Simulation and Modeling

By

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Simulation and Modeling

L-3, T-1, P-1.5

References:

1. G. Gorden, " System simulation"
2. Jerry Banks, John S. Carson, II Barry L. Nelson , David M. Nocol, "Discrete Event system simulation"

Introduction to Modeling and simulation

System

- The term system is derive from the Greek word systema, which means an organized relationship among functioning units or components.
- System exists because it is designed to achieve one or more objectives.
- We come into daily contact with the transportation system, the telephone system, the accounting system, the production system, and for two decades the computer system.
- There are more than a hundred definitions of the word system, but most seem to have a common thread that suggests that a system is an orderly grouping of interdependent components linked together according to a plan to achieve a specific objective.

System

- The study of the systems concepts, then, has three basic implications:

1. A system must be designed to achieve a predetermined objective
2. Interrelationships and interdependence must exist among the components
3. The objectives of the organization as a whole have a higher priority than the objectives of its subsystems.

System

- Klir* gives a collection of 24 definitions one such definition is “ A system is a collection of components wherein individual components are constrained by connecting interrelationships such that the system as a whole fulfills some specific functions in response to varying demands”

*Klir, George J. , an approach to general systems theory, New York: Van Nostrand Reinhold Co, 1969

Some keywords to know …

- System
  - It is a collection of entities that act and interact together toward the accomplishment of some logical end (computer, network, communication systems, queuing systems etc.)
- Simulation
  - It is an experiment in a computer where the real system is replaced by the execution of the program
  - It is a program that mimics (imitate) the behaviour of the real system

Some keywords to know …

- Model
  - It is a simplification of the reality
  - A (usually miniature) representation of something; an example for imitation or emulation
  - A model can be Analytical (Queuing Theory) or by Simulation.

- Performance evaluation (of a system)
  - It means quantifying the service delivered by the System
  - Experimental, Analytical, or by simulation

Introduction

- **System**

· A system exists and operates in time and space.

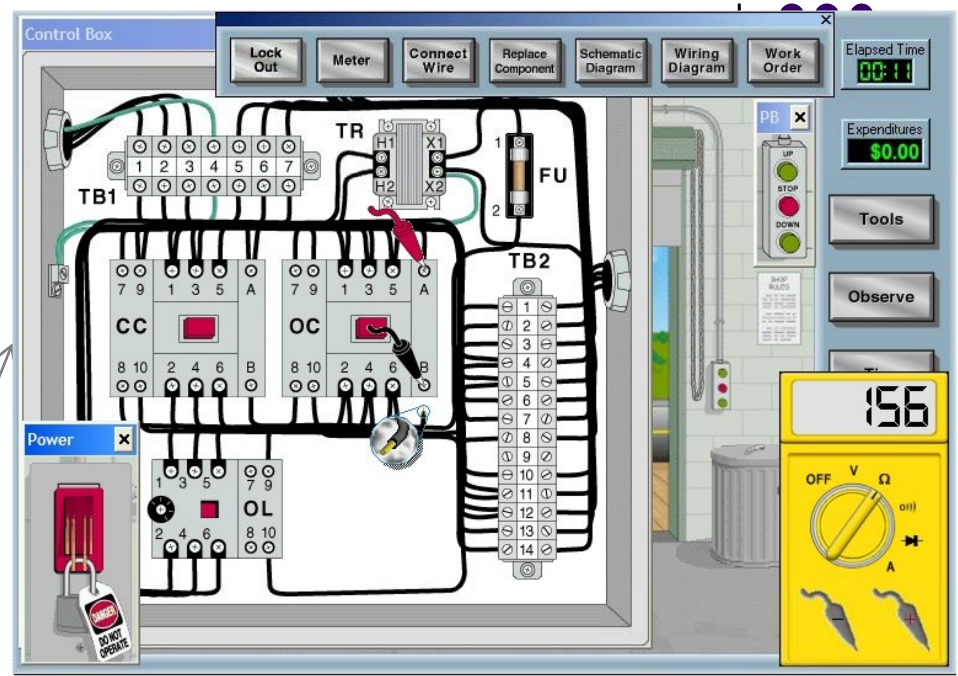
- **Model**

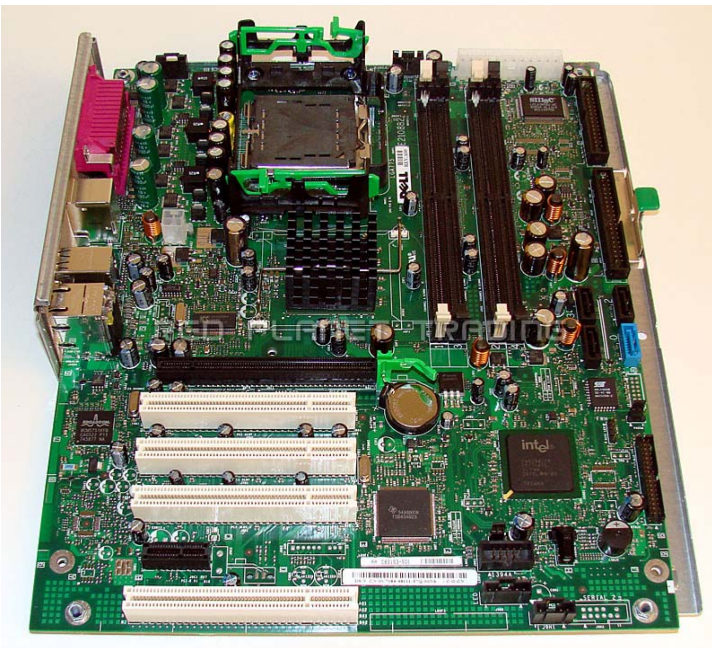
· A model is a simplified representation of a system at some particular point in time or space intended to promote understanding of the real system.

- **Simulation**

· 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.

