General Systems Theory

Systems Analysis & Design

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Outline

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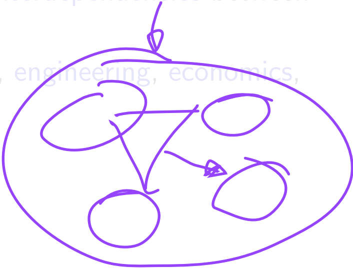
What is General Systems Theory?

- General Systems Theory (**GST**) is an `interdisciplinary framework` for understanding and analyzing complex systems.
- It was introduced by **Ludwig von Bertalanffy** in the 1940s.

applied methodology

- GST focuses on the interconnections and interdependencies between components of a *system*.
- It is widely applied in fields such as biology, engineering, economics, and social sciences.



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Timeline of General Systems Theory

ideas → no foundation

- **1940s**: Ludwig von Bertalanffy introduces GST. → feedback
- **1948**: Norbert Wiener publishes *Cybernetics*.
- **1956**: Jay Forrester develops *Systems Dynamics*. → chaos
- **1972**: Donella Meadows publishes *The Limits to Growth*.
- **1980s**: GST influences *complexity science* and *network theory*.

General Systems Theory I

System thinking

Thinking

engineer
different
point-of-view

high
understanding

- In **general systems theory** the idea is to see a problem since different autonomous study areas, it helps to create a better full-picture of a problem or situation.

random

- Systems are **dynamical**, for that reason you need to define boundaries and constraints to control analysis. Also, some systems are highly susceptible to changes from the environment.

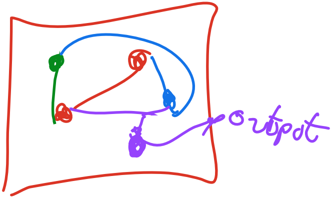
General Systems Theory II

- **Ludwig Von Bertallanfy** started to write a book, but he just had some ideas and not the enough background to develop them.
- He waited twenty years for mathematical and computational **concepts evolution**, and then he was capable to finish the book citing more applied concepts.

Simulation
Probability & Statistics
Cellular Automata
Artificial Intelligence

System Sciences

General Systems Theory III



- In nature, in real-world, **everything is a system**. However, more you go dive to understand the problem, more the complexity arises.
- In this point, **systems theory** is useful. Some **patterns** could be detected, some **details** could be discarded.

abstraction

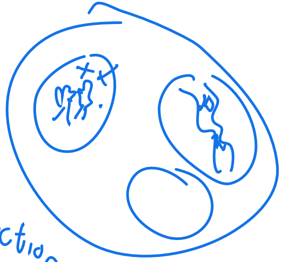
chaotic attractors

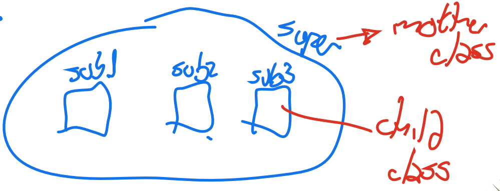
Machine Learning

General Systems Theory IV

- **Systems hierarchies** are useful to split big problems into components, work on specific components, and then just connect as the context leads.
- A **system** could be represent by multiple internal systems. Big system is called **super system**, internal ones are called **subsystems**.

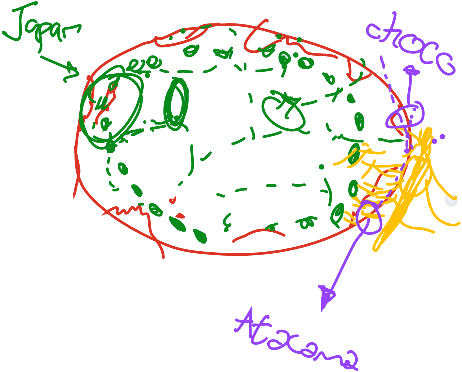
Abstraction






```
A exten B {
   A(){
      super();
   }
```

General Systems Theory V



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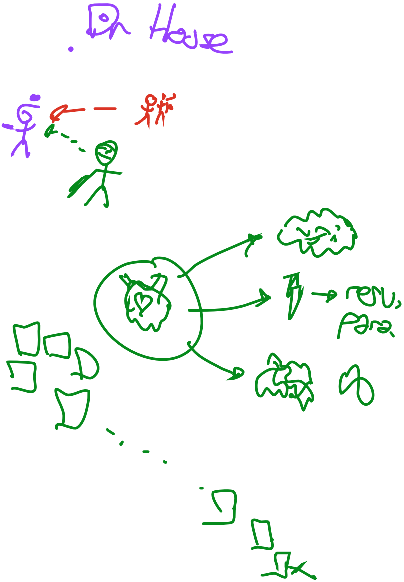
- The human body is a **system**, and inside there are many **subsystems**. Each **subsystem** it's basically connected to each other, and if one fails, it is like a domino effect.

