Chapter 0

Introduction and Motivation: What are we talking about—and what is it good for?

Some of today's slides/figures borrowed from:
Richard Fujimoto
James Kurose, Keith W. Ross
Michael Menth, Dirk Staehle, Phuoc Tran-Gia

Modelling & Simulation

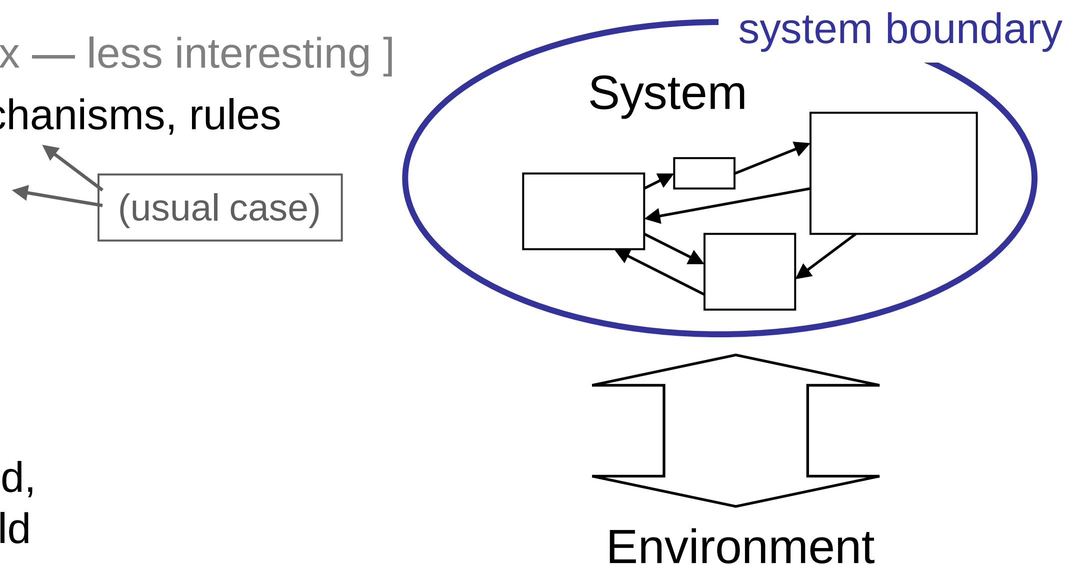
Model: A representation of a system (or: entity, process, …)

Simulation: The process of exercising a model to characterize the behaviour of the modelled system / entity / process over time

Computer simulation: A simulation where the system doing the emulating is a computer program

What is a system?

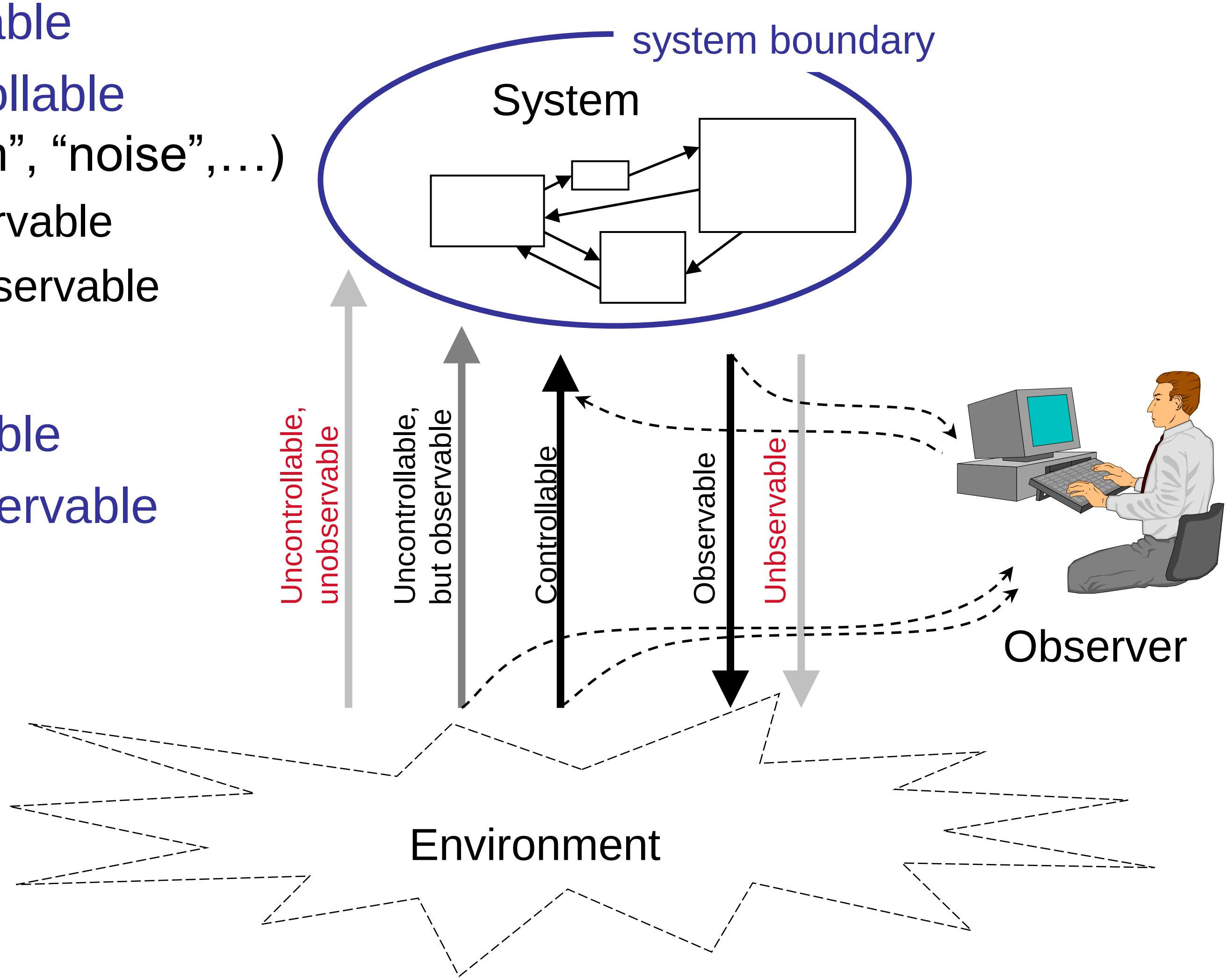
- Actually, a very vague notion—pretty much anything can be a system!
  - ‘A system is what is distinguished as a system.’ (Brian Gaines)
- A system is something that we want to see separated from its environment through an (arbitrarily chosen) **boundary:**
  - **Inside** the system:
    - [opaque, i.e., black box — less interesting]
    - or some structure, mechanisms, rules
    - or even sub-systems
  - **Outside** world (not part of the system!):
    - Environment, context
    - Interaction: Input from outside world, output into outside world



