Systems Engineering 520

System Architecture, Behavior and Optimization

Course Introduction

Huseyin Topaloglu

School of Operations Research and Industrial Engineering

Lecture 1

Cornell University

Overview

- Course Intro
- Review of Systems Engineering Design Process
- Fast-Pass Case Study
- Overview of Tools and Their Applicability

System Architecture, Behavior and Optimization

- Staff:
  - Huseyin Topaloglu (ht88)
  - Abhas Borkar (asb77)
  - Hunaid Lotia (hzl3)
- Goals
  - More analytical and computational view of systems engineering design process
  - Focus is on tools useful for design and analysis
  - Coverage is at intermediate/advanced level

Background Assumed

- Familiarity with Applied Systems Engineering I or similar course (e.g. Software Engineering) is needed to be able to put the tools in context
- Freshman calculus
  - Differentiation, integration
- Basic knowledge of probability and statistics
  - Probability distributions, conditional probability, expectation, central limit theorem, confidence intervals
  - We will begin with a quick review of necessary probability and statistics tools
- Some programming is required
  - Any programming language of your choice
  - MS Excel's VBA will be used for illustrations
  - At times, it will be unavoidable to use MS Excel

Course Administration

- The course is cross-listed with
  - SYSEN 521 / CEE505 / COMS 505 / ELEE513 / MAE592 / ORIE 513
- Course Packet
  - Campus publishing
- Web site
  - Categorized under Engineering > Systems Engineering
  - Make sure that you enroll with this year's version
- Requirements
  - Exam I + Exam II + Assignments + Project + Participation + [Readings]

Grading Guidelines

• Homework	20%
• Participation	5%
• Exam I (Mar. 29, 7:30 pm)	25%
• Exam II (Final exam week)	25%
• Project (Due May 4, 4:00 pm)	25%