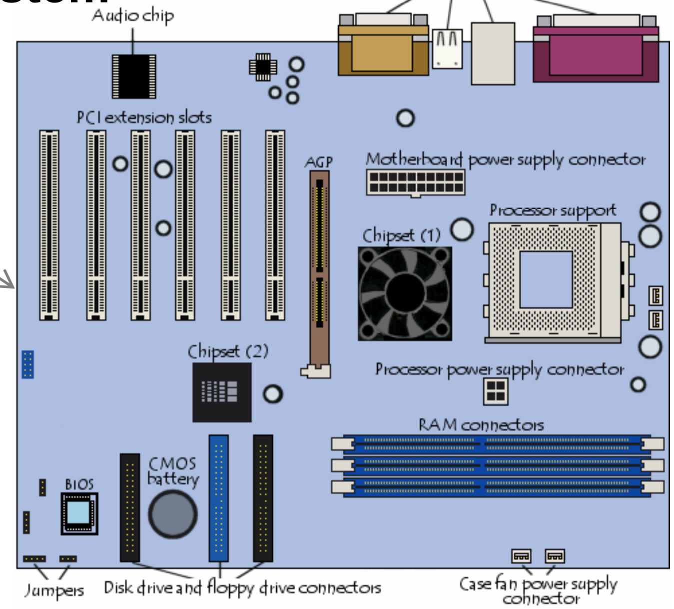
Examples



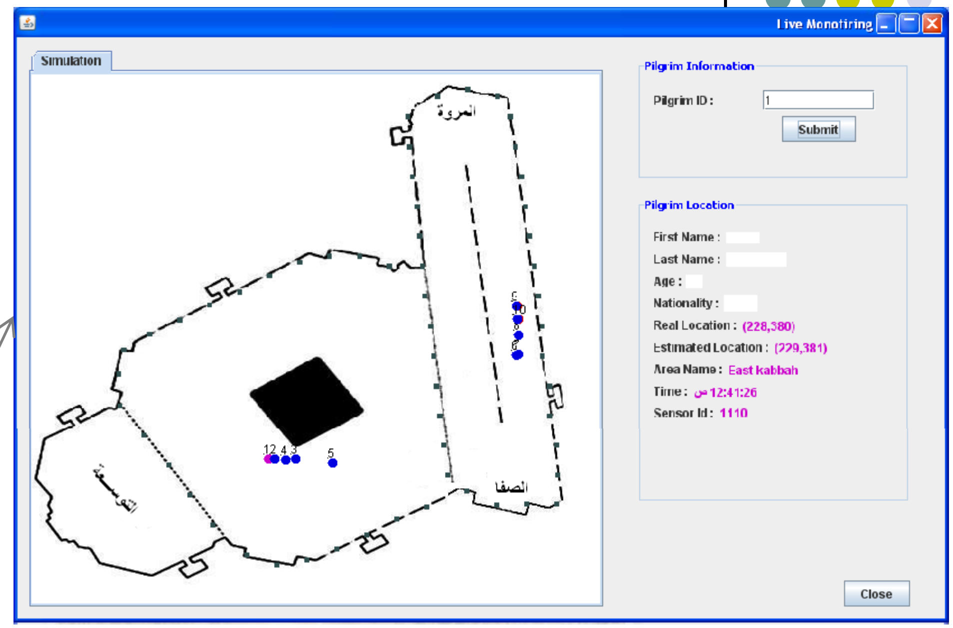


Real System (Motherboard)

