add time dimension ← study ↗ + play

Systems Simulation

Systems Analysis & Design

Validation

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Outline

1. Basic Concepts
2. Cellular Automata
3. Digital Twins

Outline

What is a simulation?

- **Simulations** are a type of real-world representation, but rarely exactly like the real world.
- Sometimes you need to **test** or **experiment** with expensive use cases. Simulations let you play with different inputs, conditions, `hyperparameter optimizations`.
- Also, there are dangerous or hard-to-reach scenarios where **simulations** become the best option.
- You should define the **level of detail** well enough to represent the expected behavior, without failing due to either high complexity or lazy simplicity.

high complexity

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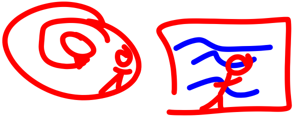

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- chemical / processes
- Construction

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Events and Stochastic Processes

- It is typical to play with **event probabilities**, creating stochastic behaviors.
- One way to simulate many systems is to use **event-based models**. Embrace the chaos and `Murphy's Law`.

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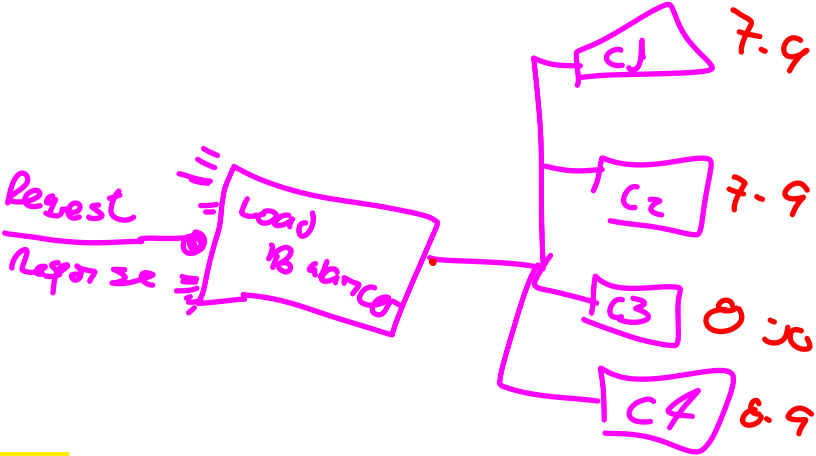
O.O.P.

A B C

Case Study: Load Balancer in a Cloud Architecture



Outline

Cellular Automata

continuous

state changes

- **Cellular Automata** are a discrete model defined by a grid of cells, each with a state. → info → object
- The state of a cell is updated based on the **states of its neighbors**.

time

1 2 3 4 t

→ Video games

Atari

cells

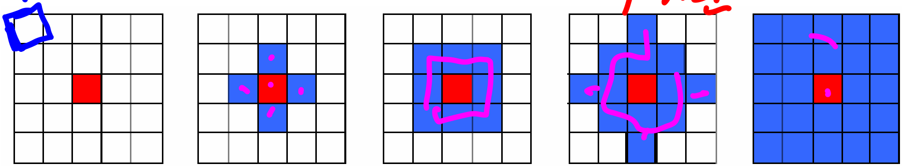


Figure: Cellular Automata Typical Neighborhoods

flow

Game of Life

- **Game of Life** is a cellular automaton devised by the British mathematician John Horton Conway in 1970.
- It is a **zero-player game**, meaning that its **evolution** is determined by its initial state, requiring no further input.

chaos

$t = 0$

- Rules:
  - Any **live** cell with fewer than two live neighbors **dies**, as if by underpopulation.
  - Any **live** cell with two or three live neighbors **lives** on to the next generation.
  - Any **live** cell with more than three live neighbors **dies**, as if by overpopulation.
  - Any **dead** cell with exactly three live neighbors becomes a **live** cell, as if by reproduction.

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0 - dead
1 - live

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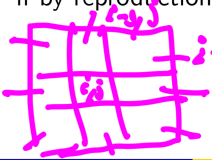
i-1, j-1

i, j-1



i-1, j+1
i, j+1

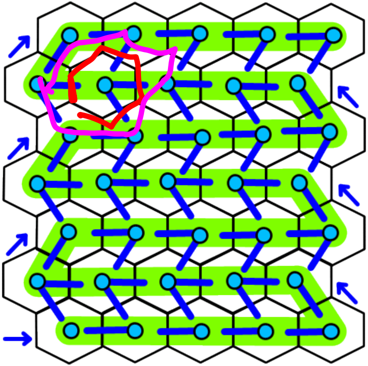
for i {
for j {

sum = $\sum_{i-1}^{i+1} \sum_{j-1}^{j+1} M_{ij}$

}
}

HoneyComb Cellular Automata

- **HoneyComb Cellular Automata** is a different topology where a cell has six neighbors.
- This representation has different dispersion properties, which can be more interesting.



