering
- Pharmaceutical engineering
- Medical devices (Medical imaging, Implants, Bionics, and Biomedical sensors)
- Clinical engineering
- Rehabilitation engineering

https://en.wikipedia.org/wiki/Biomedical_engineering
https://en.wikipedia.org/wiki/Bioinformatics

Bioinformatics

- **Informatics:** set of digital codes and a language
- **Bioinformatics:** Study of biological (or life) information (digital code for studying properties of bio-systems)

Computer scientists, Mathematicians, Data Scientist etc.

Develop tools, software, algorithms

Store and analyze the data.

+

Biologists

collect molecular data: DNA & Protein sequences, gene expression, etc.

=

Bioinformaticians

Study biological questions by analyzing molecular data

Bioinformatics

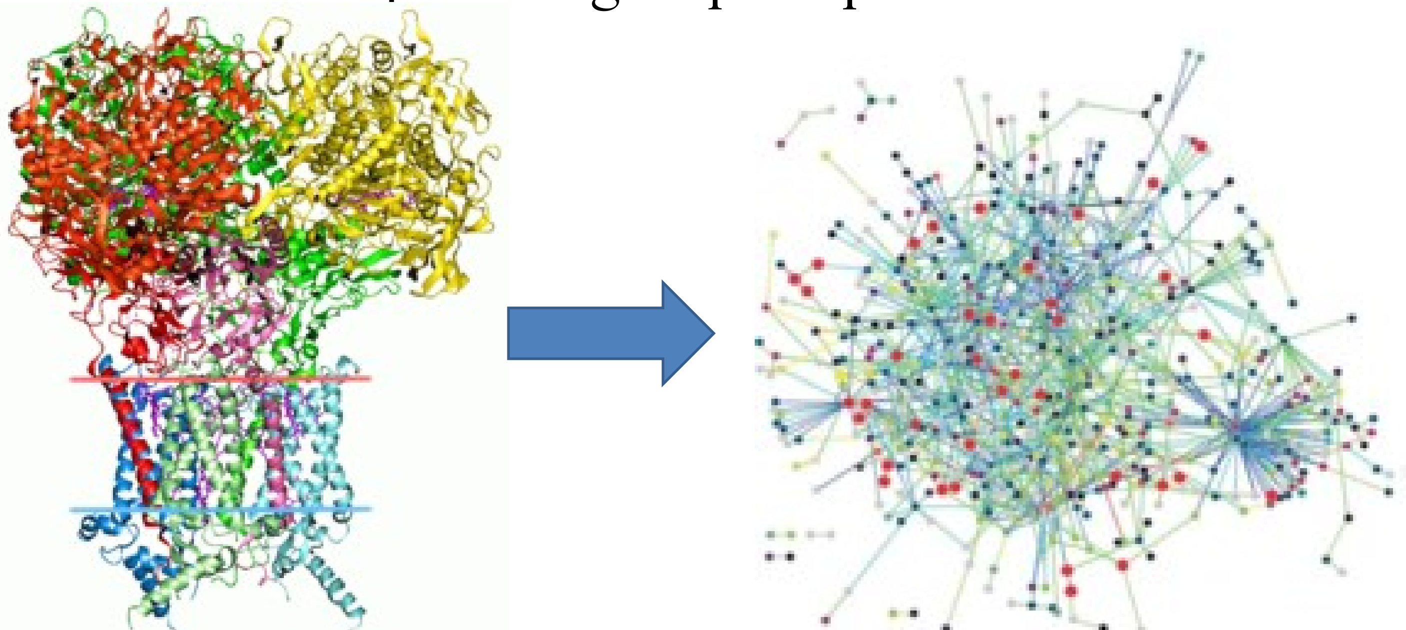
- Computers became essential in molecular biology when protein sequences, amino acid sequences, protein domains, protein structures etc.
- Sequences of genetic material are frequently used in bioinformatics and are easier to manage using computers than manually.
- DNA sequencing is still a non-trivial problem as the raw data may be noisy or afflicted by weak signals. Algorithms have been developed for base calling for the various experimental approaches to DNA sequencing.

5'ATGACGTGGGA3'
3'TACTGCACCCT5'

https://en.wikipedia.org/wiki/Bioinformatics

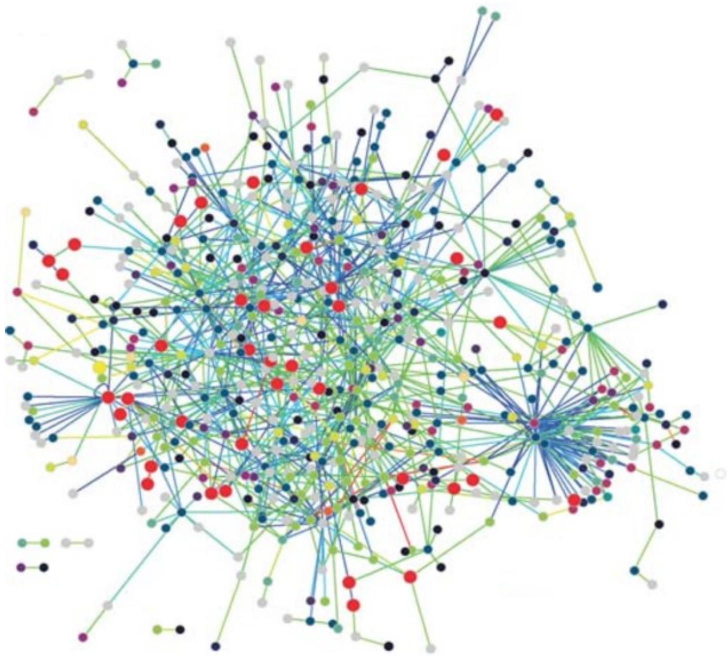
Molecular interaction networks

- BME: Tens of thousands of three-dimensional protein structures are determined by X-ray crystallography and protein Nuclear Magnetic Resonance (NMR) spectroscopy.
- Bioinformatics: Protein–protein interaction identifies, predicts, and catalog physical interactions between pairs or groups of proteins.



https://en.wikipedia.org/wiki/Bioinformatics

Network analysis



- Study of relationships within biological networks
  - metabolic or
  - protein–protein interaction networks.
- Biological networks can be constructed from
  - a single type of molecule or entity (such as genes),
  - many different data types, such as proteins, small molecules, gene expression data.
- Abbreviation recognition – identify the long-form and abbreviation of biological terms
- Named entity recognition – recognizing biological terms such as gene names
- Protein–protein interaction – identify which proteins interact with which proteins from text

Systems biology

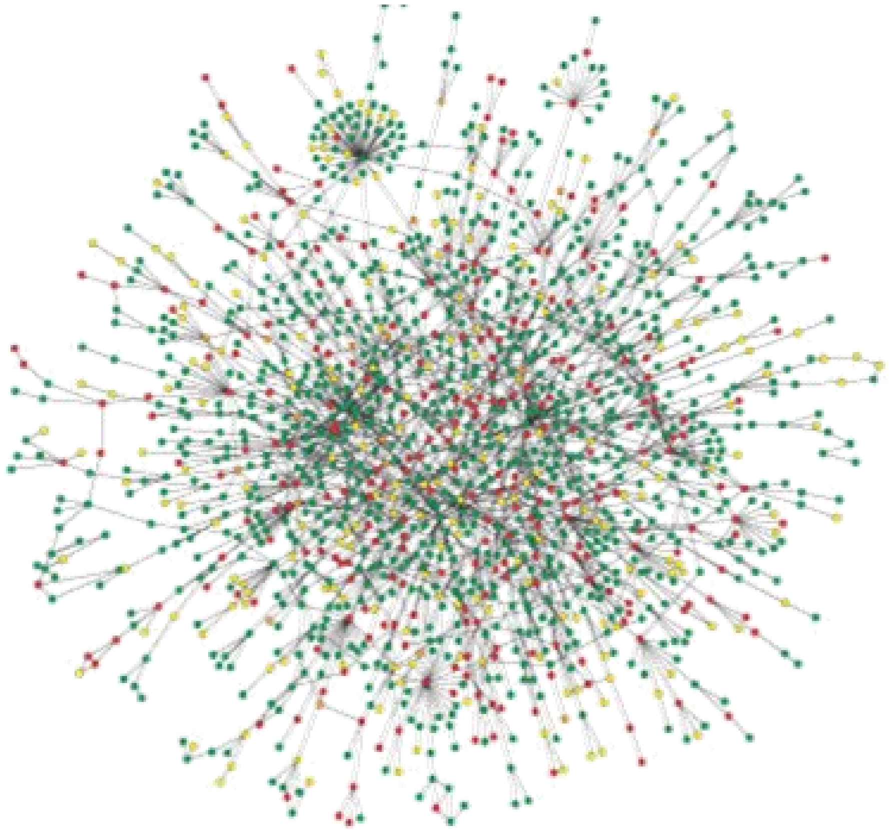
- It involves the use of computer simulations of cellular subsystems (such as the networks of metabolites and enzymes that comprise metabolism.
- Signal transduction pathways and gene regulatory networks) to both analyze and visualize the complex connections of these cellular processes.
- Artificial life or virtual evolution attempts to understand evolutionary processes via the computer simulation of simple (artificial) life forms.

Bio Interactions

- Protein-Protein Interaction
- DNA-Protein interactions
- GeneNet (Gene networks)
- Biomolecular Interaction
- Molecular interactions
- Protein and Biochemical Interactions

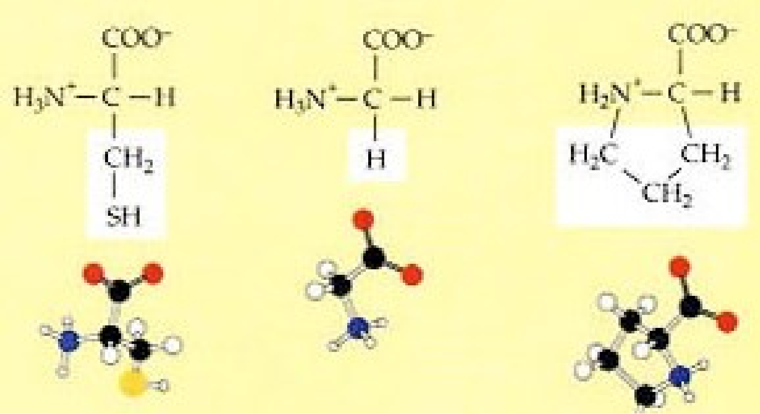
Nodes: proteins

Links: physical interactions (binding)



Bioinformatics Visualization

- Amino Acid to Graph



- Human Hemoglobin

>gi|14456711|ref|NM_000558.3| **Homo sapiens hemoglobin, alpha** 1 (HBA1), mRNA

```
ACTCTTCTGGTCCCCACAGACTCAGAGAGAACCCACCATGGTGCTGTCT
CCTGCCGACAAGACCAACGTCAAGGCCGCCTGGGGTAAGGTCGGCGCGC
ACGCTGGCGAGTATGGTGCGGAGGCCCTGGAGAGGATGTTCCTGTCCTT
CCCCACCACCAAGACCTACTTCCCGCACTTCGACCTGAGCCACGGCTCT
GCCCAGGTTAAGGGCCACGGCAAGAAGGTGGCCGACGCGCTGACCAACG
CCGTGGCGCACGTGGACGACATGCCCAACGCGCTGTCCGCCCTGAGCGA
CCTGCACGCGCACAAGCTTCGGGTGGACCCGGTCAACTTCAAGCTCCTA
AGCCACTGCCTGCTGGTGACCCTGGCCGCCCACCTCCCCGCCGAGTTCA
CCCCTGCGGTGCACGCCTCCCTGGACAAGTTCCTGGCTTCTGTGAGCAC
CGTGCTGACCTCCAAATACCGTTAAGCTGGAGCCTCGGTGGCCATGCTT
CTTGCCCCTTGGGCCTCCCCCCAGCCCCTCCTCCCCTTCCTGCACCCGT
ACCCCCGTGGTCTTTGAATAAAGTCTGAGTGGGCGGC
```

Bio-Informatics Databases

- KEGG (Kyoto Encyclopedia of Genes and Genomes)
  - http://www.genome.ad.jp/kegg/
  - Institute for Chemical Research, Kyoto University
- PathDB
  - http://www.ncgr.org/pathdb/index.html
  - National Center for Genomic Resources
- SPAD: Signaling PAthway Database
  - Graduate School of Genetic Resources Technology. Kyushu University.
- Cytokine Signaling Pathway DB.
  - Dept. of Biochemistry. Kumamoto Univ.
- EcoCyc and MetaCyc
  - Stanford Research Institute
- BIND (Biomolecular Interaction Network Database)
  - UBC, Univ. of Toronto

Natural Language Processing

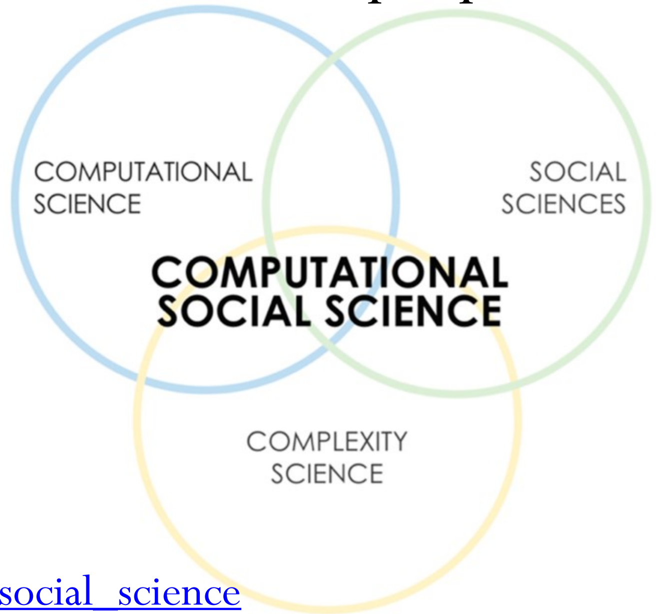
- Text mining or analytics is the process of analyzing quality information from text; by automatically discovering and extracting unknown information from text resources.
  - Regular Expressions (Regex), Text Pattern matching

- Sentiment analysis involve analysis of labeled or unlabeled natural language based affectivity of words and concepts made from WordNet and ConceptNet.
  - Positive, Negative, and Neutral Sentiments

https://en.wikipedia.org/wiki/Text_mining

Interdisciplinary Examples

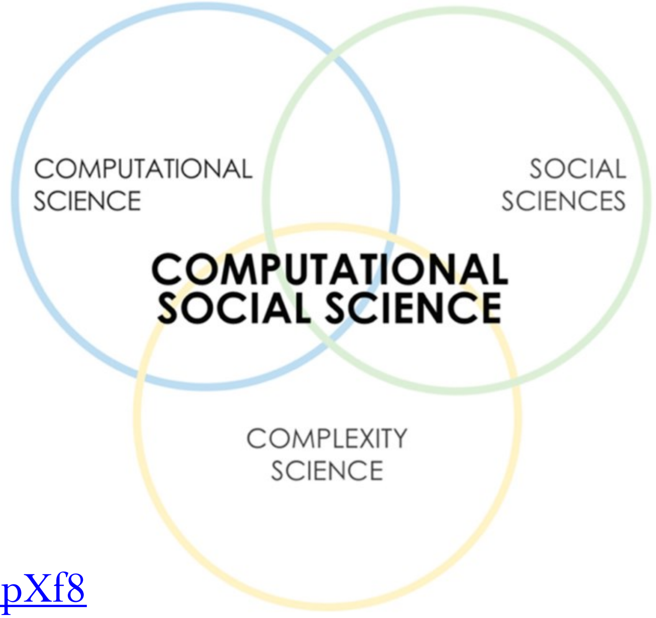
- Computational social science is sub-disciplines concerned with computational approaches to the social sciences.
  - Sub-field, Natural Language processing
- Human–Computer Interaction (HCI) studies the design and use of computer technology, focused on the interfaces between people (users) and computers.
  - SixthSense



https://en.wikipedia.org/wiki/Computational_social_science
https://en.wikipedia.org/wiki/Human%E2%80%93computer_interaction

Sixth Sense

- Gesture-based wearable computer system developed at MIT Media Lab by
  - Steve Mann in 1994 and 1997 (headworn gestural interface),
  - 1998 (neckworn version), and
  - Pranav Mistry (also at MIT Media Lab), in 2009, developed both hardware and software for headworn and neckworn versions of it.



https://www.youtube.com/watch?v=E8GU-dGpXf8
https://en.wikipedia.org/wiki/SixthSense

Systems theory

Systems theory

- Interdisciplinary study of interconnected component or entities, which can be natural or machine.
- System has following properties
  - It is bounded by space and time.
  - It gets influenced by its environment.
  - It has structure and purpose, and functioning.
  - It expresses Synergy (means working together).
  - It expresses Emergence (means properties or behaviors appears only when the component or entities interact).

https://en.wikipedia.org/wiki/Systems_theory

Systems theory

- It model a system's dynamics, constraints, conditions, principles (purpose, measure, methods, tools), and resource optimization.
- Change in a system’s component or entities may affect other entities or the whole system.
- Predict changes in patterns of behavior.
- System learns and adapts with its environment.
- Systems support and maintain other systems to prevent failure.

https://en.wikipedia.org/wiki/Systems_theory

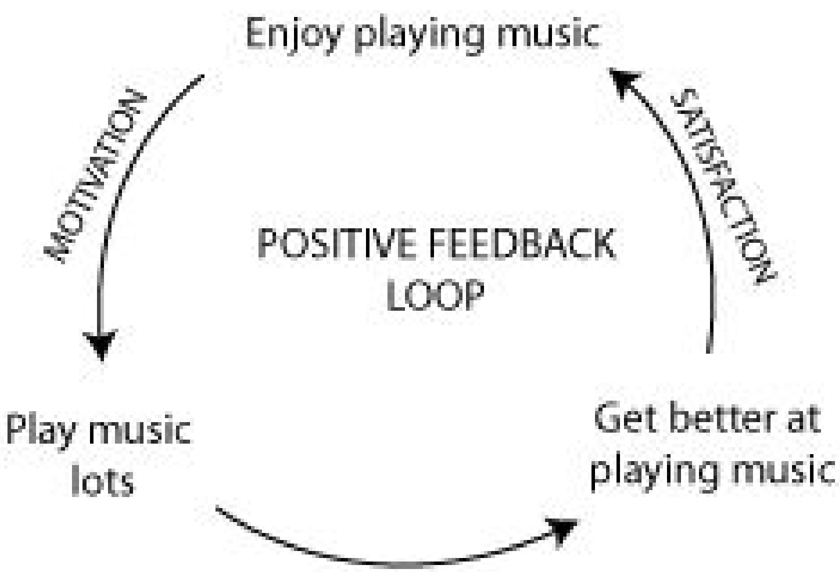
Dynamic/Active or Passive System

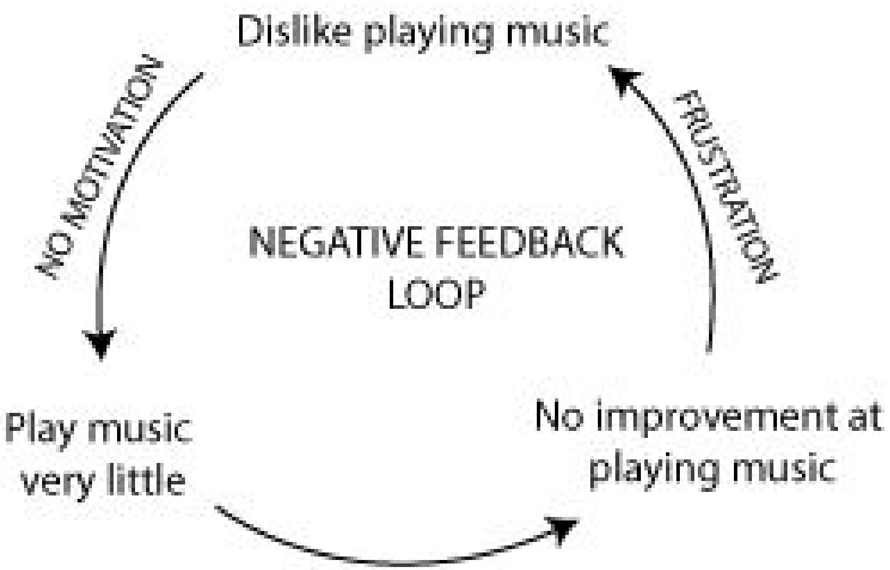
- Dynamic or Active systems has components that interact in behaviors and processes.
- Passive systems has components that are being processed.
- Example
  - a program/code file is passive and
  - same code is a active process executing on RAM and CPU.

https://en.wikipedia.org/wiki/Systems_theory

Fundamental Concepts

- System has interconnected component.
- Boundaries: Outer components of a system in an environment.
- Feedback loop: Process to self-correct based on reactions from other systems in the environment.