Models of the system



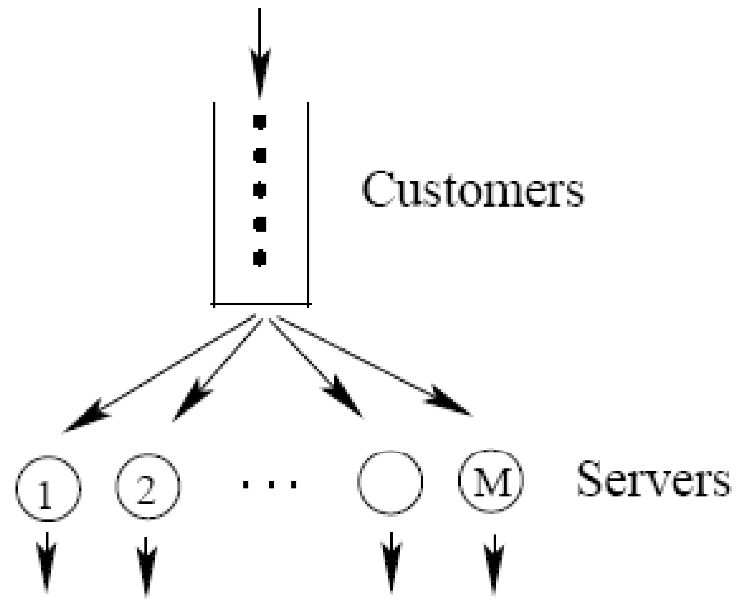
Examples

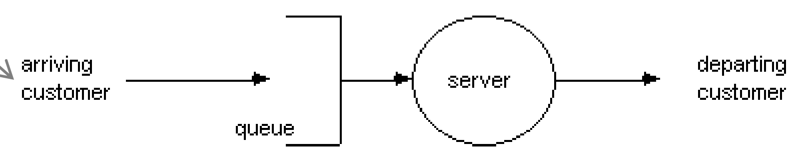


Simulation models of the system

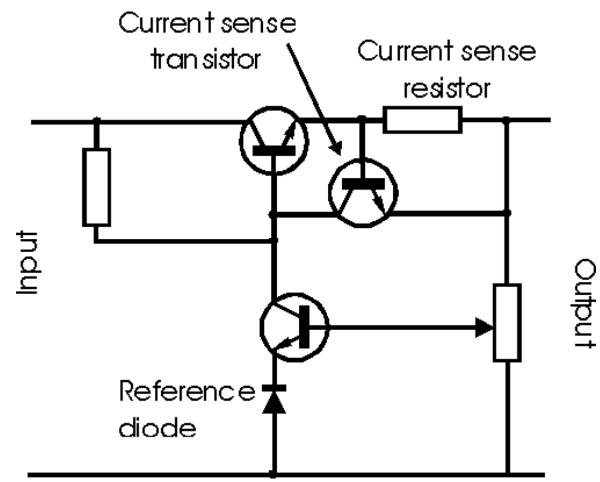
Examples

Models of the System





Example

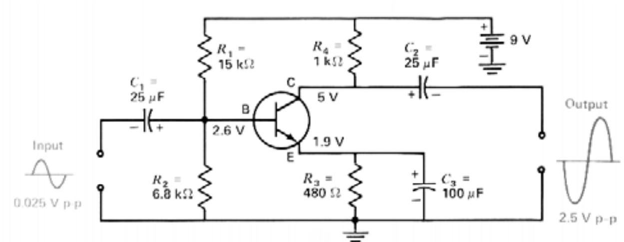


Models of the System

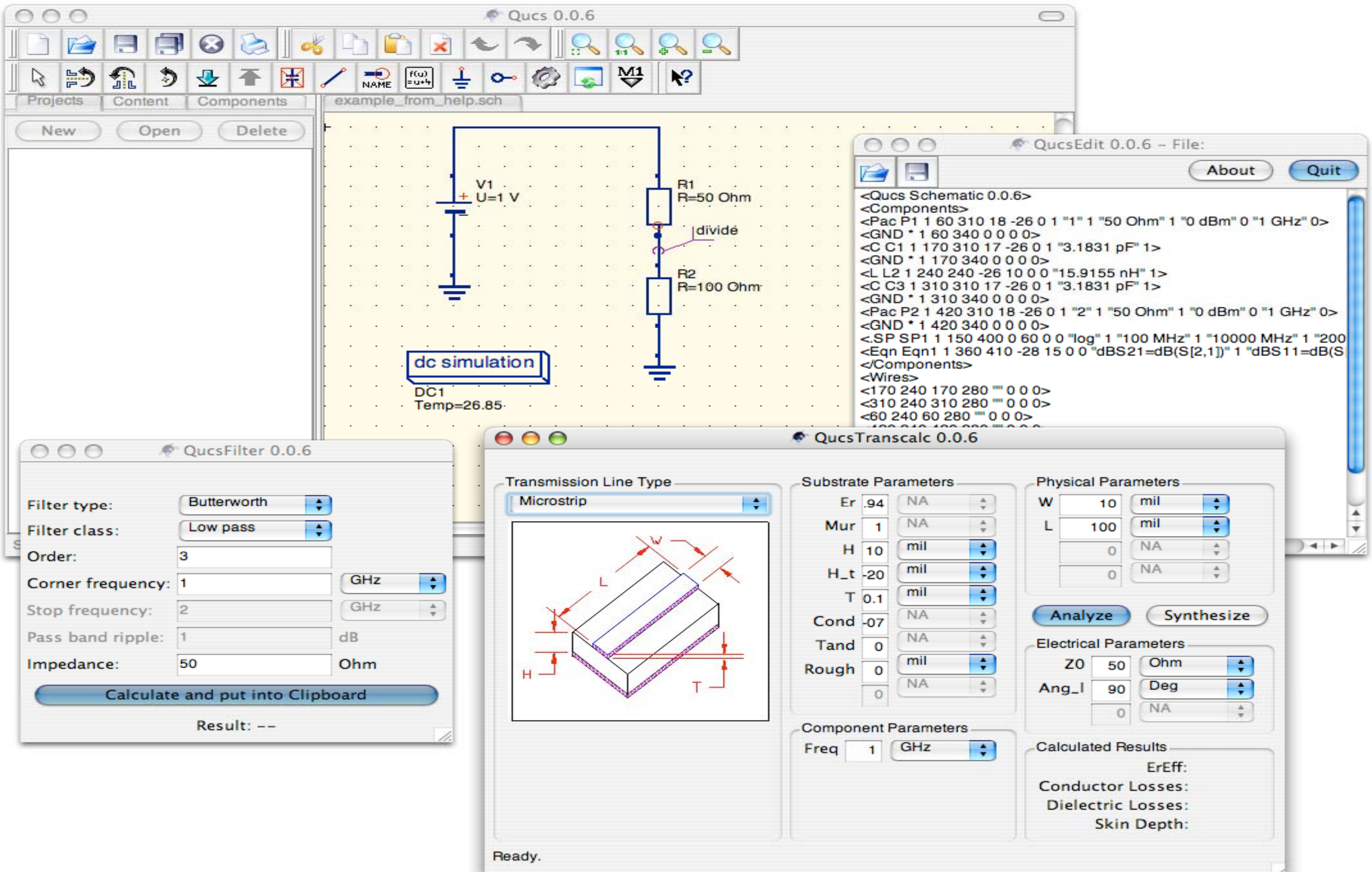
$$I = \frac{E}{R} \qquad E = IR$$

$$R = \frac{E}{I} \qquad P = EI$$

$$hfe = \frac{I_c}{I_b} \qquad I_b = \frac{I_c}{hfe}$$



Examples



Circuit Simulator

Concept of Simulation

- Simulation is the representation of a real life system by another system, which depicts the important characteristics of the real system and allows experimentation on it.
- In another word simulation is an imitation of the reality.
- Simulation has long been used by the researchers, analysts, designers and other professionals in the physical and non-physical experimentations and investigations.

Why Simulate?

