Simulation

Modeling and Performance Analysis with Discrete-Event Simulation

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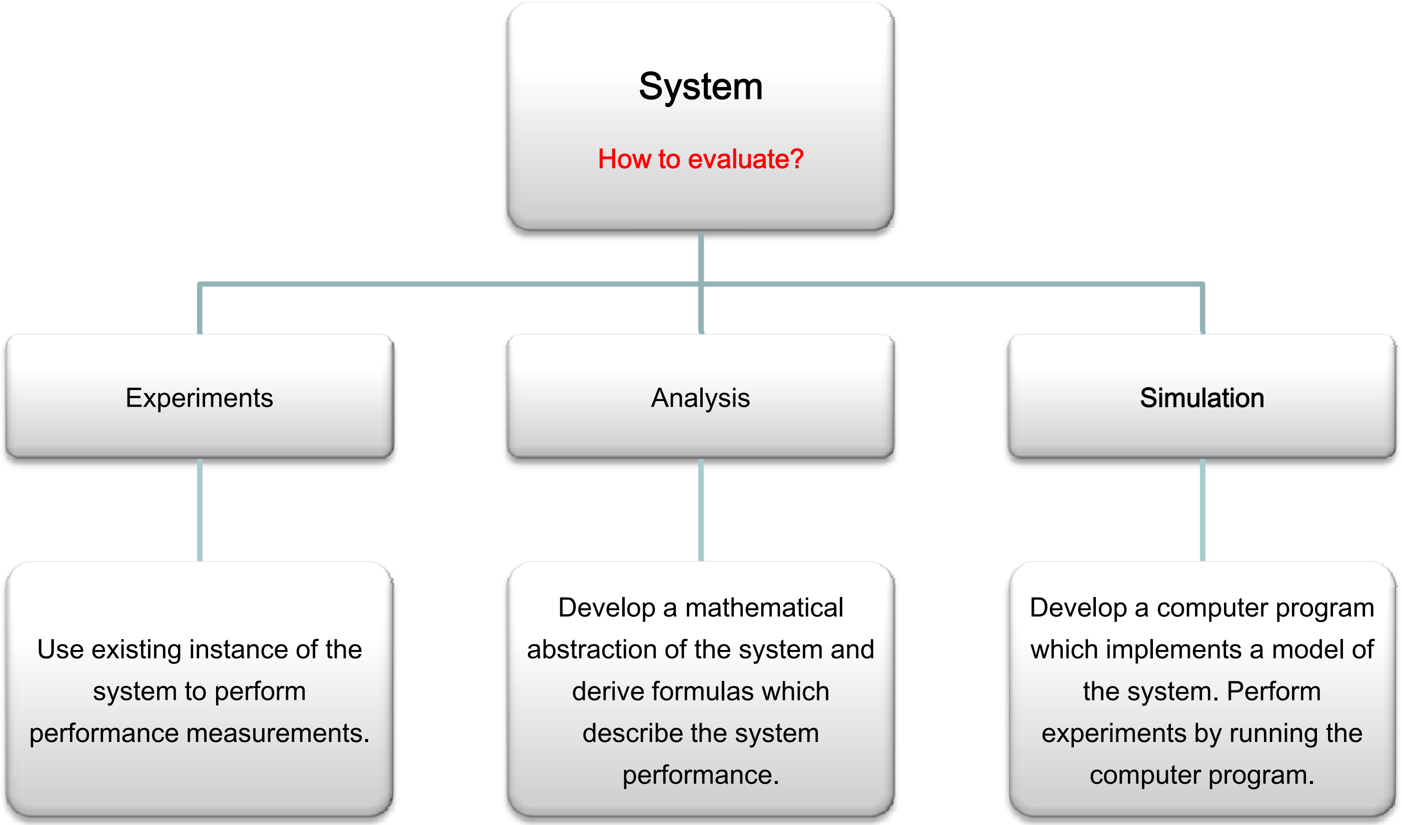
Chapter 1

Introduction to Simulation

Introduction to Simulation

- Given a system, how do you evaluate its performance?



Introduction to Simulation

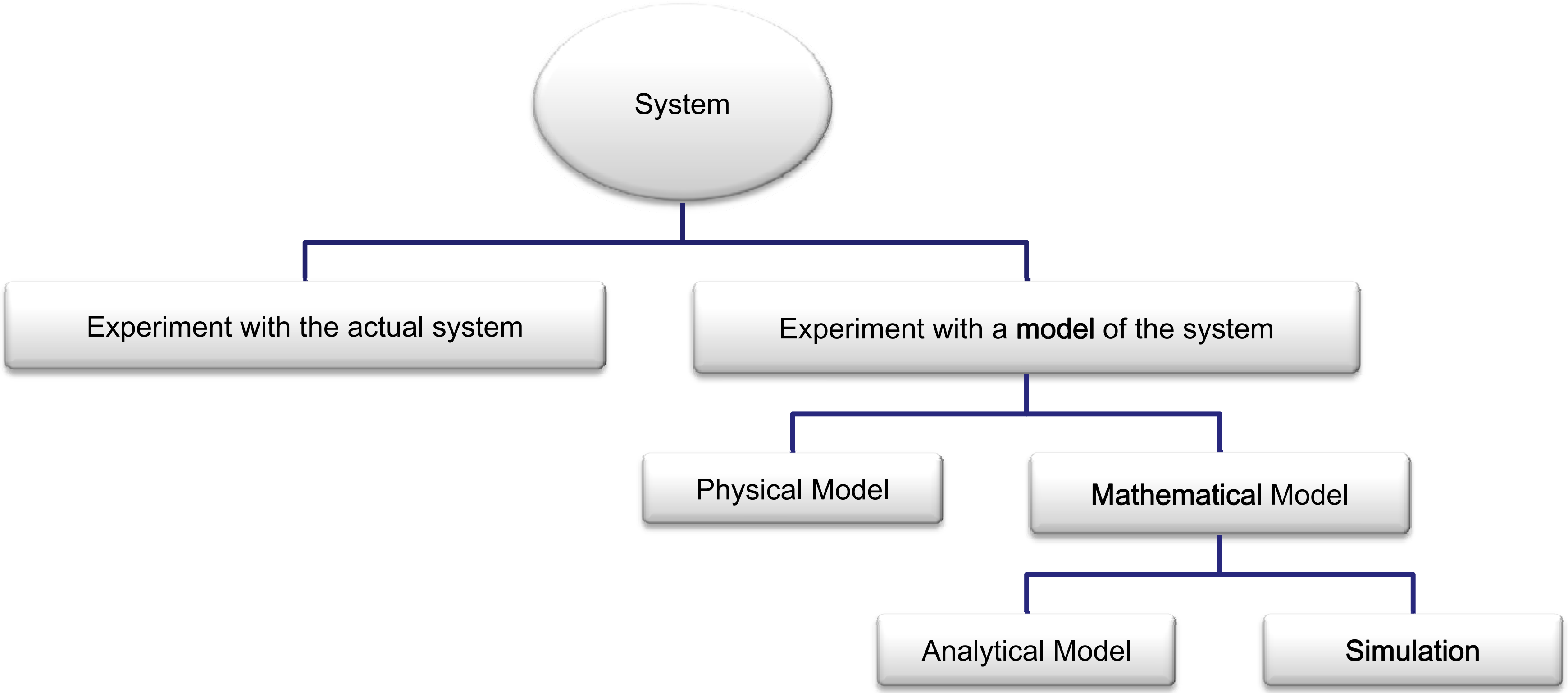
- **How to study a system?**
  - Measurements on an existing system
    - What to do, if system does not exist in reality?
    - What to do, if changes are very expensive or time consuming?
  - Mathematical analysis
    - Good solutions, but only feasible for simple systems.
    - Real world systems are too complex, e.g., factory, computer, network etc.
    - ➡ Other course from Informatik 4
      Modeling and Evaluation of Communication Systems
  - Simulation
    - Build the behavior of a system within a program

