Simulation of Computer Networks

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Vorbemerkungen

- Lehrstuhl für Praktische Informatik IV
  - http://www.informatik.uni-mannheim.de/pi4
  - Rechnernetze und Multimedia-Technik
- Seit August 2001
  - Bis Ende 2003 Projekt FleetNet
  - Bis Sept 2005 Projekt Network on Wheels
  - Seit 01.10. Landes-Stelle
- Gegenwärtige Arbeitsgebiete:
  - Wireless ad hoc networks, insbesondere: vehicular ad hoc networks

Simulation von Rechnernetzen

- Vertieft Vorlesungen ‘Rechnernetze’
- Widmet sich den Fragen:
  - Wie kann ich Protokolle ausprobieren?
  - Wie kann ich verschiedene Netzkonfigurationen quantitativ vergleichen (ohne die Netze zu bauen)?
- Soll Hilfestellung für Studien-/Diplomarbeiten
  - In vielen Arbeiten wird simuliert.

Prüfungsregelung

- 3 ECTS Punkte
- mündliche oder schriftliche Prüfung (je nach Nachfrage)

Sprechzeiten, Vorlesungsfolien

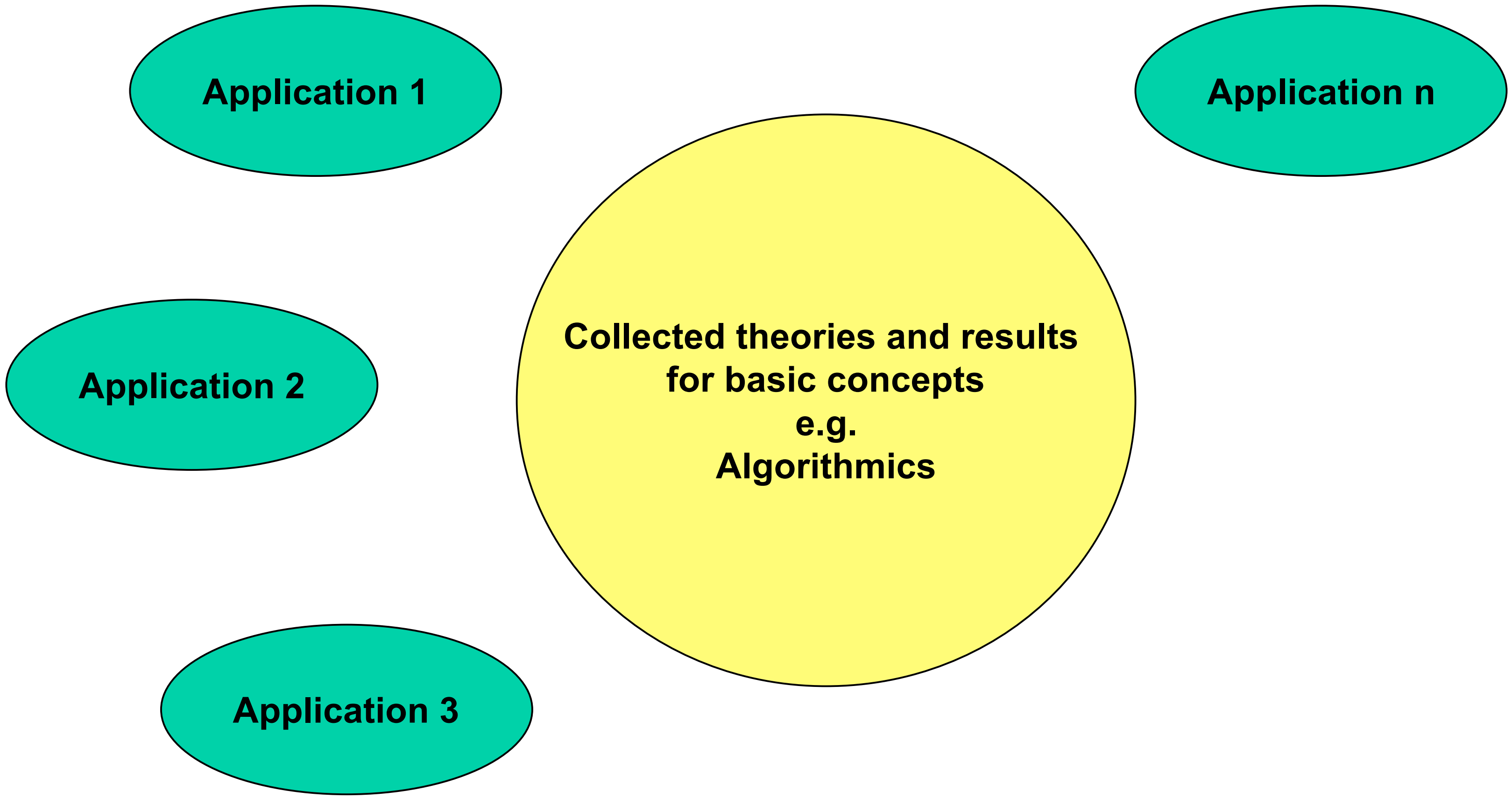
» **Holger Füßler (Sprechstunde nach Vereinbarung)**

- **Am besten per e-mail Termin vereinbaren**
- **(fuessler@informatik.uni-mannheim.de)**

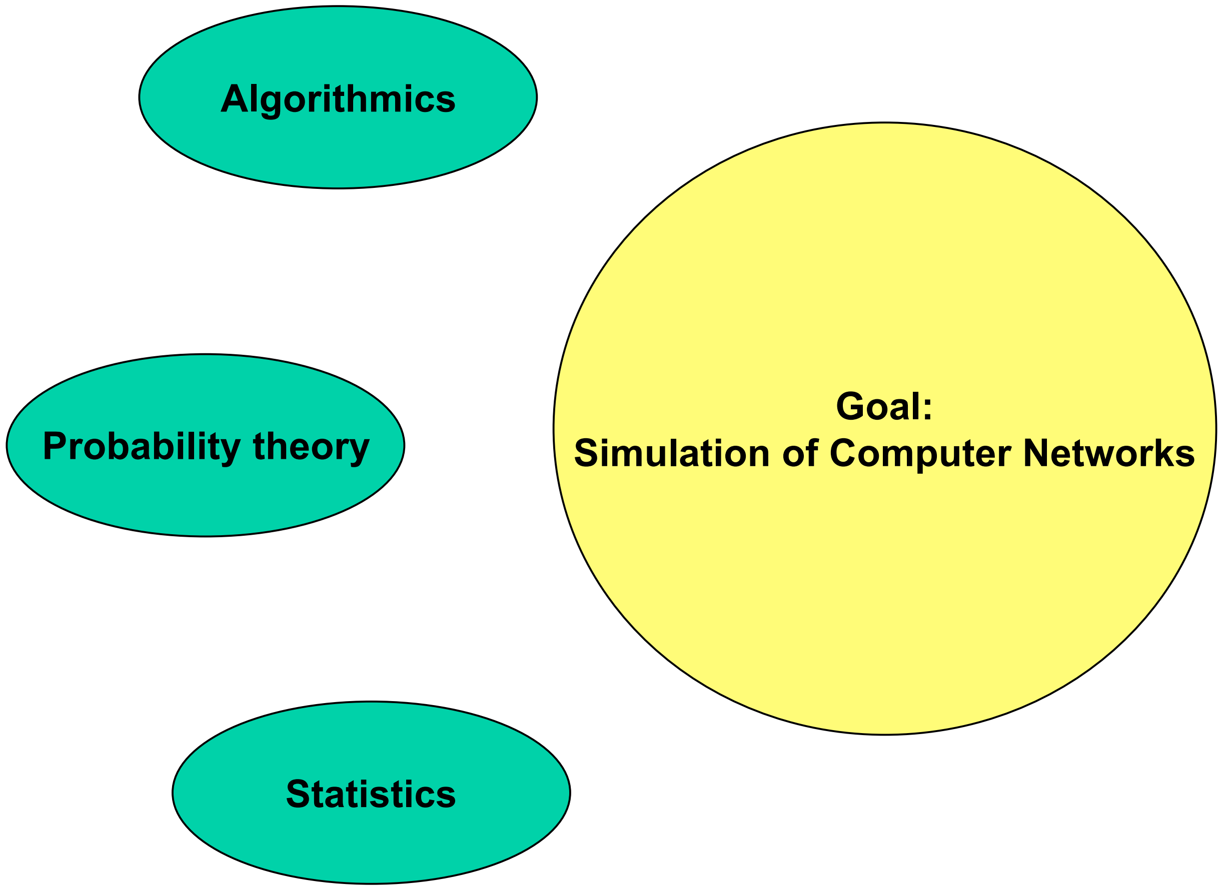
» **Die Vorlesungsfolien finden sich unter**

