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Simulation and Modeling, CS-331

Chapter 1

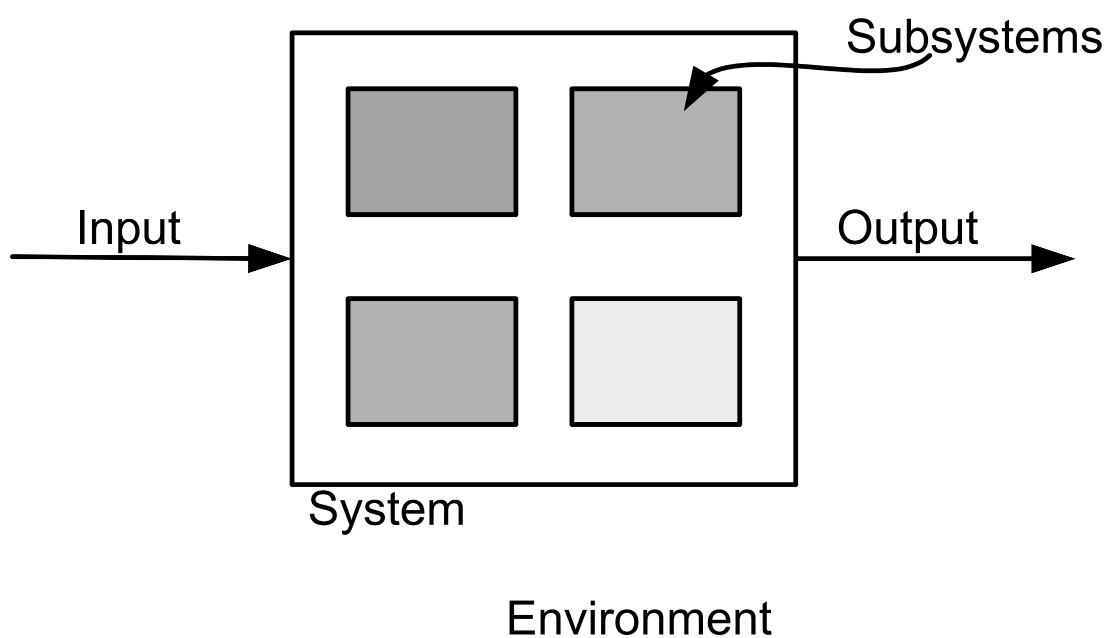
- System concepts
- System modeling
- Mathematical models: their nature and assumptions
- Calibration and validation

System

-Assembly of objects joined in some regular interaction or interdependence.

-A system exists and operates in time and space.

-bounded inside system boundary



System Concepts - terms

State

A variable characterizing an attribute in the system such as no. of jobs waiting for processing.

Activity/event

An occurrence at a point in time which may change the state of the system

- Endogenous – activities occurring within the system
- Exogenous – activities occurring in the environment that affect the system

Entity

An object that passes through the system

e.g. cars

Entity is associated with an event

System Concepts - terms

Queue

- physical queue of entity/task
- any place where entities are waiting for something to happen for any reason

Creating

Causing an arrival of a new entity to the system at some point in time

Scheduling

The act of assigning a new future event to an existing entity

Random variable

A random variable is a quantity that is uncertain, such as inter-arrival time between two incoming flights or number of defective parts in a shipment

System Concepts - terms

Random variate

A random variate is an artificially generated random variable.

Distribution

A distribution is the mathematical law which governs the probabilistic features of a random variable.

System Concepts

System environment

The changes occurring outside the system that affect the system is system environment

Defining a ***system boundary*** is an important step

- if small system boundary, may not include necessary components
- if larger boundary, high degree of error propagation, management difficulties etc.

Closed system – that is not affected by the exogenous events. Practically, unrealizable

Open system – affected by the exogenous events

System - A Simple Example

Building a simulation of a gas station with a single pump served by a single service man. Assume that arrival of cars as well their service times are random.

At first identify the

- states: number of cars waiting for service and number of cars served at any moment
- events: arrival of cars, start of service, end of service
- entities: these are the cars
- queue: the queue of cars in front of the pump, waiting for service
- random realizations: inter-arrival times, service times
- distributions: we shall assume exponential distributions for both the inter-arrival time and service time.