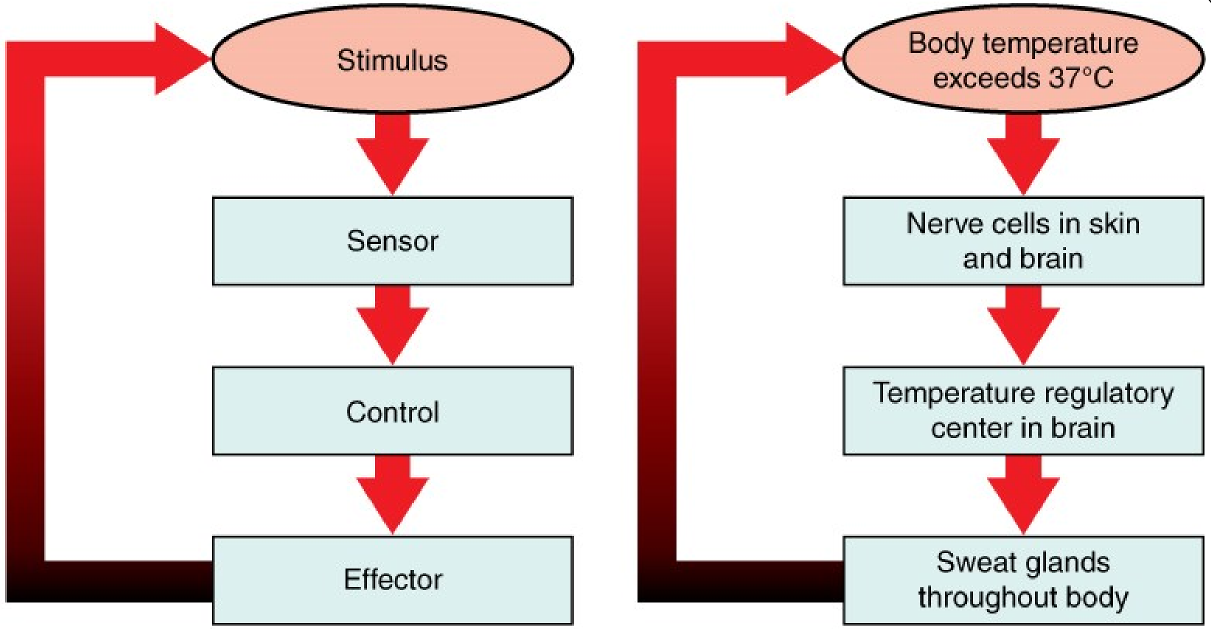


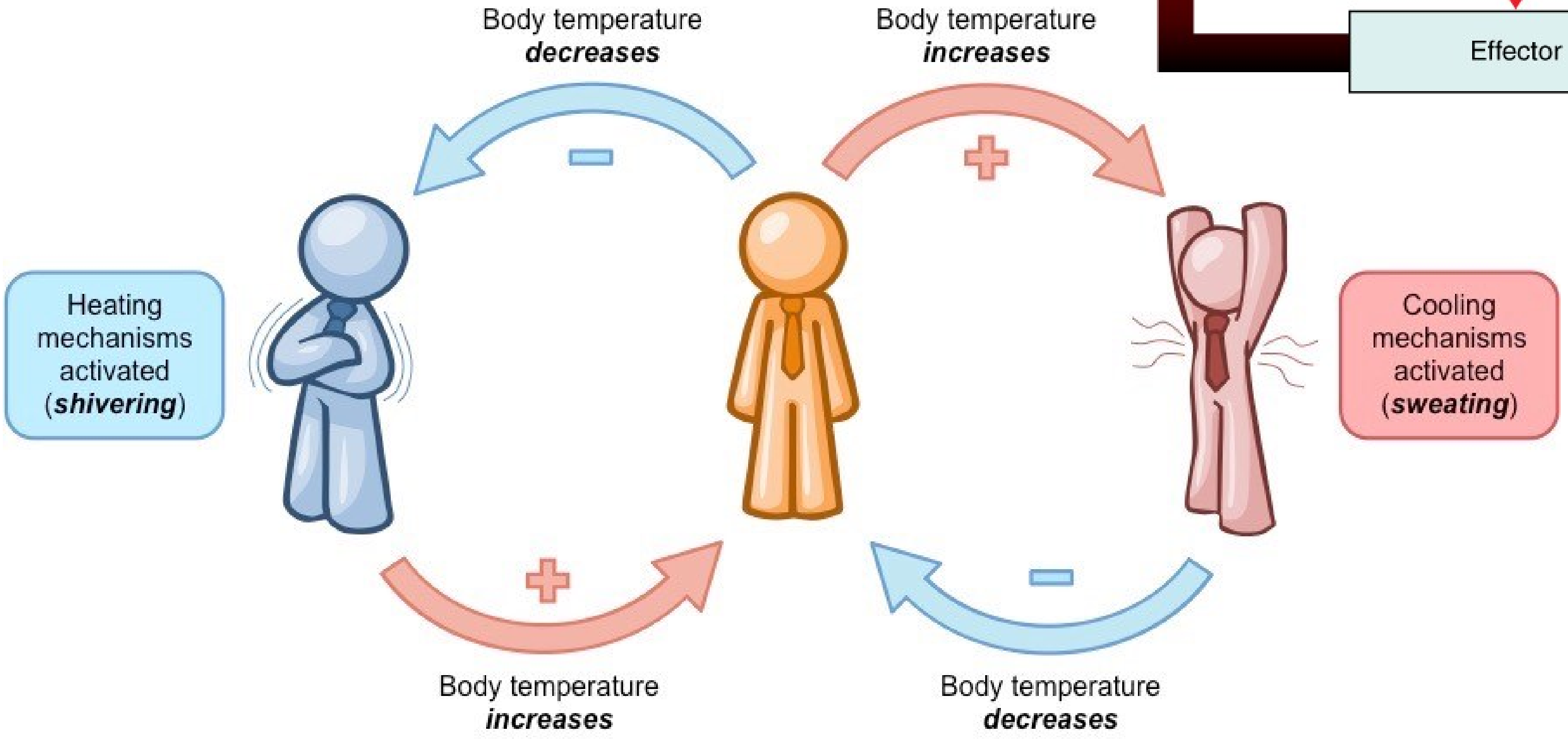


https://en.wikipedia.org/wiki/Systems_theory

Fundamental Concepts

- Adaptation: Tendency of making internal changes to protect itself and to maintain functionalities.

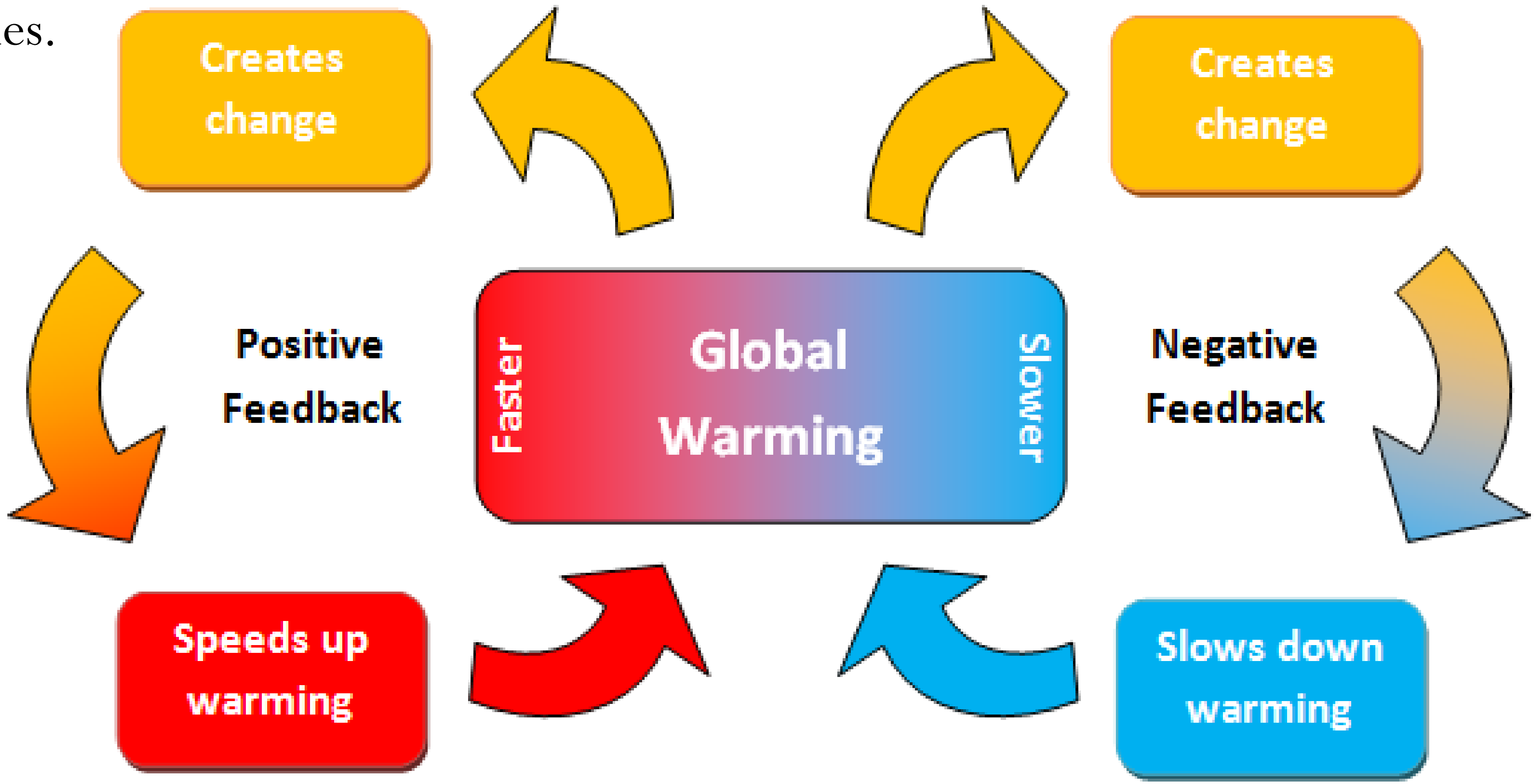




https://en.wikipedia.org/wiki/Systems_theory

Fundamental Concepts

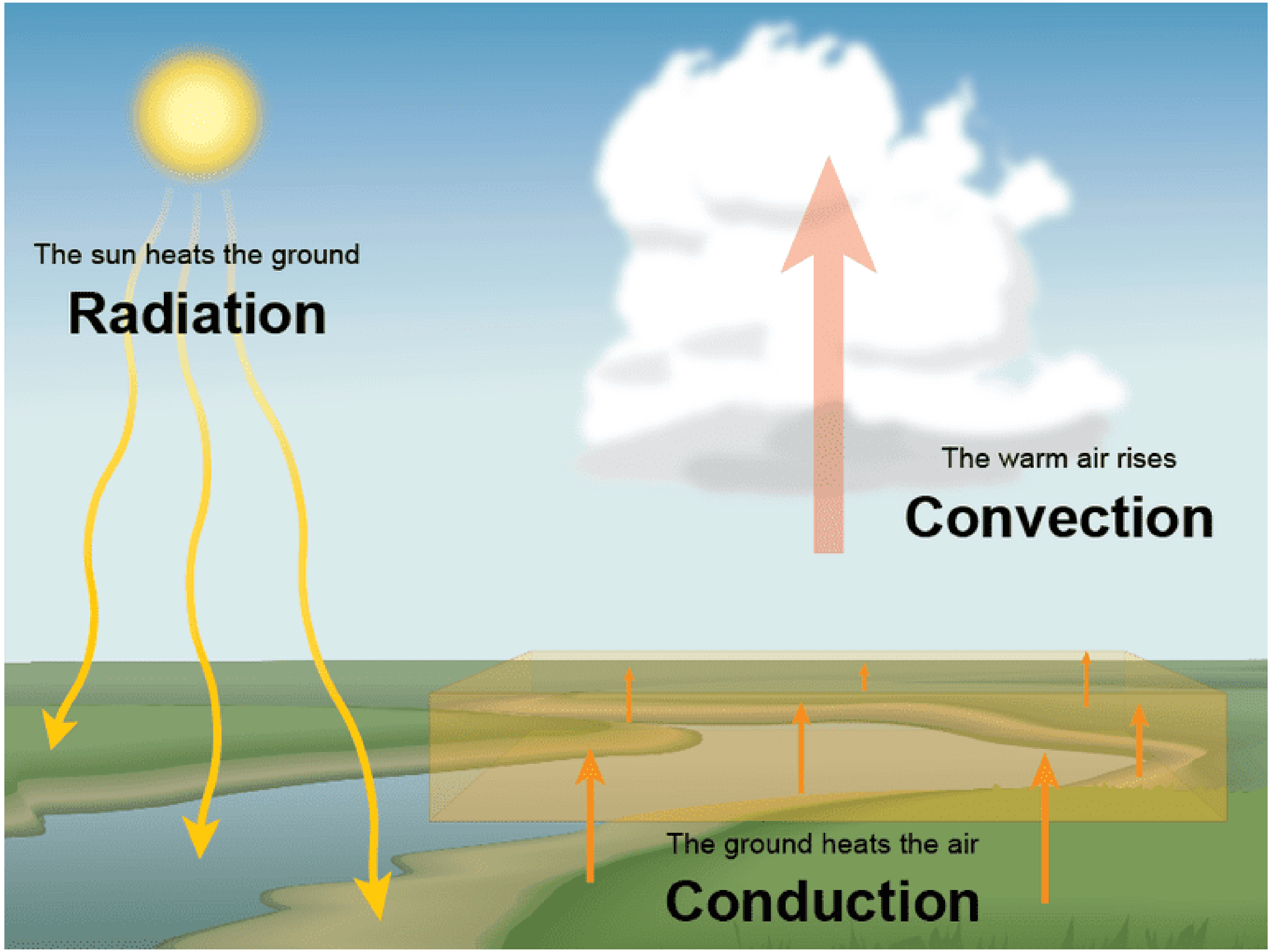
- Homeostasis: Tendency to be resilient w.r.t external disruption and to maintain functionalities.



https://en.wikipedia.org/wiki/Systems_theory

Fundamental Concepts

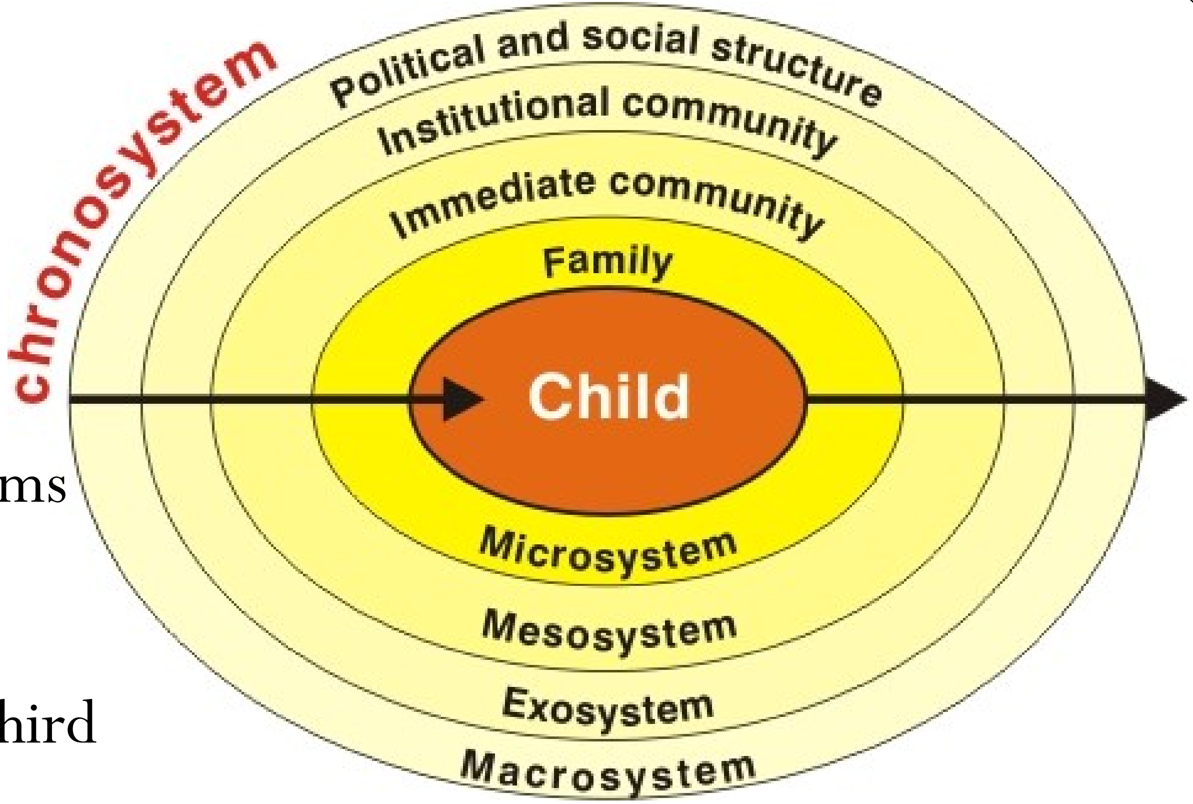
- Reciprocal transactions: Cyclical interactions such that systems influence one another.
- Throughput: Rate of energy transfer between a system and its environment over time.