- **http://www.informatik.uni-mannheim.de/pi4/lectures/ws0506/netsim/**
- **geschützter Bereich**
- **User: studi**
- **pwd: charlemagne**

Some lectures are like this …



NetSim is like this …



… requires broad knowledge on various fields

Prerequisites/Literature

- Basics (Grundstudium) in CS / Math / Statistics
- Networking: Rechnernetze

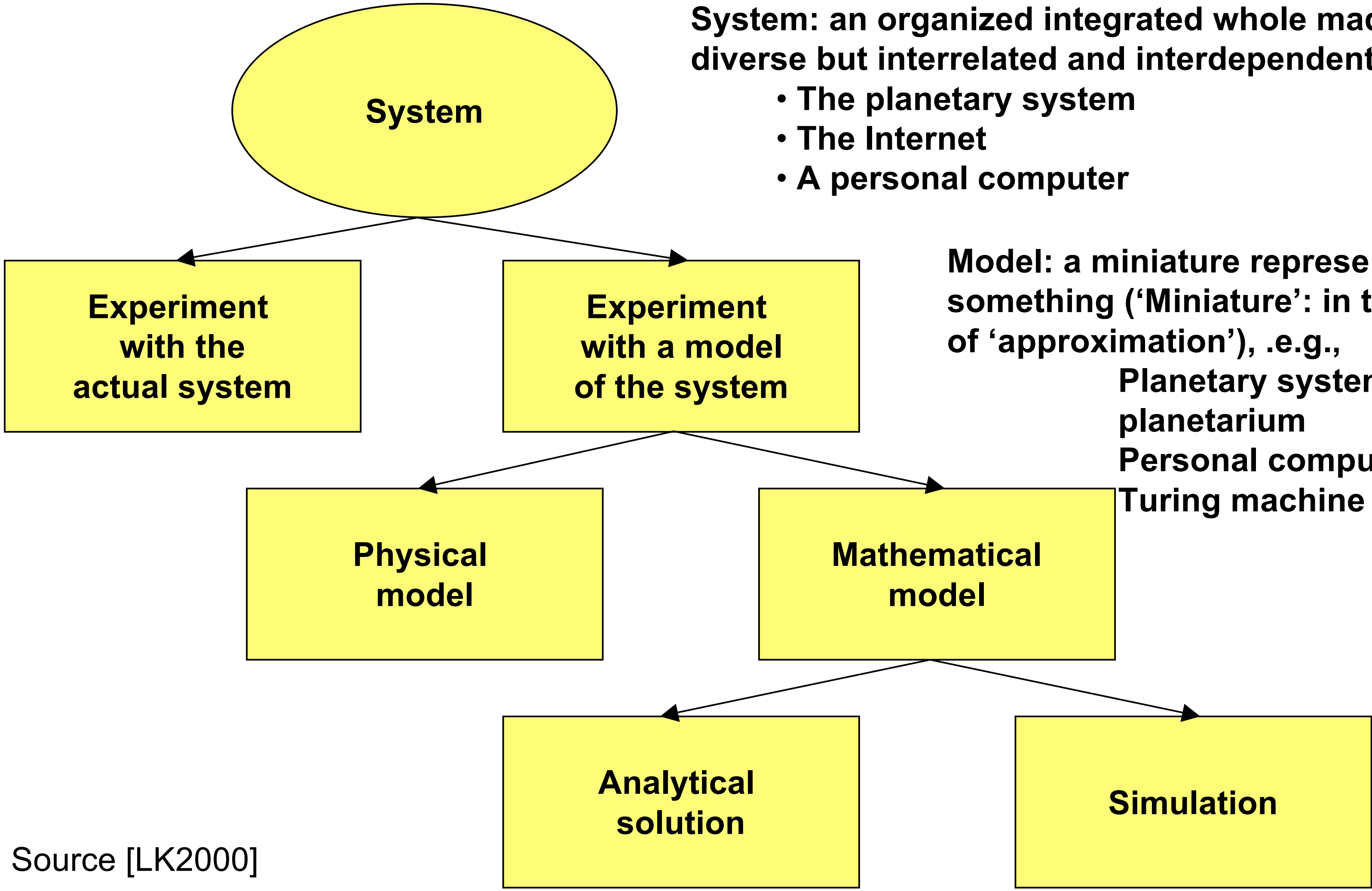
- Averill M. Law, W. David Kelton: “Simulation Modeling and Analysis”, McGraw-Hill, 3rd edition, 2000.
- Sheldon M. Ross: “Simulation”, 2nd edition, Academic Press, 1997.
- Stochastics, statistics: Anderson et al: “Schätzen und Testen”
- Computer networks: Andrew S. Tanenbaum: “Computer Networks”
- Pointers to original work is given on a ‘per lecture basis’.

Start of NetSim

Overview of first lecture

- » **Part I: An ‘abstract’ view to simulations (top-down)**
  - **Simulation as *one* strategy to study a system**
  - **The big picture**
- » **Part II: A ‘concrete’ simulation example (bottom-up)**
- » **Part III: Course overview**
  - **Elements needed for simulation of computer networks**

I Ways to study a system



System: an organized integrated whole made up of diverse but interrelated and interdependent parts

- The planetary system
- The Internet
- A personal computer

Model: a miniature representation of something ('Miniature': in the sense of 'approximation'), .e.g.,

Planetary system – planetarium
Personal computer – Turing machine

Source [LK2000]

I Simulation: advantages

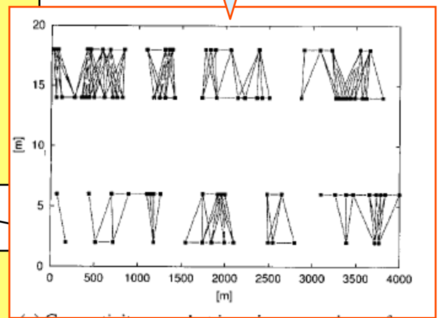
- Experiment with the actual system: too expensive, sometimes impossible (e.g., system does not exist yet)
  - Simulation is relatively inexpensive
  - Simulation works for concepts and ideas
- Experiment with a physical model: still expensive, needs a lot of work, some things cannot be ‚miniaturized' (e.g., radio propagation characteristics)
  - Simulation is cost-effective
  - Simulation allows for various degrees of accuracy
- Analytical treatment: most times models are too complex
  - Simulation allows for observation of the models behavior over time

I Example: vehicular ad hoc networks

System

- Experiment with the actual system
- Experiment with a model of the system
  - Physical model
  - Mathematical model
    - Analytical solution
    - Simulation

Models:
- Movement pattern
- Communication protocols
- Data traffic
- and their interactions



$$E\{C\} = \frac{1}{\alpha^2\beta^2} \sum_{\xi_1=1}^{\alpha} \sum_{\psi_1=1}^{\beta} \sum_{\xi_2=1}^{\alpha} \sum_{\psi_2=1}^{\beta} c(\xi_1, \psi_1, \xi_2, \psi_2) \,.$$