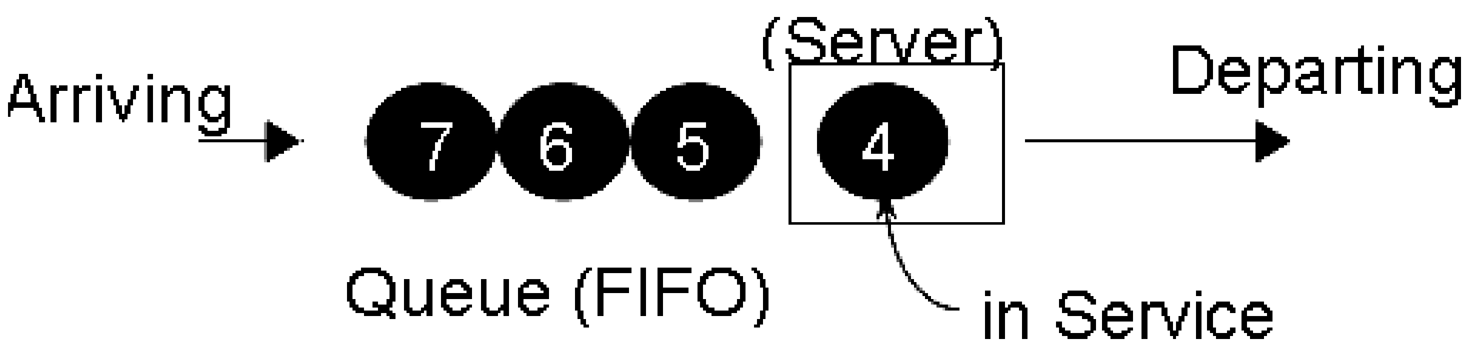
System - A Simple Example

Let's represent the system as;

1. Upon the entity arrival event, create next arrival
2. If the server is free, send entity for start of service.
3. Otherwise put it on the queue.
4. At event of service start: Server becomes occupied. Schedule end of service for this entity.
5. At event of service end: Server becomes free. If any entities waiting in queue: remove first entity from the queue; send it for start of service.

Here, we must consider some initial conditions for example, the creation of the first arrival.

System - A Simple Example



Stochastic activities

If the output of an activity is determined by the inputs, it is said to be ***deterministic***.

But if the output of an activity varies then it is known as ***stochastic activity***. Such random occurrence of activity itself constitutes part of the environment.

Truly stochastic – no known explanation for the activities randomness

Stochastic activities - classification

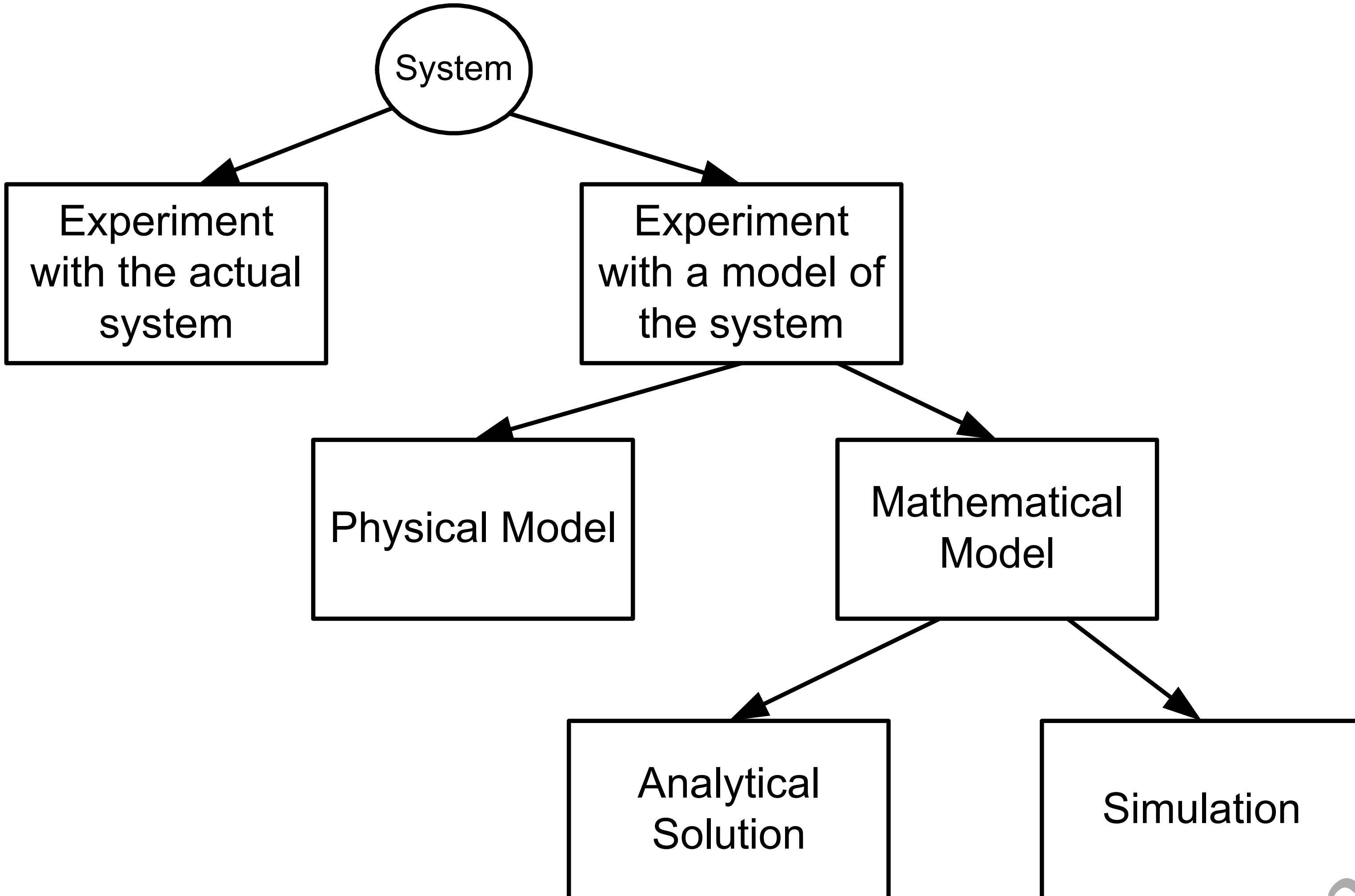
		Change in the Sate of the System	
		Continuous	Discrete
Time	Continuous	Level of water behind dam	Number of customers in the bank
	Discrete	Weekdays’ range of temperature	Sales at the end of the day

