General Systems Theory

Systems Analysis & Design

Author: Eng. Carlos Andrés Sierra, M.Sc.
cavirguezs@udistrital.edu.co

Lecturer
Computer Engineering Department
School of Engineering
Universidad Distrital Francisco José de Caldas

2025-I

UNIVERSIDAD DISTRITAL
FRANCISCO JOSÉ DE CALDAS

Outline

1. Basic Concepts
2. Information Theory and Entropy
3. Graphs and Networks Theory
4. Paradigms Supporting GST

UNIVERSIDAD DISTRITAL
FRANCISCO JOSÉ DE CALDAS

Outline

1 Basic Concepts

2 Information Theory and Entropy

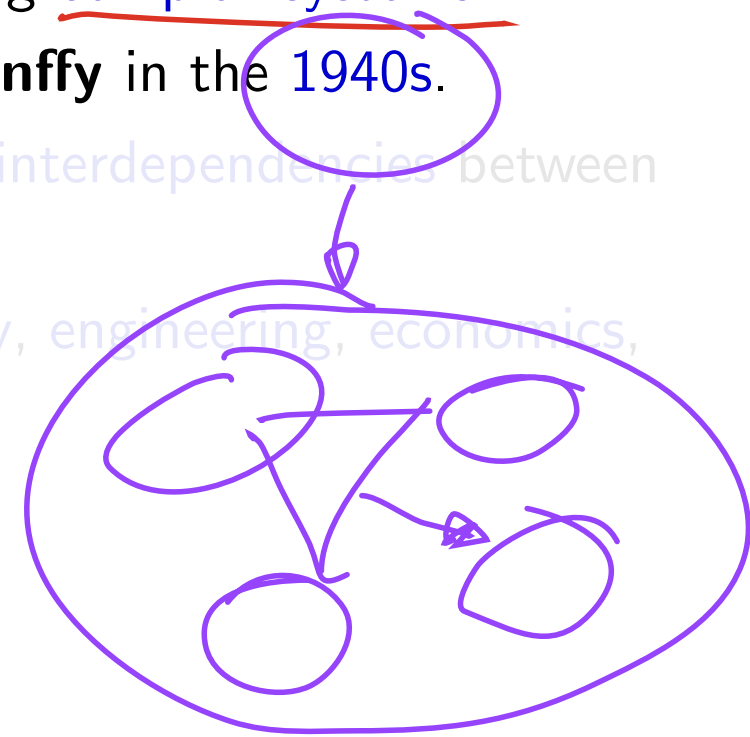
3 Graphs and Networks Theory

4 Paradigms Supporting GST

UNIVERSIDAD DISTRITAL
FRANCISCO JOSÉ DE CALDAS

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.



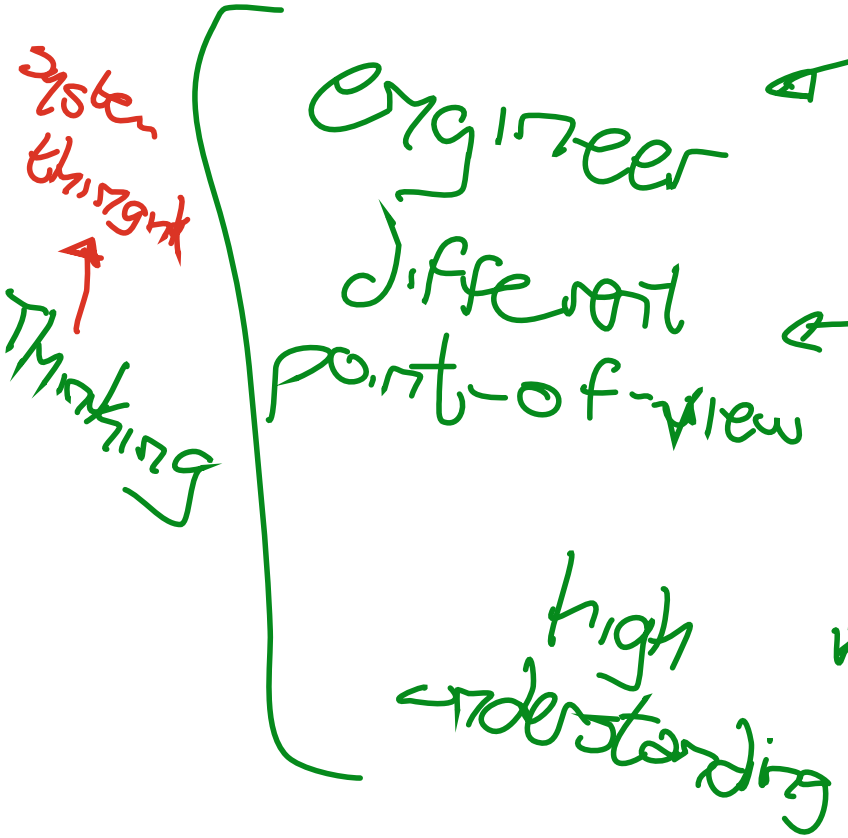
What is General Systems Theory?