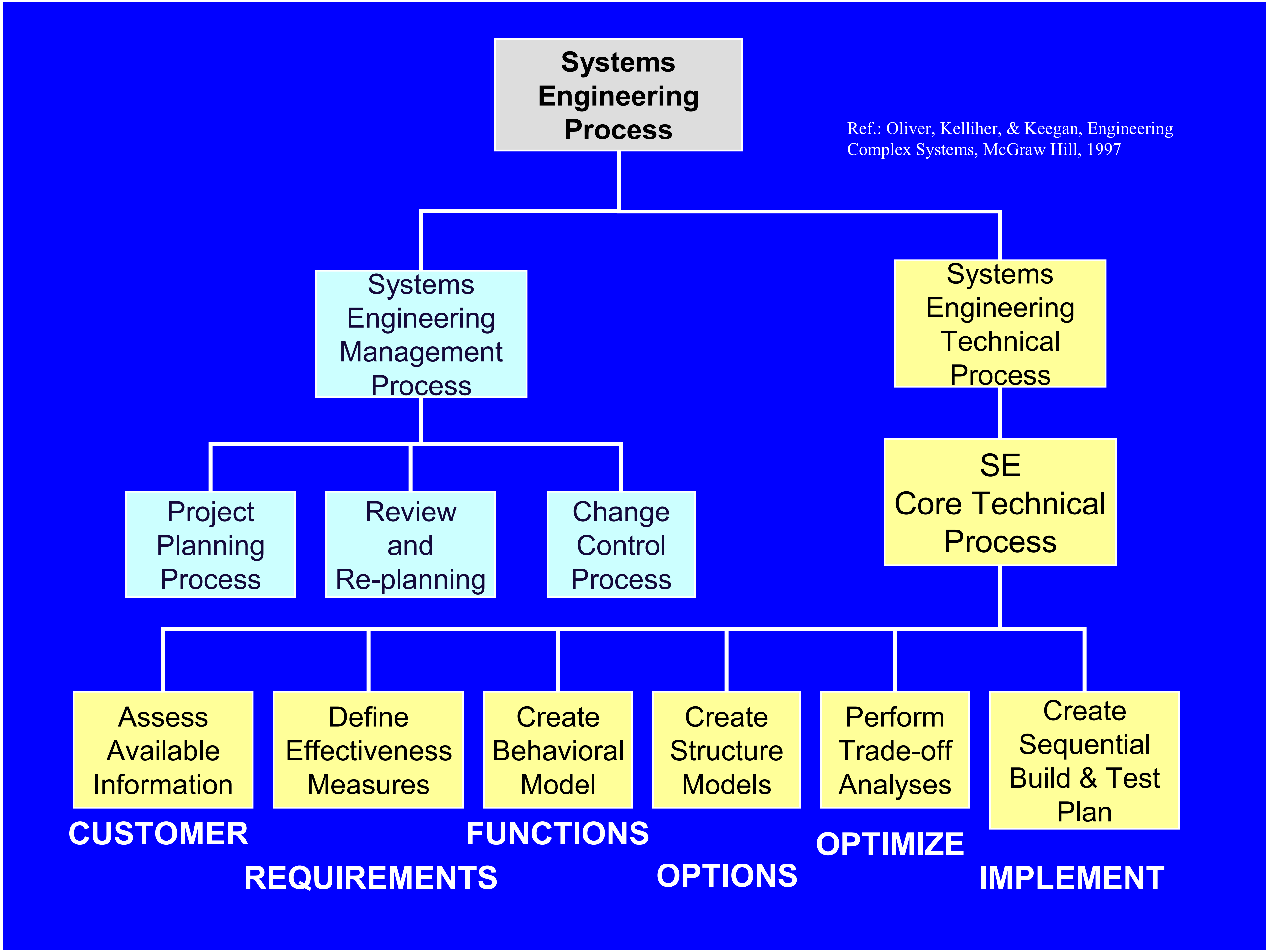
Project

- Students identify a project of interest to themselves, a sponsor or your supervisor
- Must use of at least one technique covered in class per team member
  - E.g. reliability analysis and simulation
- A default project topic will be offered
- Students will submit a short project proposal

Emphasis on Tools

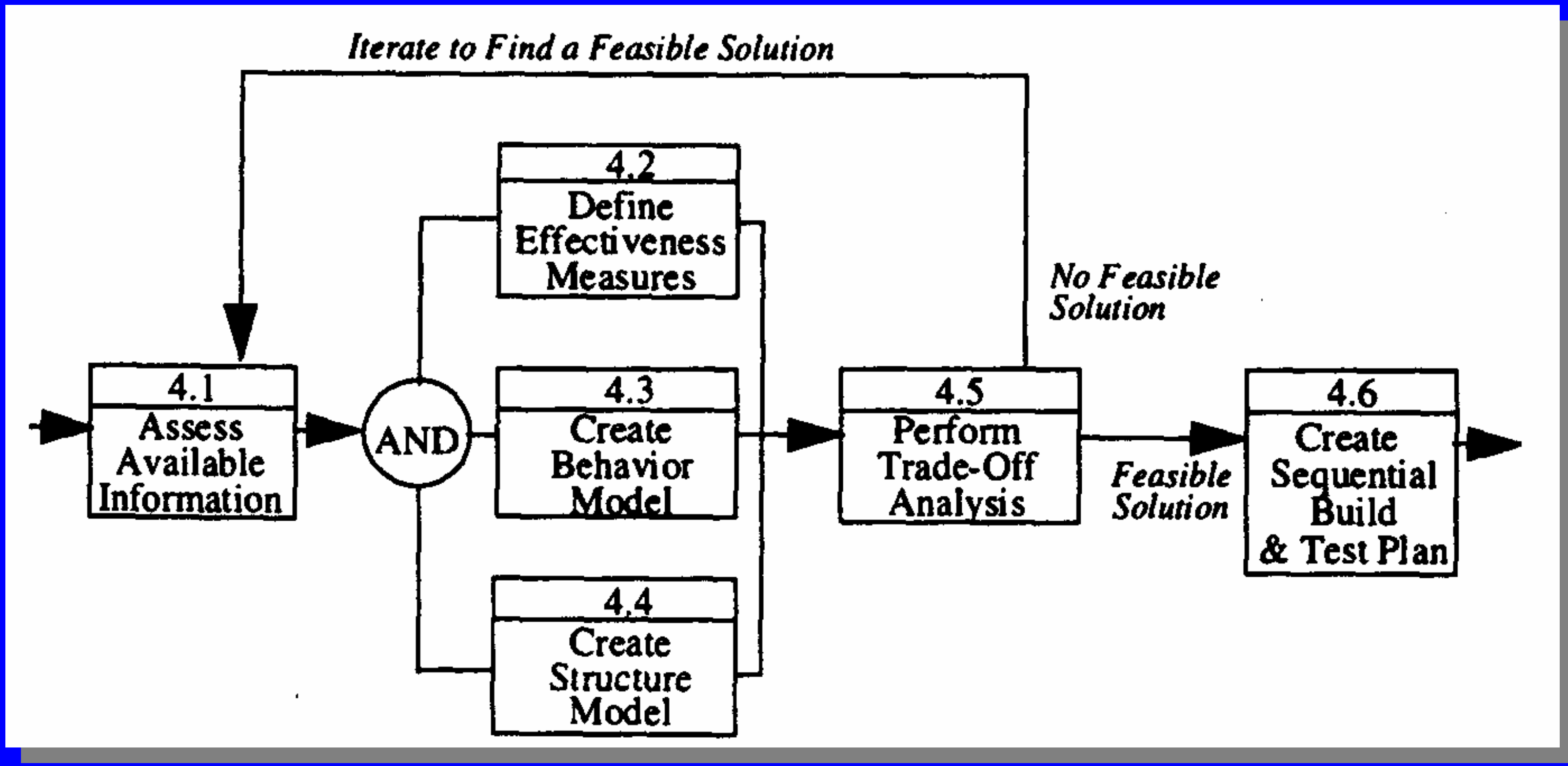
- Simulation
  - Monte Carlo simulation, discrete-event simulation, systems dynamics and multi-agent simulation
- Optimization
  - Nonlinear unconstrained and constrained optimization, linear optimization, decomposition, Lagrangian duality, network reliability, optimization under uncertainty, optimal control
- Probabilistic Analysis
  - Reliability, network reliability, decision-making under uncertainty