- It may be too difficult, hazardous, or expensive to observe a real, operational system
- Parts of the system may not be observable (e.g., internals of a silicon chip or biological system)

Uses of simulations

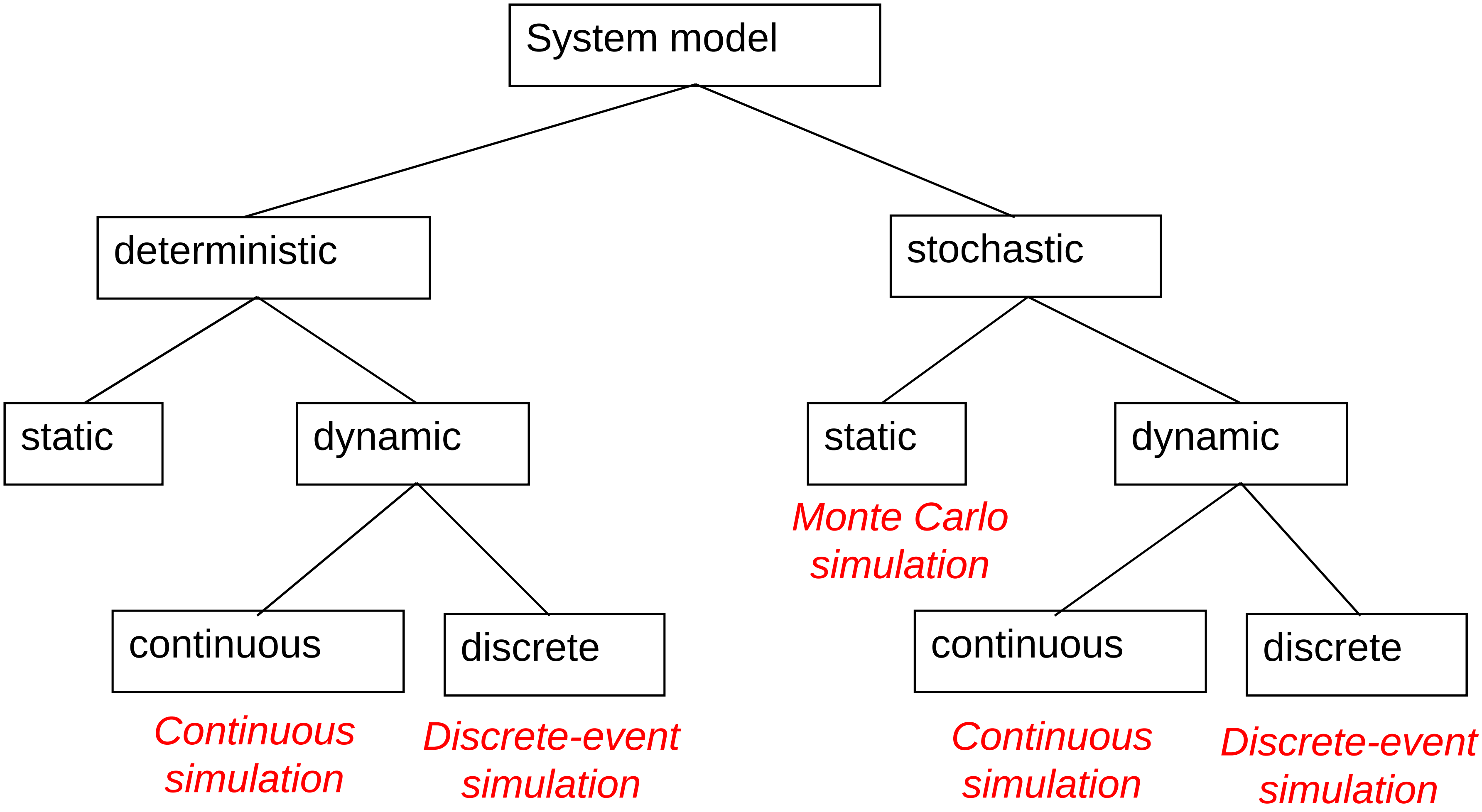
- Analyze systems before they are built
  - Reduce number of design mistakes
  - Optimize design
- Analyze operational systems
- Create virtual environments for training, entertainment

When to use Simulation

- Over the years tremendous developments have taken place in computing capabilities and in special purpose simulation languages, and in simulation methodologies.
- The use of simulation techniques has also become widespread.
- Following are some of the purposes for which simulation may be used.

1. Simulation is very useful for experiments with the internal interactions of a complex system, or of a subsystem within a complex system.
2. Simulation can be employed to experiment with new designs and policies, before implementing
3. Simulation can be used to verify the results obtained by analytical methods and reinforce the analytical techniques.
4. Simulation is very useful in determining the influence of changes in input variables on the output of the system.
5. Simulation helps in suggesting modifications in the system under investigation for its optimal performance.

Types of Simulation Models



Types of Simulation Models

- Simulation models can be classified as being static or dynamic, deterministic or stochastic and discrete or continuous.
- A static simulation model represents a system, which does not change with time or represents the system at a particular point in time.
- Dynamic simulation models represent systems as they change over time.
- Deterministic models have a known set of inputs, which result into unique set of outputs.
- In stochastic model, there are one or more random input variables, which lead to random outputs.
- System in which the state of the system changes continuously with time are called continuous systems while the systems in which the state changes abruptly at discrete points in time called discrete systems.