- **The content of this course is described in the subtitle**
  - Modeling and Performance Analysis of … by means of Discrete-Event Simulation

Introduction to Simulation

- There are many open questions
  - What is a system?
  - What is a model?
  - What is performance and how to measure it?
  - On what does performance depend?
  - How to build a model?
  - How to numerically evaluate it?
  - How to interpret such results?

Introduction to Simulation



Introduction to Simulation

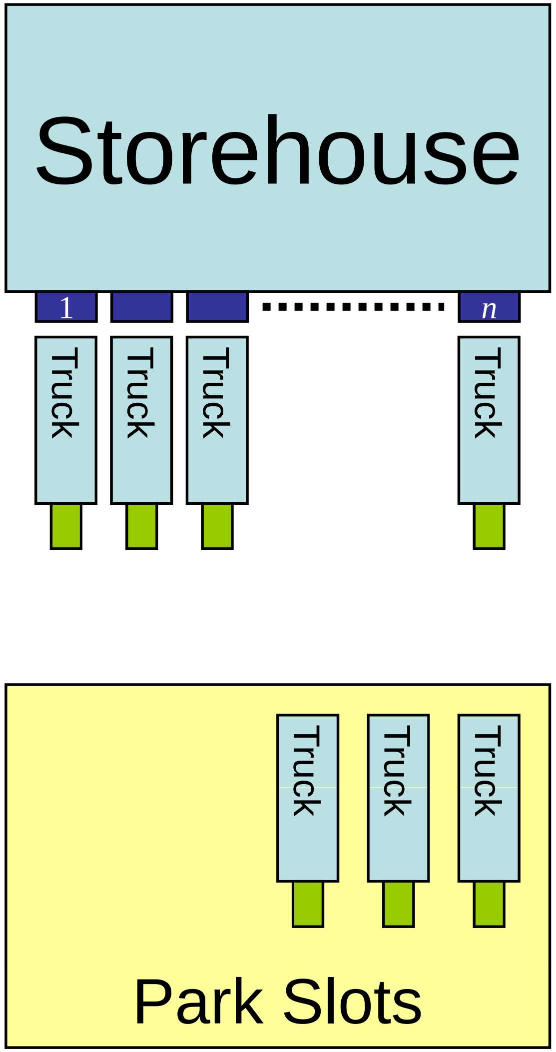
- Simulation is used to imitate the real world
  - It is not as new as we think ;-)
- According to Elmaghraby [1968]
  - Aid to thought
  - Communication
  - Training/Education
  - Experimentation
  - Predicting
  - Entertainment (this is a new application)
    - Video games

Wooden mechanical horse simulator during WW1

A soldier in a heavy-wheeled-vehicle driver simulator

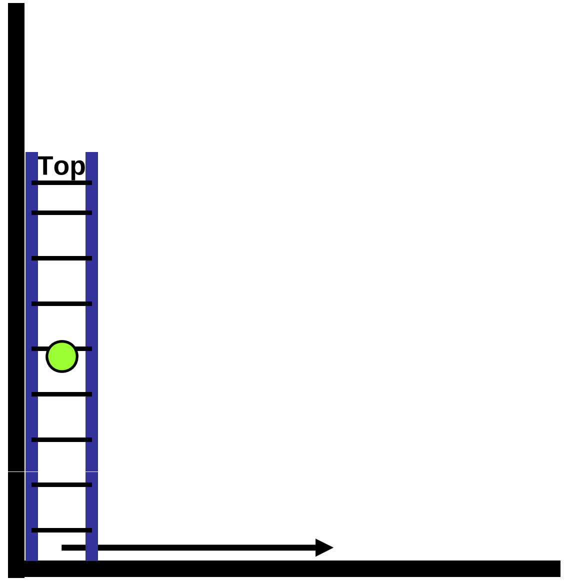
Introduction – Example 1

- A storehouse with n loading berths
- There are several 100 trucks daily to serve
- Loading time of a truck is 50 minutes
- Goal
  - Cost-effective loading **and** short waiting time
- Usually 2 customer types
  - Type 1: Full load with only one product
  - Type 2: Load consisting of several products
- Proposals
  - Fast loading berth for Type 1 customers
  - Special berth for Type 2 customers
- Problem
  - Cannot experiment, changes are expensive!

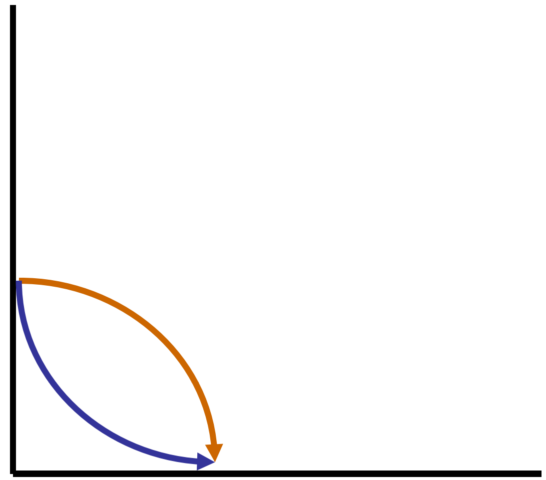


Introduction – Example 2

- Experiment
  - Sliding of a leader on the wall
  - A leader is at the wall
  - We draw the bottom of the leader and the top of the leader is leant on the wall and slides down.