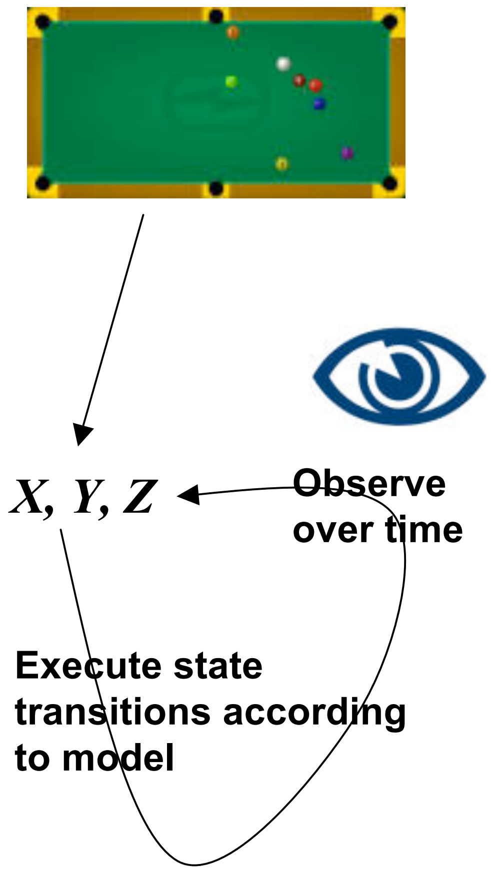
I The nature of simulation

» **Systems, system state, and system state changes**

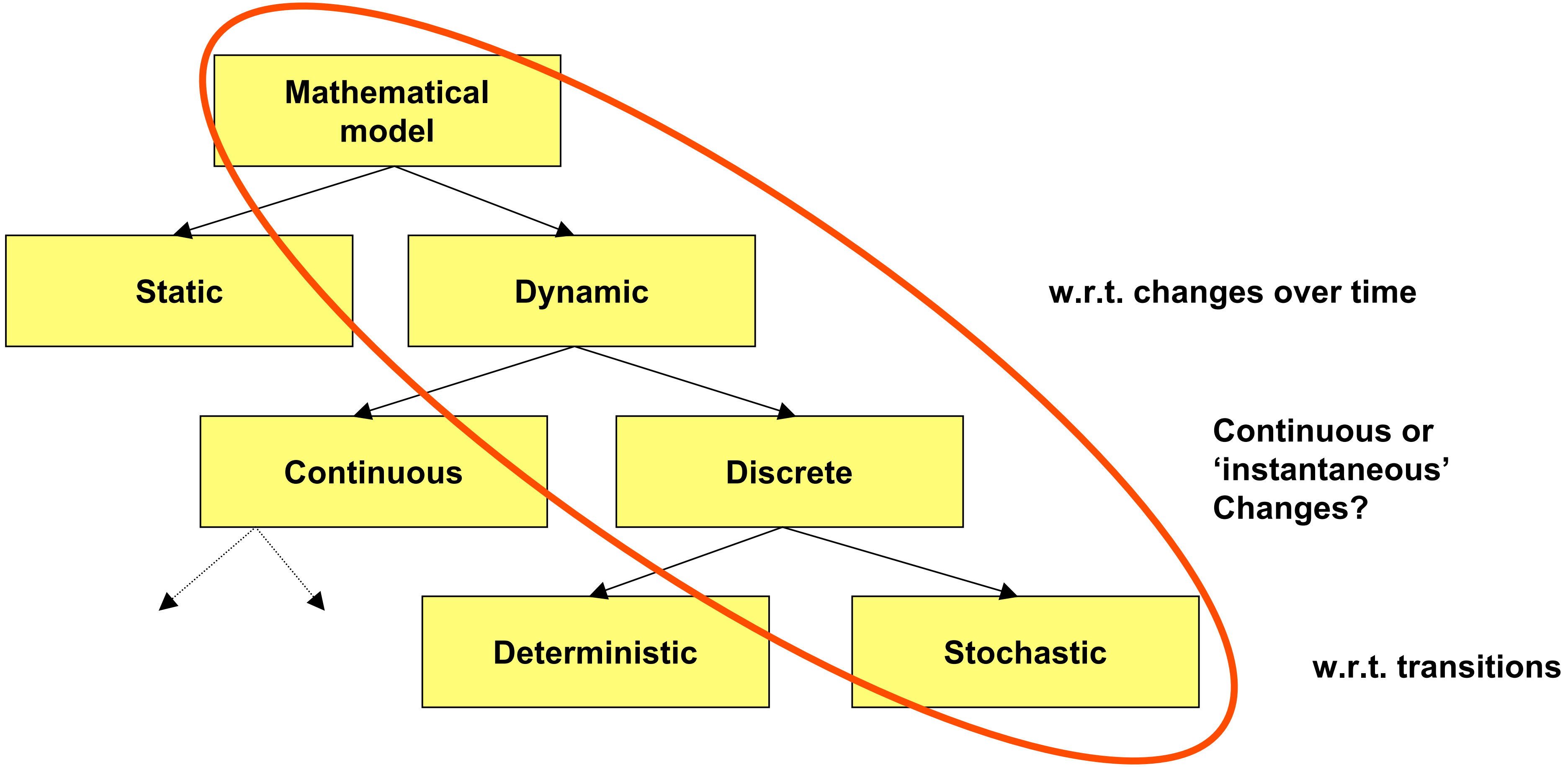
- **We define the *state* of a system to be that collection of variables necessary to describe a system at a particular time, relative to the objectives of the study**
- **In dynamic systems, the state of the systems changes over time**
- **Usually, the local behavior of the system is known but the ‚evolution' of the system on a global scale is unknown.**

» **Simulation**

- **Step 1: build a (virtual) model w.r.t. system states and their corresponding state transitions**
- **Step 2: execute the model, i.e., the transition rules, and observe the output**



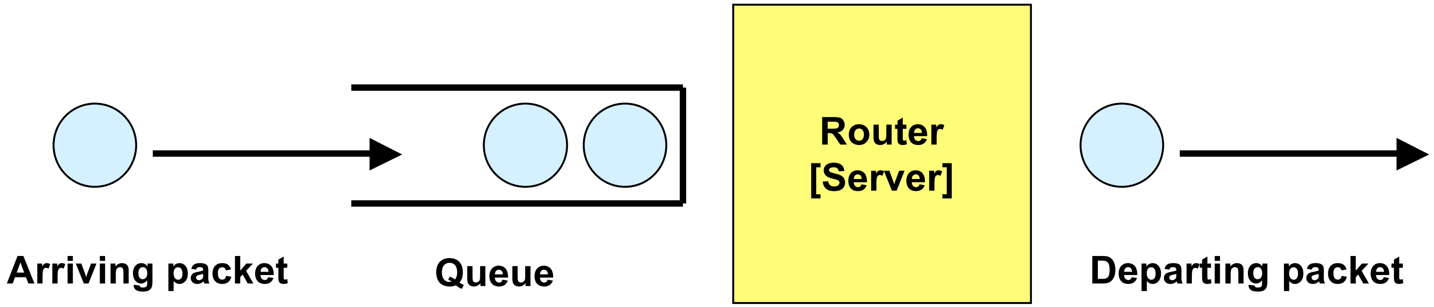
I Classification of models and simulation types



→ **Our focus: discrete event simulation**

Relevant class for computer networks

II Classical introductory example: M/M/1 queue



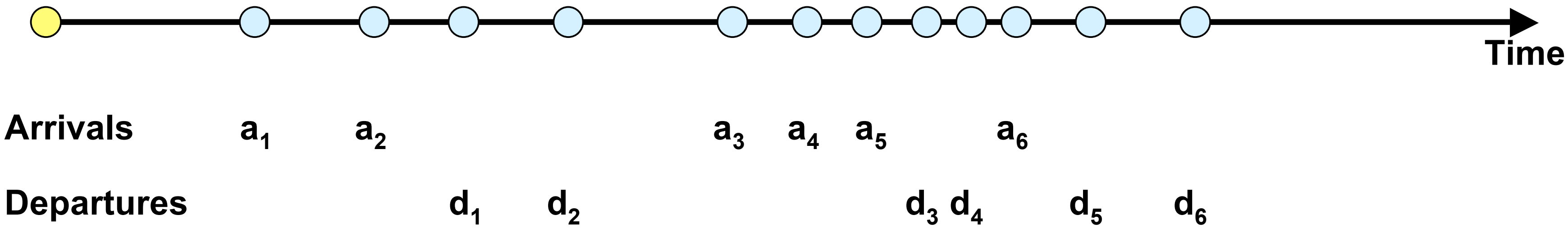
- Queuing systems as delay models
- Arrival process: ‘M’ for ‘memoryless’ (thus, exponentially distributed inter-arrival times)
- Service process: ‘M’ for ‘memoryless’ (thus, exponentially distributed service times)
- Number of queuing stations: 1

β=1.0 s for inter-arrival times

β=0.5 s for service times

$$f(x) = \frac{1}{\beta} e^{-x/\beta} \quad \forall x \geq 0$$

II Introductory example: next-event time advance



- **Events:**
  - Packet arrivals
  - Departure: depends on arrival, delay, and service time
- **Next-event time advance mechanism:**
  - Simulation clock advances to next event
    - State of system is updated
    - Knowledge of the times of occurrence of future events is updated
    - Go to next event
  - Thus, periods of inactivity are ‚skipped'.