https://en.wikipedia.org/wiki/Systems_theory

Fundamental Concepts

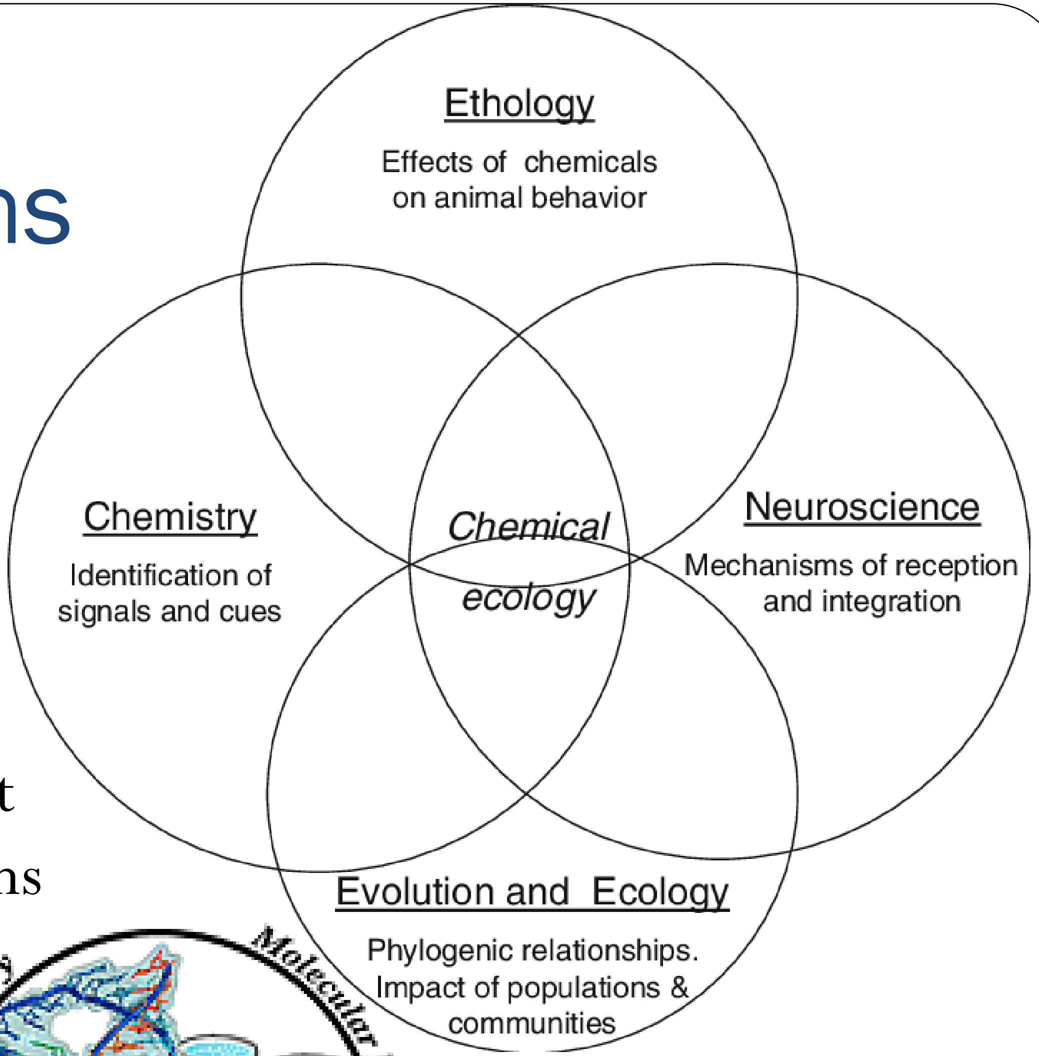
- Microsystem: The system closest to the client.
- Mesosystem: Relationships among systems in an environment.
- Exosystem: A relationship between two systems that has an indirect effect on a third system.
- Macrosystem: A larger system that influences clients, policies, administration, and culture.
- Chronosystem: A system composed of significant life events affecting adaptation.

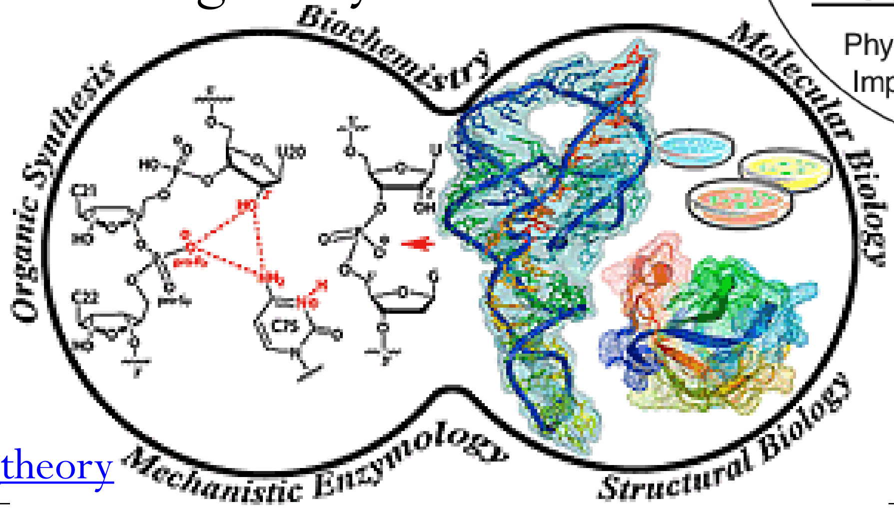


https://en.wikipedia.org/wiki/Systems_theory

Systems Theory Applications

- **Systems biology** is bioscience research focusing on complex interactions in biological systems.
- **Systems chemistry** studies networks of interacting molecules.
- **Systems ecology** is a field of ecology (subset Earth science) that studies of ecological systems i.e. ecosystems.

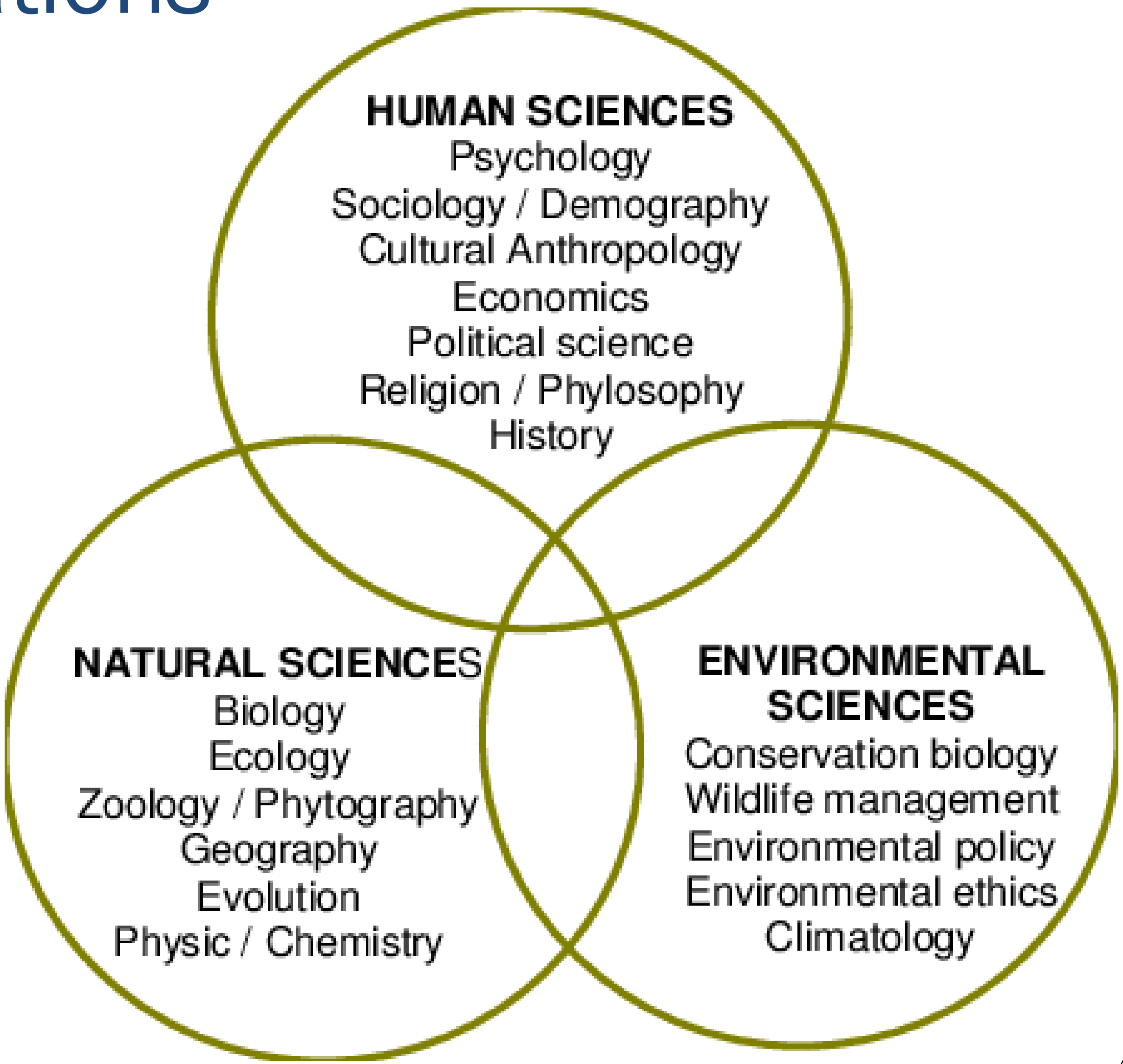




https://en.wikipedia.org/wiki/Systems_theory

Systems Theory Applications

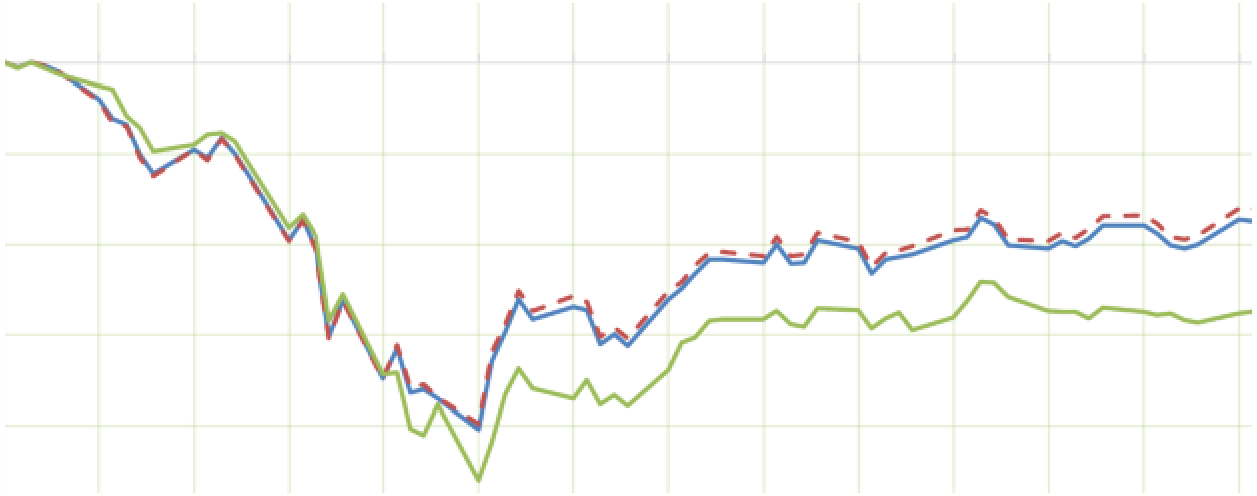
- **Systems psychology** studies human behavior and experience in complex systems.
- **Systems thinking** ability or skill to perform problem solving in complex system. With the Systems theory, the System Thinking can be learned.



https://en.wikipedia.org/wiki/Systems_theory

Systems Theory Applications

- **System dynamics** is a technique to study nonlinear characteristic of complex systems over time.
- **Systems engineering** enables the realization, deployment, and maintenance of successful systems with the applied engineering efforts.

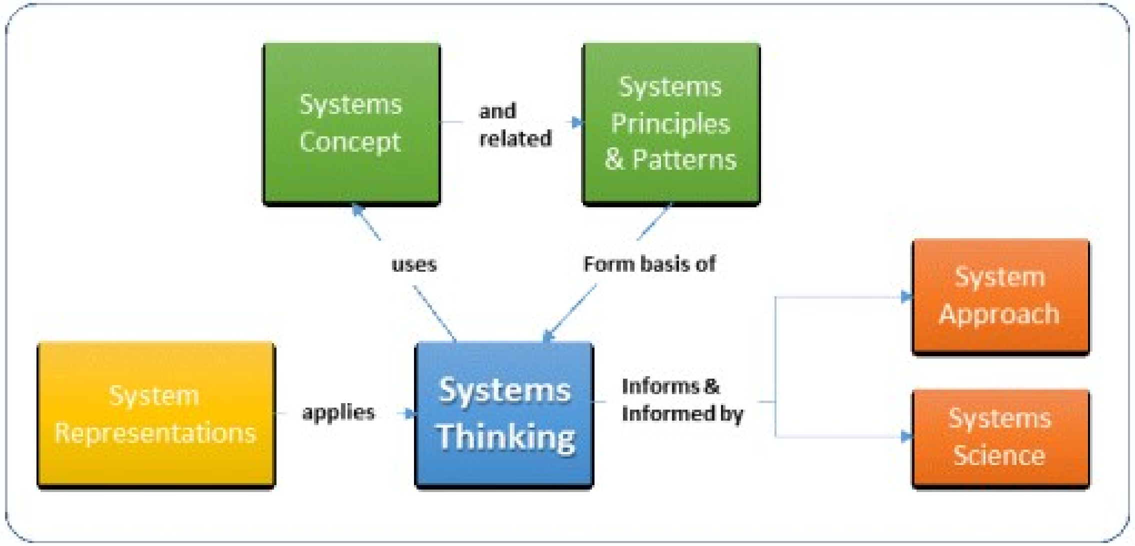


https://en.wikipedia.org/wiki/Systems_theory

Systems Thinking

Systems Thinking

- Focuses and emphasizes on
  - behavior of the whole rather than the individual parts.
  - the interfaces between/among the subsystems.
- Ability to think about interactions between components of a system and their effect on functionalities.
- Understanding or Intervening in problem situations, based on the principles and concepts of the systems paradigm.



[8] "Systems Engineering Jr. Handbook", *INCOSE LA Chapter and The Creativita Institute*.

Systems Thinking and Artificial Intelligence

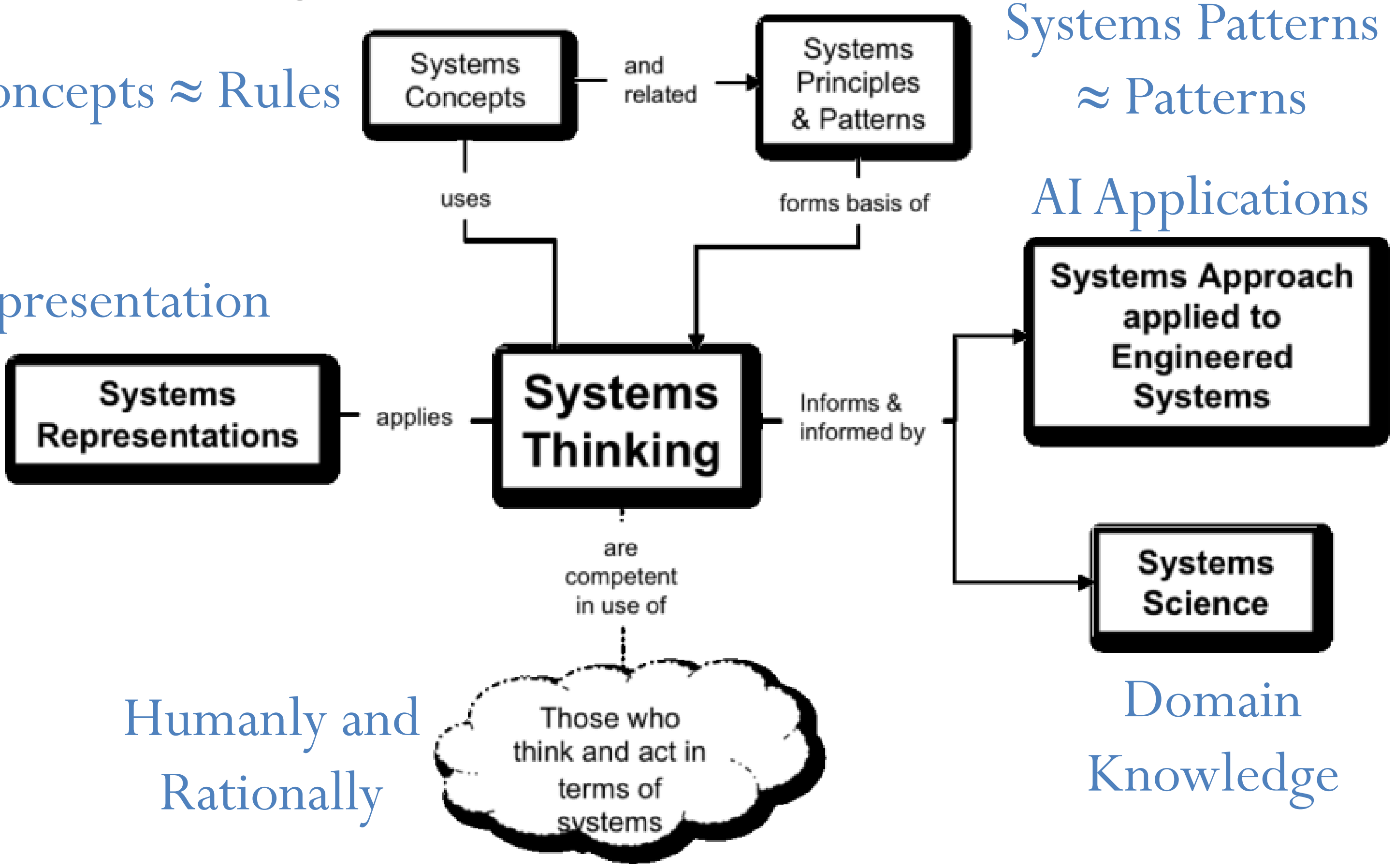
- Relationship between the System Thinking with other concepts of Systems Engineering.