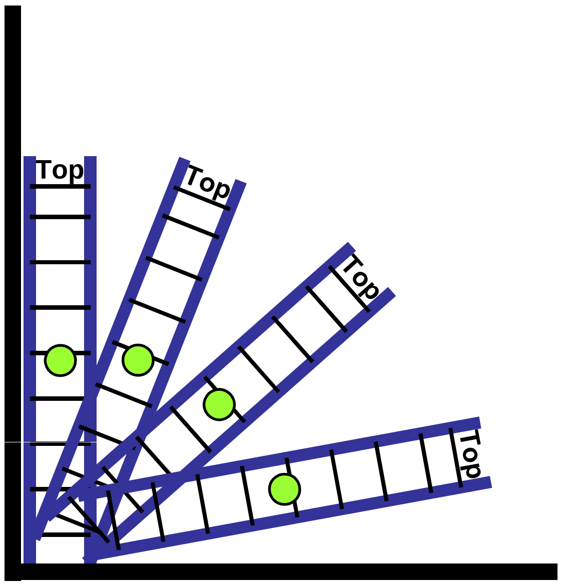


- Question: Which shape draws the center of the leader?
  - Concave
  - Convex



Introduction – Example 2

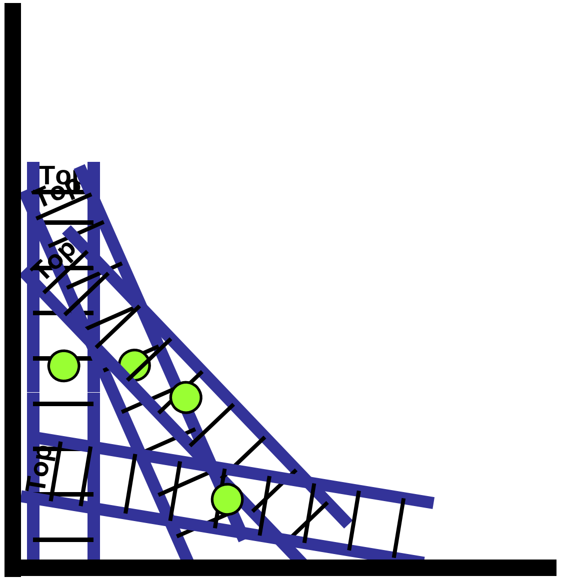
- Variant: The leader falls down from the wall
- The resulting shape is convex.



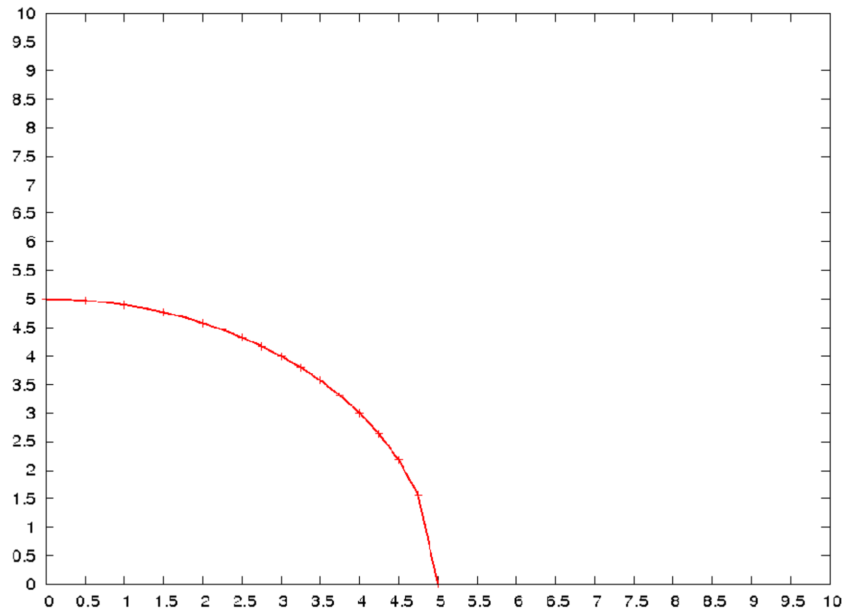
Experiment 1: Leader falls down from the wall

Introduction – Example 2

- One intuitively thinks the driven shape will be concave.
- However, the resulting shape is also convex.
- Astonished?

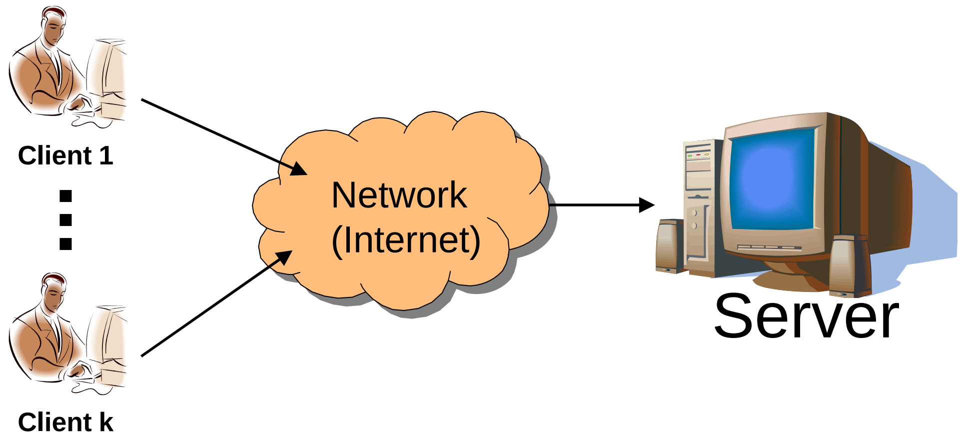


Experiment 2: Leader slides down on the wall

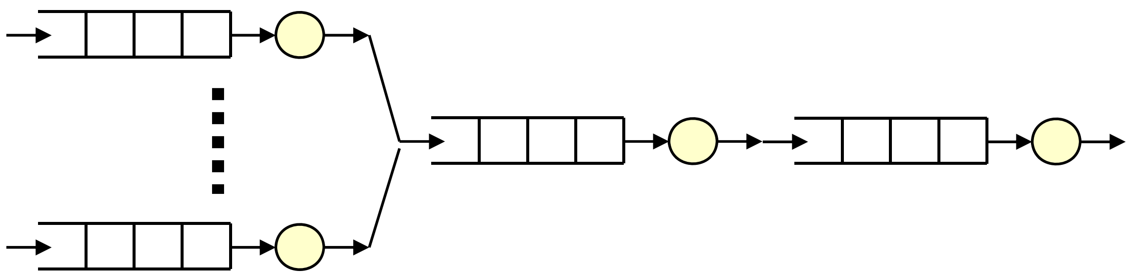


Introduction – Example 3

- Clients request some service from a server over a network.
  - Client = User and web browser
  - Service = web page
  - Server = web server
  - Network = local network, Internet, wireless network