II Introductory example: performance measures

Statistics for performance measures:

» **Average packet delay in queue:**

- **Assume n packets are sent**
- **Denote the delay of packet i by D_i**

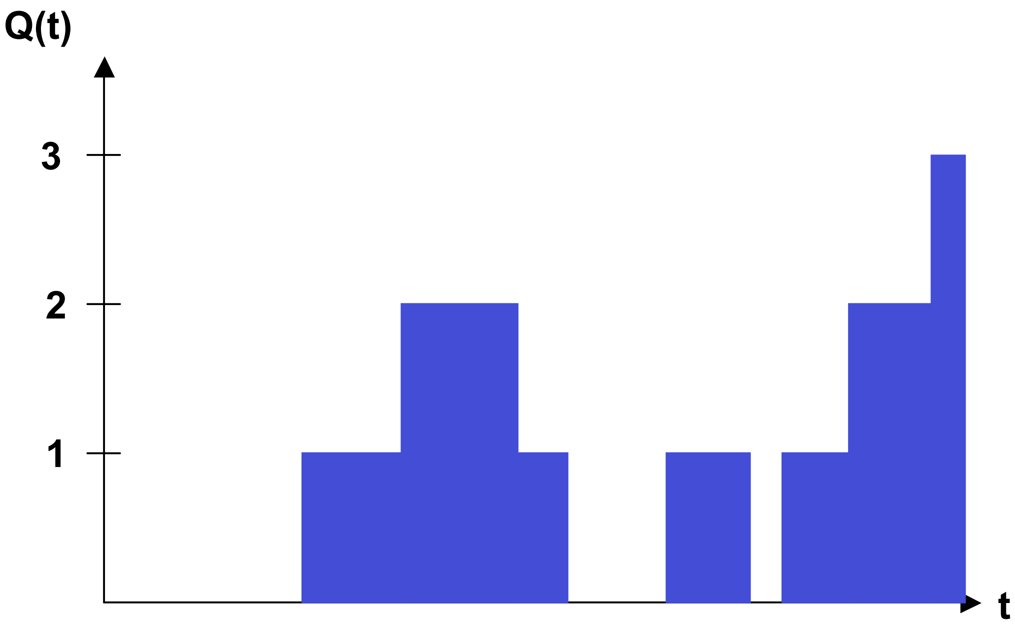
$$\hat{d}(n) = \frac{\sum_{i=1}^{n} D_i}{n}$$

Estimator or 'statistic'

II Introductory example: performance measures

» **Time-average number of packets in queue**

- **Let Q(t) denote the number of packets in the queue at time t**
- **Let T(n) denote the total simulation time for n packets.**