- A system has a **purpose**
  - Nobody defines something as a system without some purpose in mind

System, environment, observer

- Input
  - Controllable
  - Uncontrollable ("random", "noise",…)
    - Observable
    - Unobservable
- Output
  - Observable
  - Non-observable



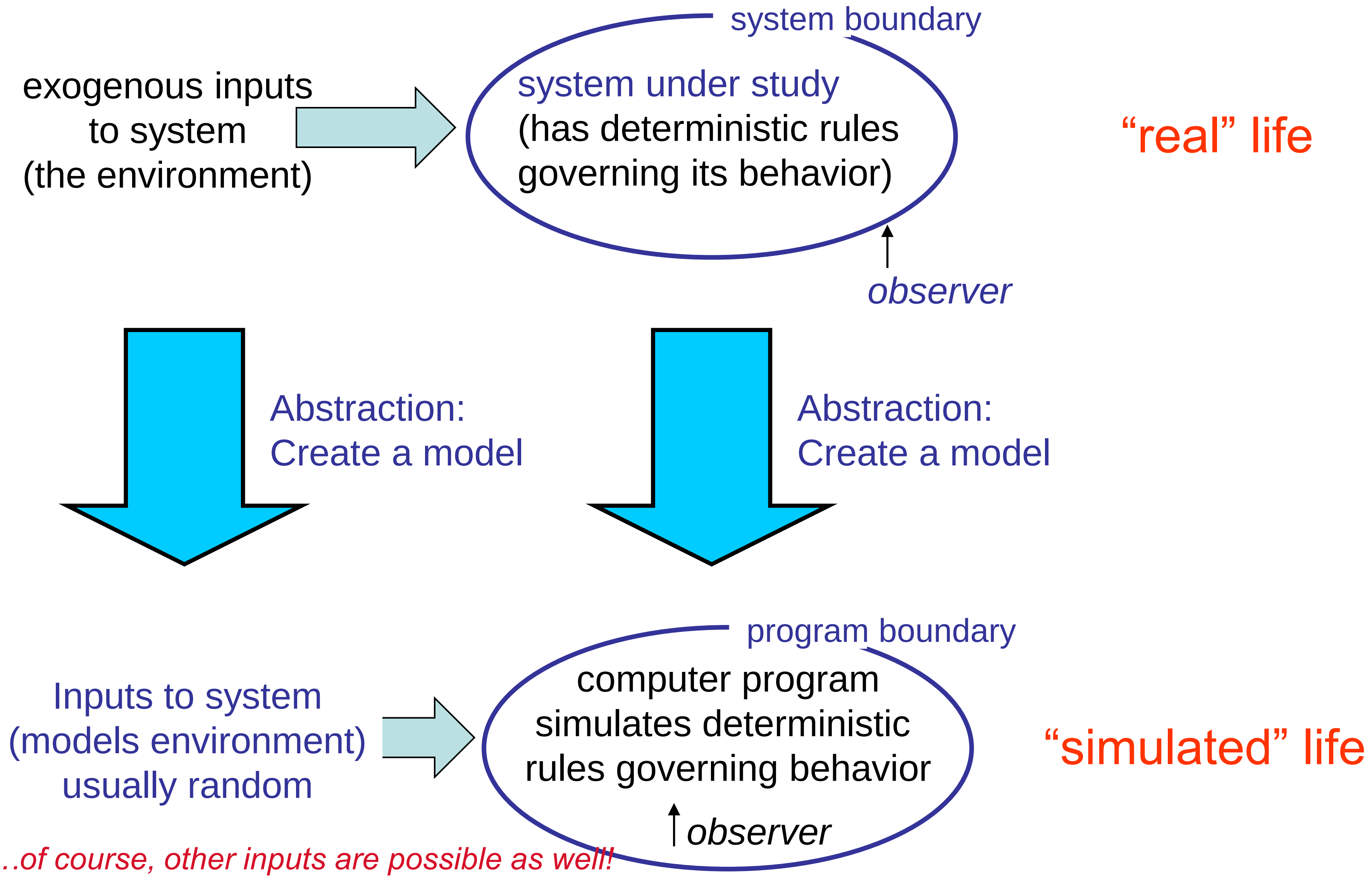
What is a model?