Systems Concepts ≈ Rules

Systems Patterns ≈ Patterns

AI Applications

Systems Representation ≈ Knowledge Representation



Humanly and Rationally

Domain Knowledge

[9] Cloutier, R. J. “The Guide to the Systems Engineering Body of Knowledge (SEBoK); v. 2.2.” *INCOSE and The Trustees of the Stevens Institute of Technology: Hoboken, NJ, USA* (2016).

Complexity, Chaos, Regularity

- Process of attention and adaptation to ensure appropriately identified boundaries, dependencies, and relationships.
- Components has cohesion, or "togetherness,“
- It simplify complexity, chaos, managing interdependency, and understanding choice.
- More complex and chaotic because of inadequate concepts to explain. Understanding reduce chaotic or complex.
- Similarities and Differences.
- Regularity is a uniformity or similarity that exists in multiple entities or at multiple times.
- Regularity in both natural systems and engineered systems.

[9] Cloutier, R. J. “The Guide to the Systems Engineering Body of Knowledge (SEBoK); v. 2.2.” *INCOSE and The Trustees of the Stevens Institute of Technology: Hoboken, NJ, USA* (2016).

Systems attributes & environment

- Any quality or property of a system element is called an attribute.
- The state of a system is a set of system attributes at a given time.
- A system event describes any change to the environment of a system, and hence its state:
  - Static - A single state exists with no events.
  - Dynamic - Multiple possible stable states exist.
  - Homeostatic - System is static but its elements are dynamic. The system maintains its state by internal adjustments.

[9] Cloutier, R. J. "The Guide to the Systems Engineering Body of Knowledge (SEBoK); v. 2.2." *INCOSE and The Trustees of the Stevens Institute of Technology: Hoboken, NJ, USA* (2016).

State and Variables

- A stable state is one in which a system will remain until another event occurs.
- State can be monitored using state variables, values of attributes which indicate the system state.
- The set of possible values of state variables over time is called the "state space".
- State variables are generally continuous but can be modeled using a finite state model (or "state machine").

[9] Cloutier, R. J. "The Guide to the Systems Engineering Body of Knowledge (SEBoK); v. 2.2." *INCOSE and The Trustees of the Stevens Institute of Technology: Hoboken, NJ, USA* (2016).

Stability and Determinism

- A system can react, respond, or act.
- A stable system is one which has one or more stable states within an environment for a range of possible events.
- Deterministic systems have a one-to-one mapping of state variables to state space, allowing future states to be predicted from past states.
- Non-Deterministic systems have a many-to-many mapping of state variables; future states cannot be reliably predicted.

[9] Cloutier, R. J. "The Guide to the Systems Engineering Body of Knowledge (SEBoK); v. 2.2." *INCOSE and The Trustees of the Stevens Institute of Technology: Hoboken, NJ, USA* (2016).

Survival Behaviour

- Systems often behave in a manner that allows them to sustain themselves in one or more alternative viable states.
- Many natural or social systems have this goal, either consciously or as a "self organizing" system, arising from the interaction between elements.
- Entropy is the tendency of systems to move towards disorder or disorganization.

[9] Cloutier, R. J. "The Guide to the Systems Engineering Body of Knowledge (SEBoK); v. 2.2." *INCOSE and The Trustees of the Stevens Institute of Technology: Hoboken, NJ, USA* (2016).

Goal Seeking Behaviour

- Some systems have reasons for existence beyond simple survival. Goal seeking is one of the defining characteristics of engineered systems:
- A goal is a specific outcome which a system can achieve in a specified time.
- An objective is a longer-term outcome which can be achieved through a series of goals.
- An ideal is an objective which cannot be achieved with any certainty, but for which progress towards the objective has value.

[9] Cloutier, R. J. "The Guide to the Systems Engineering Body of Knowledge (SEBoK); v. 2.2." *INCOSE and The Trustees of the Stevens Institute of Technology: Hoboken, NJ, USA* (2016).

Control Behaviour

- Cybernetics, the science of control, defines two basic control mechanisms:
- Negative feedback, maintaining system state against set objectives or levels.
- Positive feedback, forced growth or contraction to new levels.
- Control behavior is a trade between:
  - Specialization, the focus of system behavior to exploit particular features of its environment, and
  - Flexibility, the ability of a system to adapt quickly to environmental change.

[9] Cloutier, R. J. "The Guide to the Systems Engineering Body of Knowledge (SEBoK); v. 2.2." *INCOSE and The Trustees of the Stevens Institute of Technology: Hoboken, NJ, USA* (2016).

Synergy

Synergy

- Synergy is two or more things functioning together to produce a result not independently obtainable.
- This may give both positive and negative effects.
- In systems engineering, Synergy describes how system behavior emerges from the interaction between elements or components or entities.
- Synergy is closely related to Emergence.
- An interaction or cooperation giving rise to a whole that is greater than the simple sum of its parts.
- Term comes from the Attic Greek, meaning "working together".

https://www.sebokwiki.org/wiki/Synergy_(glossary)
https://en.wikipedia.org/wiki/Synergy

Synergy

- In an organization synergy is the ability of a group to outperform even its best individual member. (Buchanan and Huczynski,1997).
- A construct or collection of different elements working together to produce results not obtainable by any of the elements alone. The elements, or parts, can include people, hardware, software, facilities, policies, documents: all things required to produce system-level results. (Blanchard 2004).

https://www.sebokwiki.org/wiki/Synergy_(glossary)
https://en.wikipedia.org/wiki/Synergy

Biological synergy

- In medicine synergy is used to describe combinations of drugs which interact in ways that enhance (i.e. magnify) one or more effects or side-effects.
- Pest synergy occur in a biological host organism population.
  - the parasite A cause 10% fatalities, and parasite B also cause 10% loss. When both parasites are present, the parasites in combination have a synergistic effect.
- Drug synergy: involved in the development of synergistic effects of drugs
  - two different antibiotics can improve the effect

https://www.sebokwiki.org/wiki/Synergy_(glossary)
https://en.wikipedia.org/wiki/Synergy

Human synergy

- Human synergy relates to human interaction and teamwork.
  - Person A is too short to reach an apple and person B is also too short. When person B sits on the shoulders of person A, they are tall enough to reach the apple.
  - If each politician gather 1 million votes, but together two politician appeals to get 2.5 million voters, their synergy produced 500,000 more votes.
  - Taking more than one musical part and putting them together to create a song.

https://en.wikipedia.org/wiki/Synergy

Corporate synergy

- Used in business or other human activity systems to describe outcomes which can only be achieved by encouraging people or organizations to work together.
- Financial benefit of a corporation expects to realize when it merges with or acquires another corporation.
  - If company A sells product X, company B sells product Y, and company A decides to buy company B, thereby increasing the revenue to sell products X and Y together.

https://www.sebokwiki.org/wiki/Synergy_(glossary)
https://en.wikipedia.org/wiki/Synergy

Computer Synergy

- The combination of human strengths and computer strengths.
- Computers can process data much more quickly than humans, but lack heuristics i.e., the ability to respond meaningfully to arbitrary stimuli.

https://www.sebokwiki.org/wiki/Synergy_(glossary)
https://en.wikipedia.org/wiki/Synergy

Cartoon Synergy

- Walt Disney did synergistic marketing techniques in the 1930s by granting dozens of firms the right to use his Mickey Mouse character in products and ads.
- Spider-Man films earned from
  - toys of webshooters (device that can shoot thin strands of a special "web fluid") and
  - spiderman posters, and
  - spiderman games.

https://en.wikipedia.org/wiki/Synergy

Project Management

Project management

- Process of leading the work of a team to achieve goals and meet success criteria at a specified time.
- Challenge: achieve all of the project goals within the given constraints.
- Project documentation: created at the beginning of the development process.

https://en.wikipedia.org/wiki/Project_management

Project management

- Benefits Realization Management (BRM)
  - enhances outcomes (benefits) of a project rather than products or outputs,
  - measures the degree to keep a project on track
- Critical Chain Project Management (CCPM)
  - applies of the Theory Of Constraints (TOC)
  - applies for planning and managing projects,
  - deals with the uncertainties inherent in managing projects,
  - considers limited availability of resources (physical, human skills)
- Earned Value Management (EVM)
  - extends techniques to improve project monitoring
  - illustrates progress towards completion in terms of work and value (cost)

https://en.wikipedia.org/wiki/Project_management

Project management

- Iterative and incremental project management
  - Complex projects are better handled with a more exploratory or iterative and incremental approach.
- Lean project management
  - focuses on delivering value with less waste and reduced time.
- Phased approach
  - breaks down in stages,
  - manages a series of steps
  - referred to as "traditional" or "waterfall".

https://en.wikipedia.org/wiki/Project_management

Four P's:

- Four contextual dynamics affecting the project, these are referred to as the four P's:
  - **Plan**: The planning and forecasting activities.
  - **Process**: The overall approach to all activities and project governance.
  - **People**: Including dynamics of how they collaborate and communicate.
  - **Power**: Lines of authority, decision-makers, organograms, policies for implementation and the like.

https://en.wikipedia.org/wiki/Project_management

Development phases

- Typical development phases of an engineering project
  - initiation,
  - planning and design,
  - Construction,
  - monitoring and controlling,
  - completion or closing.

https://en.wikipedia.org/wiki/Project_management

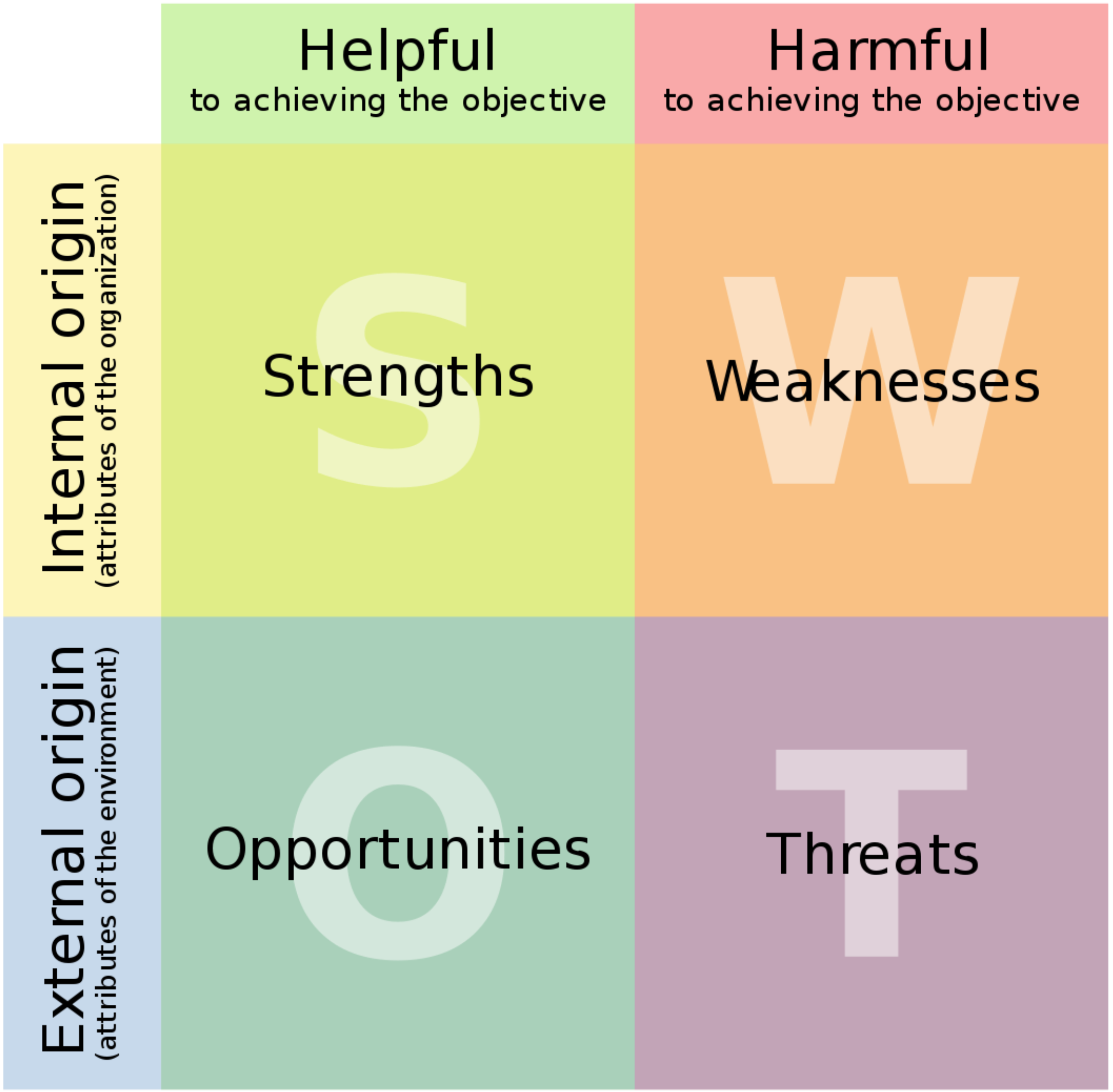
Risk management

- "Cost, Schedule, Performance, and Risk" are the four elements make trade-offs and track program status.
- Applies proactive identification of future problems and understanding of their consequences allowing predictive decisions about projects.

https://en.wikipedia.org/wiki/Project_management

SWOT Analysis

- project characteristics that give
  - *Strengths*: advantage over others
  - *Weaknesses*: a disadvantage relative to others.
- elements in the environment
  - *Opportunities*: resources exploit to its advantage.
  - *Threats*: causes trouble



https://en.wikipedia.org/wiki/SWOT_analysis

SWOT Analysis

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  - *Strengths*: advantage over others
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- elements in the environment
  - *Opportunities*: resources exploit to its advantage.
  - *Threats*: causes trouble

	Strengths 1. 2. 3. 4.	Weaknesses 1. 2. 3. 4.
Opportunities 1. 2. 3. 4.	Opportunity-Strength strategies *Use strengths to take advantage of opportunities* 1. 2.	Opportunity-Weakness strategies *Overcome weaknesses by taking advantage of opportunities* 1. 2.
Threats 1. 2. 3. 4.	Threat-Strength strategies *Use strengths to avoid threats* 1. 2.	Threat-Weakness Strategies *Minimize weaknesses and avoid threats* 1. 2.

https://en.wikipedia.org/wiki/SWOT_analysis

Gantt Chart

There are seven tasks, labeled a through g. Some tasks can be done concurrently (a and b) while others cannot be done until their predecessor task is complete (c and d cannot begin until a is complete). Each task has three time estimates: the optimistic (O), normal (M), and pessimistic (P). The expected time (TE) is time estimated using the formula (O + 4M + P) ÷ 6.

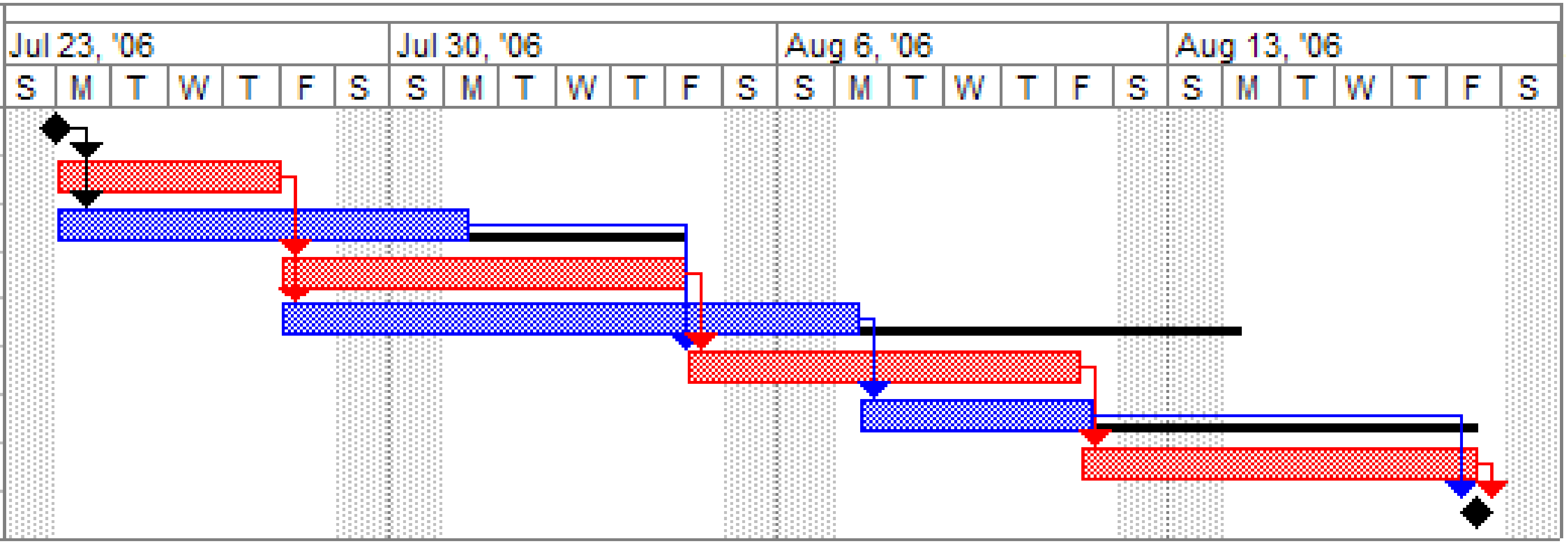
Activity	Predecessor	Time estimates			Expected time (T_E)
		Opt. (O)	Normal (M)	Pess. (P)	
a	—	2	4	6	4.00
b	—	3	5	9	5.33
c	a	4	5	7	5.17
d	a	4	6	10	6.33
e	b, c	4	5	7	5.17
f	d	3	4	8	4.50
g	e	3	5	8	5.17

https://en.wikipedia.org/wiki/Gantt_chart

Gantt charts

- A Gantt chart created with
  - the critical path is in red,
  - the slack is in black lines connected to non-critical activities,
  - assume Saturday and Sunday are not work days and thus excluded from the schedule, some bars on the Gantt chart are longer if they cut through a weekend.