gold
litium
uranium
copper

General Systems Theory V



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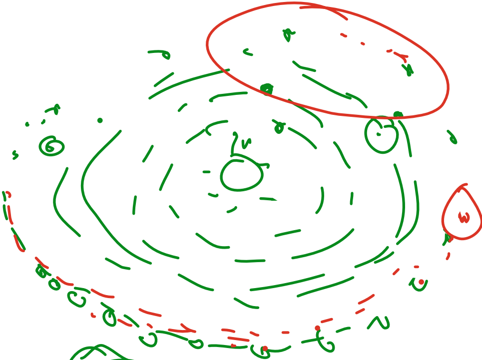
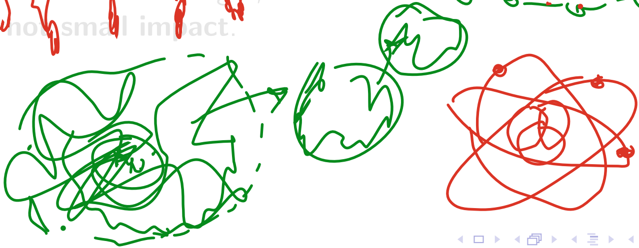
General Systems Theory VI

- **Everything** in the real-world, in the universe, **is a system**. The hardest thing is to get the right representation.
- Remember **concepts** as: snowball effect, butterfly effect, domino effect. The message is the same, be careful with **details**, failures and changes, there is **no small impact**.





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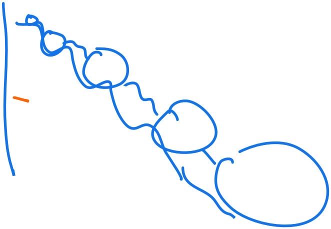
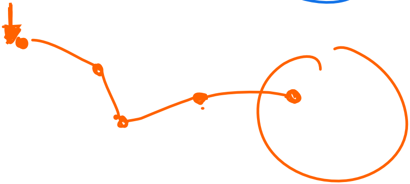
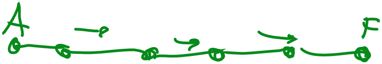
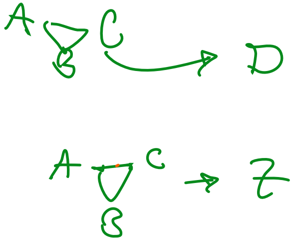






General Systems Theory VII



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- **Black-box** is a type of model when you want to get the desired output based on specific input, but yo don't want to expose the **process** to achieve it.

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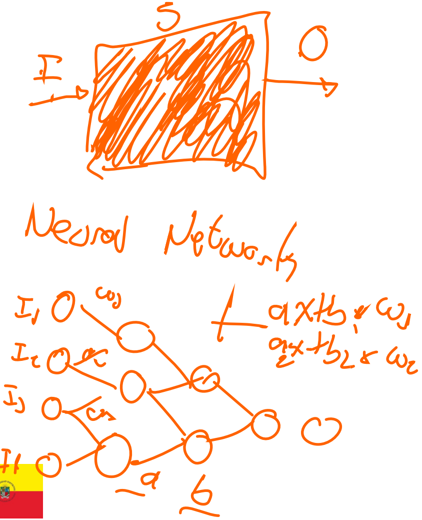

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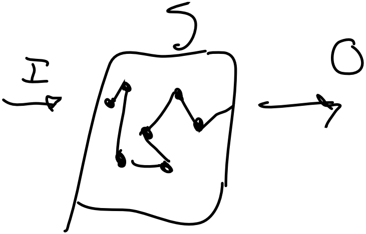
General Systems Theory VIII

- **White-box** are models where the processes are open to check, validate, follow step-by-step. It is useful when you want to understand how the system **works**.

Ants



- **Critical Systems Practice** is a methodology to deal with **Critical Systems Thinking** study field. CSP has 4 main stages: *Explore*, *Produce*, *Intervene*, and *Check* — *EPIC*.

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Ex. → understanding

Pro → schema
design
simulation

Int → play

Ch. → report

Outline

What is Information Theory?

Format

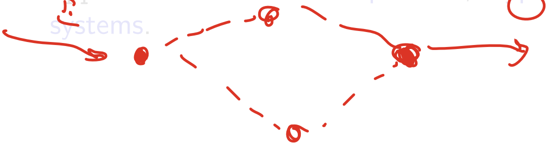
- **Information theory** studies the quantification, storage, and transmission of information.

miss / corrupt

- It was founded by **Claude Shannon** in 1948.

Information Flow

- Key concepts include entropy, redundancy, and channel capacity.
- Applications: data compression, cryptography, and communication systems.