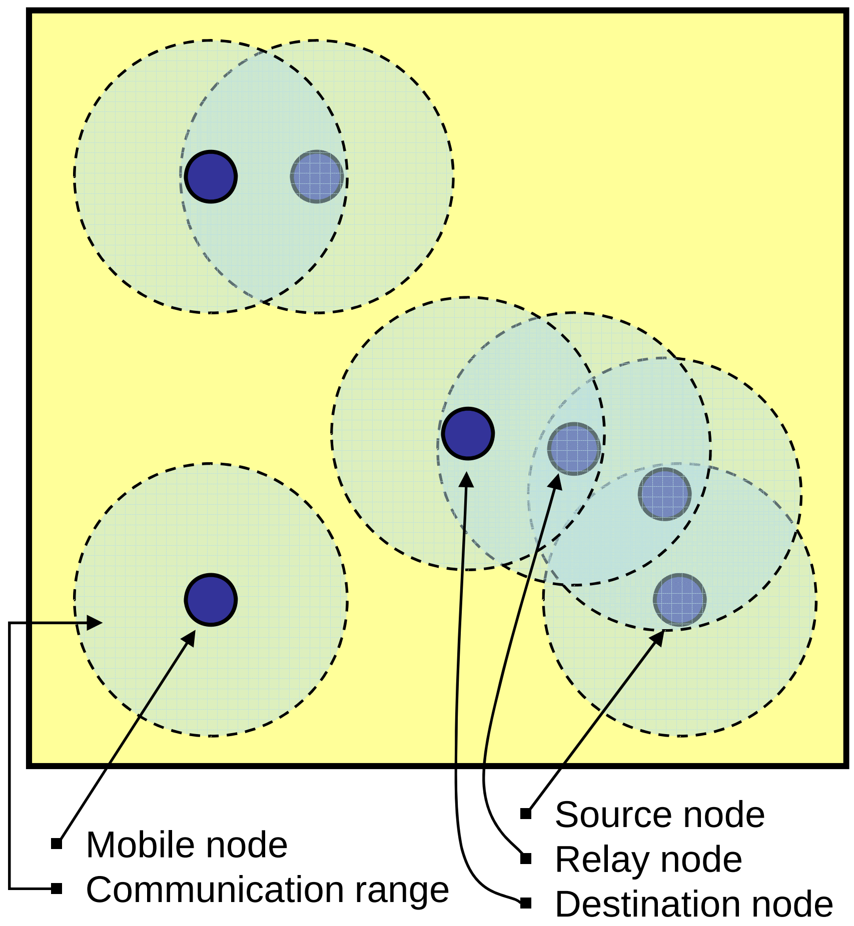


- Analysis
  - Performance of the server
  - Performance of the network
- Attention
  - In this examples the server as well as the network is depicted very simple!



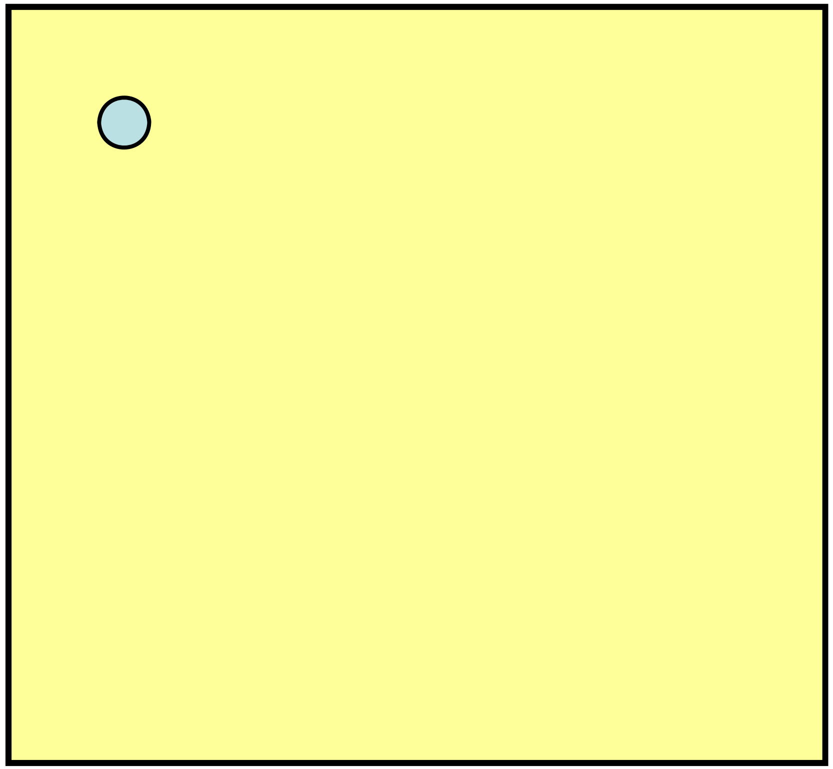
Introduction – Example 4

- Mobile multi-hop ad-hoc network (MANET)
  - Wireless network consisting of mobile nodes
  - No infrastructure, i.e. no Access Points or Base Stations
  - Two nodes can communicate if there are in communication range
  - Typically, the source and destination nodes of a connection are several hops away
  - Thus, all nodes have to relay data for others



Introduction – Example 4

- For the analysis of a MANET a mobility model is needed
- Assumption
  - Movement area: Rectangle without obstacles
- Simple model: Random-Waypoint mobility model
  - A node selects uniformly a point on the simulation area $p=(x, y)$
  - Velocity $v \in [v_{min}, v_{max}]$
  - Pause time t_{pause}
  - The node moves to the point p with velocity v
  - Stays for t_{pause} time units on p and restarts movement