- 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.

Timeline of General Systems Theory

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

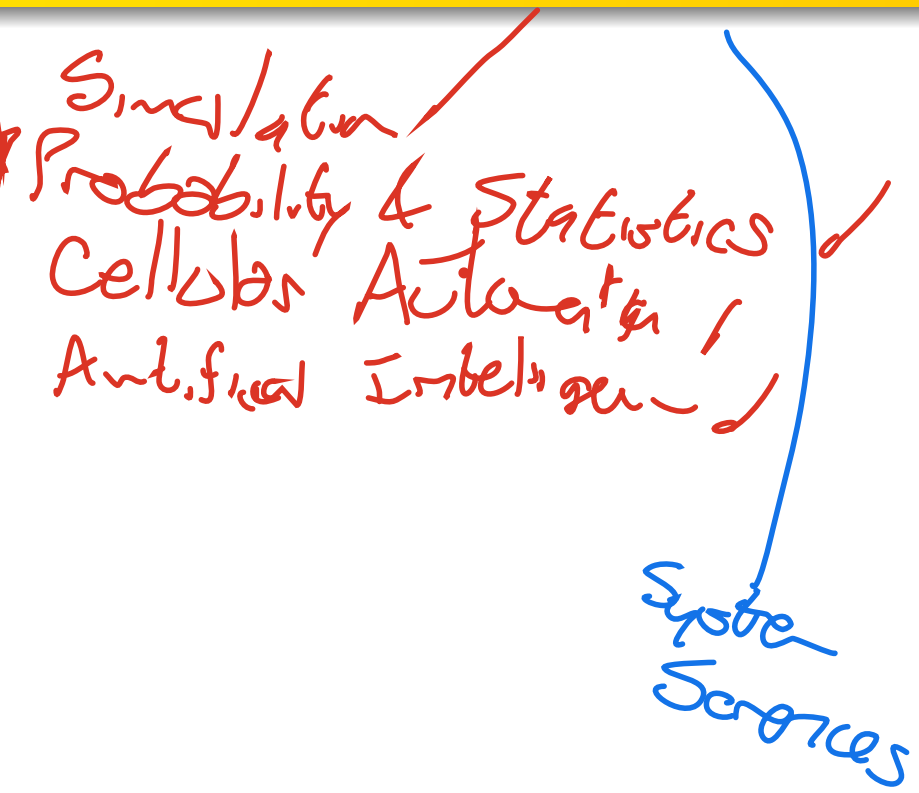
General Systems Theory I



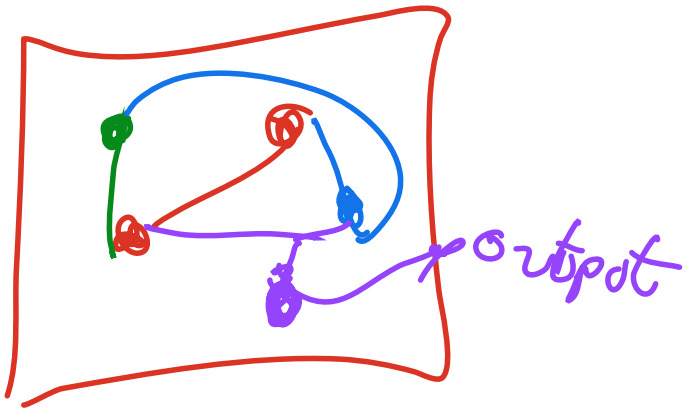
- In **general systems theory** the idea is to see a problem since different autonomous study areas, it helps to create a better full-picture of a problem or situation.
- Systems are **dynamical**, for that reason you need to define boundaries and constraints to control analysis. Also, some systems are 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.



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

fractic attractors

Machine Learning

UNIVERSIDAD DISTRITAL
FRANCISCO JOSÉ DE CALDAS

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**.

General Systems Theory V

- In nature ,you could think an ecosystem is a **super system** composed by different **subsystems**: water system, solar system, predator-victim , forest system,. . .
- 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.

UNIVERSIDAD DISTRITAL
FRANCISCO JOSÉ DE CALDAS

General Systems Theory V

- In nature ,you could think an ecosystem is a **super system** composed by different **subsystems**: water system, solar system, predator-victim , forest system,. . .
- 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.

UNIVERSIDAD DISTRITAL
FRANCISCO JOSÉ DE CALDAS

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 **not small impact**.

UNIVERSIDAD DISTRITAL
FRANCISCO JOSÉ DE CALDAS

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 **not small impact**.

UNIVERSIDAD DISTRITAL
FRANCISCO JOSÉ DE CALDAS

General Systems Theory VII

- Sometimes you have an **expected output**. Major part of the time it's hard to achieve it, you must be prepared for everything.
- **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.

UNIVERSIDAD DISTRITAL
FRANCISCO JOSÉ DE CALDAS

General Systems Theory VII

- Sometimes you have an **expected output**. Major part of the time it's hard to achieve it, you must be prepared for everything.
- **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.