Stochastic vs. Deterministic

- Stochastic simulation: a simulation that contains random (probabilistic) elements, e.g.,
  - Examples
    - Inter-arrival time or service time of customers at a restaurant or store
    - Amount of time required to service a customer
  - Output is a random quantity (multiple runs required analyze output)
- Deterministic simulation: a simulation containing no random elements
  - Examples
    - Simulation of a digital circuit
    - Simulation of a chemical reaction based on differential equations
  - Output is deterministic for a given set of inputs

Static vs. Dynamic Models

- Static models
  - Model where time is not a significant variable
  - Examples
    - Determine the probability of a winning solitaire hand
  - Static + stochastic = Monte Carlo simulation
    - Statistical sampling to develop approximate solutions to numerical problems
- Dynamic models
  - Model focusing on the evolution of the system under investigation over time
  - Main focus of this course

Continuous vs. Discrete

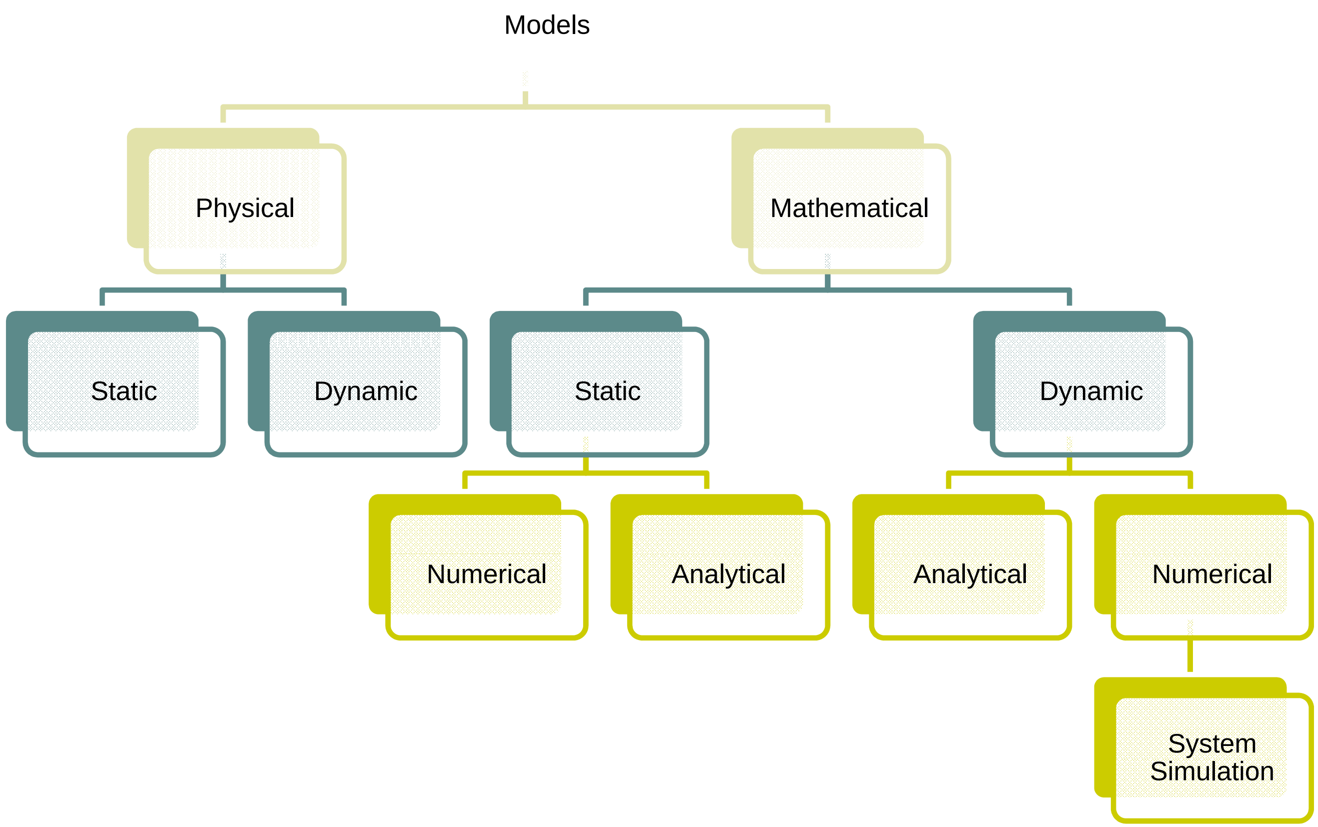
- Discrete
  - State of the system is viewed as changing at discrete points in time
  - An event is associated with each state transition
    - Events contain time stamp
- Continuous
  - State of the system is viewed as changing continuously across time
  - System typically described by a set of differential equations

Types of Models

- Models used in system studies have been classified in many ways.
- The classification that will be used here are illustrated in the Figure 1.

. Types of models

- Figure 1.



Types of models

- Models will first be separated into physical models or mathematical models.
- Physical models are based on some analogy between such systems as mechanical and electrical or electrical and hydraulic.
- In a physical model of a system, the system attributes are represented by such measurements as a voltage or the position of a shaft.

Types of models

- The system activities are reflected in the physical laws that drive the model.
- Mathematical models use symbolic notation and mathematical equation to represent a system.
- The system attributes are represented by variables, and the activities are represented by mathematical functions that interrelate the variables.

Differences between static modeling and dynamic modeling

- The most notable difference between static and dynamic models of a system is that while a dynamic model refers to runtime model of the system, static model is the model of the system not during runtime.
- Another difference lies in the use of differential equations in dynamic model
- Dynamic models keep changing with reference to time whereas static models are at equilibrium of in a steady state.
- Static model is more structural than behavioral while dynamic model is a representation of the behavior of the static components of the system.