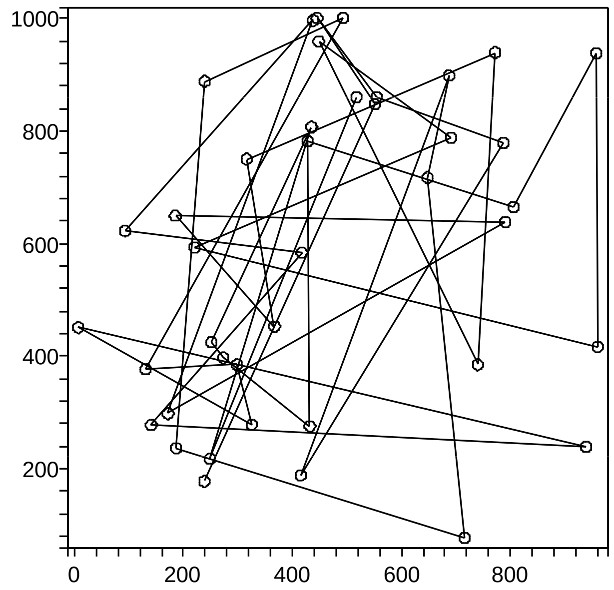


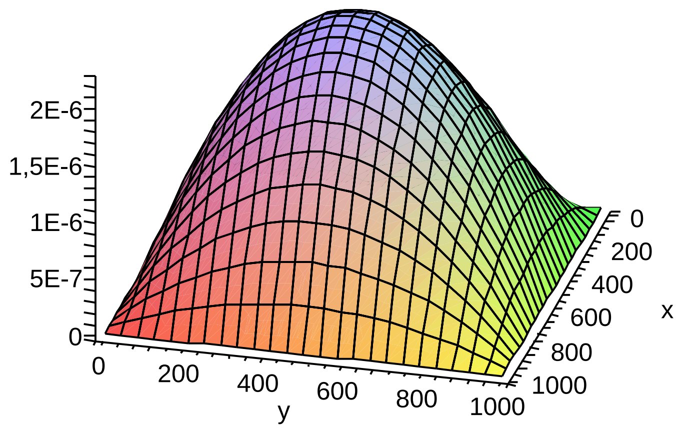
Introduction – Example 4

- What's about the probability that a node is on point $p = (x,y)$ on the movement area?
  - Uniformly distributed?
    - Since x and y are uniformly selected.
  - Are some areas preferred?

- What's about the influence of the parameters?
  - Velocity
  - Pause time

- Although simple to describe, mathematically it is hard to get a closed form formulae.





Introduction to Simulation

- **What is a simulation?**
  - A simulation is the imitation of the operation of a real-world system over time.

- **What is the method?**
  - Generate an artificial history of a system
  - Draw inferences from the artificial history concerning the characteristics of the system

- **How it is done?**
  - Develop a **model**
  - Model consists of entities (objects)

When simulation is appropriate

- Simulation can be used for the following purposes:
  - Simulation enables the **study of experiments** with internal interactions
  - Informational, organizational, and environmental changes can be simulated to see the model's **behavior**
  - Knowledge from simulations can be used to **improve** the system
  - Observing results from simulation can give **insight to** which variables are the most important ones
  - Simulation can be used as **pedagogical device** to reinforce the learning material
  - Simulations can be used to **verify** analytical results, e.g. queueing systems
  - Animation of a simulation can show the system in action, so that the plan can be **visualized**

When simulation is not appropriate

- Simulation should not be used, in the case
  - when problem is solvable by common sense
  - when the problem can be solved mathematically
  - when direct experiments are easier
  - when the simulation costs exceed the savings
  - when the simulation requires time, which is not available
  - when no (input) data is available, but simulations need data
  - when the simulation cannot be verified or validated
  - when the system behavior is too complex or unknown

- Example: human behavior is extremely complex to model

Advantages and disadvantages of simulation

- ## Advantages of simulation
  - Policies, procedures, decision rules, information flows can be explored **without disrupting** the real system
  - New hardware designs, physical layouts, transportation systems can **tested** without committing resources
  - Hypotheses about how or why a phenomena occur can be **tested** for feasibility
  - **Time** can be **compressed** or **expanded**
    - Slow-down or Speed-up
  - Insight can be obtained about the **interaction of variables**
  - Insight can be obtained about the **importance of variables** to the performance of the system
  - **Bottleneck analysis** can be performed to detect excessive delays
  - Simulation can help to understand **how the system operates** rather than how people think the system operates
  - "**What if**" questions can be answered

Advantages and disadvantages of simulation

- Disadvantages of simulation
  - Model building requires training, it is **like an art**.
    - Compare model building with programming.
  - Simulation results can be **difficult to interpret**
    - Most outputs are essentially **random variables**
    - Thus, not simple to decide whether output is randomness or system behavior
  - Simulation can be **time consuming** and expensive
    - Skimping in time and resources could lead to useless/wrong results
- The disadvantages are offset as follows
  - Simulation packages contain models that only **need input data**
  - Simulation packages contain **output-analysis capabilities**
  - Sophistication in computer technology improves **simulation times**
  - For most of the **real-world problems** there are **no closed form solutions**

Areas of Application

- Application areas of simulation
  - Manufacturing applications
  - Semiconductor manufacturing
  - Construction engineering and project management
  - Military applications
  - Logistics, supply chain and distribution applications
  - Transportation models and traffic
  - Business process simulation
  - Health care
  - Call-center
  - Computers and Networks
  - Games
  - ...

Systems and System Environment

- System
  - A system is a group of objects that are joined together in some regular interaction or interdependence toward the accomplishment of some purpose.
  - Example: Automobile factory
    - Machines, parts, and workers operate jointly to produce a vehicle
  - Example: Computer network
    - User, hosts, routers, lines establish a network
- System environment
  - Everything outside the system, but affects the system
- Attention
  - It is important to decide on the boundary between the system and the system environment
  - This decision depends on the **purpose of the study**

Components of a System

- In order to understand and analyze a system, we need some terms
- General Terminology

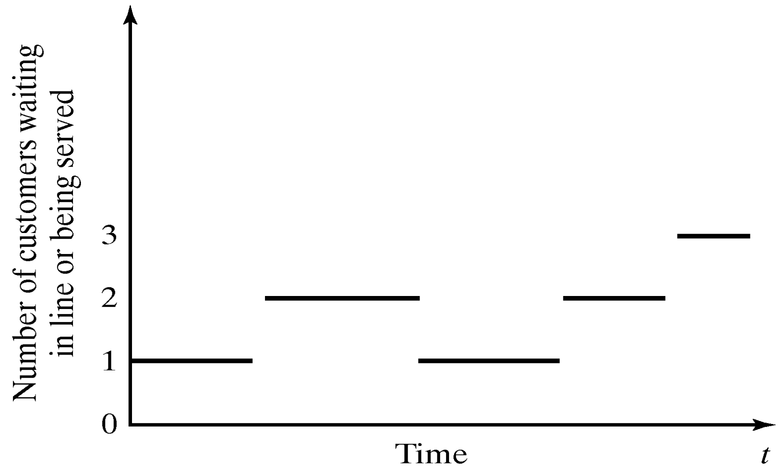
• Entity	Object of interest in the system
• Attribute	Property of an entity
• Activity	A time period of specified length
• System state	Collection of variables required to describe the system at any time
• Event	An instantaneous occurrence that might change the state of the system
• Endogenous	Activities and Events occurring within the system
• Exogenous	Activities and Events in the environment (outside the system) that affect the system