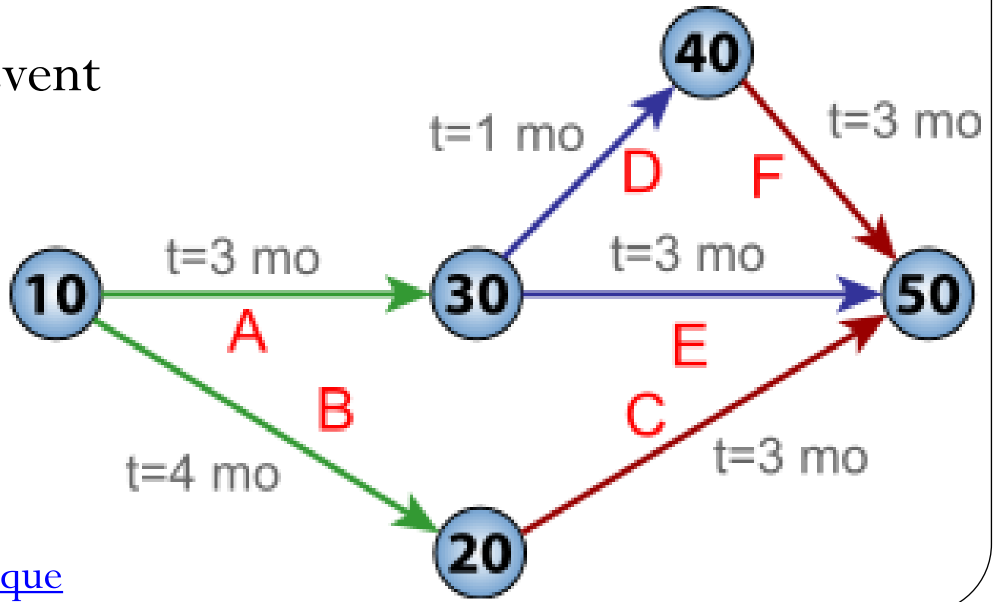
ID	Task Name	Predecessors	Duration
1	Start		0 days
2	a	1	4 days
3	b	1	5.33 days
4	c	2	5.17 days
5	d	2	6.33 days
6	e	3,4	5.17 days
7	f	5	4.5 days
8	g	6	5.17 days
9	Finish	7,8	0 days



https://en.wikipedia.org/wiki/Gantt_chart

Program Evaluation and Review Technique (PERT)

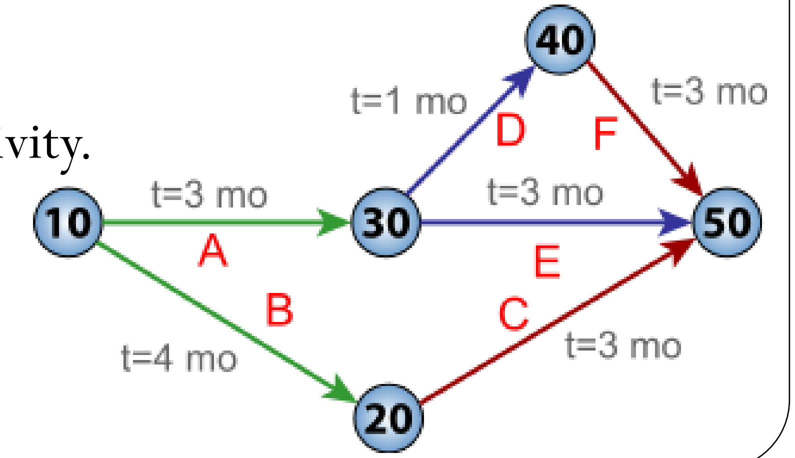
- Building blocks are
  - events with connections to its predecessor and successor events.
- **PERT Event (node or vertice)**
  - a point marked as start or completion of one or more activities
  - consumes no time and uses no resources
- **Predecessor event** immediately precedes some other event.
- **Successor event** immediately follows some other event
- An event
  - can have multiple predecessor events and successor events.
  - can be the predecessor and the successor of multiple events.



https://en.wikipedia.org/wiki/Program_evaluation_and_review_technique

Program Evaluation and Review Technique (PERT)

- PERT also known as activities and sub-activities:
- **PERT activity (edge and link)**
  - the actual performance of a task which consumes time and requires resources (such as labor, materials, space, machinery).
  - It represents the time, effort, and resources required to move from one event to another.
  - A PERT activity cannot be performed until the predecessor event has occurred.
- **PERT sub-activity:** a PERT activity can be further decomposed into a set of sub-activities.
  - all the properties of activities;
  - a sub-activity has predecessor or successor events just like an activity.
  - decomposed again into finer-grained sub-activities.



https://en.wikipedia.org/wiki/Program_evaluation_and_review_technique

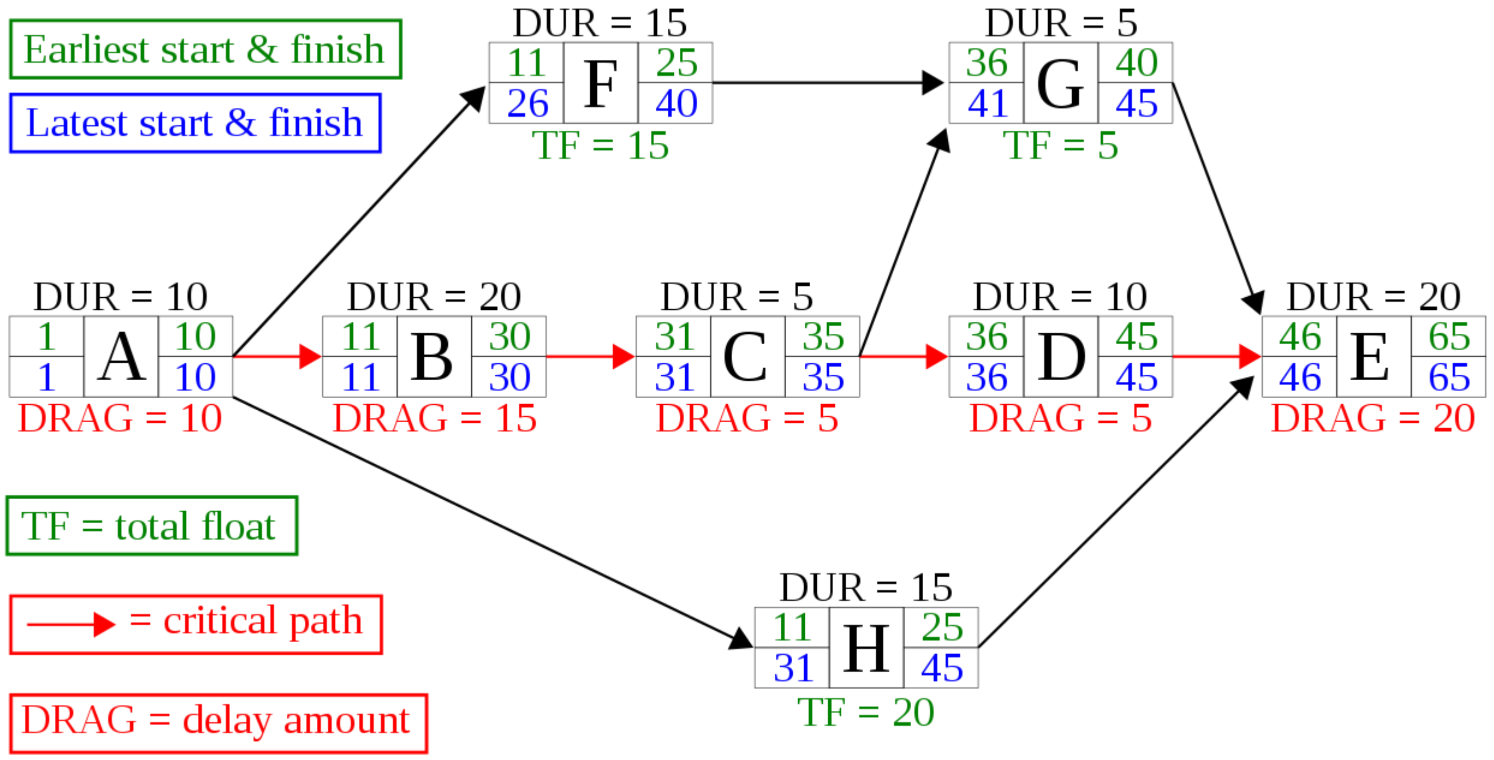
Critical path

- **Total Float calculation:**
  - Individual events on the critical path prior to the constraint might be able to be delayed without elongating the critical path; this is the **'total float'** of that task.
- **Drag calculation:**
  - If a critical path activity has nothing in parallel, its **drag** is equal to its duration.
  - If a critical path activity has another activity in parallel, its **drag** is equal to whichever is less: its duration or the total float of the parallel activity with the least total float.

https://en.wikipedia.org/wiki/Critical_path_method

Critical path

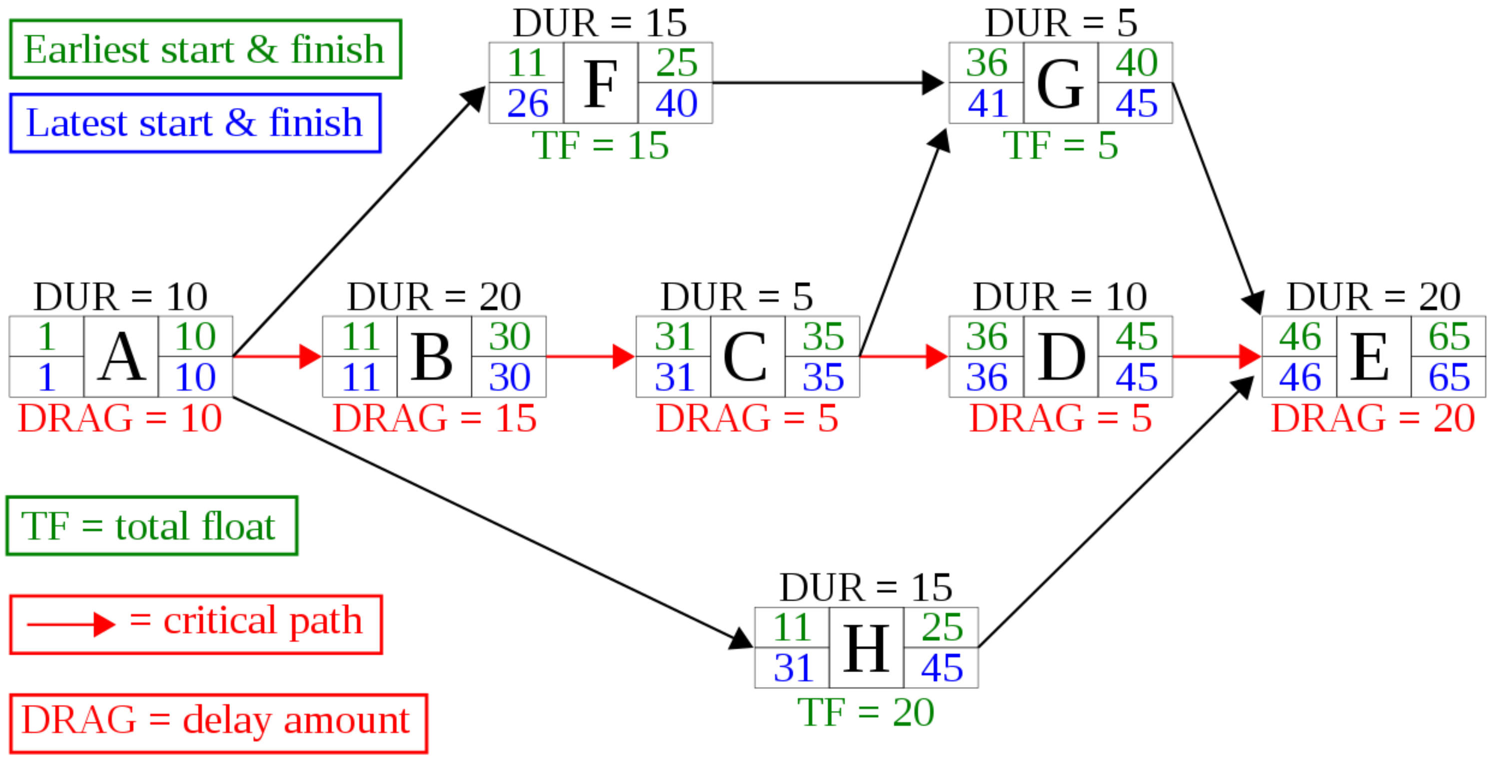
- The longest stretch of dependent activities and measuring the time required to complete them from start to finish.
  - Activities A, B, C, D, and E comprise the critical path.



https://en.wikipedia.org/wiki/Critical_path_method

Critical path float and drag

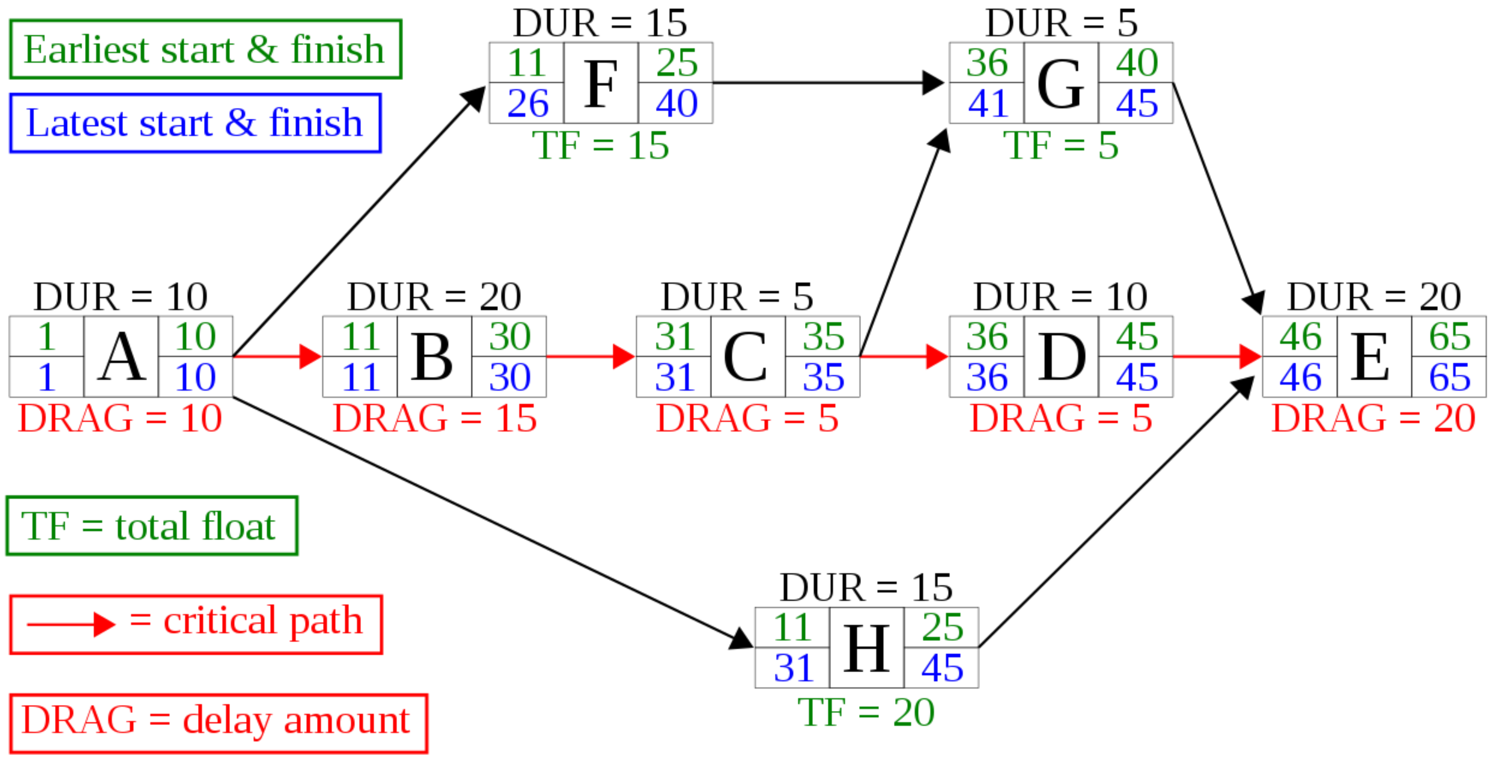
- Activities F, G, and H have floats of 15 days, 5 days, and 20 days
- Activities on the critical path have drag, they delay project completion