A model …

- is a system, too!
- mimics behaviour/characteristics of another system
- is material or immaterial
  - Material model: architecture models, or e.g.,:

  - Models we'll be talking about: normally immaterial
- allows experimental manipulation
- Purpose:
  - Simplification of original model: Reduction of complexity
  - Retaining those characteristics of original model that are important to the observer

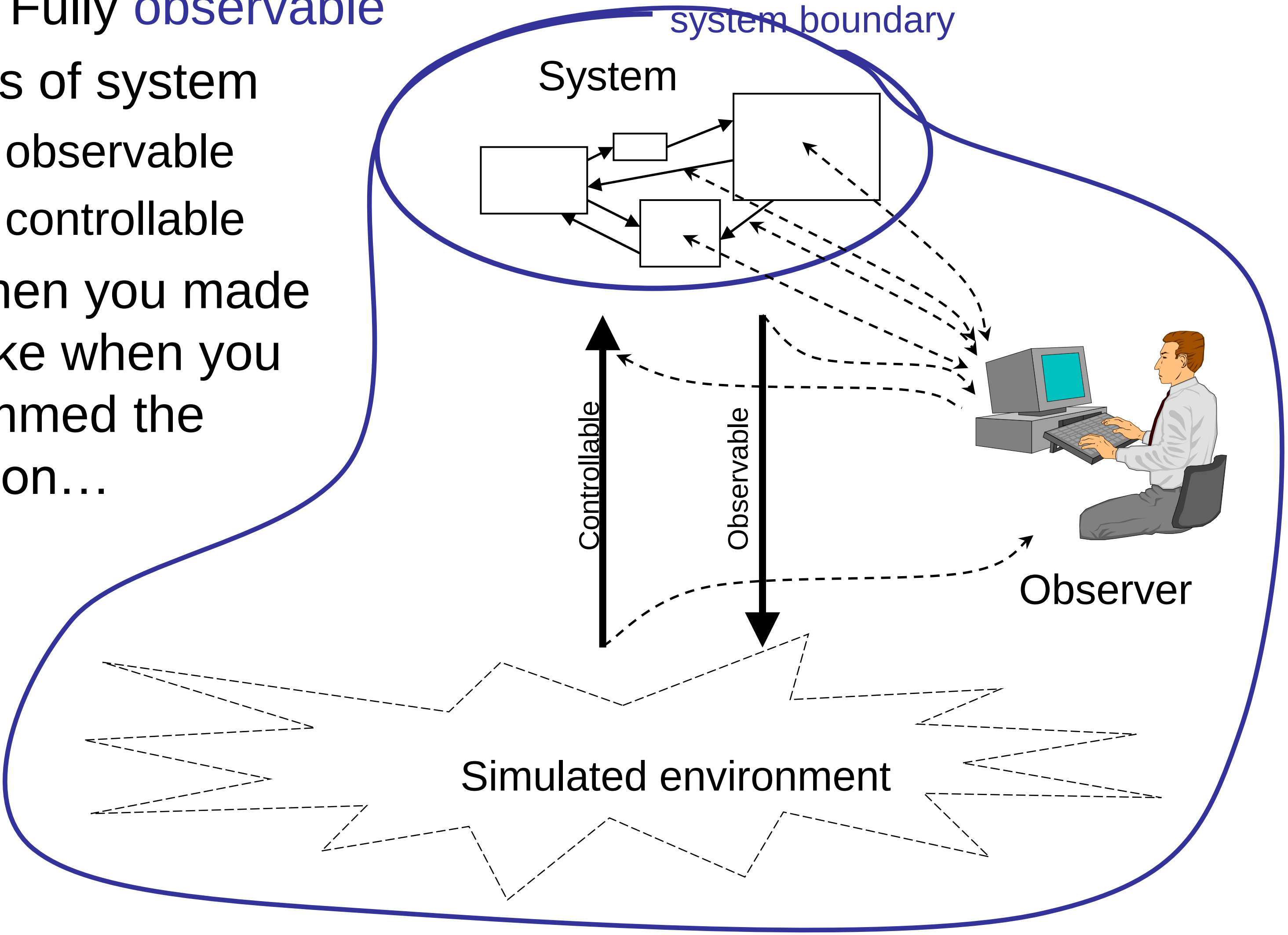
Simulation is exercising a model (actually: two!)

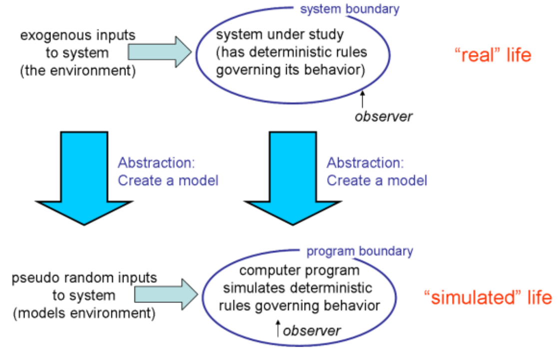


…of course, other inputs are possible as well!

System, environment, observer in simulation

- Input: Fully controllable
- Output: Fully observable
- Internals of system
  - Fully observable
  - Fully controllable
- If not, then you made a mistake when you programmed the simulation…



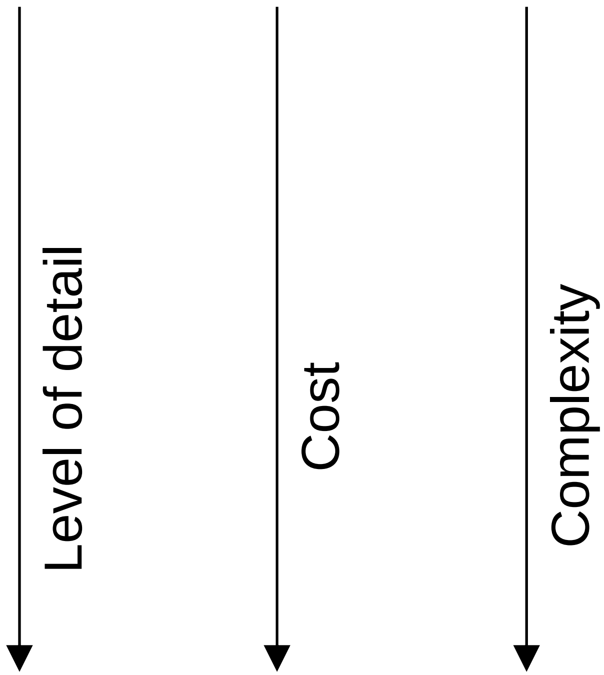


The evaluation spectrum:

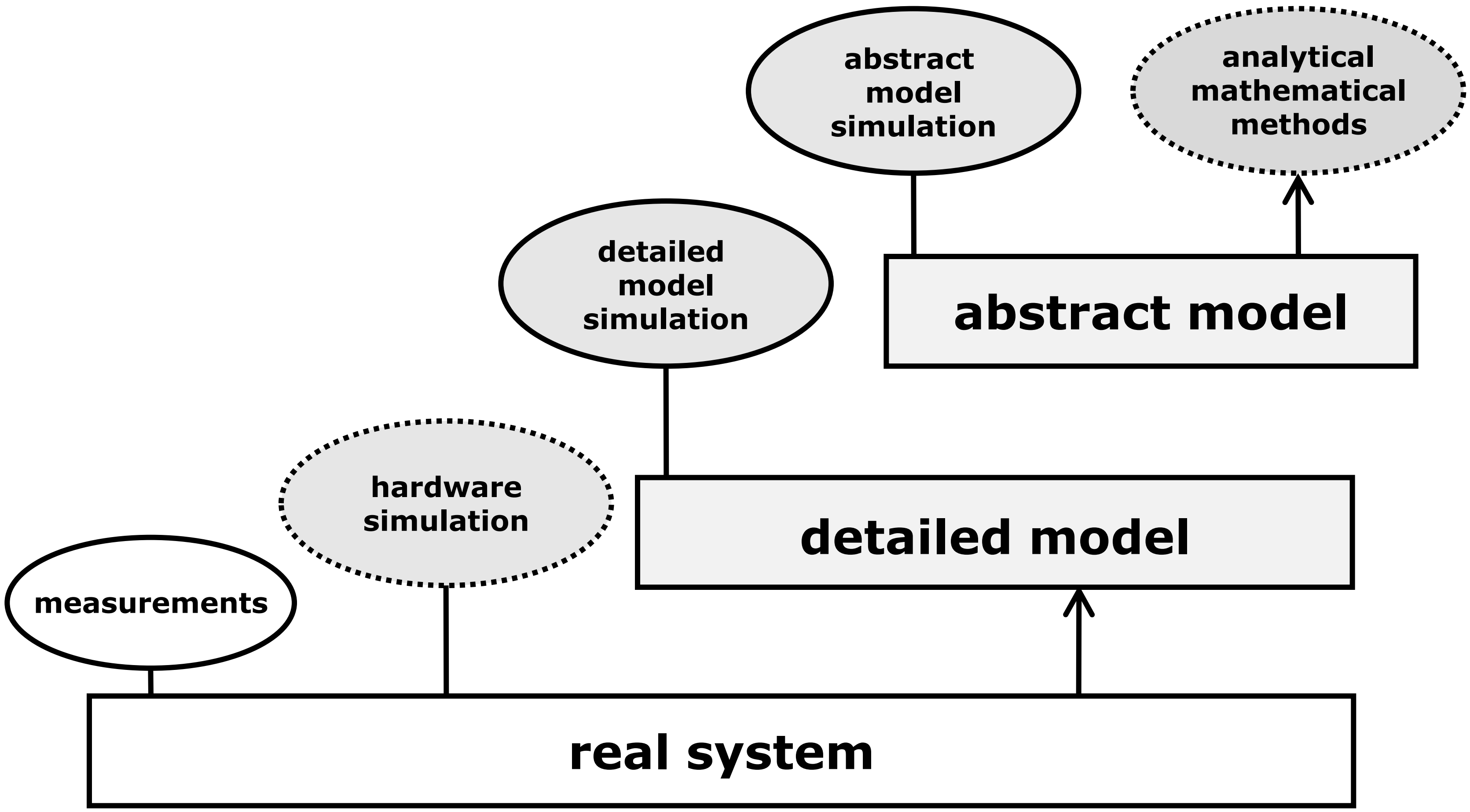
- Purely mathematical model using closed-form expressions
- Numerical models
- Simulation
- Emulation
- Prototype
- Operational system

↑ less detailed

↓ more detailed



In addition to last week's evaluation spectrum:



When to use simulations (1/2)

- It may be too difficult, hazardous, or expensive to observe a real, operational system.
  Examples:
  - Virus epidemy
  - New routing protocol in the Internet
- There is only one real system, but we want to quickly evaluate alternatives and what-if scenarios.
  Examples:
  - Different router configurations
  - Different types of network traffic (realistic, low rate, full rate,…)

When to use simulations (2/2)

- Parts of the system may be unavailable / not be observable.
  Examples:
  - Internals of a biological system
  - Internals of a switch chip
- The original system runs on a very slow timescale, and/or we want to make predictions.
  Examples:
  - Climate predictions (10s to 1000s of years)
  - Milky way eating Sagittarius dwarf (100 mio years and more)
- It may be too difficult or intractable to model a system in detail using only closed-form expressions ("formulae").
  Examples:
  - Physical processes in atmosphere (weather, climate,…)
  - n-bodies problem, $n \geq 3$
  - Complex network with many TCP hosts

Simulation: Advantages

- Save lives
- Save money
- Save time (?)
  - Buying hardware, connecting and configuring a huge test network takes longer than setting up a simulation (…usually)
- Find bugs (in design) in advance
  - The earlier a bug is detected, the less its removal will cost
- More generally applicable than analytic/numerical techniques
- Detail: can simulate system details at arbitrary level

Simulation: Drawbacks

- Caution: Does model reflect reality? Or is it too oversimplified?
- Large scale systems = Lots of resources to simulate, especially if accurate simulation is required
- Large scale systems = Lots of resources for simulator:
  - May be slow (computationally expensive: 1 min real time could be hours of simulated time!)
  - May eat huge amounts of RAM
  - May write out gigabytes of output (…which needs to be analyzed after!)
- It’s an art: determining right level of model complexity
- Statistical uncertainty in results:
  - Was the simulation accurate/detailed enough?
  - Are the observed effects just artefacts/statistical outliers? Remember: Some input comes from a (pseudo-)random generator!