Types of Systems

Discrete – system for which the state variables change instantaneously at separated points in time

Continuous – system for which the state variables change continuously with respect to time

System Study



Types of Systems

- Experiment with actual system vs. Experiment a model of the system
  - If possible and cost effective, only then do the actual system experiment. Most of the systems are rarely feasible. E.g. test of bridge
- Physical model vs. Mathematical model
  - Physical models – iconic model (like small samples). They do not represent the internal properties.
  - Whereas the mathematical model represents a system in terms of logical and quantitative relationships that are manipulated and changed to see how the model reacts.

Types of Systems

If model is simple enough, use traditional mathematical analysis … get exact results, lots of insight into model

Mathematical Analysis includes;

- Queuing theory
- Differential equations
- Linear programming

Types of Systems

Analytical solution vs. simulation

How the mathematical model can be used to answer question of interest about the system. If the model is simple enough, can be studied analytically.

e.g. d = rt. If we know d and r, then we can find t.

But, situations might come in which the mathematical model is highly complex so that analytical study is not sufficient. In such case, simulation is used.

Simulation

- Broadly interpreted, computer simulation refers to methods for studying a wide variety of models of systems
  - Numerically evaluate on a computer
  - Use software to imitate the system's operations and characteristics, often over time
- Can be used to study simple models but should not use it if an analytical solution is available
- Real power of simulation is in studying complex models
- Simulation can tolerate complex models

Simulation - Advantages

- Flexibility to model things as they are (even if messy and complicated)
- Allows uncertainty, non-stationarity in modeling
  - Danger of ignoring system variability
  - Model validity
  - Advances in computing/cost ratios
- Estimated that 75% of computing power is used for various kinds of simulations
- Dedicated machines
- Far easier to use (GUIs)
- Statistical design & analysis capabilities

Simulation - Problems

- Don’t get exact answers, only approximations, estimates
  - Also true of many other modern methods
  - Can bound errors by machine round-off
- Get random output (RIRO) from stochastic simulations
  - Statistical design, analysis of simulation experiments
  - Exploit: noise control, replicability, sequential sampling, variance-reduction techniques
  - Catch: ***"standard" statistical methods seldom work***

Kinds of Simulation

Static vs. Dynamic

Does time have a role in the model?

Continuous-change vs. Discrete-change

Can the “state” change continuously or only at discrete points in time?

Deterministic vs. Stochastic

Is everything for sure or is there uncertainty?

Most operational models:

Dynamic, Discrete-change, Stochastic

Using Computers to Simulate

Simulation languages

- GPSS, SIMSCRIPT, SLAM, SIMAN
- Popular, still in use
- Learning curve for features, effective use, syntax

High-level simulators

- Very easy, graphical interface
- Domain-restricted (manufacturing, communications)
- Limited flexibility — model validity?