	Week	Date	Topic
	1	Jan. 22	Course introduction, FastPass case study, review of probability, statistics and calculus
Simulation	2	Jan. 29	Introduction to simulation modeling, Monte Carlo simulation, random variable generation
			Discrete-event simulation
	4	Feb. 12	Output analysis for simulation models
Prob. analysis ←			Reliability analysis
Optimization	6	Feb. 26	Nonlinear unconstrained optimization
			Nonlinear constrained optimization, duality and decomposition
	8	Mar. 12	Linear optimization, optimal control
	9	Mar. 19	**Spring Break**
Prob. analysis ←			Multi-attribute decision making, optimization under uncertainty
			Exam I, Mar. 29, 7:30 pm
Simulation			Systems dynamics modeling
			Dynamical systems analysis
Prob. analysis ←			Network reliability
Architecture			Documenting architectures
			Product platforms
			Project Due, May 3, 4:00 pm



Systems Engineering Process
Ref.: Oliver, Kelliher, & Keegan, Engineering Complex Systems, McGraw Hill, 1997
Systems Engineering Management Process
Systems Engineering Technical Process
Project Planning Process
Review and Re-planning
Change Control Process
SE Core Technical Process
Assess Available Information
Define Effectiveness Measures
Create Behavioral Model
Create Structure Models
Perform Trade-off Analyses
Create Sequential Build & Test Plan
CUSTOMER
REQUIREMENTS
FUNCTIONS
OPTIONS
OPTIMIZE
IMPLEMENT

Orientation

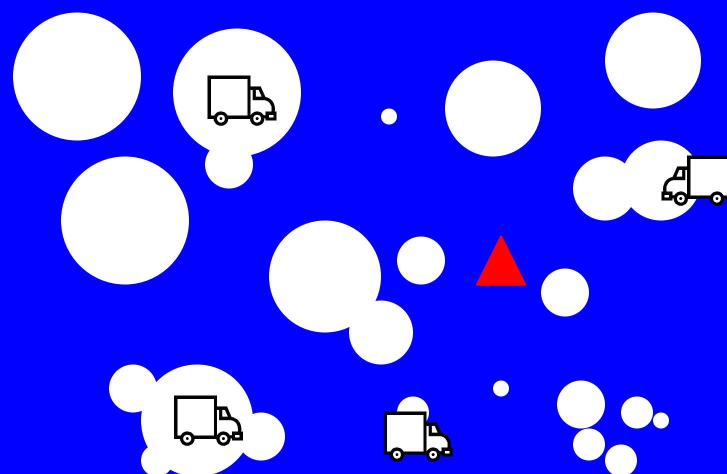


Four Themes of Systems Engineering

- What matters?
  - Requirements
- How should the system respond?
  - Function
- How should the system be structured?
  - Structure
- Will it work?
  - Validation