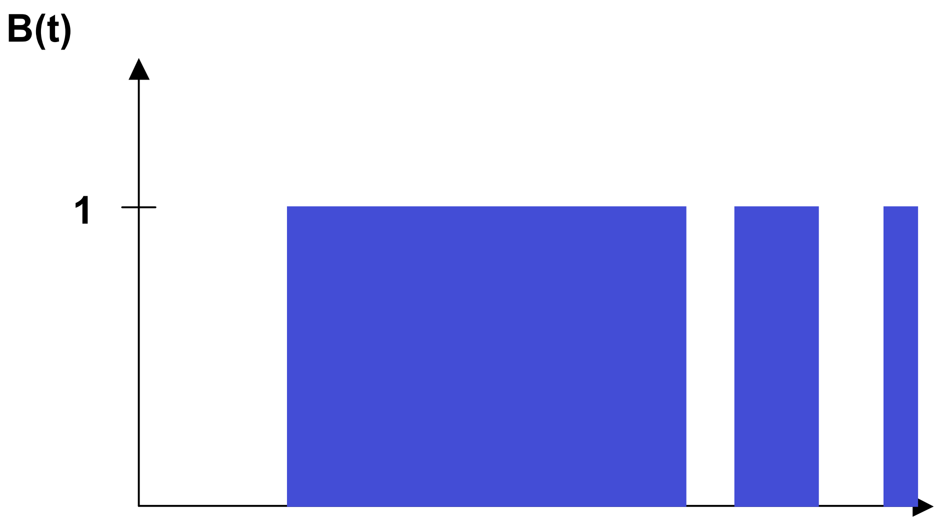


$$\hat{q}(n) = \frac{\int_0^{T(n)} Q(t)dt}{T(n)}$$

II Introductory example: performance measures

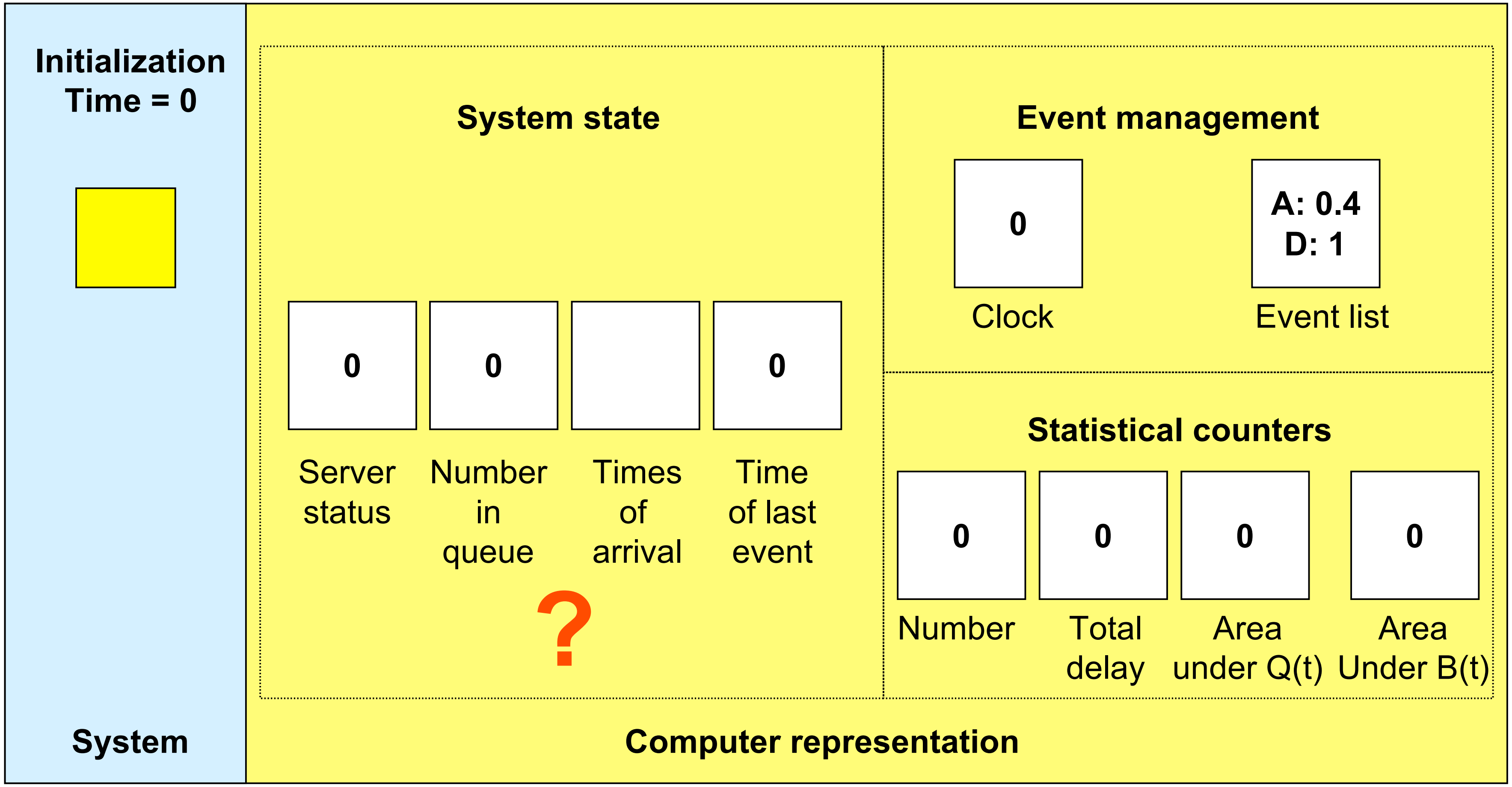
» **Router/Server utilization**

– **Let B(t) be one if the server is busy at time t and zero otherwise.**



$$\hat{u}(n) = \frac{\int_0^{T(n)} B(t)dt}{T(n)}$$

II Introductory example: execute model



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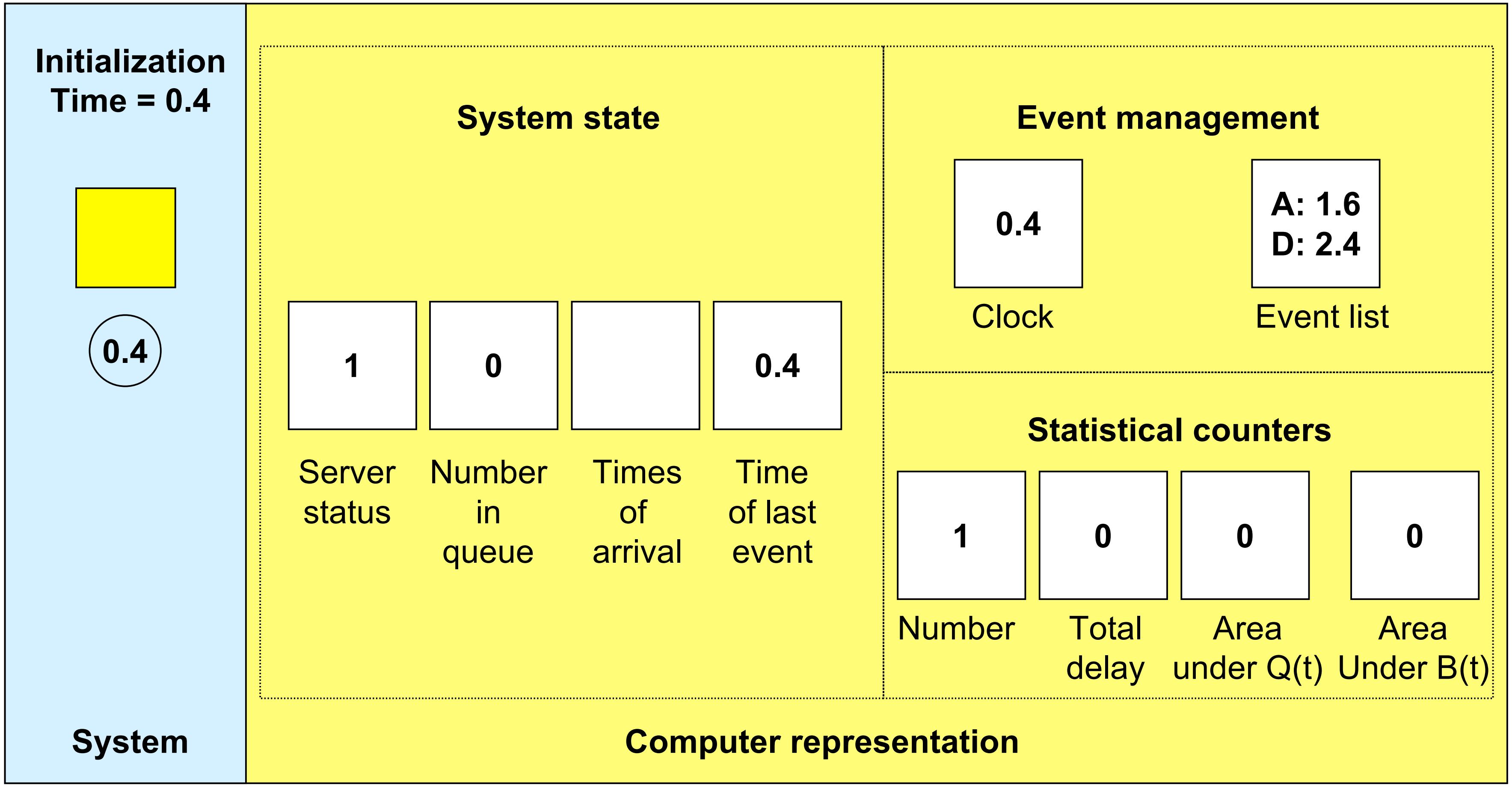

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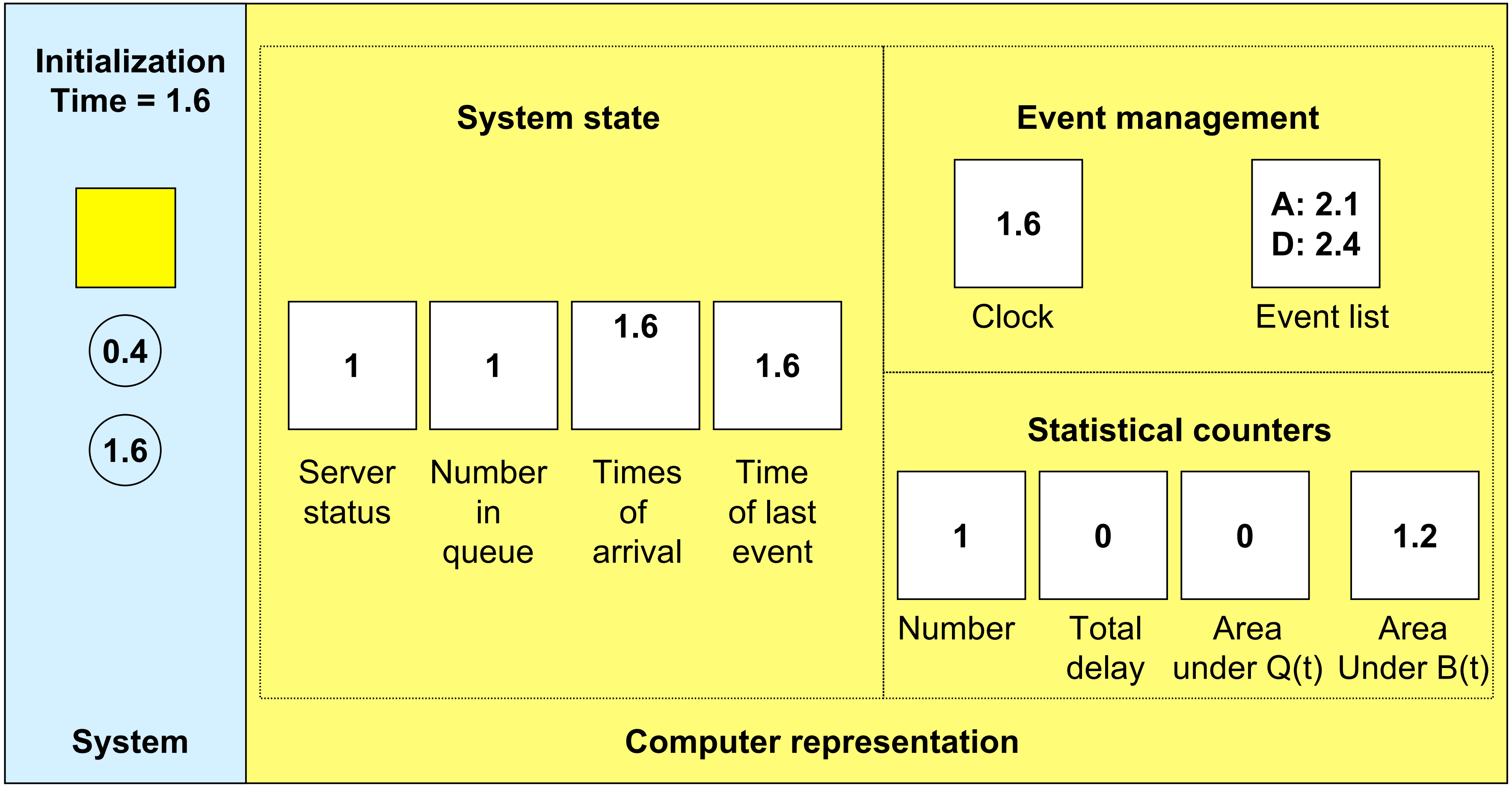