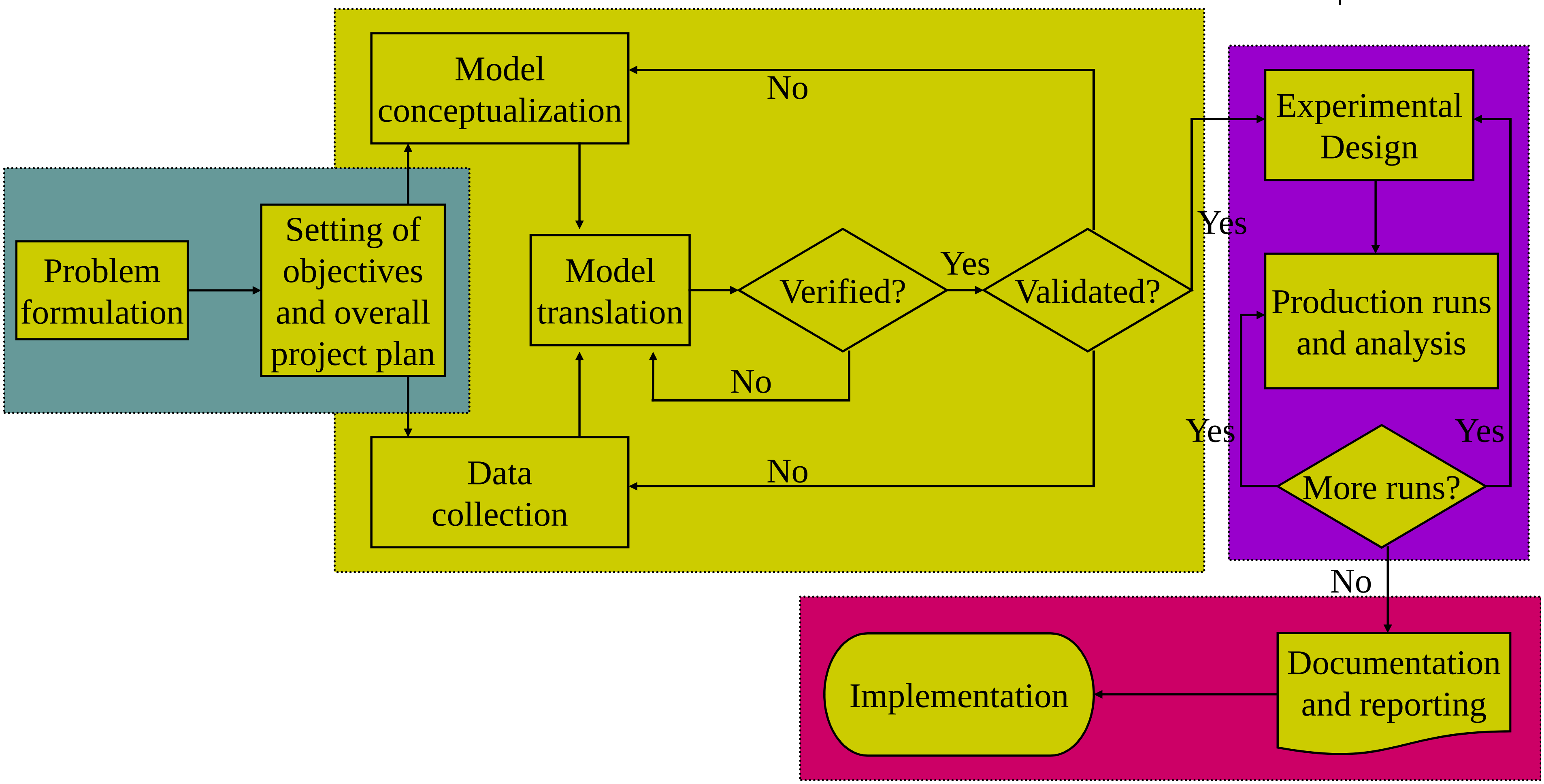
Differences between static modeling and dynamic modeling

- Static modeling includes class diagram and object diagrams and help in depicting static constituents of the system.
- Dynamic modeling on the other hand consists of sequence of operations, state changes, activities, interactions and memory.
- Static modeling is more rigid than dynamic modeling as it is a time independent view of a system.
- It cannot be changed in real time and this is why it is referred to as static modeling.
- Dynamic modeling is flexible as it can change with time as it shows what an object does with many possibilities that might arise in time.

Steps in simulation study

- Problem formation
- Model construction
- Data Collection
- Model programming
- Validation
- Design of experiment
- Simulation run and analysis
- Documentation
- Implementation

STEPS IN A SIMULATION STUDY



Phases In Simulation Study

This process is divide into four phases

- Phase1: Problem Formulation: This includes problem formulation step.
- Phase2:Model Building:This includes model construction, data collection, programming, and validation of model.
- Phase3: Running the Model: This includes experimental design, simulation runs and analysis of results.
- Phase4: Implementation: This includes documentation and implementation.