https://en.wikipedia.org/wiki/Critical_path_method

Critical path drag calculation

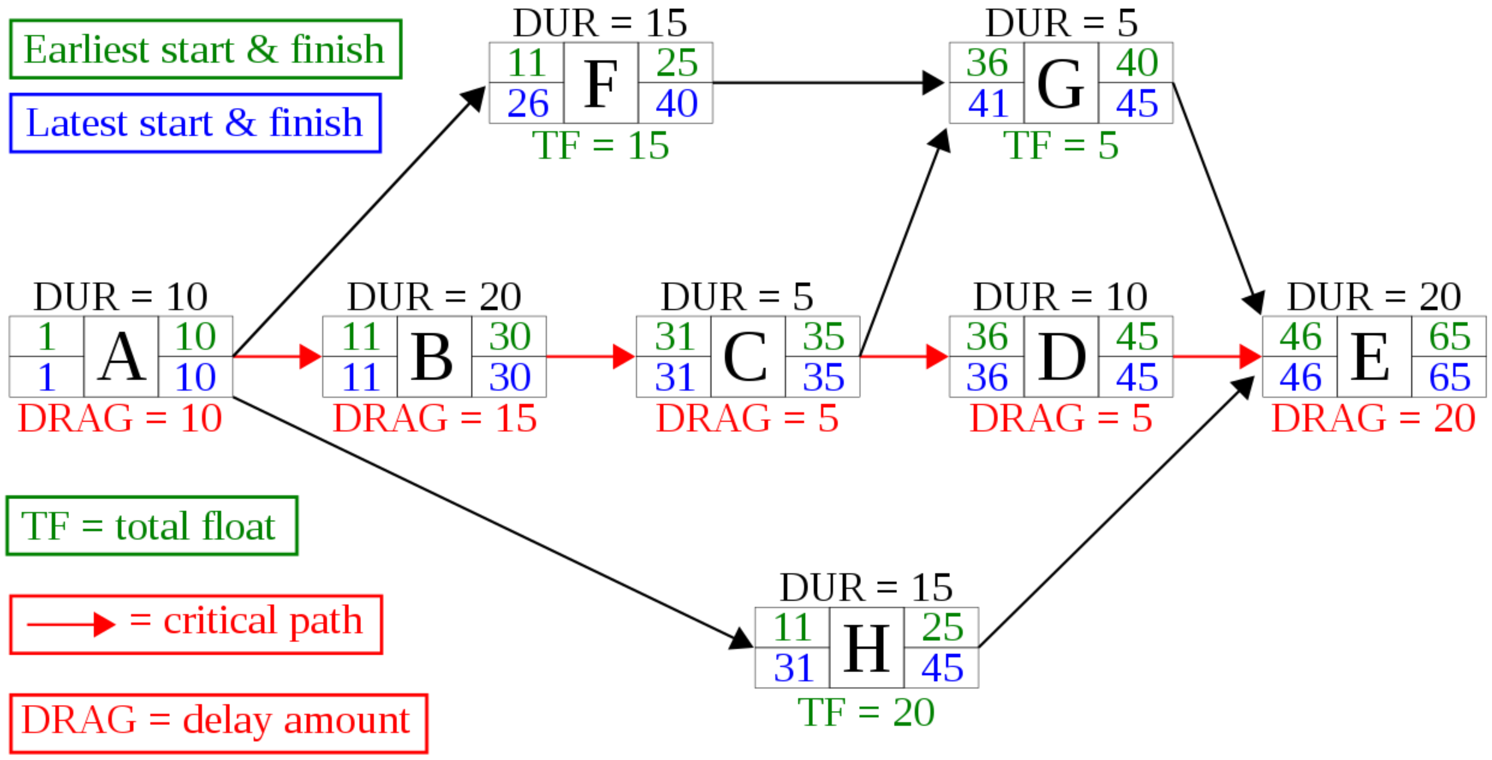
- If activity has nothing in parallel, its drag is equal to its duration A and E have drags of 10 days and 20 days



https://en.wikipedia.org/wiki/Critical_path_method

Critical path drag calculation

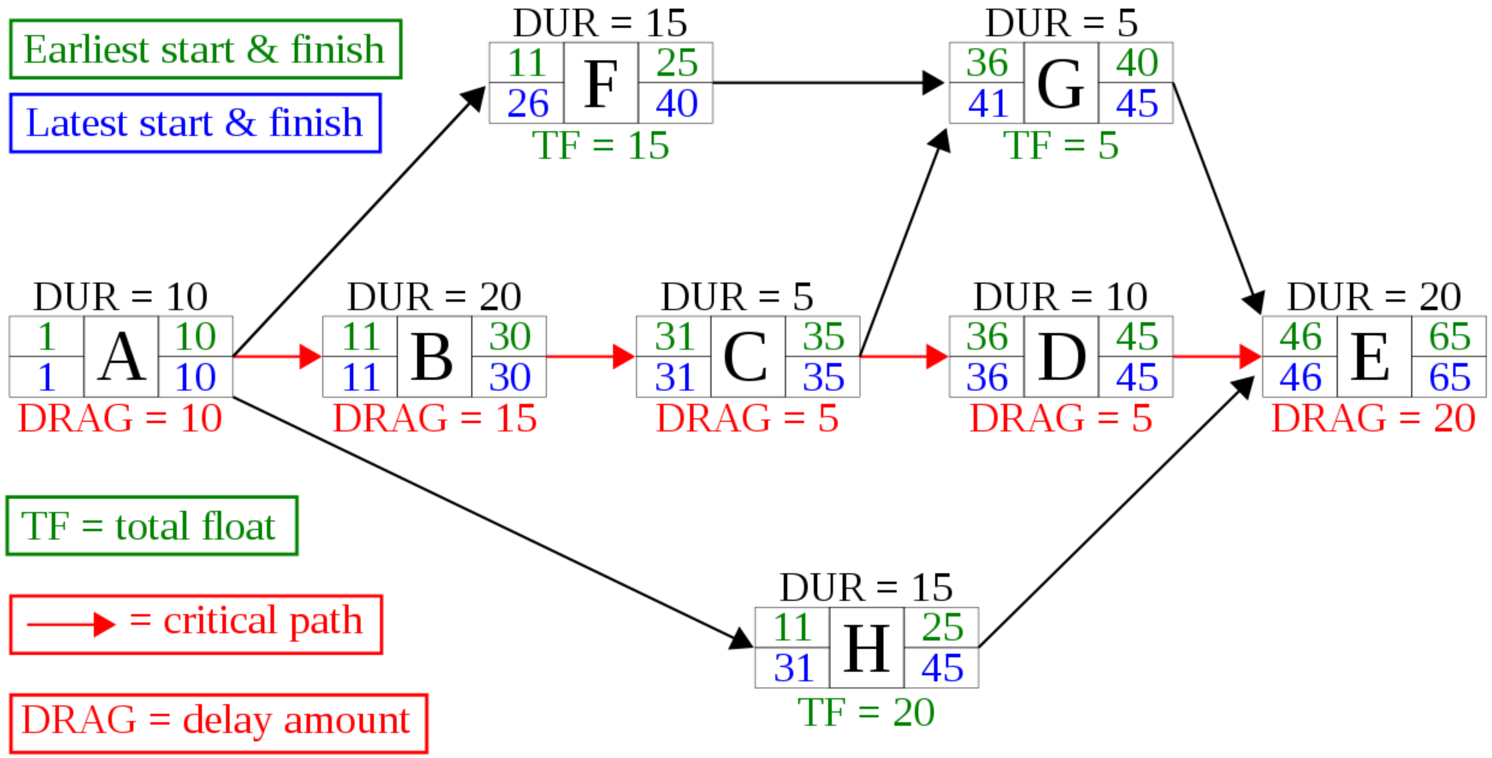
- If a critical path activity has another activity in parallel, its drag is equal to whichever is less: its duration or the total float of the parallel activity with the least total float.



https://en.wikipedia.org/wiki/Critical_path_method

Critical path drag calculation

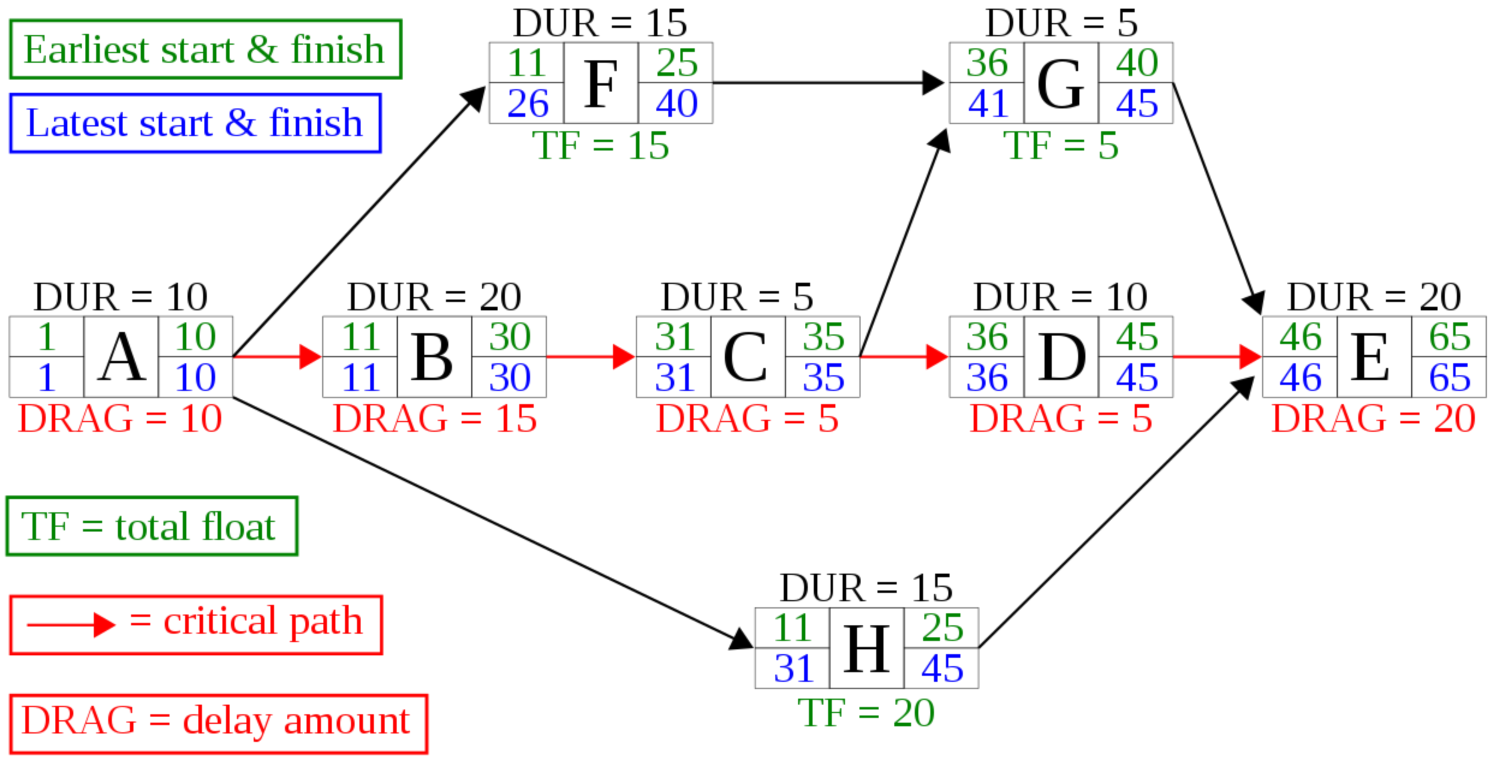
- B and C are both parallel to F (float of 15) and H (float of 20), B has a duration of 20 and drag of 15 (equal to F's float), while C has a duration of only 5 days and thus drag of only 5.



https://en.wikipedia.org/wiki/Critical_path_method

Critical path drag calculation

- Activity D, with a duration of 10 days, is parallel to G (float of 5) and H (float of 20) and therefore its drag is equal to 5, the float of G.



https://en.wikipedia.org/wiki/Critical_path_method

Engineering Domains
(Industry 4.0)

Industrial Revolution

TIME LINE

- Industry 1.0: transition from hand production methods to machines through the use of steam power and water power.
  - textile manufacturing, iron industry, 1760s to 1840s
- Industry 2.0 (Technological Revolution, 1870s to 1910s)
  - extensive railroad, telegraph networks, electrification

- Industry 3.0 (Digital Revolution, late 20th century)
  - Electronics, Computer, Boolean logic, communication technologies
- Industry 4.0 automation of traditional manufacturing and industrial practices, using modern smart technology.
  - machine-to-machine communication (M2M), the internet of things (IoT), improved communication and self-monitoring, and smart machines.
  - Mobile devices, Location detection, Human-machine interfaces, Authentication, 3D printing, Smart sensors, Big data analytics, E-Governance, Augmented reality/ wearables, Cloud computing, Data visualization

https://en.wikipedia.org/wiki/Fourth_Industrial_Revolution

Industry 4.0

TIME LINE

- Civil engineering
- Mechanical engineering and Industrial engineering
  - ➔ Manufacturing engineering
  - ➔ Process engineering
- Mechanical engineering and Electrical engineering
  - ➔ Control engineering
  - ➔ Aerospace engineering
- Mathematics and Electrical engineering
  - ➔ Software Engineering
  - ➔ Computer Science and Engineering
- Transdisciplinary (crosses many disciplines)
  - ➔ Cybernetics
  - ➔ Artificial Intelligence
  - ➔ Data Science and Analytics

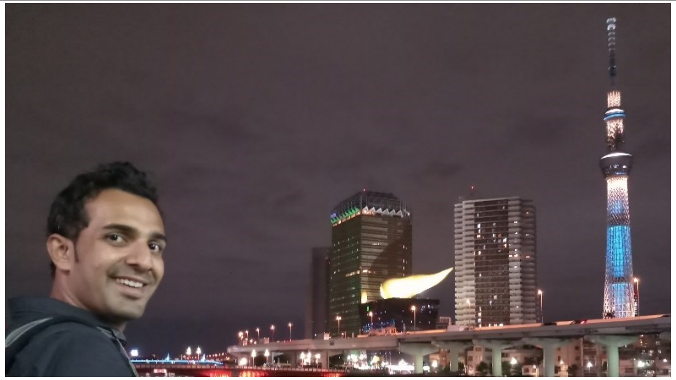
TIME LINE

Civil engineering

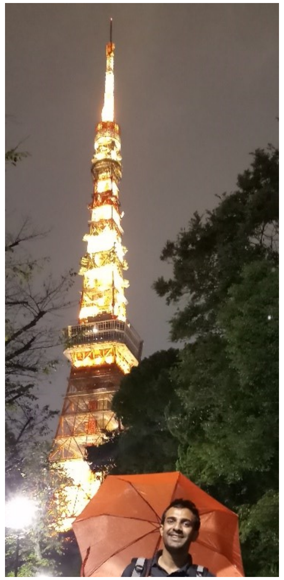
- Deals with the design, construction, and maintenance of the physical and naturally built environment, including public works such as roads, bridges, canals, dams, airports, sewerage systems, pipelines, structural components of buildings, and railways
- Sub-disciplines: Coastal engineering, Construction engineering, Earthquake engineering, Environmental engineering, Forensic engineering, Geotechnical engineering, Materials science and engineering, Structural engineering, Transportation engineering, Municipal or urban engineering, Water resources engineering
- Communities: American Society of Civil Engineers, etc.

https://en.wikipedia.org/wiki/Civil_engineering

Civil engineering



- London Bridge
  - Modern bridge (1971–present), Victorian stone arch (1832–1968)
  - Medieval stone arch (1176–1832), Various wooden bridges (AD 50 – 1176)
- Tokyo Tower (1958) (332.9 meters)
  - communications and observation tower, tallest between 1958 – 1967
- Sky tree (2011 - present) (634 meters)
  - broadcasting and observation tower, tallest tower at present



1958	1967	Tokyo Tower	Japan	Tokyo	332.6 m (1,091 ft)
1967	1975	Ostankino Tower	Russia	Moscow	540.1 m (1,772 ft)
1975	2009	CN Tower	Canada	Toronto	553.33 m (1,815.4 ft)
2009	2011	Canton Tower	China	Guangzhou	604 m (1,982 ft)
2011	present	Tokyo Skytree	Japan	Tokyo	634 m (2,080 ft)

https://en.wikipedia.org/wiki/London_Bridge https://en.wikipedia.org/wiki/Tokyo_Tower
https://en.wikipedia.org/wiki/List_of_tallest_towers

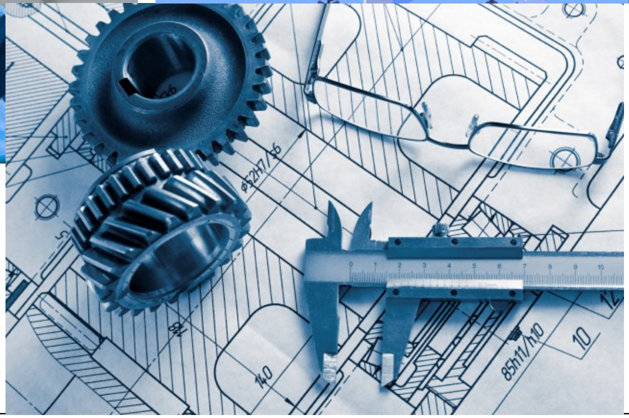
Industrial engineering

- Concerned with the optimization of complex processes, systems, or organizations by developing, improving and implementing integrated systems of people, money, knowledge, information and equipment.
- Sub Disciplines:
  - Energy Engineering, Human Factors & Safety Engineering, Manufacturing Engineering, Operations Engineering & Management, Operations Research & Optimization, Policy Planning, Production Engineering, Quality & Reliability Engineering, Supply Chain Management & Logistics
- Völklingen Ironworks, Saarland Germany,
  - started operation in 1880s and in 1986 plant closed
  - 1994 UNESCO (World Heritage site),
  - museum focusing on making of iron,
  - preserved blast furnaces and old factory.

https://en.wikipedia.org/wiki/Industrial_engineering
https://en.wikipedia.org/wiki/V%C3%B6lklingen_Ironworks

Manufacturing engineering

- To plan the practices of manufacturing; to research and to develop tools, processes, machines and equipment; and to integrate the facilities and systems for producing quality products with the optimum expenditure of capital.
- Industries where manufacturing engineers are generally employed include:
  - Aerospace industry,
  - Automotive industry,
  - Computer industry,
  - Food processing industry,
  - Textile industry,
  - Pharmaceutical industry,
  - Pulp and paper industry,
  - Toy industry



https://en.wikipedia.org/wiki/Manufacturing_engineering

Process engineering

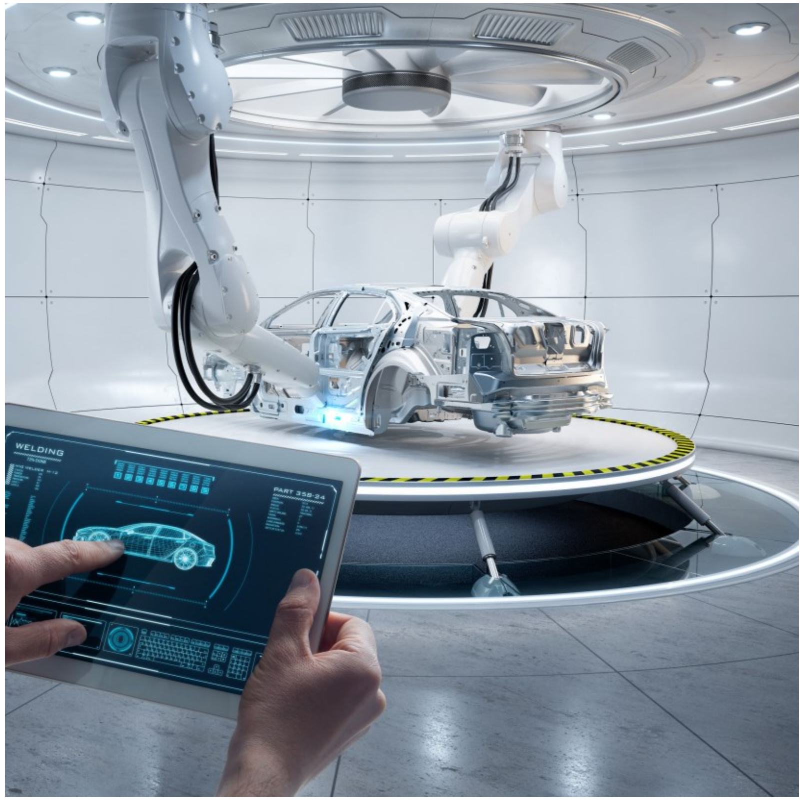
- Transform raw material and energy into products that are useful to society.
- Applied on a vast range of industries, such as agriculture, automotive, biotechnical, chemical, food, material development, mining, nuclear, petrochemical, pharmaceutical, and software development.
- Sub disciplines:
  - Process design,
  - Process control,
  - Process operations,
  - Process Economics, and
  - Process Data Analytics.