System Analysis

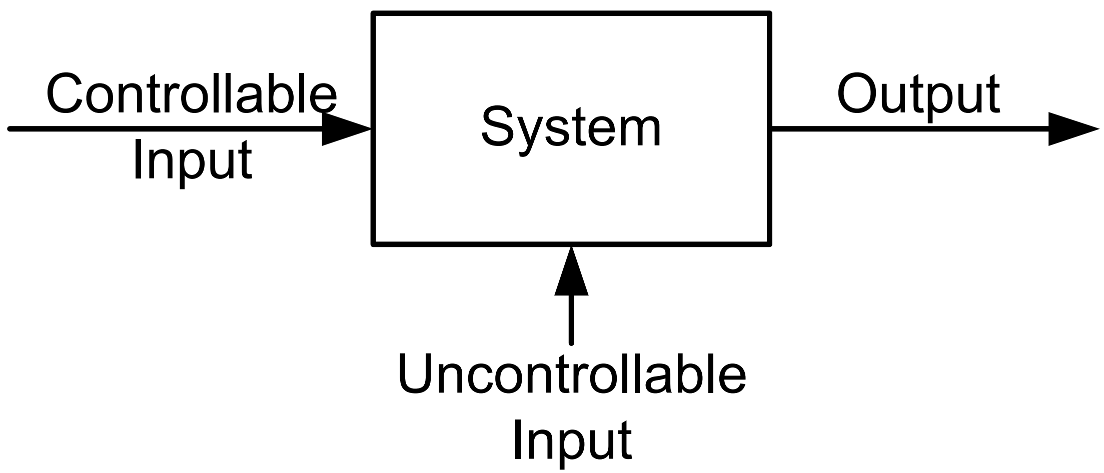
- Descriptive Analysis
- Prescriptive Analysis
- Post-prescriptive Analysis

System Analysis

Descriptive Analysis includes:

1. Problem Identification & Formulation

Identify controllable and uncontrollable inputs.



Identify constraints on the decision variables. Define measure of system performance and an objective function. Develop a preliminary model structure to interrelate the inputs and the measure of performance.

System Analysis

2. Data Collection and Analysis

   Regardless of the method used to collect the data, the decision of how much to collect is a trade-off between cost and accuracy.

3. Computer Simulation Model Development

   Acquiring sufficient understanding of the system to develop an appropriate conceptual, logical and then simulation model is one of the most difficult tasks in simulation analysis.

4. Model Validation, Verification, and Calibration

Verification focuses on the internal consistency of a model

Validation is concerned with the correspondence between the model and the reality.

The term validation is applied to those processes which seek to determine whether or not a simulation is correct with respect to the "real" system. More prosaically, validation is concerned with the question "Are we building the right system?".

Verification, on the other hand, seeks to answer the question "Are we building the system right?" Verification checks that the implementation of the simulation model (program) corresponds to the model. Validation checks that the model corresponds to reality.