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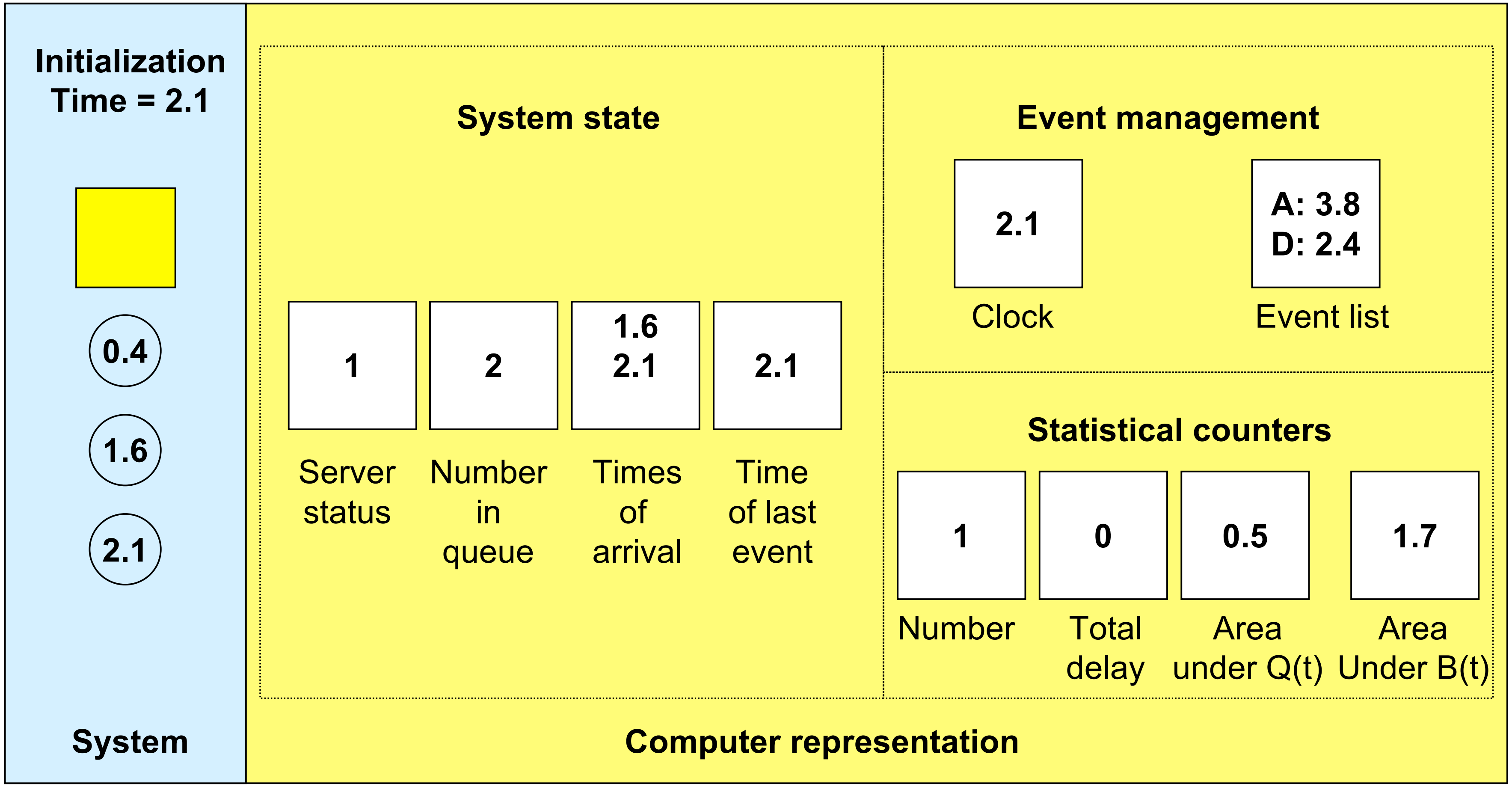
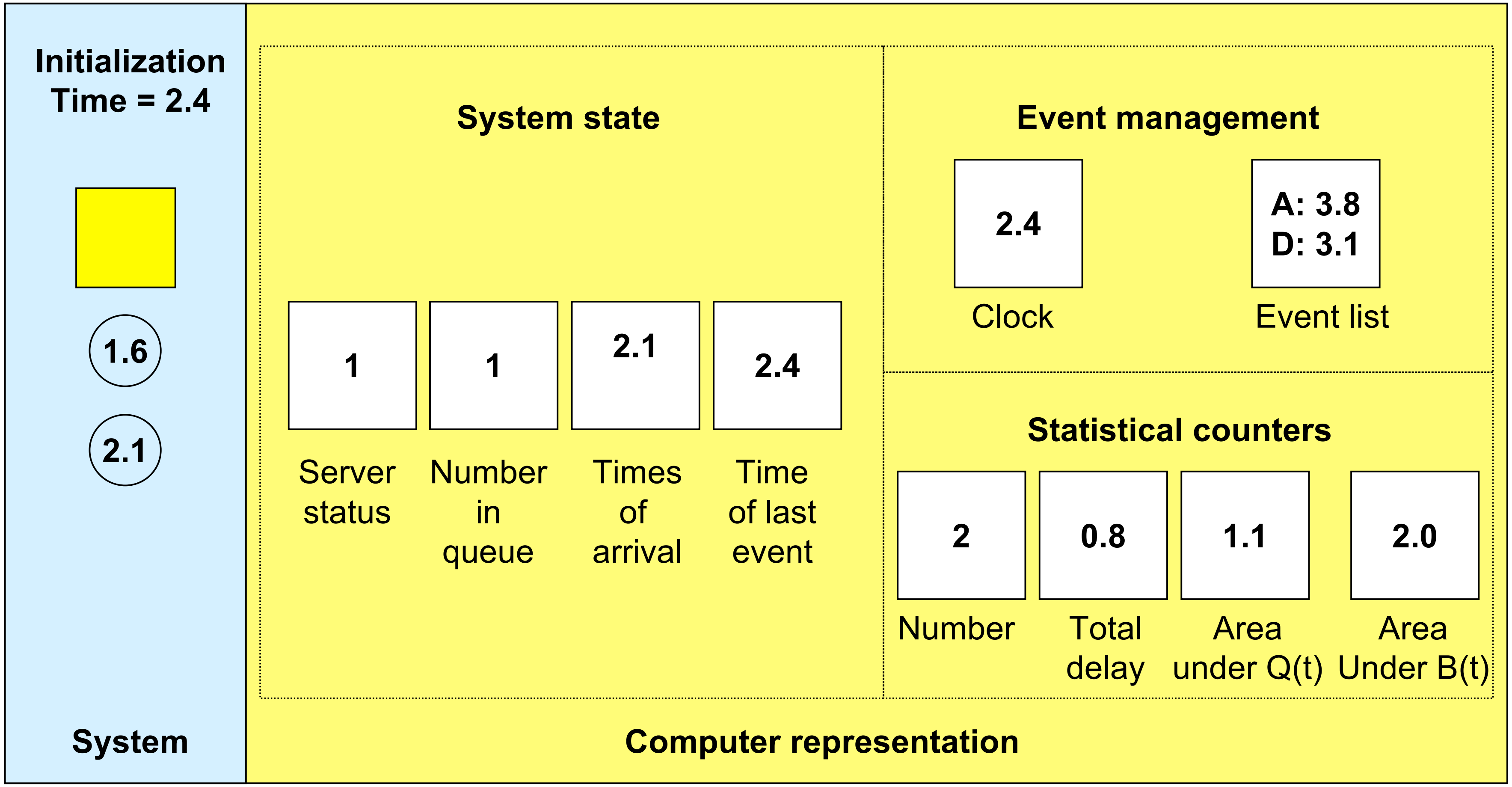
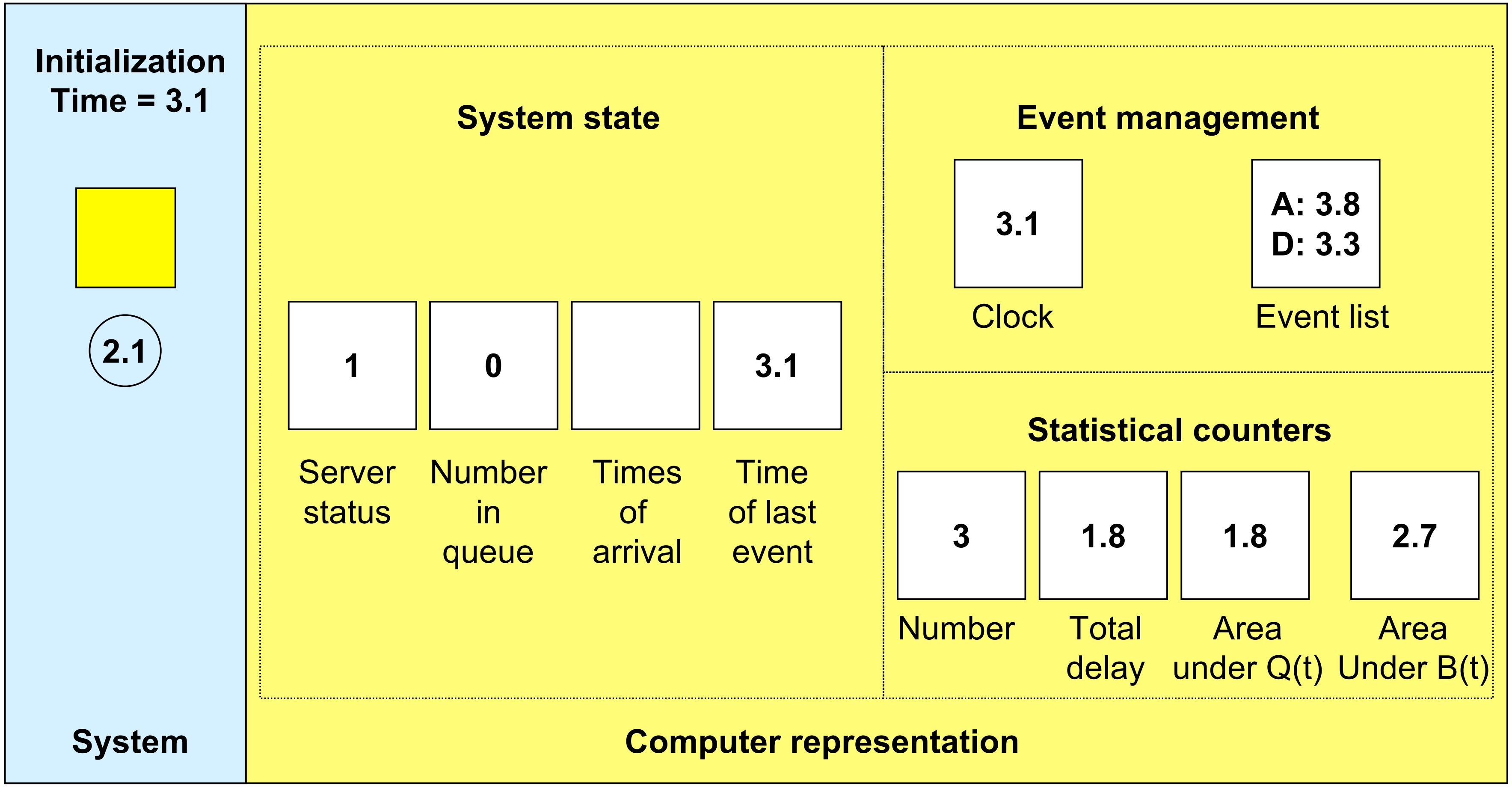