→ Sparse matrix

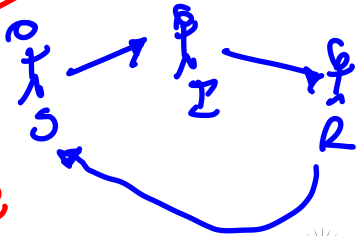
SIR Model

SARS (2004)

discrete

- **SIR Model** is a compartmental model used to represent the transmission of a contagious disease.
- The **model** divides the population into three compartments: **S** for the number of susceptible individuals, **I** for the number of infected individuals, and **R** for the number of recovered individuals.
- The model is defined by the following differential equations where β is the transmission rate and γ is the recovery rate:
  - $\frac{dS}{dt} = -\beta \cdot S \cdot I$
  - $\frac{dI}{dt} = \beta \cdot S \cdot I - \gamma \cdot I$
  - $\frac{dR}{dt} = \gamma \cdot I$

Prob.



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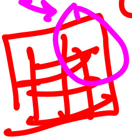


Chaotic Systems

0 0 0 1 1 0 0 0 = 24

0 1 0 1 0 0 0 0 = 10

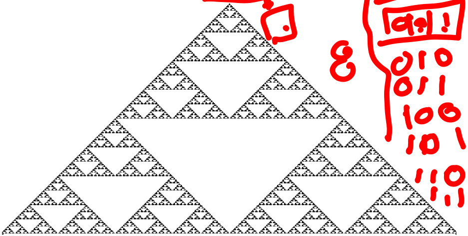
8 bits → 1 byte

- **Chaotic Systems** are a class of dynamical systems that exhibit sensitive dependence on initial conditions.
- This means that the future behavior of the system is **highly dependent** on the initial conditions.
- The **Lorenz System** is a well-known example of a chaotic system.
- Using **cellular automata** to simulate chaotic systems is a common practice. Many **fractals** can be created using what are called chaotic rules.

4D ~ 3.7D

3D 2.1D

2D 1.9D



8

000 = 0

001 = 0

010 = 0

011 = 1

100 = 1

101 = 0

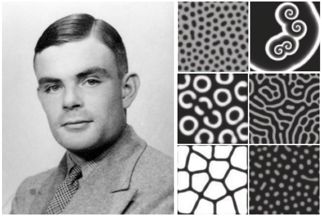
110 = 0

111 = 0

Sierpinsky

Turing Morphogenesis

- **Turing Morphogenesis** is a theory of biological development that explains how patterns form in living organisms.
- The theory is based on the idea that chemical signals can interact to create patterns in living organisms.
- The reaction-diffusion model is a common way to simulate **Turing morphogenesis**.
- The model is defined by a set of reaction and diffusion equations that describe how the chemical signals interact.



Outline

What are Digital Twins?

- A **Digital Twin** is a *virtual model* that accurately reflects a physical object or system.
- **Digital twins** enable real-time monitoring, simulation, and analysis of the `physical counterpart`.
- They are `widely used` in manufacturing, smart cities, healthcare, and energy systems.
- By integrating `sensor data`, **digital twins** help in predictive maintenance and process optimization.

Applications of Digital Twins

- **Manufacturing**: Monitor equipment performance and predict failures.
- **Urban Planning**: Model city infrastructure to optimize traffic and resource use.
- **Healthcare**: Simulate patient-specific treatments and optimize procedures.
- **Energy Systems**: Analyze grid performance and integrate renewable energy sources.

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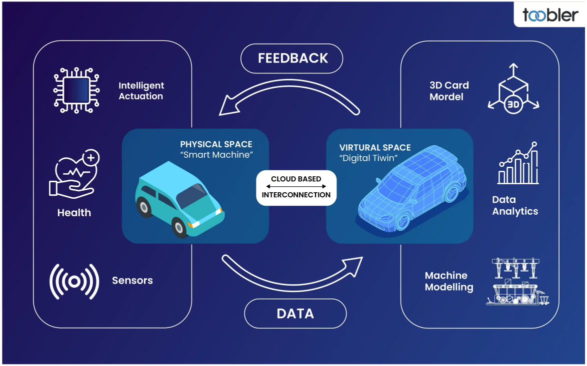
Benefits of Digital Twins

- Enhanced **decision-making** through real-time data analysis.
- Improved efficiency and reduced operational costs.
- *Better understanding* of system behavior and performance.
- Increased collaboration between `teams` and `stakeholders`.



Challenges of Digital Twins

- Data integration and management.
- Ensuring data security and privacy.
- Maintaining the accuracy of the digital twin.
- Managing the complexity of the physical system.
- Ensuring interoperability between different systems and platforms.
- Scalability to accommodate large-scale systems.
- Cost of implementation and maintenance.
- User training and adoption.
- Regulatory compliance and standardization.
- Ethical considerations in data usage and analysis.
- Environmental impact of digital twin technologies.

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Thanks!

Questions?

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