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order/disorder

degradation level

compress

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Entropy in Information Theory

- **Entropy** measures the uncertainty or randomness in a `system`.
- **High entropy**: more uncertainty $\rightarrow$ less predictability.
- **Low entropy**: less uncertainty $\rightarrow$ more predictability.
- Formula: $H(X) = -\sum p(x) \log_2 p(x)$, where $p(x)$ is the probability of event x.

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Applications of Entropy

- **Data Compression**: Reducing file sizes by removing redundancy.
- **Cryptography**: Ensuring secure communication by maximizing entropy.
- **Systems Analysis**: Measuring the complexity and uncertainty of systems.
- **Thermodynamics**: Understanding energy distribution in physical systems.

Outline

What is Graph Theory?

- **Graph theory** studies the relationships between nodes (*vertices*) and edges (*connections*).
- Introduced by **Leonhard Euler** in 1736.
- `Applications`: social networks, transportation systems, computer networks.

Key Concepts in Graph Theory

- **Node (Vertex)**: A point in the graph.
- **Edge**: A connection between two nodes.
- **Degree**: The number of edges connected to a node.
- **Path**: A sequence of edges connecting nodes.
- **Cycle**: A path that starts and ends at the same node.

What is Network Theory?

- **Network theory** extends graph theory to study real-world systems.
- Focuses on structure, dynamics, and functionality.
- `Examples`: Internet, power grids, biological networks.

Case of Study: Metabolic Network

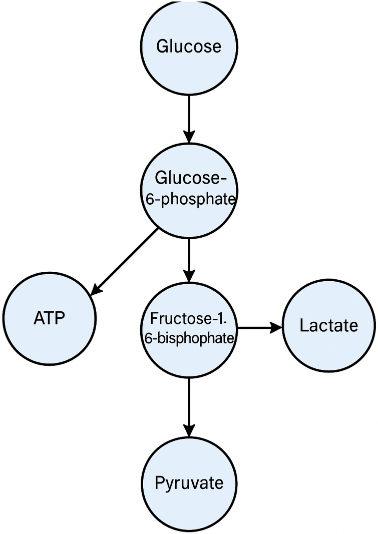

Figure: Metabolic network of *glycolysis pathway*.

Outline

Key Paradigms in General Systems Theory

- **Cybernetics**: Studies control and communication in systems.
- **Systems Thinking**: Focuses on interconnections and feedback loops.
- **Complexity Science**: Explores emergent behavior in complex systems.
- **Systems Dynamics**: Models time-dependent behavior of systems.
- **Agents Theory**: Studies individual agents and their interactions in systems.
- **Network Theory**: Analyzes relationships and connections in systems.
- **Cellular Automata**: Models discrete systems with simple rules.
- **Fuzzy Logic**: Deals with uncertainty and imprecision in systems.
- **Chaos Theory**: Studies sensitive dependence on initial conditions.
- **Game Theory**: Analyzes strategic interactions between agents.
- ...

Cybernetics and GST

- Founded by **Norbert Wiener** in 1948.
- Focuses on feedback, control, and adaptation.
- *Applications*: robotics, artificial intelligence, management systems.

Systems Thinking and GST

- Emphasizes holistic understanding of systems.
- `Key` principles: interdependence, feedback, emergence.
- `Applications`: organizational management, ecology, policy-making.

Complexity Science and GST

- Studies non-linear, adaptive, and emergent systems.
- `Examples`: ecosystems, financial markets, social systems.
- `Tools`: agent-based modeling, network analysis.

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Systems Dynamics and GST

- Developed by **Jay Forrester** in the 1950s.
- Models feedback loops and time delays.
- `Applications`: supply chain management, urban planning, climate change.

Agents Theory and GST

- Studies individual agents and their interactions.
- Key concepts: autonomy, adaptation, learning.
- Applications: multi-agent systems, social networks, game theory.

Network Theory and GST

- Studies relationships and connections in systems.
- Key concepts: nodes, edges, centrality.
- Applications: social networks, transportation systems, biological networks.

Cellular Automata and GST

- Models discrete systems with simple rules.
- `Key` concepts: cells, states, neighborhoods.
- `Applications`: pattern formation, biological systems, computer graphics.

Fuzzy Logic and GST

- Deals with uncertainty and imprecision.
- `Key` concepts: fuzzy sets, membership functions, fuzzy rules.
- `Applications`: control systems, decision-making, pattern recognition.

Chaos Theory and GST

- Studies sensitive dependence on initial conditions.
- Key concepts: chaotic systems, bifurcations, strange attractors.
- Applications: weather prediction, financial markets, biological systems.

Game Theory and GST

- Studies strategic interactions between agents.
- Key concepts: players, strategies, payoffs.
- Applications: economics, political science, biology.

Outline

Thanks!

Questions?

Repo: *https://github.com/EngAndres/ud-public/tree/main/courses/systems-analysis*

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