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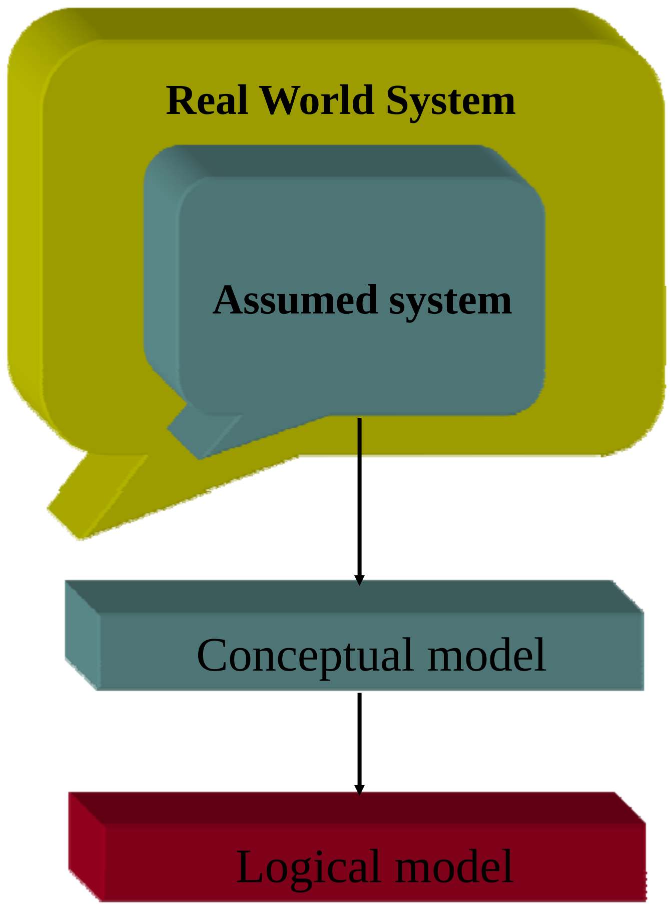
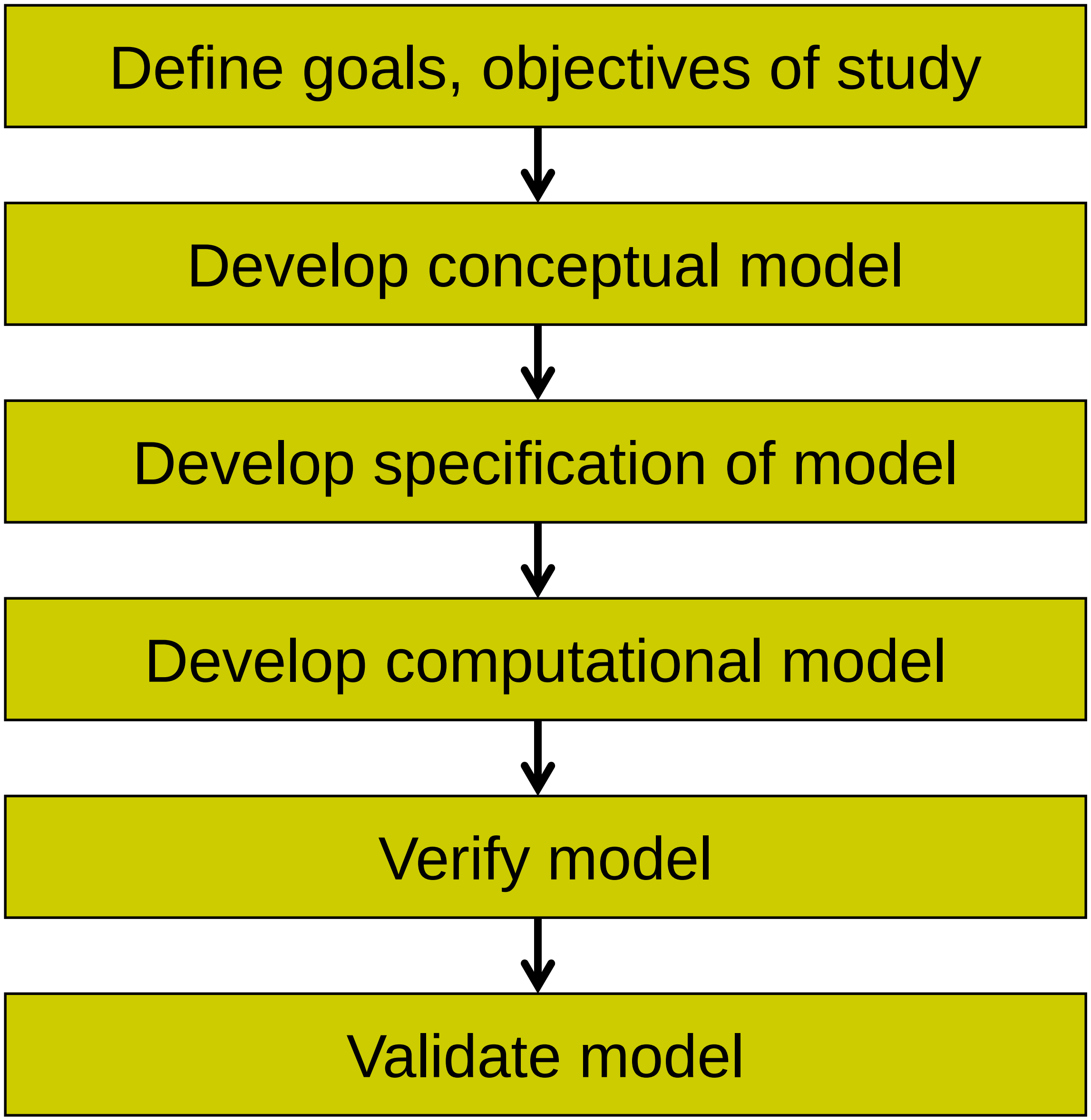
MODEL CONCEPTUALIZATION



Model Development Life Cycle



Fundamentally an iterative process

Develop Specification Model

- A more detailed specification of the model including more specifics
- Collect data to populate model
  - Traffic example: Road geometry, signal timing, expected traffic demand, driver behavior
  - Empirical data or probability distributions often used
- Development of algorithms necessary to include in the model
  - Example: Path planning for vehicles

Develop Computational Model

- Executable simulation model
- Software approach
  - General purpose programming language
  - Special purpose simulation language
  - Simulation package
  - Approach often depends on need for customization and economics
    - Where do you make your money?
    - Defense vs. commercial industry
- Other (non-functional) requirements
  - Performance
  - Interoperability with other models/tools/data

Verification

- Did I build the model right?
- Does the computational model match the specification model?
- Largely a software engineering activity (debugging)
- Not to be confused with correctness (see model validation)!

Validation

- Did I build the right model?
- Does the computational model match the actual (or envisioned) system?
- Typically, compare against
  - Measurements of actual system
  - An analytic (mathematical) model of the system
  - Another simulation model
- By necessity, always an incomplete activity!
  - Often can only validate portions of the model
  - If you can validate the simulation with 100% certainty, why build the simulation?

Advantages of Simulation

- Simulation helps to learn about real system, without having the system at all. For example the wind tunnel testing of the model of an aeroplane does not require a full sized plane.
- Many managerial decision making problems are too complex to be solved by mathematical programming.
- In many situations experimenting with actual system may not be possible at all. For example, it is not possible to conduct experiment, to study the behavior of a man on the surface of moon. In some other situations, even if experimentation is possible, it may be too costly and risky,
- In the real system, the changes we want to study may take place too slowly or too fast to be observed conveniently. Computer simulation can compress the performance of a system over years into a few minutes of computer running time.

Advantages of Simulation

- Conversely, in systems like nuclear reactors where millions of events take place per second, simulation can expand the time to required level.