System Analysis

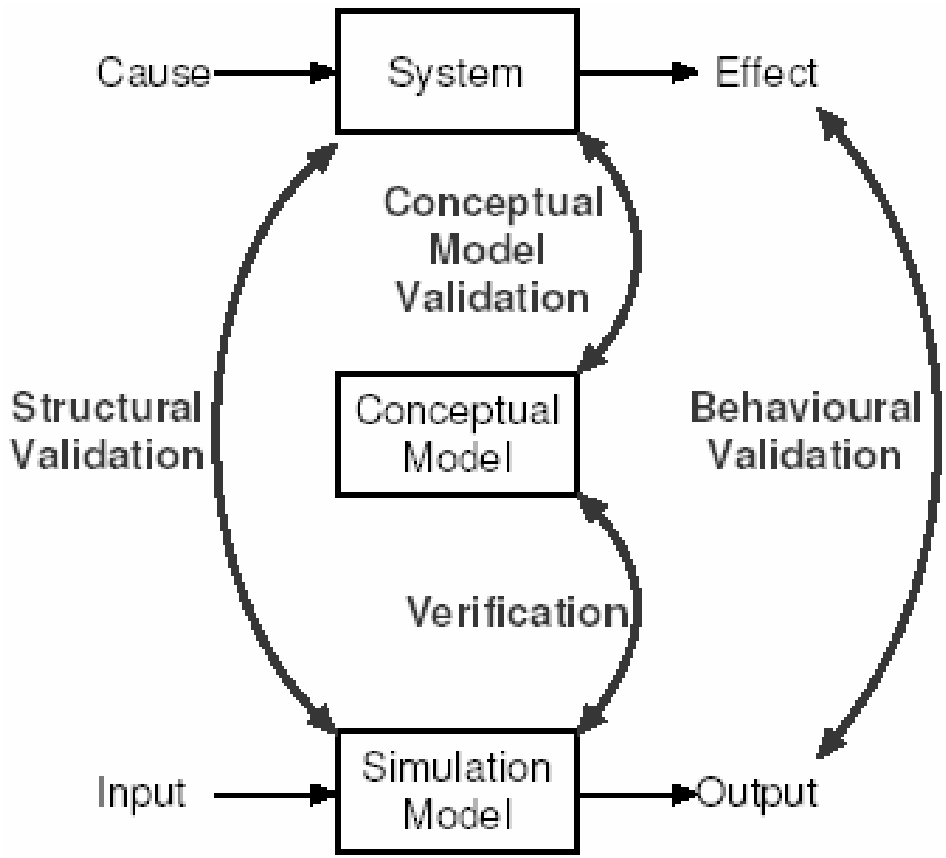
Validation

The process of comparing the model's output with the behavior of the phenomenon. In other words: comparing model execution to reality (physical or otherwise)

Verification

The process of comparing the computer code with the model to ensure that the code is a correct implementation of the model.

System Analysis



Verification and validation activities

Validation & Verification – 3 approaches

- The development team make the decision as to whether the model is valid. This is a subjective decision based on the results of the various tests and evaluations conducted as part of the model development process.
- “independent verification and validation” (IV&V), uses a third (independent) party to decide whether the model is valid (extremely costly)
- determining whether a model is valid is to use a scoring model. Scores (or weights) are determined subjectively when conducting various aspects of the validation process and then combined to determine category scores and an overall score for the simulation model. (infrequently used)

Validation techniques

Animation

The model's operational behavior is displayed graphically as the model moves through time.

Comparison to Other Models

Various results of the simulation model being validated are compared to results of other (valid) models.

Degenerate Tests

The degeneracy of the model's behavior is tested by appropriate selection of values of the input and internal parameters.

Event Validity

The "events" of occurrences of the simulation model are compared to those of the real system to determine if they are similar.

Validation techniques

Extreme Condition Tests

The model structure and output should be plausible for any extreme and unlikely combination of levels of factors in the system.

Face Validity

"Face validity" is asking people knowledgeable about the system whether the model and/or its behavior are reasonable.

Fixed Values

Fixed values (e.g., constants) are used for various model input and internal variables and parameters. This should allow the checking of model results against easily calculated values.

Validation techniques

Historical Data Validation

If historical data exist (or if data are collected on a system for building or testing the model), part of the data is used to build the model and the remaining data are used to determine (test) whether the model behaves as the system does.

Internal Validity

Several replications (runs) of a stochastic model are made to determine the amount of (internal) stochastic variability in the model.

Turing Tests

People who are knowledgeable about the operations of a system are asked if they can discriminate between system and model outputs

Validation techniques

Multistage Validation

consists of

(1) developing the model's assumptions on theory, observations, general knowledge, and function,

(2) validating the model's assumptions where possible by empirically testing them,

(3) and comparing (testing) the input-output relationships of the model to the real system.

and many more…

Validation and verification - 4 musts

Data Validity

Data are needed for three purposes: for building the conceptual model, for validating the model, and for performing experiments with the validated model. In model validation we are concerned only with the first two types of data.

Conceptual model validity

Conceptual model validity is determining that

(1)the theories and assumptions underlying the conceptual model are correct, and

(2) the model representation of the problem entity and the model's structure, logic, and mathematical and causal relationships are "reasonable" for the intended purpose of the model

Validation and verification - 4 musts

Model verification

Computerized model verification ensures that the computer programming and implementation of the conceptual model are correct.

Operational validity

Operational validity is concerned with determining that the model's output behavior has the accuracy required for the model's intended purpose over the domain of its intended applicability. This is where most of the validation testing and evaluation takes place.

Documentation - required and very important.