II Introductory example: execute model

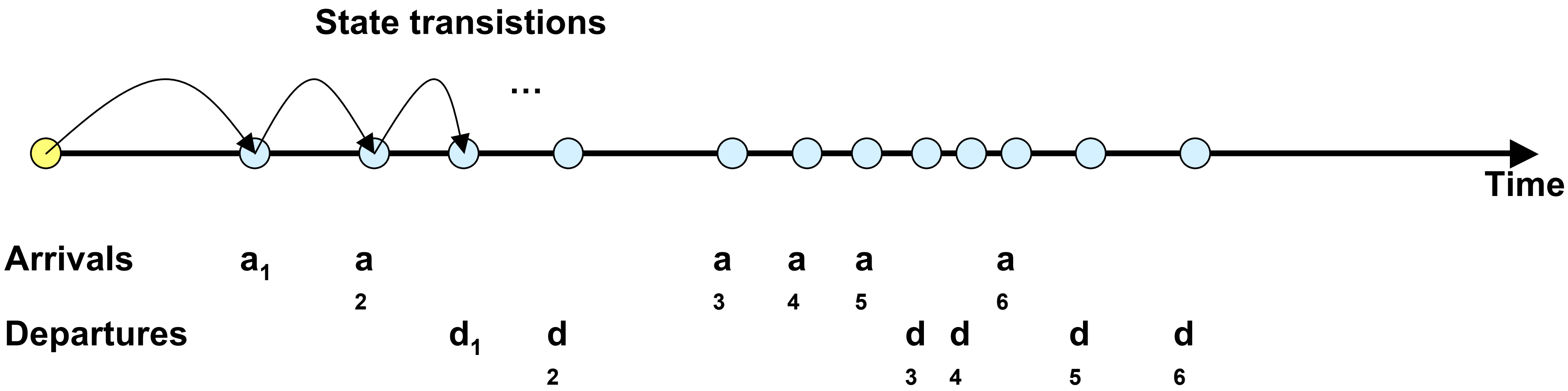


II Introductory example: execute model



… see [LK2000] for continuation of this example

II Introductory example: event logic



- Depending on the *event type,* a specific *event handler* is called that performs the appropriate state transition
- A state transition also includes generation of new events

II Introductory example: output

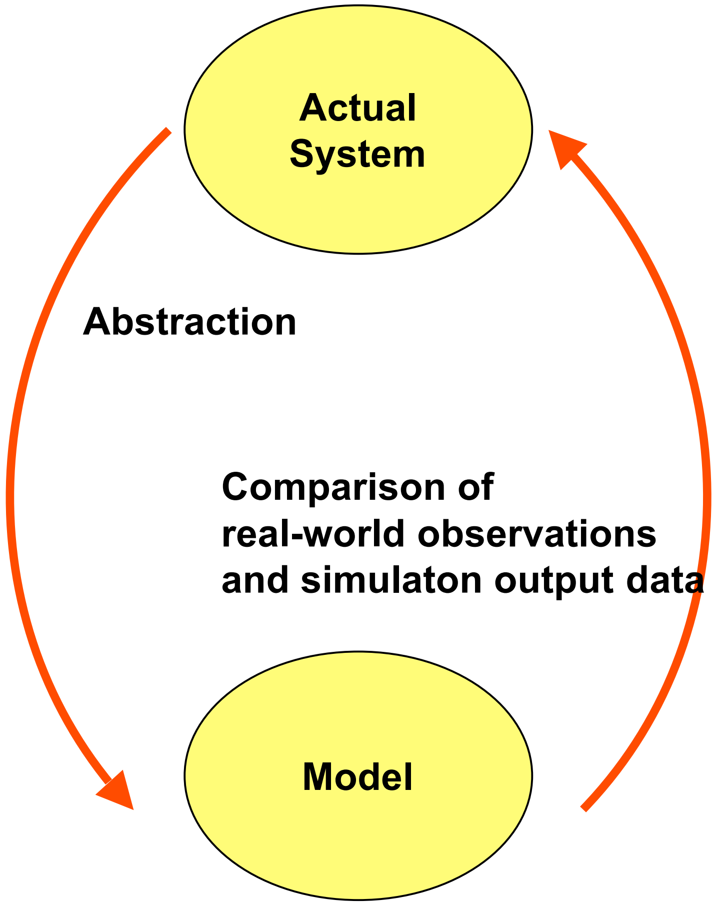
- n=1000
- Average delay in queue: 0.43 s
- Time-averaged number in queue: 0.418
- Server utilization: 0.46

  [Taken from LK2000]