UNIVERSIDAD DISTRITAL
FRANCISCO JOSÉ DE CALDAS

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

UNIVERSIDAD DISTRITAL
FRANCISCO JOSÉ DE CALDAS

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

UNIVERSIDAD DISTRITAL
FRANCISCO JOSÉ DE CALDAS

Outline

1 Basic Concepts

2 Information Theory and Entropy

3 Graphs and Networks Theory

4 Paradigms Supporting GST

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, redundancy, and channel capacity.
- Applications: data compression, cryptography, and communication systems.

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, redundancy, and channel capacity.
- Applications: data compression, cryptography, and communication systems.

UNIVERSIDAD DISTRITAL
FRANCISCO JOSÉ DE CALDAS

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, redundancy, and channel capacity.
- Applications: data compression, cryptography, and communication systems.

UNIVERSIDAD DISTRITAL
FRANCISCO JOSÉ DE CALDAS

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.

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.

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

1 Basic Concepts

2 Information Theory and Entropy

3 Graphs and Networks Theory

4 Paradigms Supporting GST

UNIVERSIDAD DISTRITAL
FRANCISCO JOSÉ DE CALDAS

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.

UNIVERSIDAD DISTRITAL
FRANCISCO JOSÉ DE CALDAS

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.

UNIVERSIDAD DISTRITAL
FRANCISCO JOSÉ DE CALDAS

Case of Study: Metabolic Network

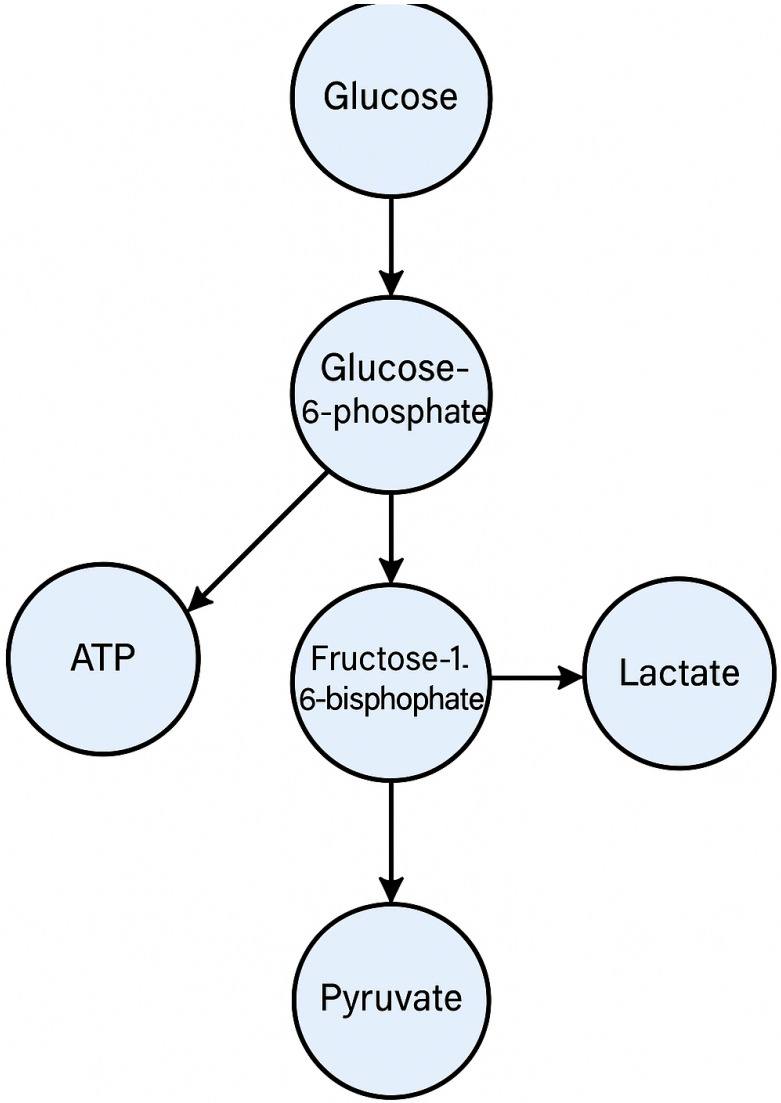


Figure: Metabolic network of *glycolysis pathway*.

Outline

1 Basic Concepts

2 Information Theory and Entropy

3 Graphs and Networks Theory

4 Paradigms Supporting GST

UNIVERSIDAD DISTRITAL
FRANCISCO JOSÉ DE CALDAS

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.

...

UNIVERSIDAD DISTRITAL
FRANCISCO JOSÉ DE CALDAS

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.

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

1 Basic Concepts

2 Information Theory and Entropy

3 Graphs and Networks Theory

4 Paradigms Supporting GST

UNIVERSIDAD DISTRITAL
FRANCISCO JOSÉ DE CALDAS

Thanks!

Questions?

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

UNIVERSIDAD DISTRITAL
FRANCISCO JOSÉ DE CALDAS