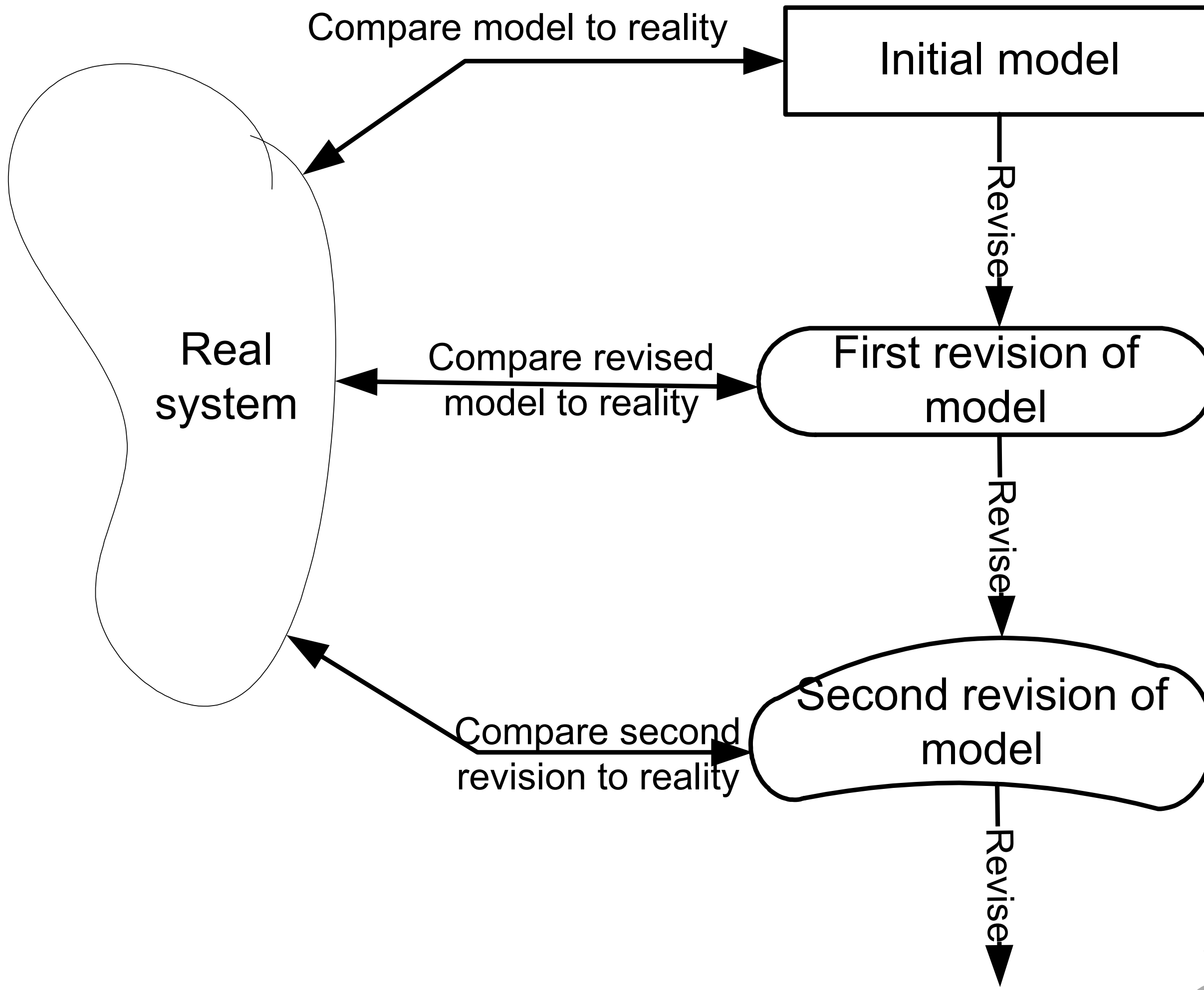
Calibration

It is an iterative process of comparing the model to the real system, making adjustments or major changes to the model, comparing the revised model to reality, making additional adjustments, comparing again and so on.

Checks that the data generated by the simulation matches real (observed) data.

The process of parameter estimation for a model. Calibration is a tweaking/tuning of existing parameters and usually does not involve the introduction of new ones, changing the model structure. In the context of optimization, calibration is an optimization procedure involved in system identification or during experimental design.

Calibration – verification and validation relationship



5. Input and Output Analysis

Discrete-event simulation models typically have stochastic components that mimic the probabilistic nature of the system under consideration.

Successful input modeling requires a close match between the input model and the true underlying probabilistic mechanism associated with the system.

The input data analysis is to model an element (e.g., arrival process, service times) in a discrete-event simulation given a data set collected on the element of interest.

This stage performs intensive error checking on the input data, including external, policy, random and deterministic variables. System simulation experiment is to learn about its behavior.

System Analysis

6. Performance Evaluation.

System Analysis

Prescriptive Analysis

Optimization or Goal Seeking

Traditional optimization techniques require gradient estimation. As with sensitivity analysis, the current approach for optimization requires intensive simulation to construct an approximate surface response function.

System Analysis

Post-prescriptive Analysis

1. Sensitivity: Users must be provided with affordable techniques for sensitivity analysis if they are to understand which relationships are meaningful in complicated models.

2. What-If Analysis: The `what-if' analysis is at the very heart of simulation models

Report Generating

Report generation is a critical link in the communication process between the model and the end user.

System Modeling

Model – body of information about a system gathered for the purpose of studying the system. a model is a representation of the construction and working of some system of interest. A model is similar to but simpler than the system it represents. One purpose of a model is to enable the analyst to predict the effect of changes to the system.