Uses and applications for simulations

- Analyze systems before they are built
  - Reduce number of design mistakes
  - Optimize design
- Analyze operational systems
  - What-if scenarios
  - Find reasons for aberrant behaviour
- Create virtual environments for training, entertainment
  - Flight simulators, battlefield simulators
  - …in fact, almost all computer games are simulations!

Applications (1): System Analysis (focus of lecture!)

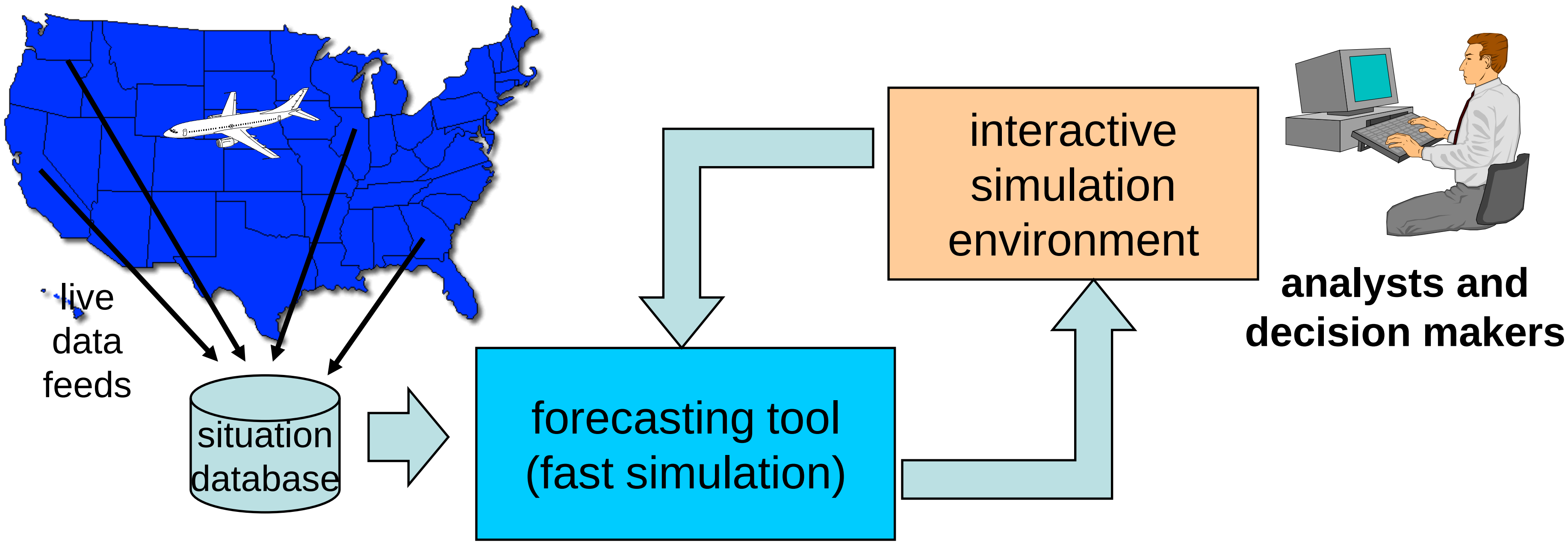
"Classical" application of simulation; here, focus is on "discrete event" simulation

- **Telecommunication networks** (focus of lecture!)
- Transportation systems
- Electronic systems (e.g., microelectronics, computer systems)
- Battlefield simulations (blue army vs. red army)
- Ecological systems
- Manufacturing systems
- Logistics

Focus is typically on planning, system design

Simulations may take a long time to run

Applications (2): On-Line Decision Aids



Simulation tool is used for fast analysis of alternate courses of action in time-critical situations

- Initialize simulation from situation database
- Faster-than-real-time execution to evaluate effect of decisions

Applications: air traffic control, battle management

Simulation results may be needed in only seconds

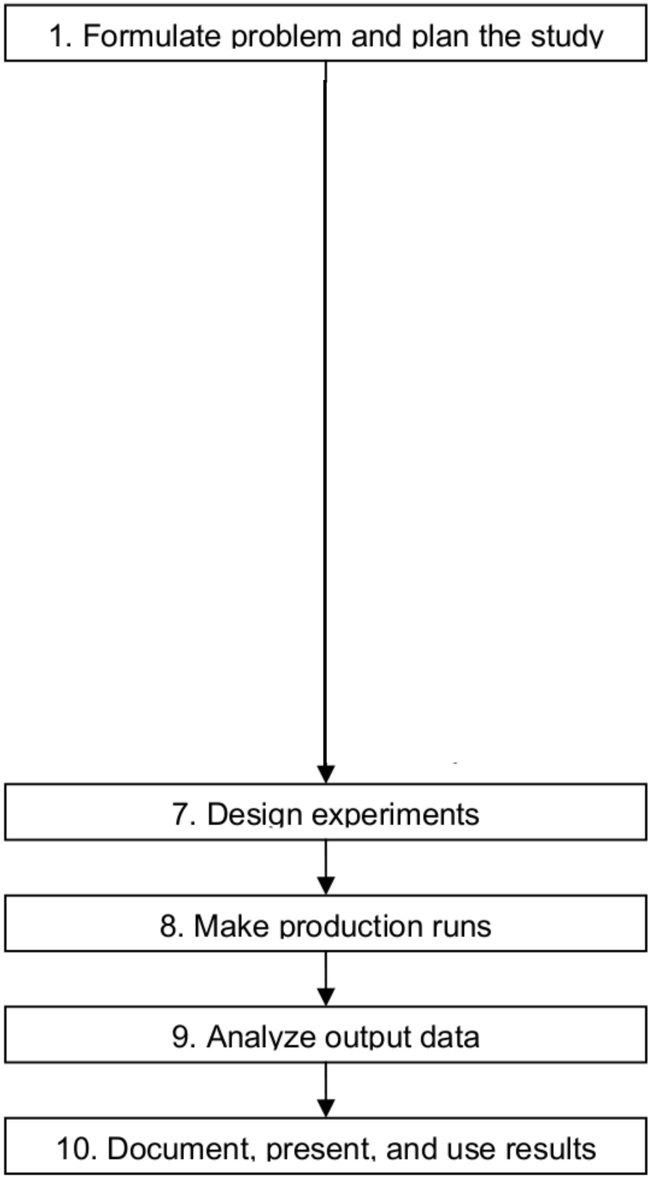
Applications (3): Virtual Environments

Uses: training (e.g., military, medicine, emergency planning), entertainment, social interaction?