- Through simulation, management can foresee the difficulties and bottlenecks, which may come up due to the introduction of new machines, equipments and processes. It thus eliminates the need of costly trial and error method of trying out the new concepts.

- Simulation being relatively free from mathematics can easily be understood by the operating personnel and non-technical managers. This helps in getting the proposed plans accepted and implemented.

- Simulation Models are comparatively flexible and can be modified to accommodate the changing environment to the real situation.

Advantages of Simulation

- Simulation technique is easier to use than the mathematical models, and can be used for wide range of situations.
- Extensive computer software packages are available, making it very convenient to use fairly sophisticated simulation models.
- Simulation is a very good tool of training and has advantageously been used for training the operating and managerial staff in the operation of complex system.Space engineers simulate space flights in laboratories to train the future astronauts for working in weightless environment.
- Airline pilots are given extensive training on flight simulators, before they are allowed to handle real planes.

Disadvantages of Simulation

- Model building requires special training. It is an art that is learned over time and through experience. Furthermore, if two models are constructed by two competent individuals, they may have similarities, but it is highly unlike that they will be the same.
- Simulation results may be difficult to interpret. Since most simulation outputs are essentially random variables, it may be hard to determine whether an observation is a result result of system interrelations or randomness.
- Simulation is used in some cases when an analytical solution is possible, or even preferable.
- Simulation modeling and analysis can be time consuming and expensive.

Areas of Applications

- Manufacturing: Design analysis and optimization of production system, materials management, capacity planning, layout planning, and performance evaluation, evaluation of process quality.

- Business: Market analysis, prediction of consumer behavior, and optimization of marketing strategy and logistics, comparative evaluation of marketing campaigns.

Areas of Applications

- Military:Testing of alternative combat strategies, air operations, sea operations, simulated war exercises, practicing ordinance effectiveness, inventory management.
- Healthcare applications; such as planning of health services, expected patient density, facilities requirement, hospital staffing , estimating the effectiveness of a health care program.

Areas of Applications

- **Communication Applications: Such as network design, and optimization, evaluating network reliability, manpower planning, sizing of message buffers.**

- **Computer Applications: Such as designing hardware configurations and operating system protocols, sharing networking. Client/Server system architecture**

- **Economic applications: such as portfolio management, forecasting impact of Govt. Policies and international market fluctuations on the economy. Budgeting and forecasting market fluctuations.**

Areas of Applications

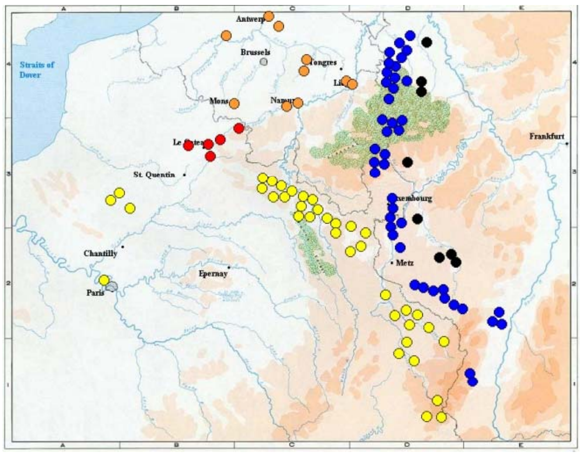
- **Transportation applications: Design and testing of alternative transportation policies, transportation networks-roads, railways, airways etc. Evaluation of timetables, traffic planning.**

- **Environment application: Solid waste management, performance evaluation of environmental programs, evaluation of pollution control systems.**

- **Biological applications; Such as population genetics and spread of epidemics.**

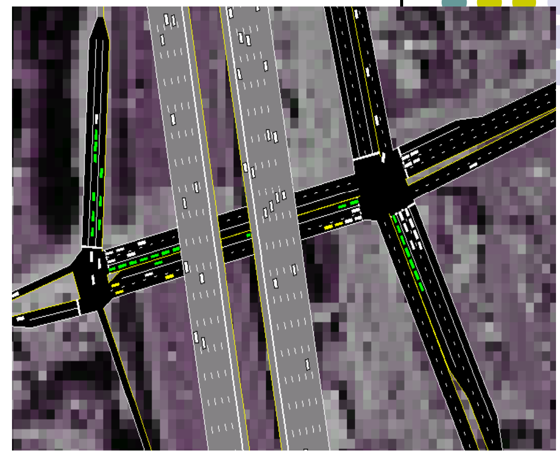
- **Business process Re-engineering: Integrating business process re-engineering with image –based work flow, using process modeling and analysis tool.**

A few more applications …



War gaming: test strategies; training

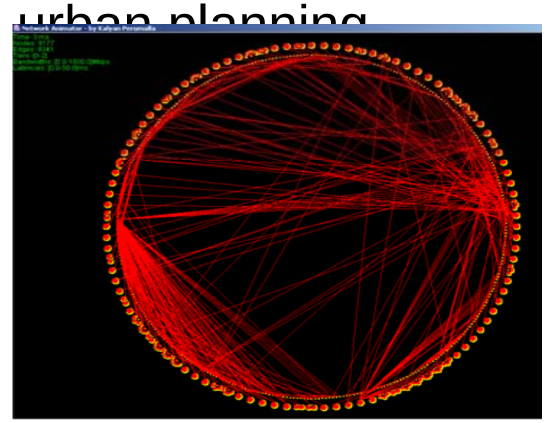
Flight Simulator



Transportation systems: improved operations; urban planning

Parallel computer systems: developing scalable software

Games



Computer communication network: protocol design

Summary

- Modeling and simulation is an important, widely used technique with a wide range of applications
  - Computation power increases (Moore's law) have made it more pervasive
  - In some cases, it has become essential (e.g., to be economically competitive)
  - Rich variety of types of models, applications, uses
- Appropriate methodologies required to protect against major mistakes.