A model is a simplified representation of a system at some particular point in time or space intended to promote understanding of the real system.

Abstraction also applies

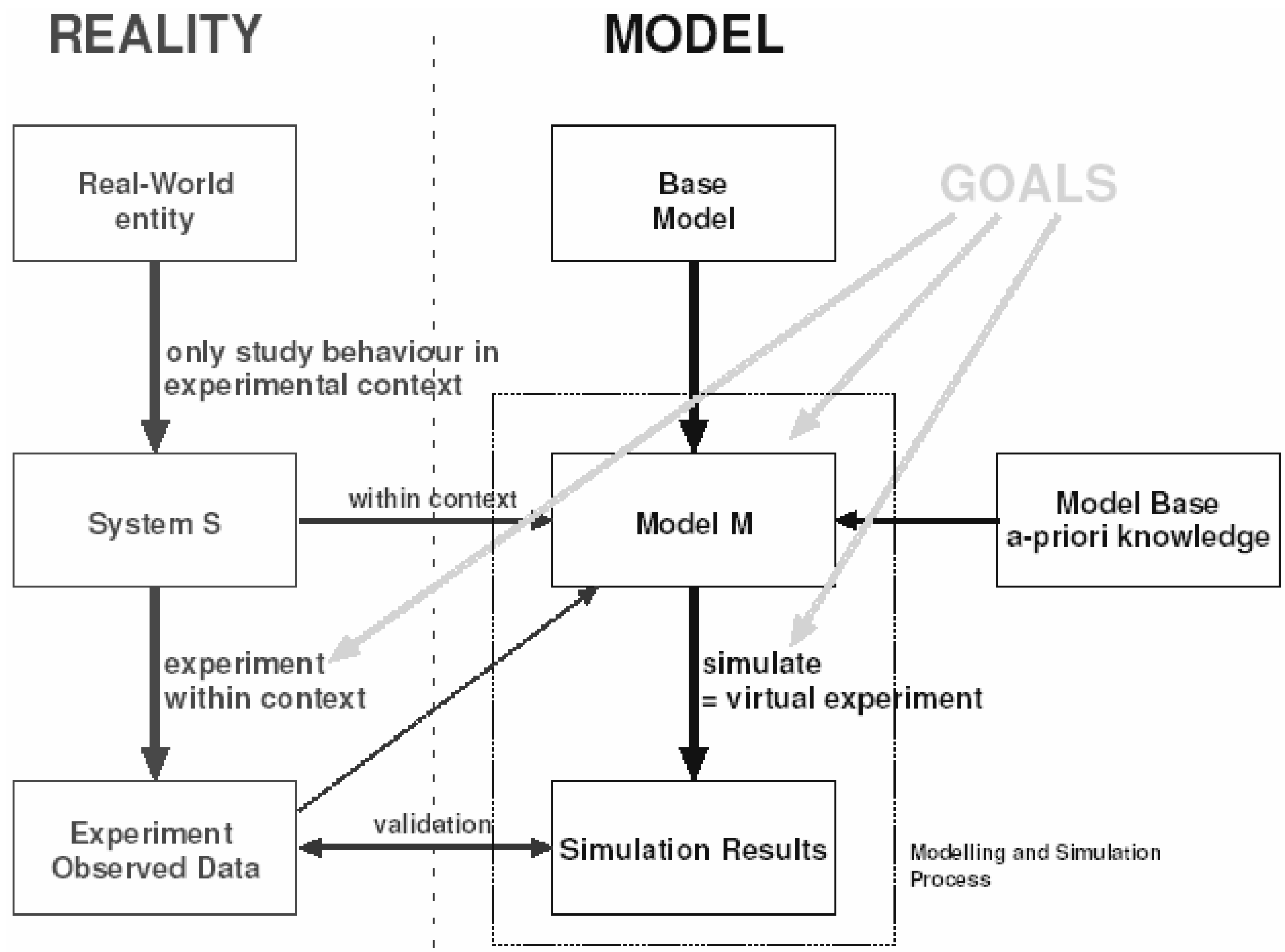
System Modeling

The model should be sufficiently detailed to permit valid conclusions to be drawn about the real system.

Modeling is the process of producing a model; On the one hand, a model should be a close approximation to the real system and incorporate most of its salient/relevant features. On the other hand, it should not be so complex that it is impossible to understand and experiment with it.

A good model is a judicious tradeoff between realism and simplicity.

System Modeling



Modelling and Simulation

System Modeling

An important issue in modeling is model validity. Model validation techniques include simulating the model under known input conditions and comparing model output with system output.