Simulations are often used in virtual environments (human-in-the-loop) to create dynamic computer generated entities

- Adversaries and helpers in video games
- Defense: Computer generated forces (CGF)
  - Automated forces
  - Semi-automated forces
- Physical phenomena
  - Trajectory of projectiles
  - Buildings "blowing up"
  - Environmental effects on environment (e.g., rain washing out terrain)

How simulation is used—typical workflow (1/6)

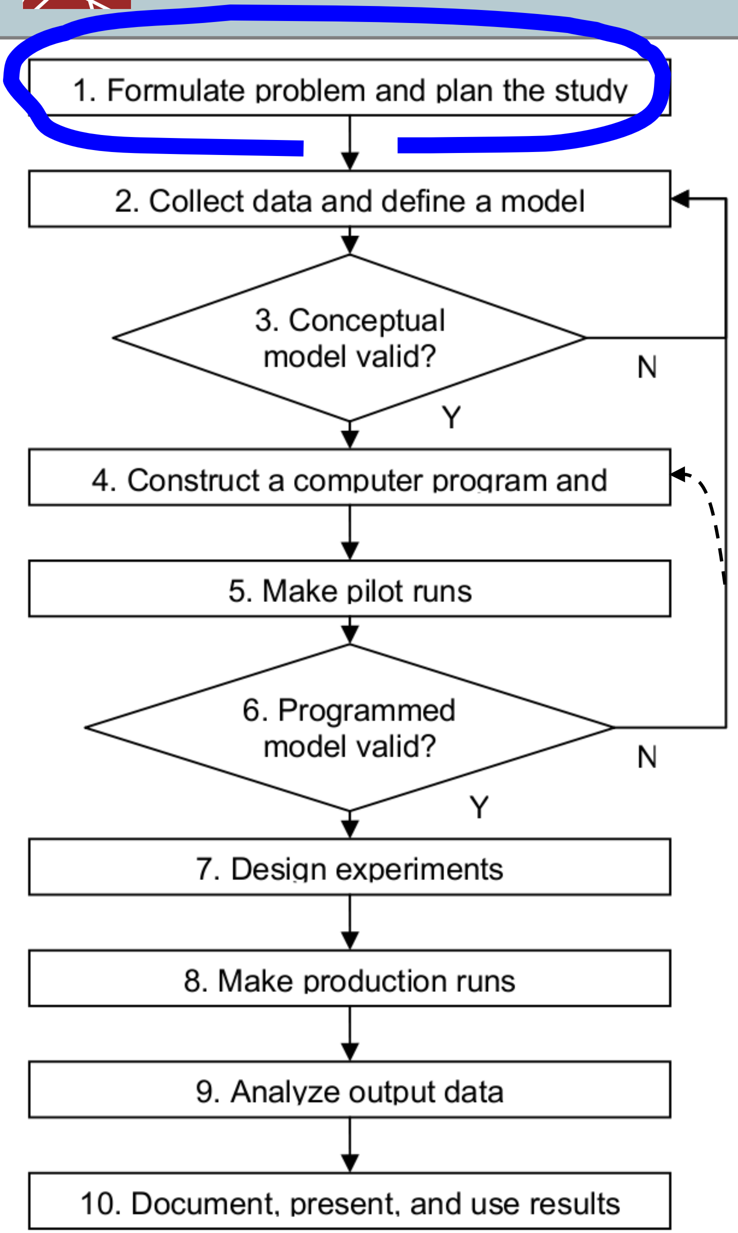


Is it that simple?

No!

- Useful simulation requires a lot of work
- Otherwise:
  trash in ⇒ trash out

How simulation is used—typical workflow (2/6)



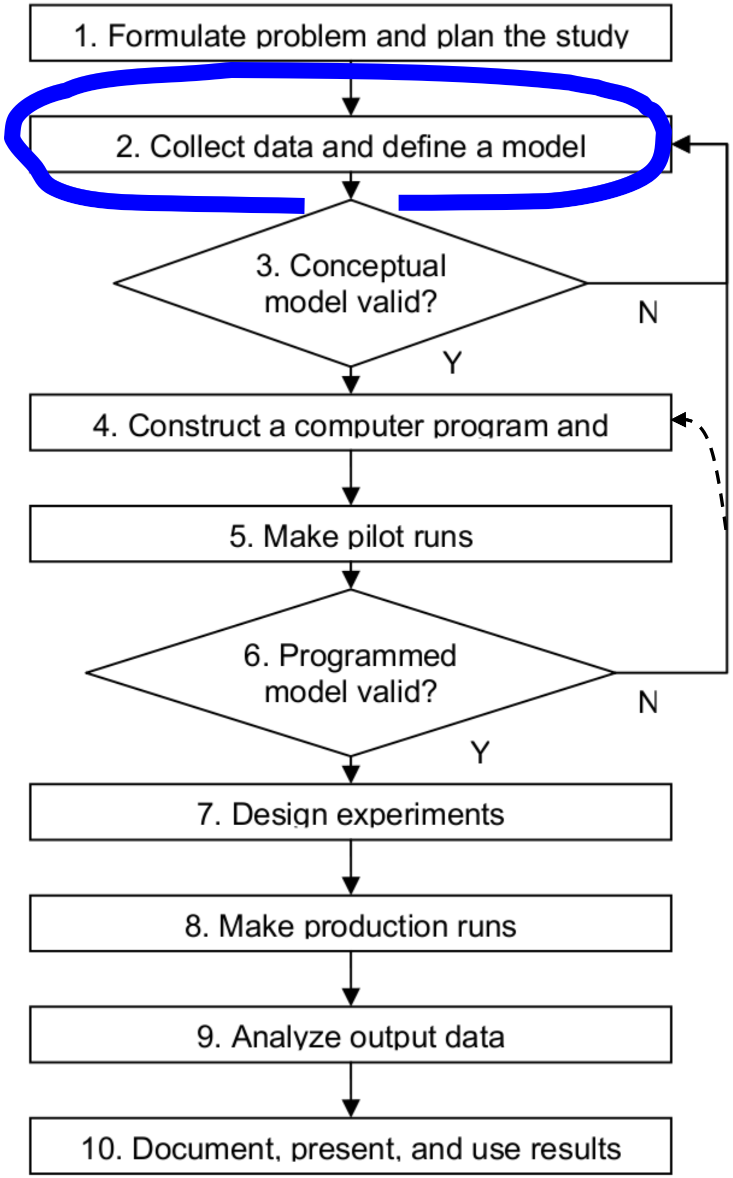
What do I want to show?