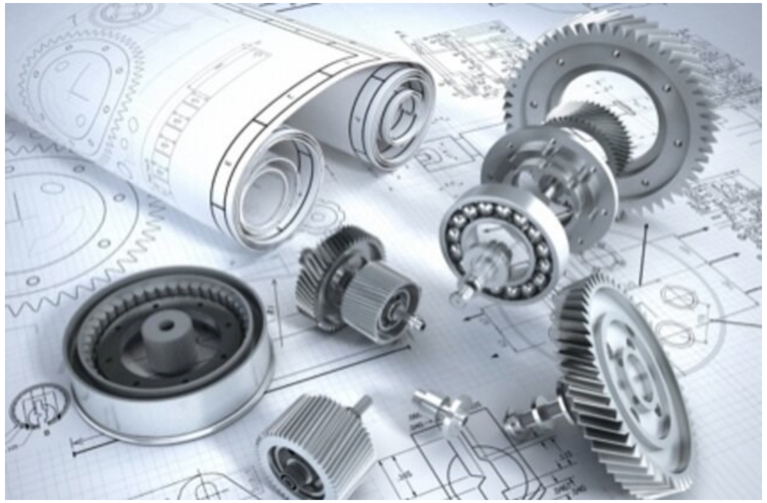
https://en.wikipedia.org/wiki/Process_engineering

Mechanical engineering

- Combines engineering physics and mathematics principles with materials science to design, analyze, manufacture, and maintain mechanical systems
- Core areas includes:
  - mechanics, dynamics, thermodynamics,
  - materials science, structural analysis, and electricity.
- Tools such as
  - Computer-aided design (CAD),
  - Computer-aided manufacturing (CAM),
  - Industrial equipment and machinery,
  - Heating and cooling systems,
  - Transport systems, Aircraft, Watercraft, Robotics,
  - Medical devices, Weapons, and Others.
- Communities:
  - American Society of Mechanical Engineers (ASME), etc.

https://en.wikipedia.org/wiki/Mechanical_engineering





Electrical engineering

- Concerned with the study, design and application of equipment, devices and systems which use electricity, electronics, and electromagnetism
- Subdomains:
  - Power engineering,
  - Telecommunications,
  - Radio-frequency engineering,
  - Signal processing,
  - Instrumentation, and Electronics.
- Communities:
  - International Electrotechnical Commission (IEC),
  - Institute of Electrical and Electronics Engineers (IEEE) and
  - Institution of Engineering and Technology (IET)

https://en.wikipedia.org/wiki/Electrical_engineering

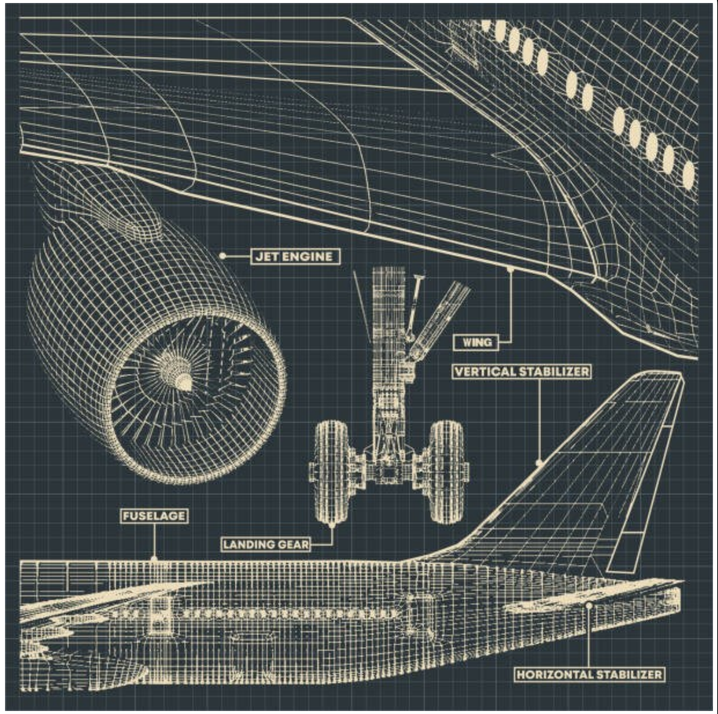
Control engineering

- Applies control theory to design equipment and systems with desired behaviors in control environments.
- Overlaps with electrical engineering and mechanical engineering
- Sensors and detectors for measuring signals.
- Without human input are **automatic control systems** (e.g. **cruise control** for regulating the **speed of a car**).
- Divisions in control theory, namely, classical and modern,
  - Classical single-input and single-output (SISO) System Design
  - Modern multiple-input and multiple-output (MIMO) System Design

https://en.wikipedia.org/wiki/Control_engineering

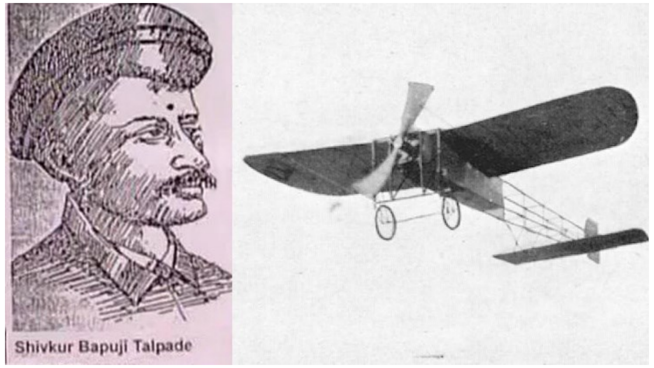
Aerospace engineering

- Concerned with the development of aircraft and spacecraft
- Overlapping branches:
  - Aeronautical engineering and Astronautical engineering
  - Avionics engineering deals with the electronics side
- Subdomains:
  - Aerodynamics,
  - Propulsion,
  - Avionics,
  - Materials science,
  - Structural analysis, and
  - Manufacturing.



https://en.wikipedia.org/wiki/Aerospace_engineering

Aerospace engineering

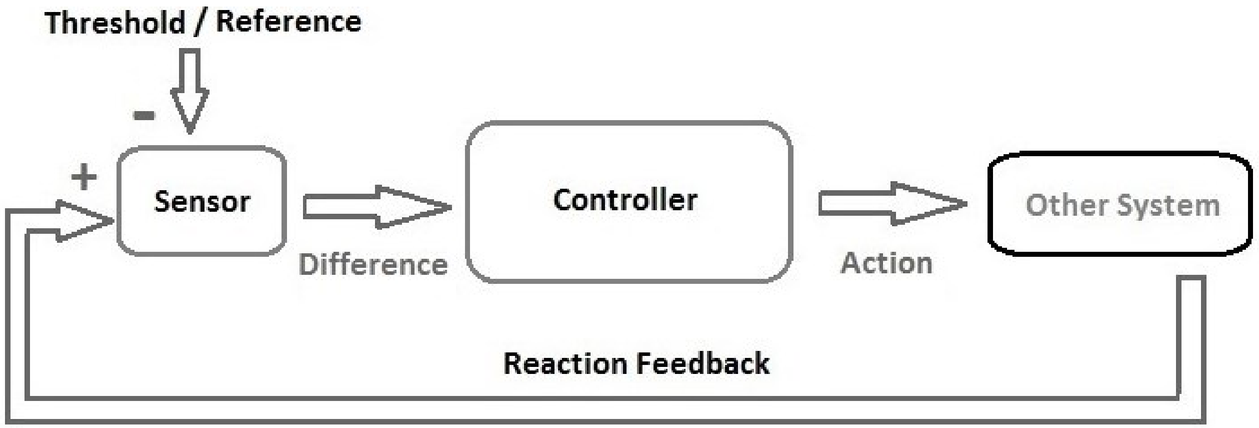


- Shivkar Bāpuji Talpade (1864 – 1916)
  - made first unmanned aircraft in 1895
  - named *Marutsakhā*, derived from the Sanskrit *Marut* ('air' or 'stream') and *sakhā* ('friend') which together mean 'Friend of wind'
  - inspired from Vimāna, ancient flying-machines
  - D. K. Kanjilal's 1985 "*Vimana in Ancient India: Aeroplanes Or Flying Machines in Ancient India*",
- In December 1903, the Wright Brothers
  - first sustained,
  - controlled flight of a powered,
  - heavier-than-air aircraft,
  - lasting 12 seconds.

https://en.wikipedia.org/wiki/Aerospace_engineering

Cybernetics (Trans-disciplinary)

- Cybernetics has its origins around 1940s from anthropology, mathematics, neuroscience, psychology, and engineering. Initial meetings such as Macy Conferences and Ratio Club.
- Its prominent during the 1950s and 1960s. It is a precursor to fields such as Computing, Artificial Intelligence, Cognitive Science, Complexity science, and Robotics.
- Concepts to explore system's - structures, constraints, and possibilities, learning, cognition, adaptation, social control, emergence, and connectivity
- Intersection of the fields of control systems, electrical network theory, mechanical engineering, neuroscience, art, architecture and design, biology, computer science, engineering, earth system science, law, management, and mathematics.
- feedback - the outcomes of actions are taken as inputs for further action.

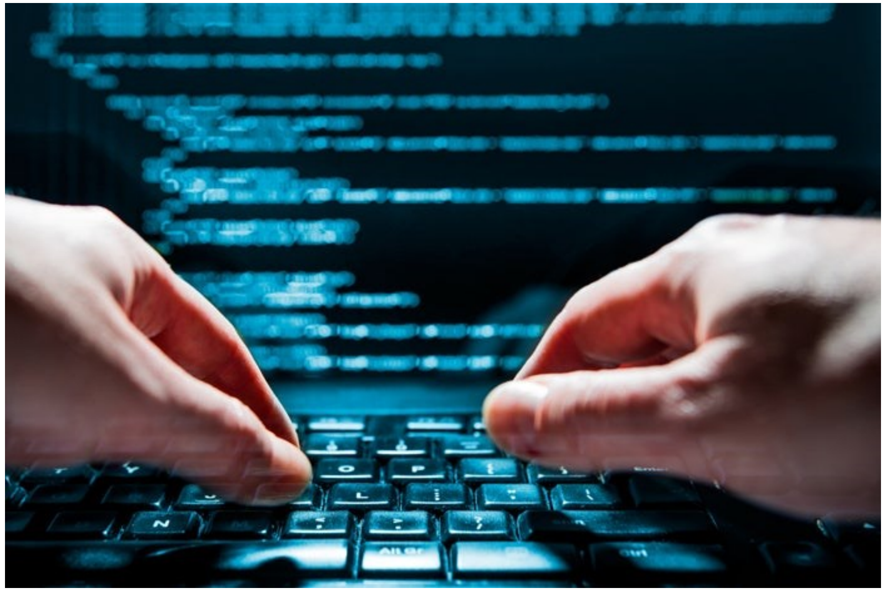


https://en.wikipedia.org/wiki/Cybernetics

Computer Science Engineering (CSE)

- Comprises scientific and engineering aspects of computing.
- In Europe, it is also an often term used to translate as Engineering Informatics
- **Systems subjects:** Programming, Algorithms, Data structures, Computer architecture, Operating systems, Computer networks, Parallel computing, Digital logic, Computer graphics, Software engineering, Database systems etc.
- **Theory subjects:** Theoretical computer science, Numerical methods, Machine learning, Programming theory etc.
- **Mathematical courses:** Discrete mathematics, Mathematical analysis, Linear algebra, Probability, Statistics, Optimization techniques etc.
- **Modern emerging computing:** Cloud computing, Computer vision, Computer Security, Data science, Robotics, Bio-inspired computing, Computational biology, Autonomic computing and Artificial intelligence.

Software engineering and AI



- Digital computers appeared in the early 1940s
  - “Stored program architecture"
  - Von Neumann architecture
  - division between "hardware" and "software"
- Programming languages started to appear in the early 1950s
  - Fortran, ALGOL, PL/I, and COBOL
- Systematic application of engineering approaches to the development of software.
- “Software Engineering” 1965 issue of COMPUTERS and AUTOMATION magazine
- Margaret Hamilton coined the term
  - "software engineering"
  - during the Apollo missions
- Communities: ICSE, FSE, ICSME, ASE, SANER

https://en.wikipedia.org/wiki/Software_engineering

Artificial Intelligence

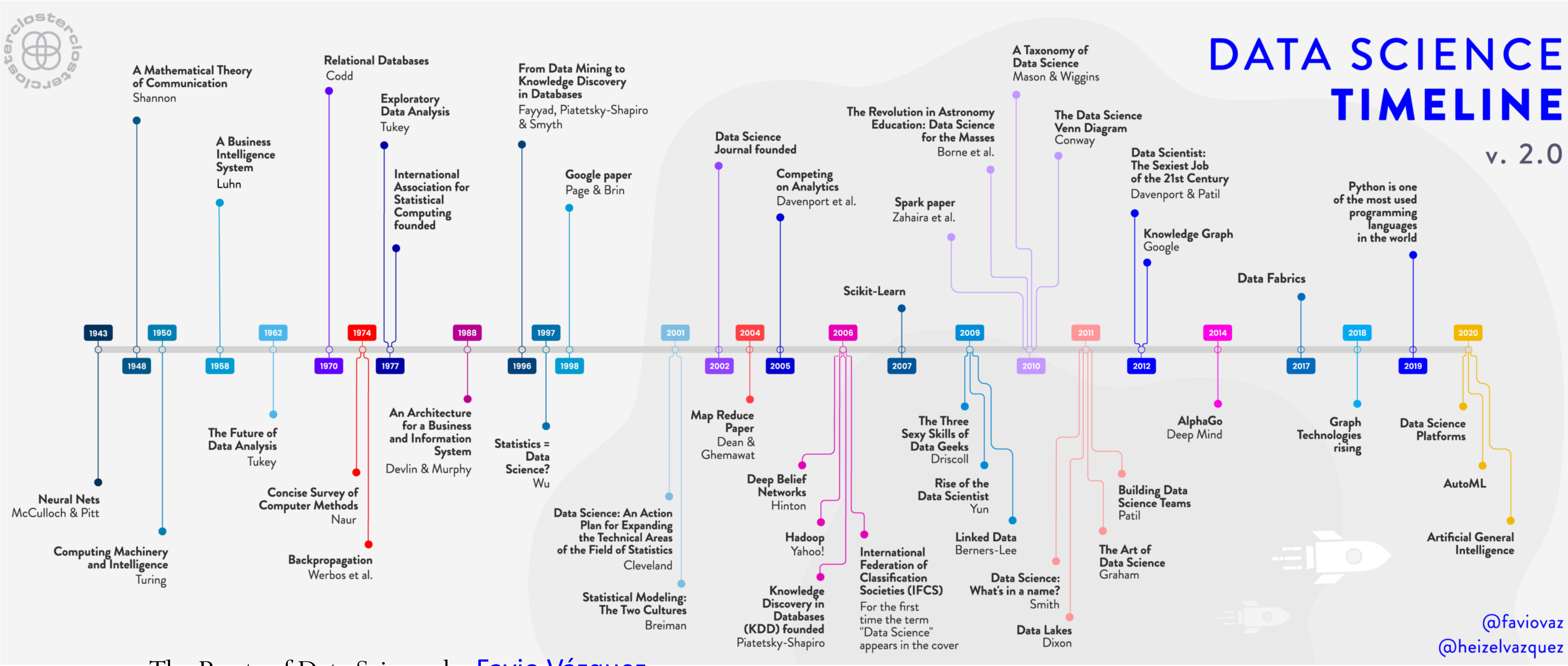
- Founded in 1956 (Dartmouth Research Project on Artificial Intelligence).
- Ancient History shows that AI was an active field of studies since ancient times.
- Simulating the brain, modeling human problem solving, formal logic, large databases of knowledge and imitating human behavior
- Search, Optimization, Formal logic,
- Artificial Neural Networks, Deep learning,
- Classifiers, Reasoning, Knowledge Representation,
- Planning, Learning, Robotics,
- Natural Language Processing, Computational Social Scienc, etc.

https://en.wikipedia.org/wiki/Artificial_intelligence

Artificial Intelligence

- (1837) Analytical Engine, (1925) Houdina Radio Control,
- (1946-1960) ENIAC heralds the dawn of Computing,
- (1946-1960) Turing Test, (1959) Machine Learning,
- (1964) Eliza Chatbot, (1966) Shakey general purpose mobile robot,
- (1960-74) Expert Systems,
- AI Winter (1974-80), AI Spring (1980-87), AI Winter (1987-93),
- (1993) Apriori algorithm: Association Rule Mining,
- (1997) Deep Blue ends Human Supremacy in Chess,
- (1998) Deep Space, (2005) Driverless Cars,
- (2011) IBM Watson beaten Human in Jeopardy,
- (2016) Alpha Go

Data Science



The Roots of Data Science by [Favio Vázquez](https://towardsdatascience.com/the-roots-of-data-science-77c71115229)