Components of System – Examples

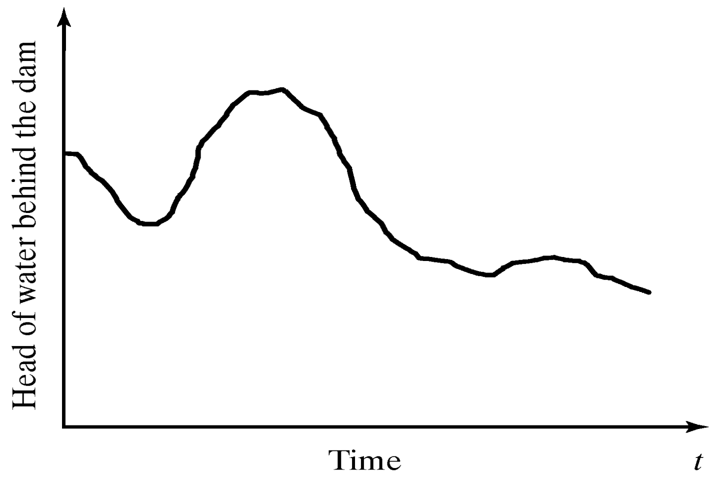
System	Entities	Attributes	Activities	Events	State Variables
Banking	Customers	Checking-account balance	Making deposits	Arrival; departure	Number of busy tellers Number of waiting customer
Rapid rail	Riders	Source Destination	Traveling	Arrival at station Arrival at destination	Number of riders at each station Number of rider in transit
Production	Machines	Speed Capacity Breakdown rate	Welding Stamping	Breakdown	Status of machines
Communications	Messages	Length Destination	Transmitting	Arrival at destination	Number of waiting messages to be transmitted
Inventory	Warehouse	Capacity	Withdrawing	Demand	Levels of inventory
Mobility model	Node	Position Velocity	Travel	End of movement	Position Velocity

Discrete and Continuous Systems

- Discrete Systems
  - State variables change only at discrete set of points
  - Example: Bank

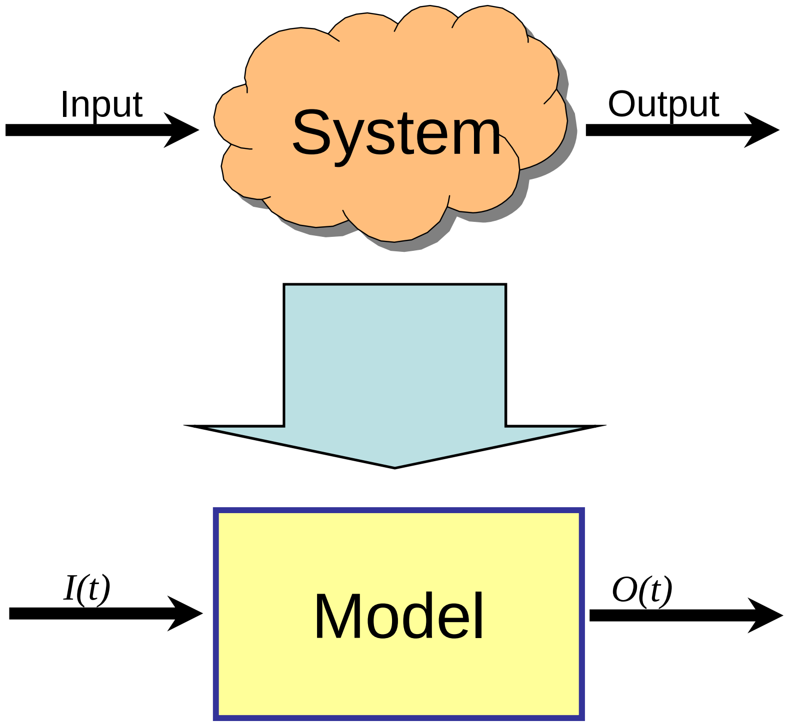


- Continuous Systems
  - State variables change continuously over time
  - Example: Head of water behind a dam



Model of a System

- What is a model?
  - A model is a representation of a system for the purpose of studying the system.
    - It is necessary to consider those aspects of the system that affect the problem under investigation
- Avoid too much detail
  - ”The tendency is nearly always to simulate to much detail rather than too little. Thus, one should always design the model around the question to be answered rather than imitate the real system exactly.” [Shannon, 1975]
- Physical model
  - Prototype of a system for the purpose of study.
- Mathematical model
  - A mathematical model uses symbolic notation and mathematical equations to represent a system.

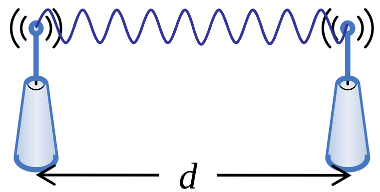


Model of a System

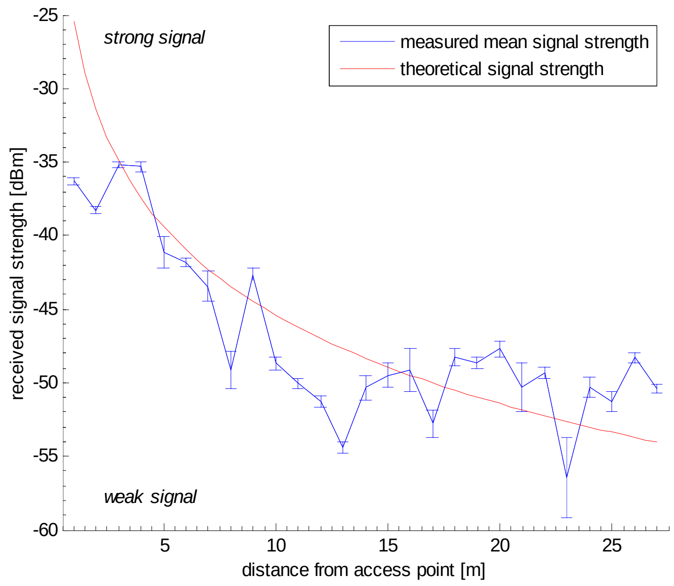
- Example 1: Movement
  - Model: $d = v \cdot t$
  - Assumptions: Constant velocity v over the whole time t
  - Advantage: Simple formulae and intuitive
  - Disadvantage: Seldom valid for a whole travel (human, car, planes)

Model of a System

- **Example 2: Radio signal propagation**
  - Free-Space-Modell
  - Model: $PL_{dB}(d) = -10\log\left(\frac{G_t G_r \lambda^2}{(4\pi)^2 d^2}\right)$
  - Assumptions:
    - Direct line of of sight (LOS) between communication peers
    - No obstacles
  - Advantages:
    - Simple asymptotic formulae for open space
  - Disadvantages:
    - Not really usefull for indoor and city environments



Measurements in Computer Science Department, Informatik 4



Simulation Models

- Simulation Model
  - A simulation model is a particular type of mathematical model of a system.