Generally, a model intended for a simulation study is a mathematical model developed with the help of simulation software. Mathematical model classifications include ***deterministic*** (input and output variables are fixed values) or ***stochastic*** (at least one of the input or output variables is probabilistic); ***static*** (time is not taken into account) or ***dynamic*** (time-varying interactions among variables are taken into account). Typically, simulation models are stochastic and dynamic.

More on simulation

A simulation of a system is the operation of a model of the system. The model can be reconfigured and experimented with; usually, this is impossible, too expensive or impractical to do in the system it represents. The operation of the model can be studied, and hence, properties concerning the behavior of the actual system or its subsystem can be inferred. In its broadest sense, simulation is a tool to evaluate the performance of a system, existing or proposed, under different configurations of interest and over long periods of real time.

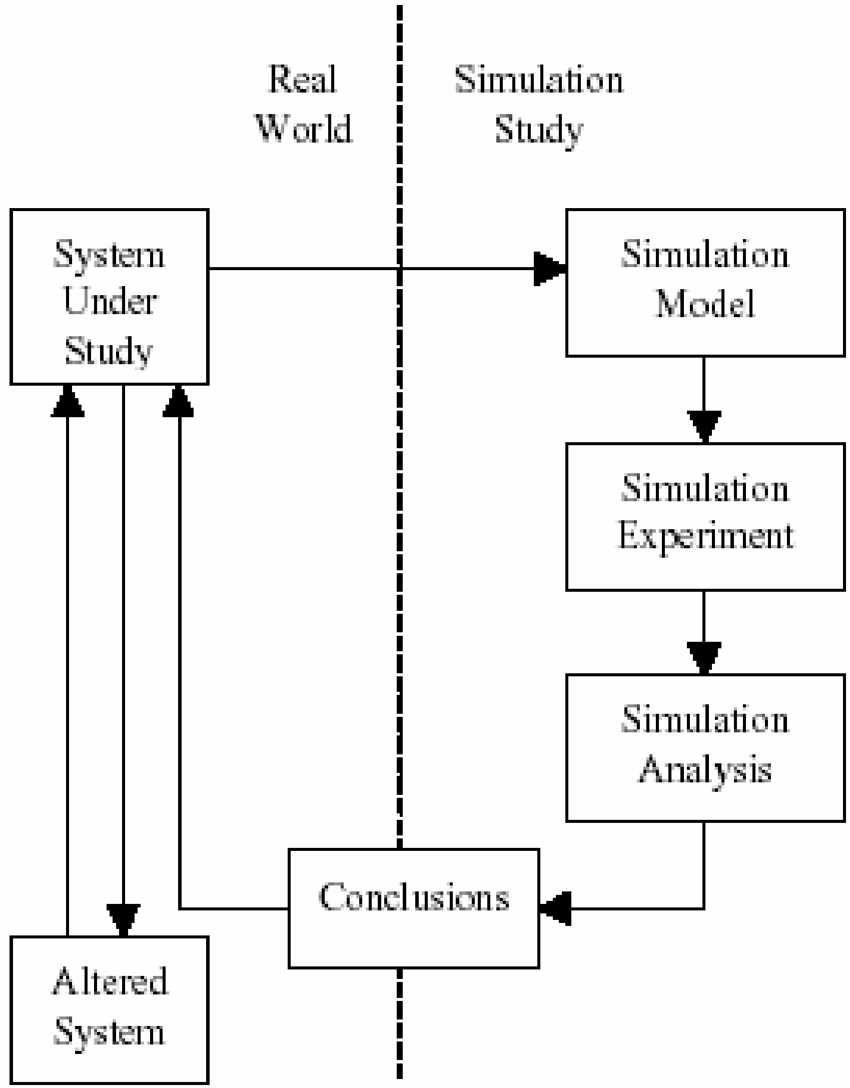
A simulation is the manipulation of a model in such a way that it operates on time or space to compress it, thus enabling one to perceive the interactions that would not otherwise be apparent because of their separation in time or space.

More on simulation

System Simulation is the mimicking of the operation of a real system, such as the day-to-day operation of a bank, or the value of a stock portfolio over a time period, or the running of an assembly line in a factory, or the staff assignment of a hospital or a security company, in a computer.

Simulation is used before an existing system is altered or a new system built, to reduce the chances of failure to meet specifications, to eliminate unforeseen bottlenecks, to prevent under or over-utilization of resources, and to optimize system performance.

Simulation - study



Simulation Model

The steps involved in developing a simulation model, designing a simulation experiment, and performing simulation analysis are:

How to develop a simulation model

Step 1. Identify the problem.

Step 2. Formulate the problem.

Step 3. Collect and process real system data.

Step 4. Formulate and develop a model.

Step 5. Validate the model.

Step 6. Document model for future use.