- Feasibility study
- Performance study
- Occurrence of specific phenomenon

❑ How can I show it?

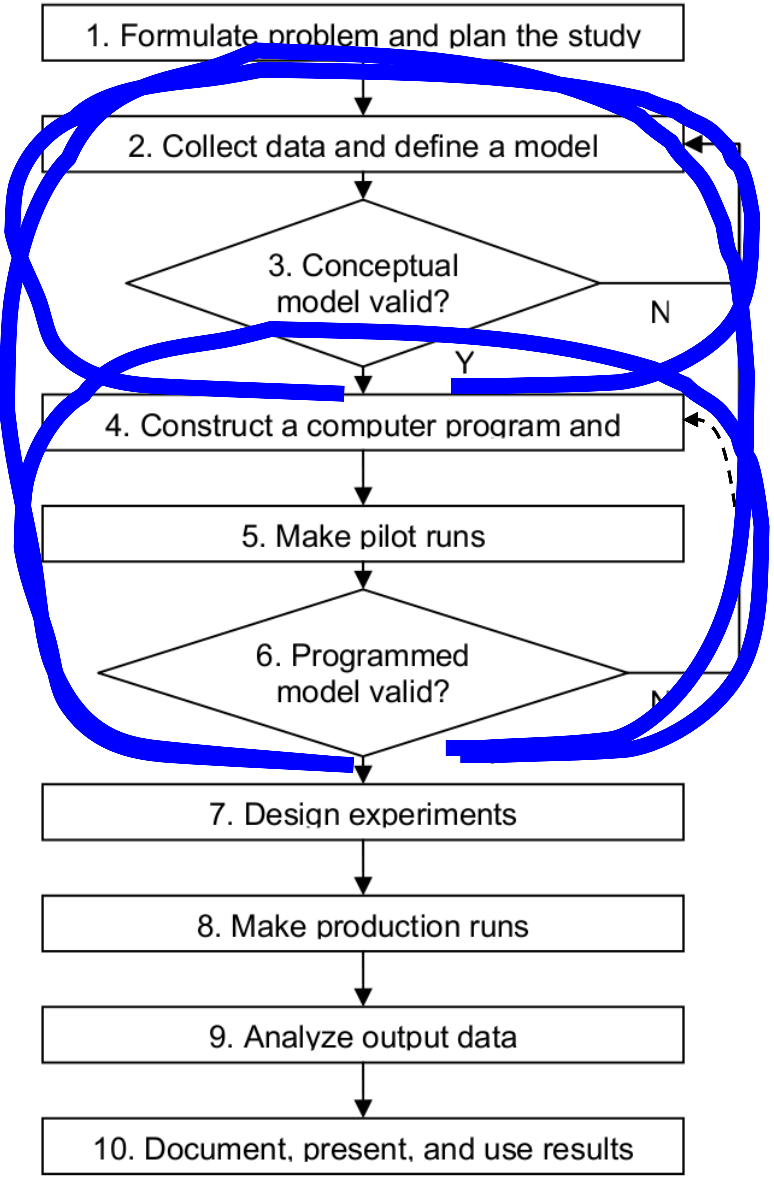
- What are the inputs of the system?
- What are the outputs?
- What can I measure; what is inaccessible?
- What may change, what will remain constant?

How simulation is used—typical workflow (3/6)



- Gain insight: How does the system behave?
- What is relevant for the model? In what detail?
- What can be left out?
- Collect measurement data for validation