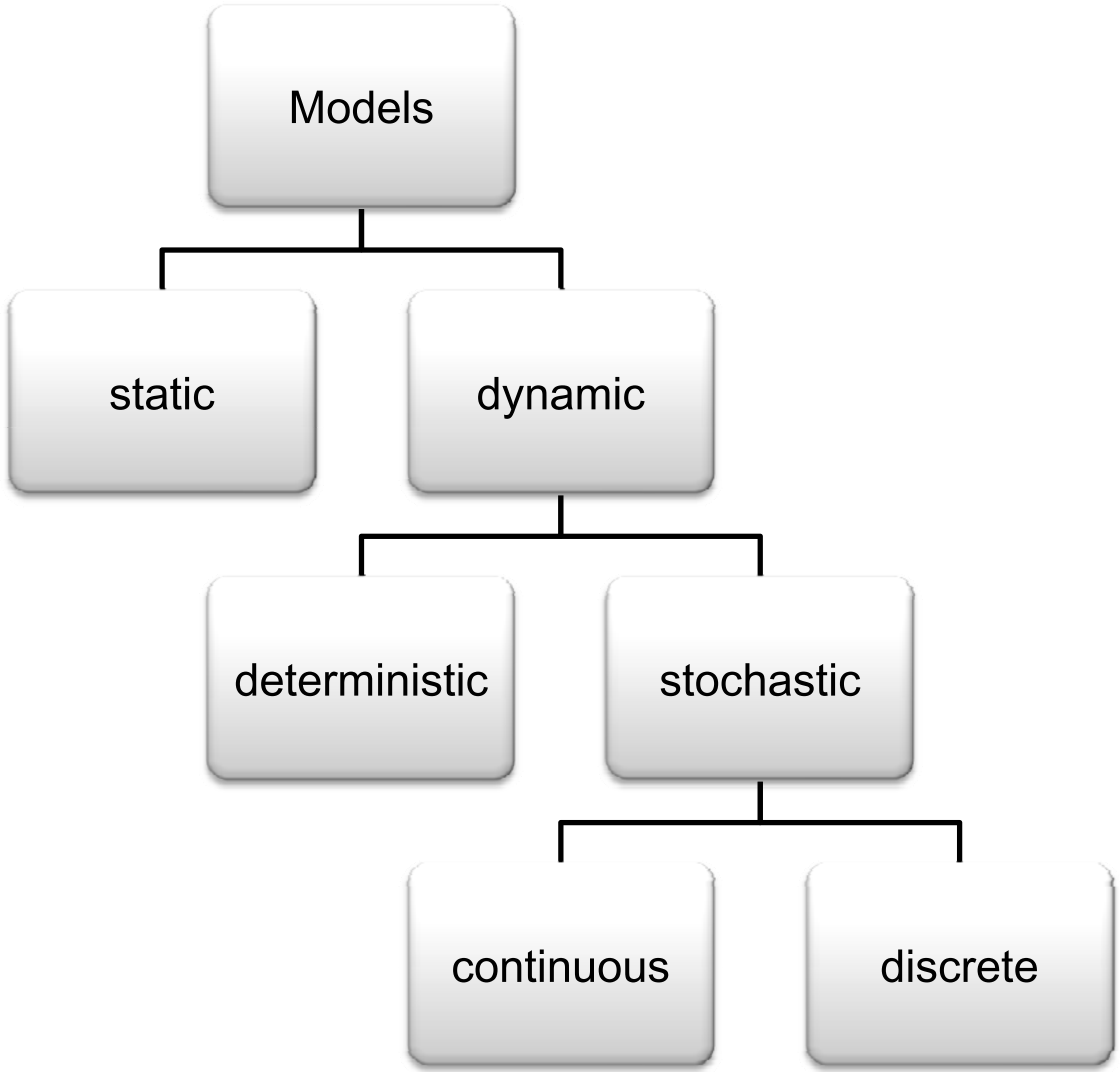
- Types of simulation models
  - Static: Represent a system at a particular point in time.
  - Dynamic: Represent a system over a time interval.

  - Deterministic: Simulation models without random variables.
  - Stochastic: Simulation models with random variables.

  - Discrete: System state changes occur only at discrete time points.
  - Continuous: System state changes occur continuously.

➡ We will focus on discrete, dynamic, and stochastic simulation models

Simulation Models

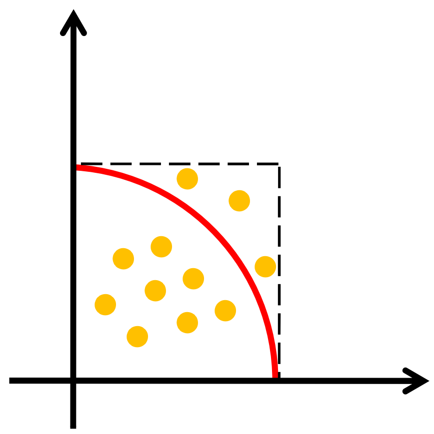


Discrete-Event System Simulation

- Discrete-event Simulation
  - System state changes only at discrete set of points in time.
  - Simulation model is analyzed by numerical methods.
  - Numerical methods employ computational procedures to “solve” mathematical models.
  - The model is rather “run” than “solved”

Simulation for static models

- Monte Carlo simulation
- Mainly used for mathematical problems which are not analytically tractable
- Example: Approximate π
  - Area of a circle: $A = \pi \cdot r^2 \quad \text{if} \quad r = 1 \ \Rightarrow A = \pi$
  - Count the number of points inside and outside a unit quarter circle.