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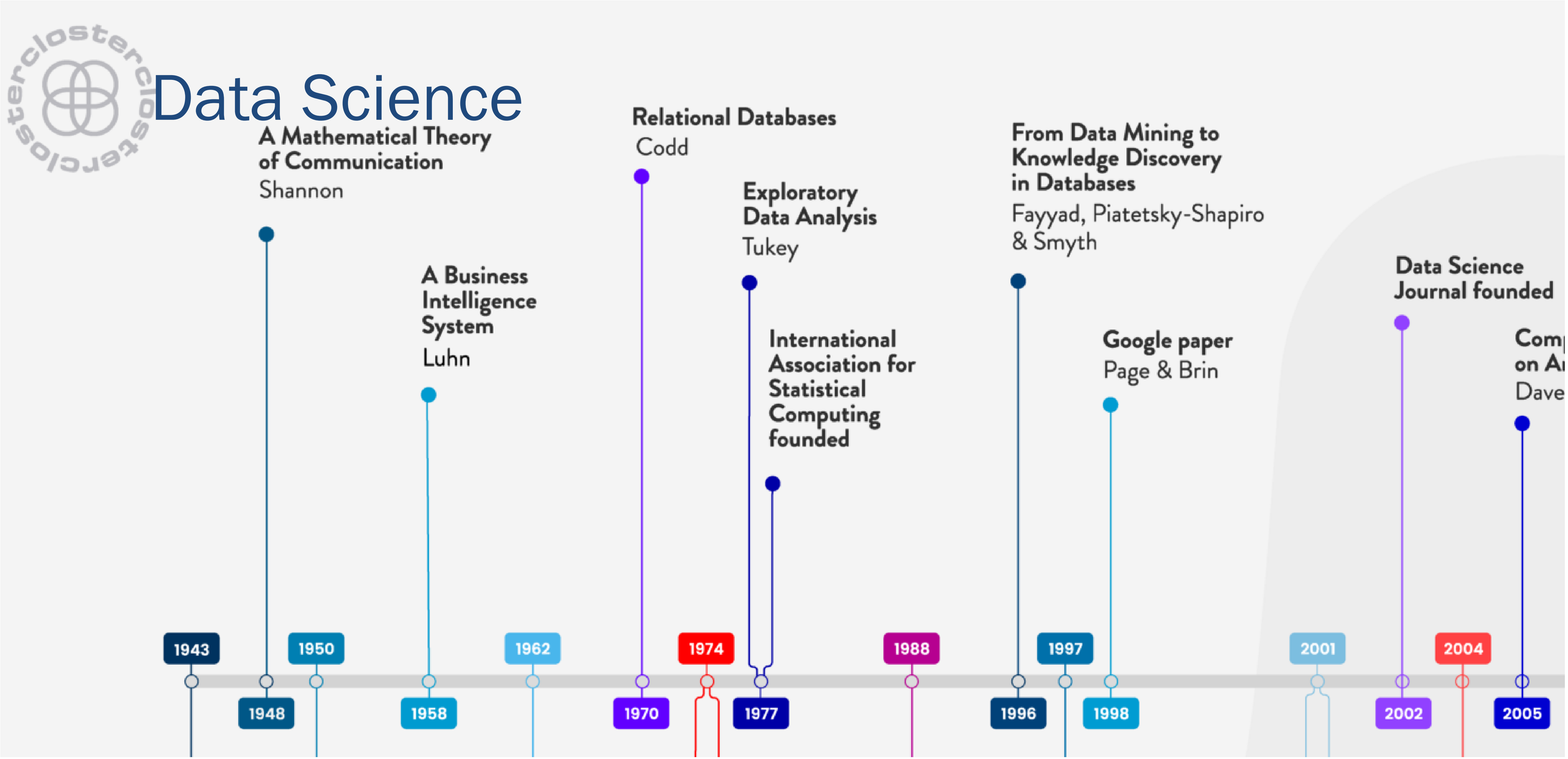
Data Science



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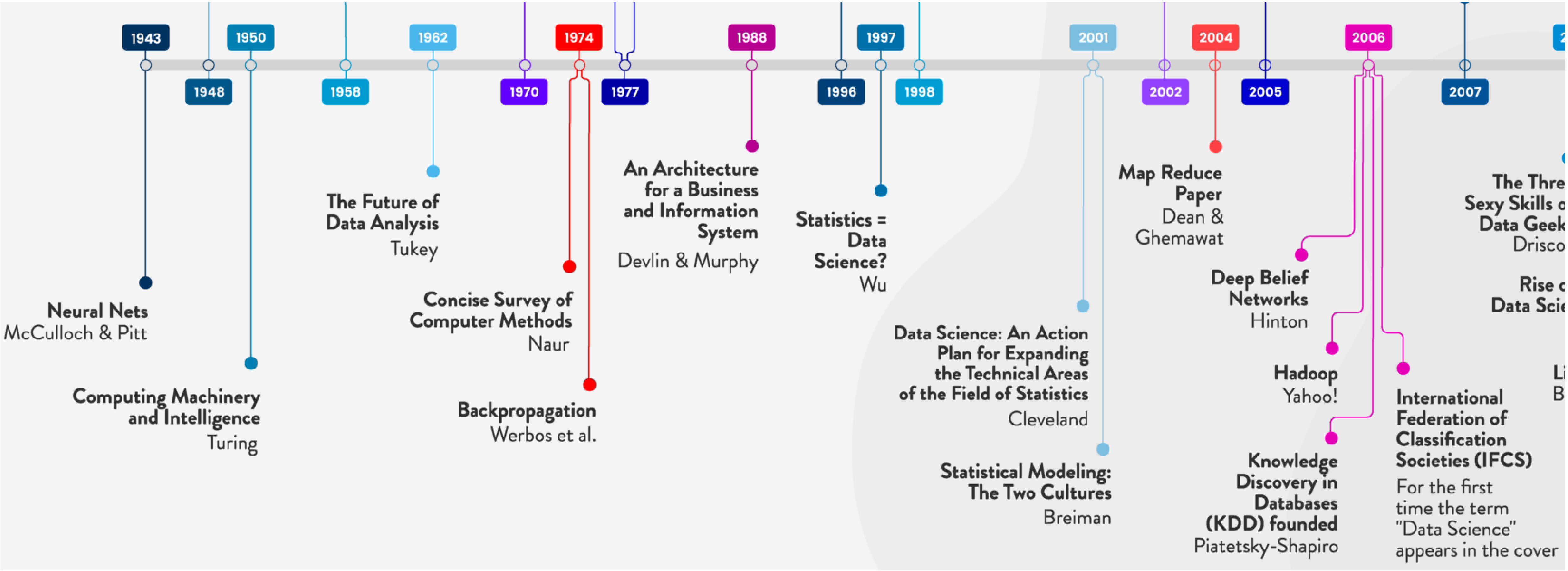

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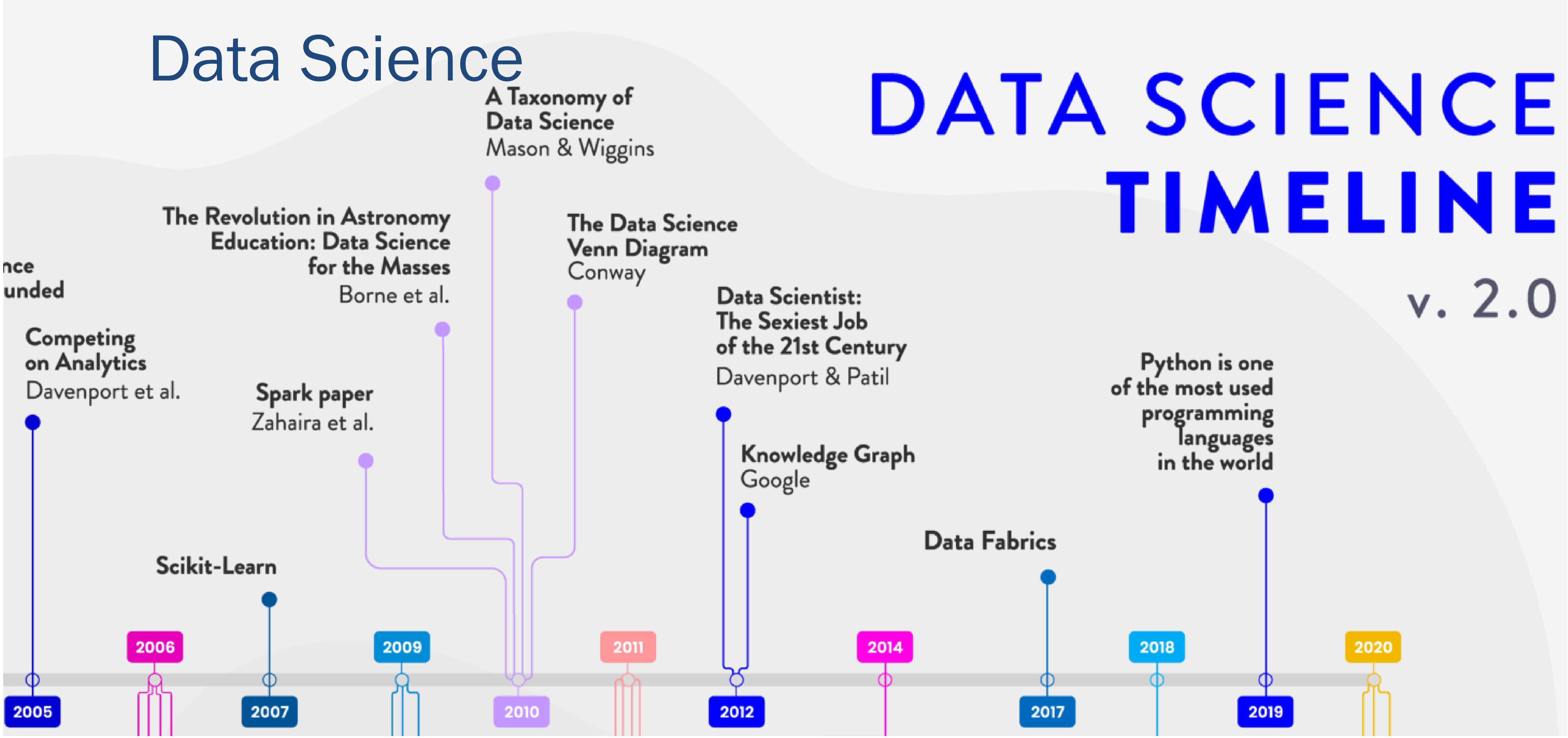

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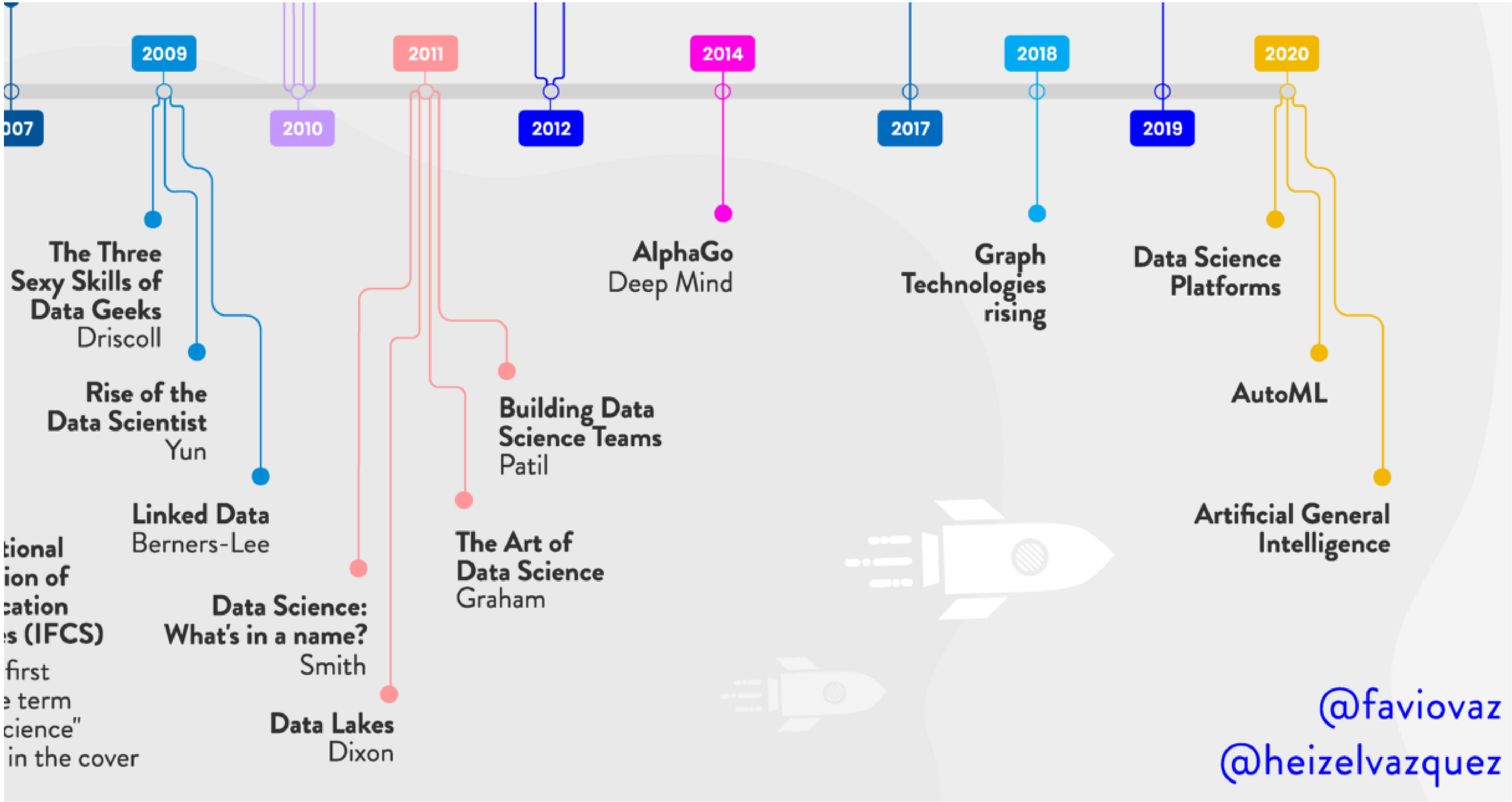
Data Science



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https://towardsdatascience.com/the-roots-of-data-science-77c71115229

Systems Engineering Communities
(INCOSE, IEEE Systems Council, and SMC Society)

INCOSE

- International Council on Systems Engineering (INCOSE)
  - formation in 1990
  - not-for-profit membership organization
  - develop and disseminate the transdisciplinary principles
  - enable the realization of successful systems.
  - connect systems engineering professionals with educational, networking, and career-advancement opportunities
  - global community of Systems engineers
- VISION: A better world through a systems approach.
- MISSION: To address complex societal and technical challenges by enabling, promoting, and advancing systems engineering and systems approaches.

https://www.incose.org/about-incose

INCOSE

- GOALS
  - To provide a focal point for dissemination of systems engineering knowledge.
  - To promote international collaboration in systems engineering practice, education, and research.
  - To assure the establishment of competitive, scale-able professional standards in the practice of systems engineering.
  - To improve the professional status of all persons engaged in the practice of systems engineering.
  - To encourage governmental and industrial support for research and educational programs that will improve the systems engineering process and its practice.

https://www.incose.org/about-incose

IEEE Systems Council

- Field of Interest covers, but is not limited to:
  - Systems thinking
  - Systems Engineering education, standards, processes, methodologies
  - Systems Modeling, simulation, integration, resilience
  - Robust design, safety & human factors, security, usability, environmental
  - Product transition: design, production, test, deployment, disposal
  - Program/project management
  - Quality Assurance
  - Mission Assurance
  - Requirements Development & Management
  - Risk Management
  - Systems Architecture
  - Systems-of-Systems

https://ieeesystemscouncil.org/about

IEEE Systems Council

- Purpose
  - Formed in 2005,
  - “promotes, encourages, and supports the technical, academic and application aspects of systems engineering and systems thinking through its own activities, and with its Society members through joint activities for the growth of Council Affiliate membership, member Society membership, and for addressing overall global challenges.”
  - Integrates multiple disciplines and specialty areas of systems engineering,
  - IEEE Systems Journal,
  - IEEE Systems Conference,

https://ieeesystemscouncil.org/about

IEEE SMC

- SMC stands for Systems, Man, and Cybernetics
- VISION: The vision of the SMC Society is to be recognized as the world leading society for the advancement of theory and application in systems science and engineering, human-machine systems, and cybernetics.
- MISSION: The mission of the SMC Society is to serve the interests of its members and the community at large by promoting the theory, practice, and interdisciplinary aspects of systems science and engineering, human-machine systems, and cybernetics. It is accomplished through conferences, publications, and other activities that contribute to the professional needs of its members.

https://www.ieeesmc.org/about-smcs

IEEE SMC

- FIELDS OF INTEREST
  - Development of systems engineering technology including problem definition methods, modeling, and simulation, methods of system experimentation, human factors engineering, data and methods, systems design techniques and test and evaluation methods.
  - Integration of the theories of communication, control, cybernetics, stochastics, optimization, and system structure towards the formulation of a general theory of systems.
  - Application at hardware and software levels to the analysis and design of biological, ecological, socio-economic, social service, computer information, and operational man-machine systems.

https://www.ieeesmc.org/about-smcs

References

[1] Goode, Harry H.; Robert E. Machol (1957). "System Engineering: An Introduction to the Design of Large-scale Systems". *McGraw-Hill*. p. 8. LCCN 56011714.

[2] Chestnut, Harold (1965). "Systems Engineering Tools". *Wiley*. ISBN 978-0-471-15448-8.

[3] "NASA Systems Engineering Handbook". *NASA*. 1995. SP-610S.

[4] "Systems Engineering Fundamentals". *Defense Acquisition University Press*, 2001.

[5] "Systems Engineering Handbook", *version 2a. INCOSE*. 2004.

[6] "Conquering Complexity: lessons in Defence systems acquisition", *The Defence Engineering Group. University College London*. 2005.

[7] "International Space Station Basics", *National Aeronautics and Space Administration (NASA)*.

[8] Choi BC, Pak AW. "Multidisciplinarity, interdisciplinarity and transdisciplinarity in health research, services, education and policy: 1. Definitions, objectives, and evidence of effectiveness". *Clin Invest Med*. 2006 Dec; 29(6):351-64. PMID: 17330451.

[8] "Systems Engineering Jr. Handbook", *INCOSE LA Chapter and The Creativita Institute*.

[9] Cloutier, R. J. "The Guide to the Systems Engineering Body of Knowledge (SEBoK); v. 2.2." *The Trustees of the Stevens Institute of Technology: Hoboken, NJ, USA* (2016).

ขอบคุณ

Thai

Grazie

Italian

תודה רבה

Hebrew

Gracias

Spanish

Спасибо

Russian

Thank You

English

شكرا

Arabic

Obrigado

Portuguese

Merci

French

多謝

Traditional Chinese

https://sites.google.com/site/animeshchaturvedi07

Danke

German

धन्यवाद

Hindi

多谢

Simplified Chinese

நன்றி

Tamil

Tamil

ありがとうございました

Japanese

감사합니다

Korean