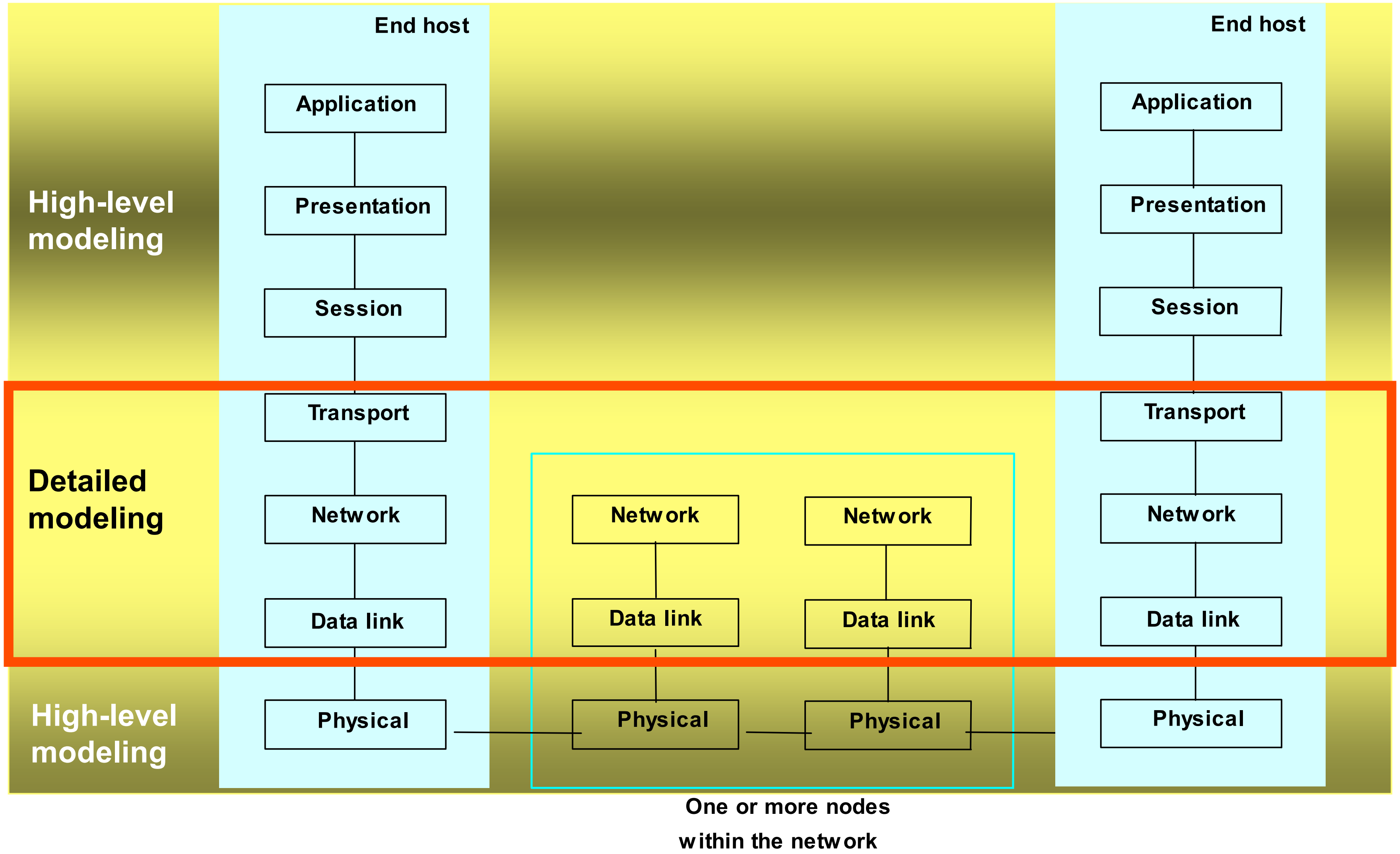
- Play with parameters in NetSim Lab 3!

III Computer networks: what is modeled and simulated?

- What is the ‘right’ level of detail?
- Usually, the following elements are modeled:
  - Topology of the network, or mobility of the nodes
  - Communication protocols as well as applications
  - Data traffic



III Simulation of computer networks: level of detail



III Trade off: accuracy vs computational costs

- **Packet-level simulation**
  - **No bit-level simulation as in digital communications**
- **Session-level simulation and aggregated flows**
  - **Coarser modeling than packet-level simulation**
  - **In movement pattern generation the difference goes by the name of microscopic vs macroscopic modeling (particles vs fluids)**
- **Internet-scale: for example, modelling of stub networks and autonomous systems (AS) as a ‚single node‘.**

- **Modeling depends on what has to be analyzed and how much computational costs one can afford.**

III Elements required for simulation of computer networks

» **Modeling**
  - **Stochastic elements (generic, i.e., required for discrete event simulations of any system)**
  - **System states and logic (computer network-centric)**
  - **Statistics (generic, i.e., required for discrete event simulations of any system)**

» **Simulation organization**
  - **Event and time management, event handlers**

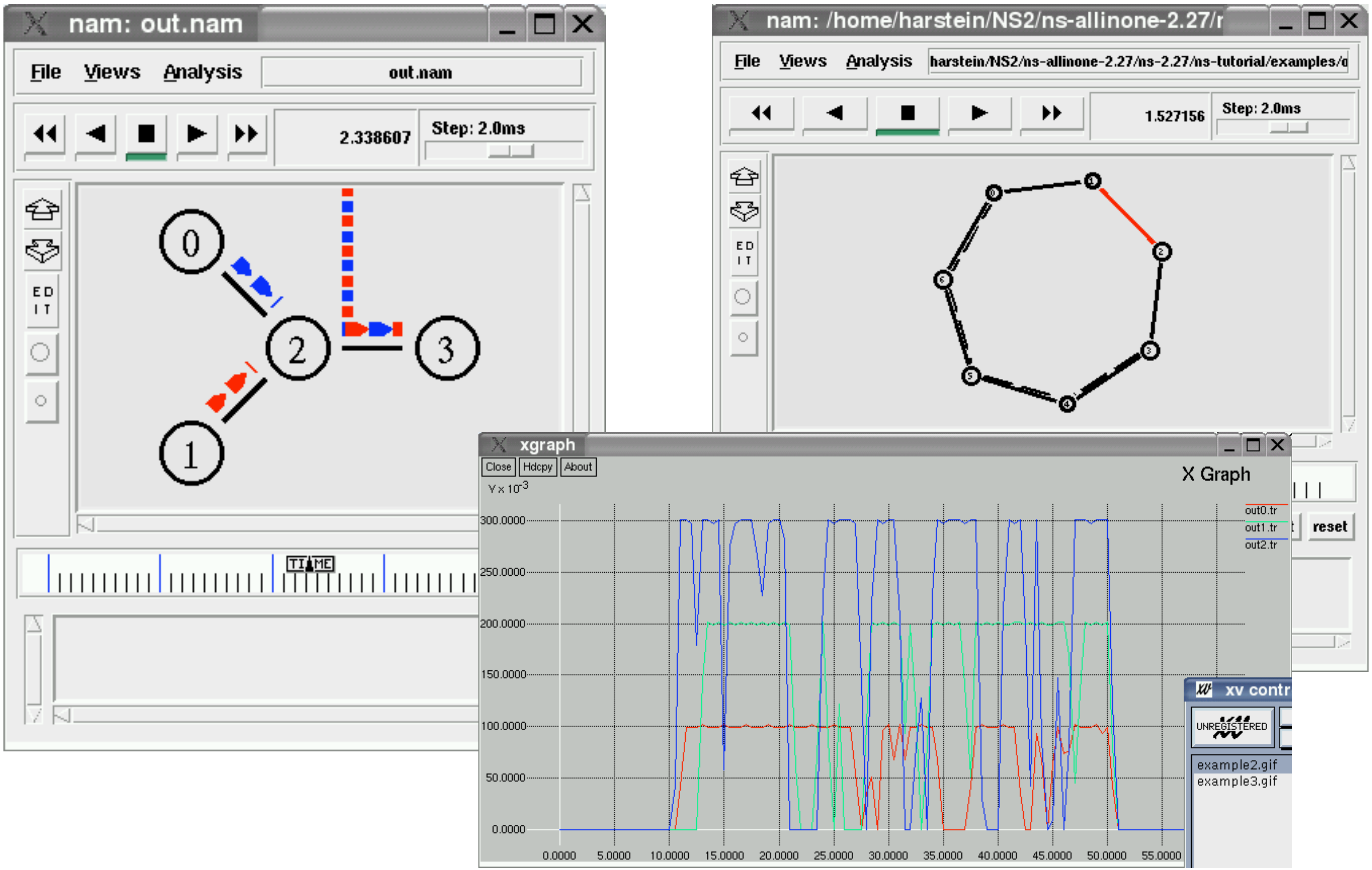
» **Output analysis**
  - **Statistics**

» **Tools**
  - **For specifying scenarios**
  - **For running simulation**
  - **For analyzing simulation output**

III Course overview

Modeling stochastic elements	**Random Number Generators, Generating discrete and continuous random variates Generating topologies, movement pattern, link characteristics, data traffic patterns**
Algorithmics of discrete event simulation	**Lists, heaps, calendar queues**
Modeling system state and logic for computer networks simulation	**Example: network simulator NS-2 nodes, links (point-to-point), agents, packets, connectors, classifiers, queues, packet scheduling, link delays, LAN MAC error modeling, transport protocols, application agent, …**
Output analysis	**Output data analysis Statistics, Tools, Visualization**

III Outlook


nam: out.nam
File Views Analysis
out.nam
2.338607
Step: 2.0ms
nam: /home/harstein/NS2/ns-allinone-2.27/r
harstein/NS2/ns-allinone-2.27/ns-2.27/ns-tutorial/examples/e
1.527156
Step: 2.0ms
xgraph
Close
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X Graph
out0.tr
out1.tr
out2.tr
reset
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example3.gif

Summary / Educational Goal

» Simulation: abstract view
  – Systems, models, system state, state transitions
  – Classification of simulation types
    • Static vs dynamic
    • Continuous vs discrete
    • Deterministic vs stochastic

» Simulation: concrete view
  – Example: M/M/1 queue
  – Execution ‘by hand’

» Elements needed for discrete event simulation
  – State variables
  – Event management
  – Statistics/Counters
  – Generation of events
  – Transition rules