Simulation of dynamic, continuous models

- System described by differential equation
- Typically involves numerical solution of these equations
- No real difference to a numerically based mathematical solution
- Typical example: predator/prey systems
  - Let $x(t)$ be the size of the prey population
  - Let $y(t)$ be the size of the predator population
- Growth rate of the prey population without predators
  - $r \cdot x(t)$
- Predator change rate
  - $-s \cdot y(t)$
- Interactions

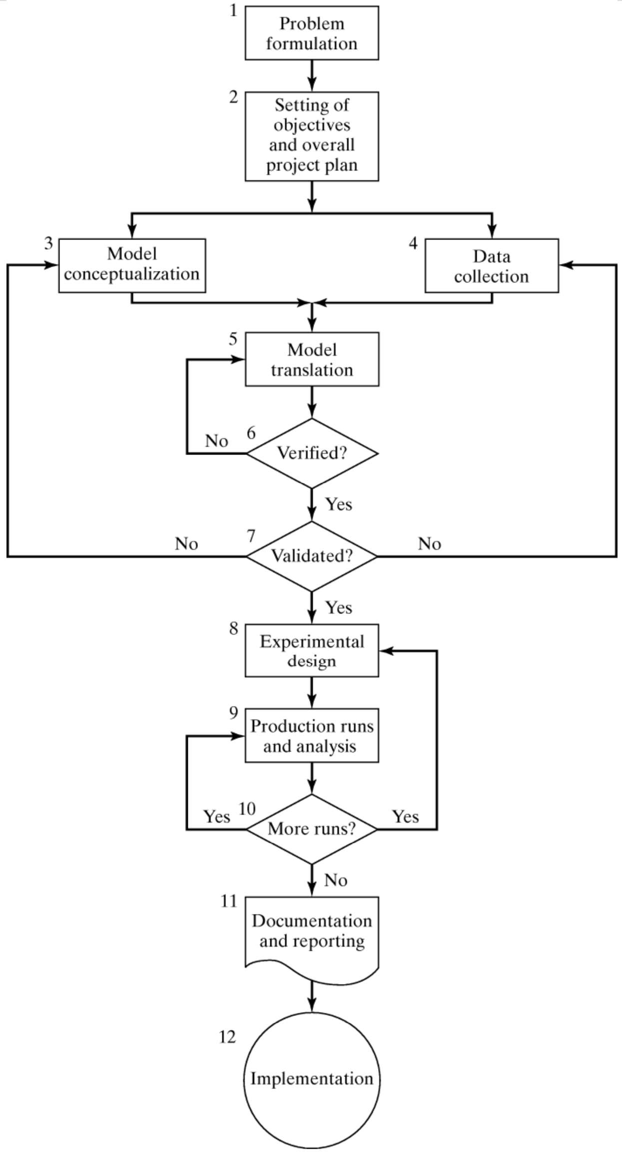
$$\frac{dx}{dt} = r \cdot x(t) - a \cdot x(t) \cdot y(t)$$

$$\frac{dy}{dt} = -s \cdot y(t) + b \cdot x(t) \cdot y(t)$$

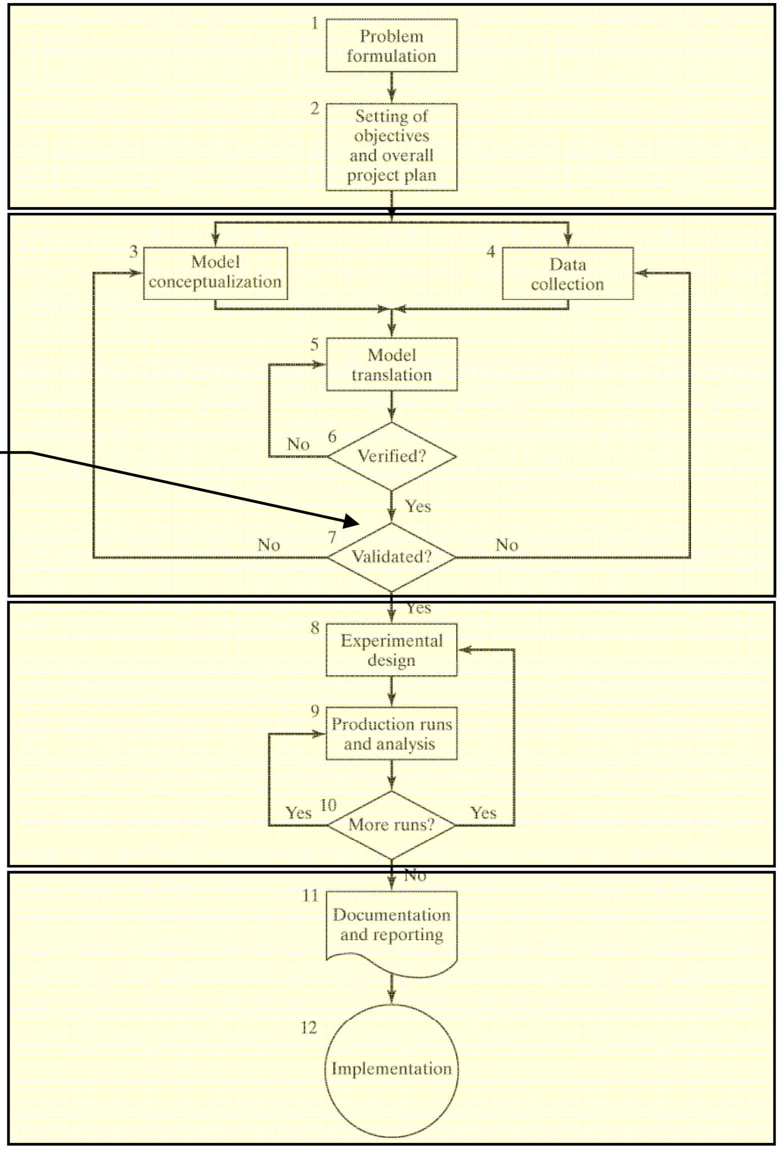
- Parameters
  - $x(0)$, $y(0)$, a, b, r, s
- Metrics
  - $x(t)$, $y(t)$
- Solve system of differential equations

Steps in a Simulation Study

1. Problem formulation
   - Clearly understand problem
   - Reformulation of the problem
2. Setting of objectives and overall project plan
   - Which questions should be answered?
   - Is simulation appropriate?
   - Costs?
3. Model conceptualization
   - No general guide
   - Modeling tools in research, e.g. UML
4. Data collection
   - How to get data?
   - Are random distributions appropriate?
5. Model translation
   - Program
6. Verified?
   - Does the program that, what the model describes?
7. Validated?
   - Do the results match the reality?
   - In cases with no real-world system, hard to validate
8. Experimental design
   - Which alternatives should be run?
   - Which paramters should be varied?
9. Production runs and analysis
10. More runs?
11. Documentation and reporting
    - Program documentation – how does the program work
    - Progress documentation – chronology of the work
12. Implementation



Steps in a Simulation Study



Phase 1: Discovery and Orientation

Phase 2: Model building and data collection

Phase 3: Run the model

Phase 4: Implementation

Most crucial step is validation.
If model is invalid results can lead to dangerous and expensive decisions!

Summary

- Motivated the course by examples
- Introduced simulation as a notion
- Discussed for what purposes simulation is useful
- Introduction of a general terminology
- Introduction of discrete-event simulation
- Discussed the steps of a simulation study