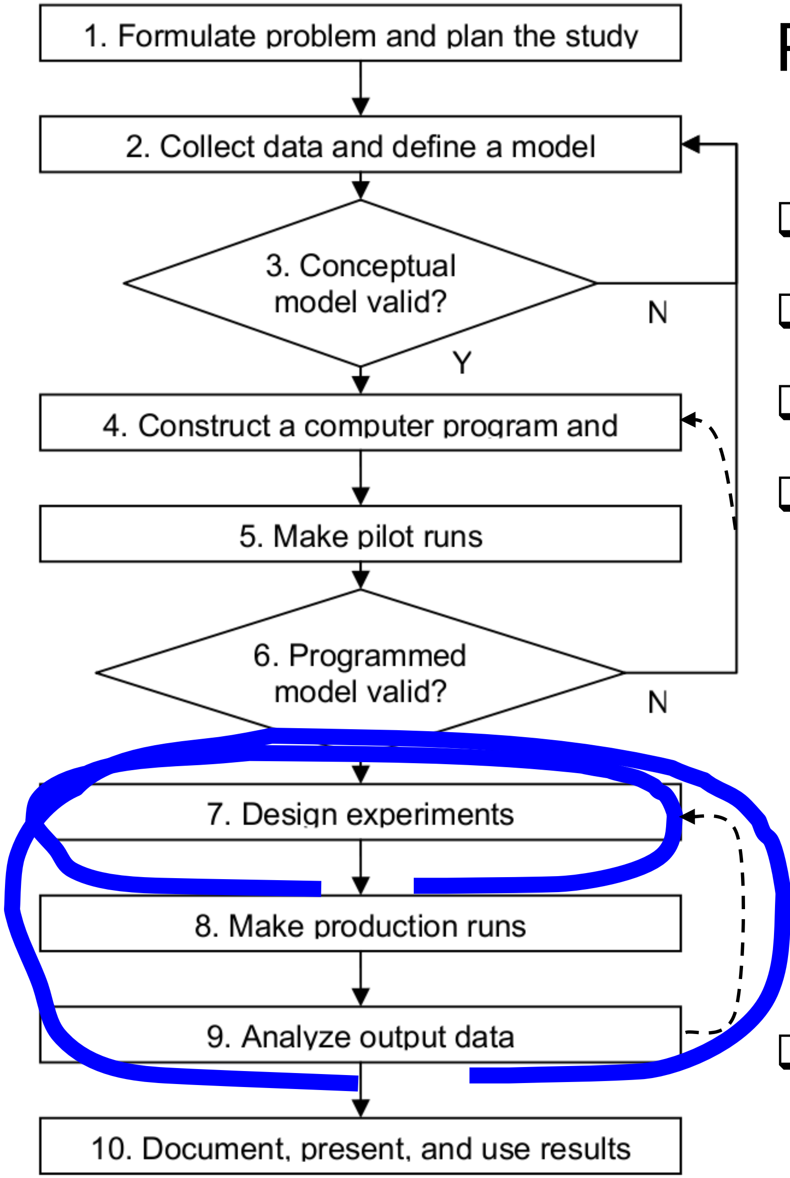
How simulation is used—typical workflow (4/6)



A model needs to be validated.

- Usual approach: Compare real data vs. simulation output
- Otherwise:
  trash in ⇒ trash out
- Validation loops:
  - Theoretical validation: Does it make sense? (steps 2 and 3)
  - Debugging: Is it correctly implemented? (steps 4–6)
  - Practical validation: Does it do the right things? (steps 2–6)
- Validation consumes a lot of time!

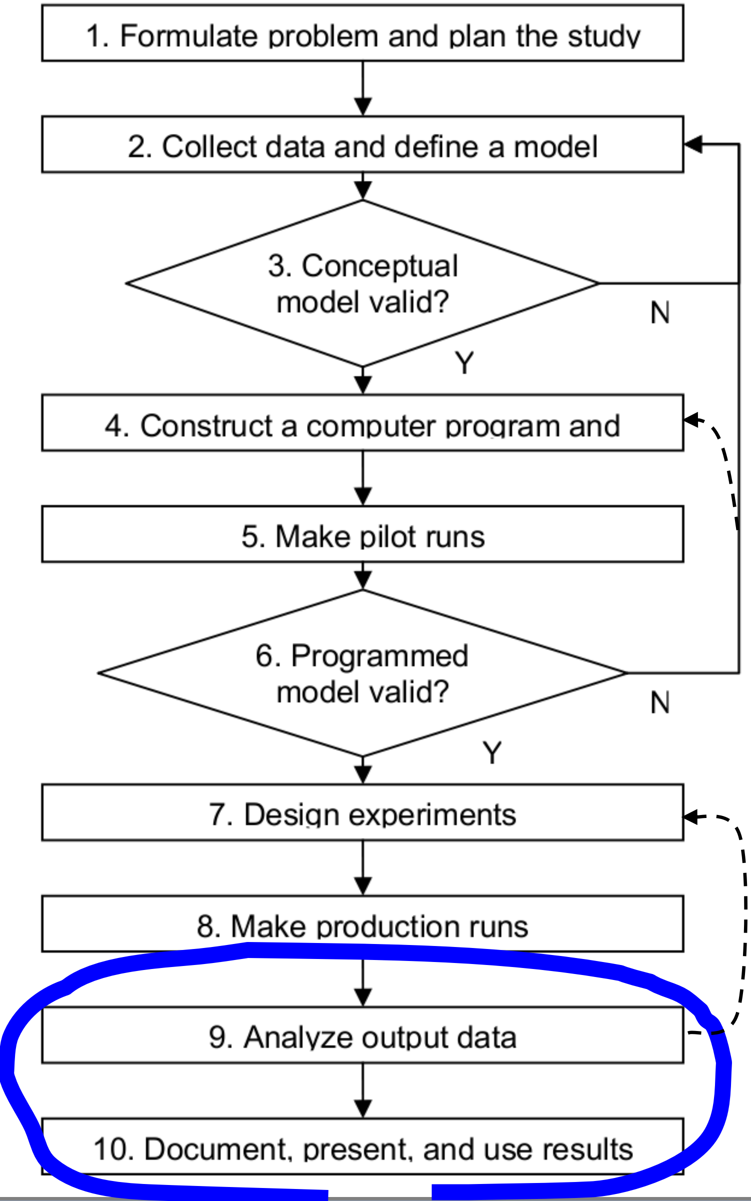
How simulation is used—typical workflow (5/6)



Remember the questions from step 1:

- What do I want to show?
- How can I show it?
- What output do I need?
- What input do I want to try out?
  - Usually infeasibly many possible input patterns
  - Selection is required
  - Experiment planning, factorial design
- Often an iterative process

How simulation is used—typical workflow (6/6)



- Analysis of simulation output
  - Numbers
  - Graphs
- Can the simulation be trusted?
  - Simplification could lead to unnatural effects
  - Random input could have induced anomal situations
  - Confidence intervals etc.
- Convincing presentation:
  - Describe model validation
  - Error estimation, confidence intervals
  - Don’t hide limitations