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.
- **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 I

- **1928**: Ludwig von Bertalanffy first proposes organismic theory as foundation for GST.
- **1940**: Bertalanffy publishes *"Der Organismus als physikalisches System"* introducing open systems concept.
- **1945**: Bertalanffy formally introduces **General Systems Theory** at University of Chicago.
- **1947**: Norbert Wiener coins the term *"Cybernetics"* at Macy Conferences.
- **1948**: Wiener publishes *Cybernetics: Or Control and Communication in the Animal and the Machine*.
- **1948**: Claude Shannon publishes *"A Mathematical Theory of Communication"* founding information theory.

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Timeline of General Systems Theory II

- **1954**: Society for General Systems Research founded by Bertalanffy, Kenneth Boulding, and others.
- **1956**: Jay Forrester develops *Systems Dynamics* at MIT, focusing on feedback loops and time delays.
- **1968**: Bertalanffy publishes *General System Theory: Foundations, Development, Applications*.
- **1972**: Donella Meadows et al. publish *The Limits to Growth* using systems dynamics modeling.
- **1975**: Fritjof Capra publishes *The Tao of Physics*, bridging systems thinking and quantum physics.
- **1976**: Richard Dawkins publishes *The Selfish Gene*, applying systems concepts to evolutionary biology.

Timeline of General Systems Theory III

- **1977**: Ilya Prigogine wins Nobel Prize for work on dissipative structures and self-organization.
- **1980s**: Emergence of *complexity science* and chaos theory, heavily influenced by GST principles.
- **1984**: Santa Fe Institute founded to study complex adaptive systems.
- **1987**: Donella Meadows et al. publish *Beyond the Limits*, updating systems models.
- **1990**: Peter Senge publishes *The Fifth Discipline*, popularizing systems thinking in management.
- **1990s-2000s**: GST influences network theory, agent-based modeling, and social network analysis.
- **2004**: Donella Meadows publishes *Thinking in Systems: A Primer* (posthumously).

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General Systems Theory I

- In **general systems theory**, the idea is to see a problem from different autonomous study areas; it helps to create a better full picture of a problem or situation.
- Systems are **dynamic**; 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 Bertalanffy** started to write a book, but he only had some ideas and insufficient background to develop them.
- He waited twenty years for mathematical and computational **concepts to evolve**, and then he was **able** to finish the book citing more applied concepts.

General Systems Theory III

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

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General Systems Theory IV

- **Systems hierarchies** are useful to split big problems into components, work on specific components, and then connect them as the context requires.
- A **system** can be represented by multiple internal systems. The big system is called a **super system**; internal ones are called **subsystems**.

General Systems Theory V

- In nature, you could think an ecosystem is a **super system** composed of different **subsystems**: water system, solar system, predator-prey system, forest system, etc.
- The human body is a **system**, and inside there are many **subsystems**. Each **subsystem** is essentially connected to the others, and if one fails, it creates a domino effect.

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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** such as: snowball effect, butterfly effect, and 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

- Sometimes you have an **expected output**. Most of the time, it's hard to achieve, so you must be prepared for everything.
- A **black box** is a type of model used when you want to get the desired output based on specific input, but you don't want to expose the **process** used to achieve it.

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General Systems Theory VIII

- **White-box** models are those where the processes are open for checking, validating, and following step by step. They are useful when you want to understand how the **system works**.
- **Critical Systems Practice** is a methodology for addressing **Critical Systems Thinking**. CSP has 4 main stages: *Explore*, *Produce*, *Intervene*, and *Check* — $EPIC$.

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What is Information Theory?

- **Information theory** studies the quantification, storage, and transmission of information.
- It was founded by **Claude Shannon** in 1948.
- Key concepts include entropy, mutual information, and channel capacity.

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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.

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What is Graph Theory?

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

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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.

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Case Study: Metabolic Network

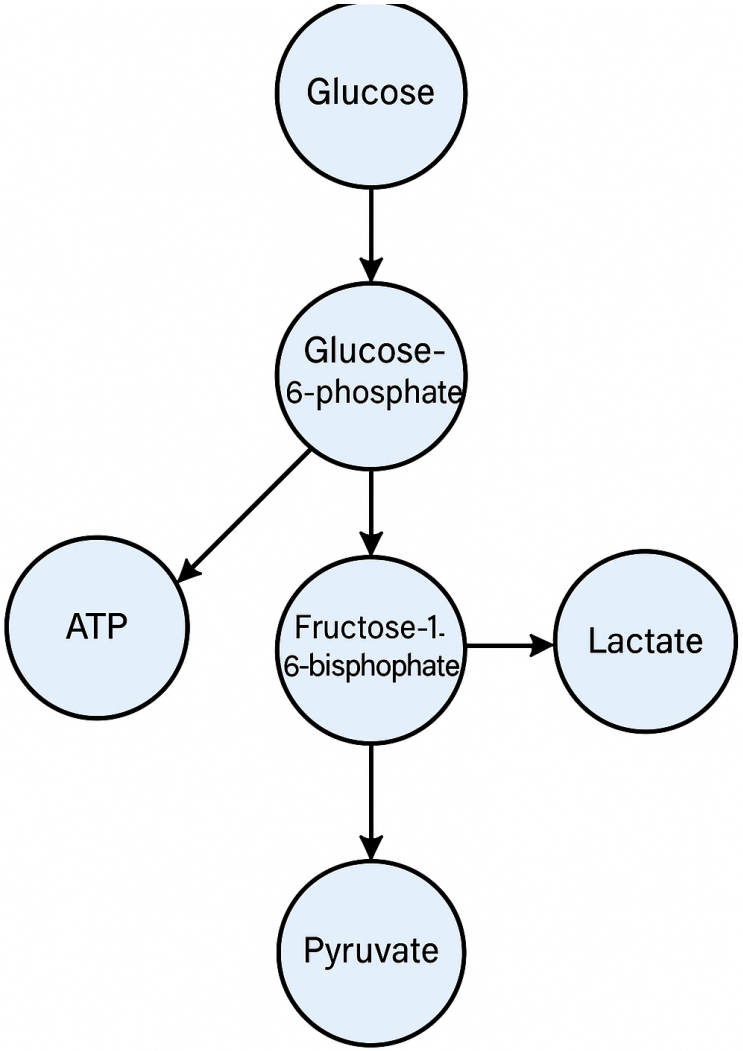

Figure: Metabolic network of *glycolysis pathway*.

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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.
- **Agent 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.

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Cybernetics and GST

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

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Systems Thinking and GST

- It emphasizes the 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.

Systems Dynamics and GST

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

Agent Theory and GST

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

Network Theory and GST

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

Cellular Automata and GST

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

Fuzzy Logic and GST

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

Chaos Theory and GST

- It 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.

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Thanks!

Questions?

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

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