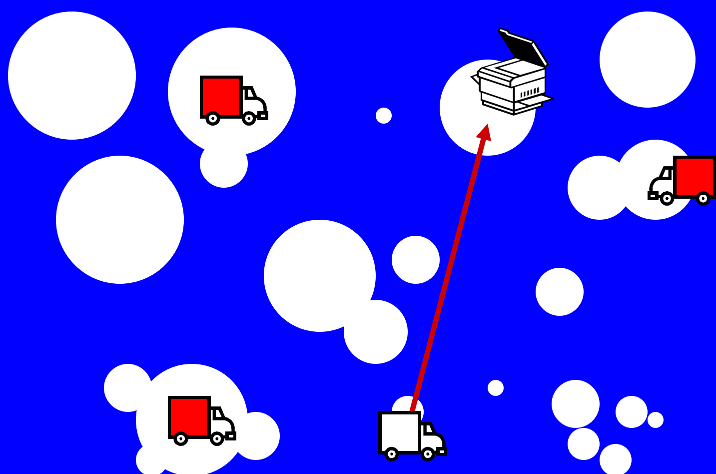
Discrete-Event Simulation

- DES usually uses a computer environment to imitate the operation of a system over time
- E.g. a copier repair system

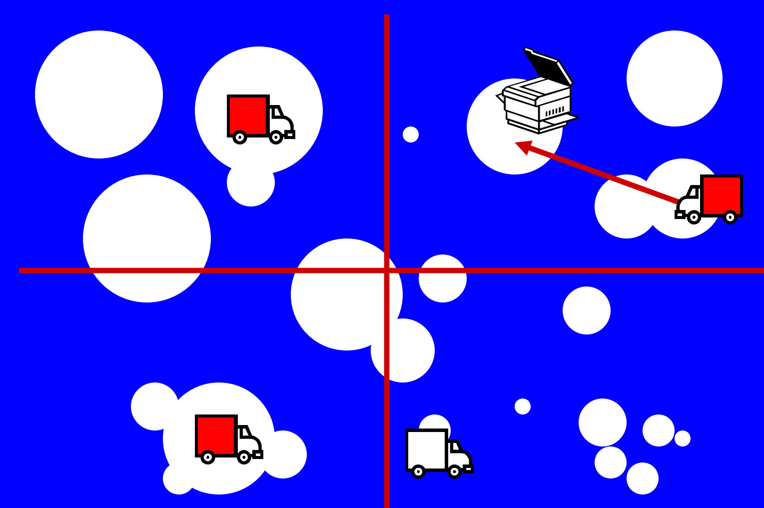


Discrete-Event Simulation

- Compare alternative systems



Serve each broken copier by the closest available repair truck



Divide into sub-regions and assign a truck to each sub-region

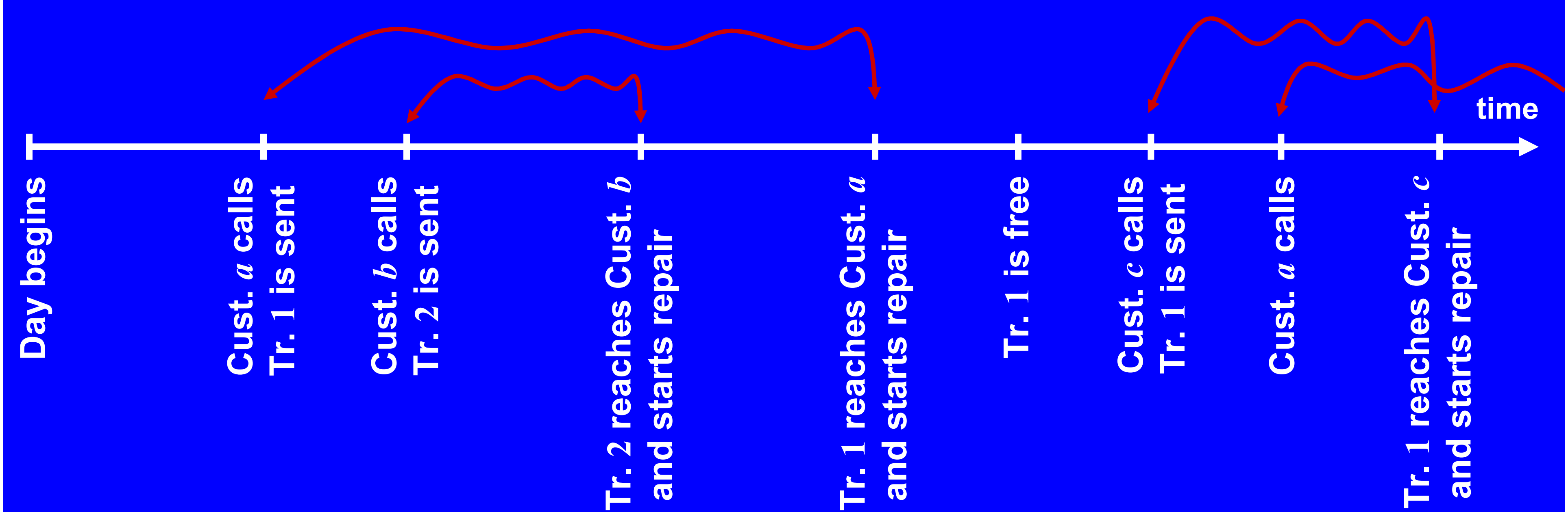
Discrete-Event Simulation

- Optimize the design parameters of an existing system
  - E.g.

- The goal is to estimate output (performance) measures with relatively high accuracy

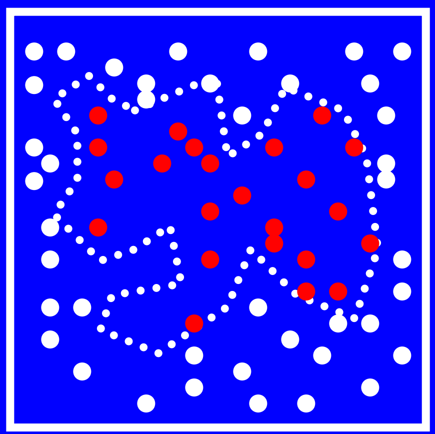
Discrete-Event Simulation

- Passage of time plays a crucial role
- Model “jumps” from event to event



Monte Carlo Simulation

- Passage of time does not play a crucial role
- Often useful for statistical estimation problems
- Accuracy is crucial



area of shape ~ [# red dots / # all dots] x area of rectangle

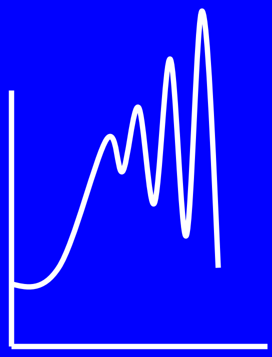
Monte Carlo Simulation

- An activity is composed of three sub-activities
  - The durations of the sub-activities respectively have exponential distr. (15min), gamma distr. (15min, 16min^2) and normal distr. (4 min, 1 min^2)
- What is the distribution of the total activity duration?

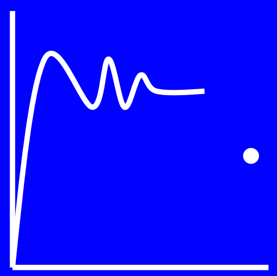
Monte Carlo Simulation

- Generate X1~Exp(15)
- Generate X2~Beta(15,16)
- Generate X3~Normal(4,1)
- Activity duration X = X1 + X2 + X3
- Do this many times to obtain many samples of activity durations
- Plot a histogram
- How do we generate samples from different probability distributions?

System Dynamics



- Passage of time plays a crucial role
- The goal is to predict the general pattern of behavior
  - A feedback control system to set the speed to a desired level
  - How quickly do we get to the desired speed and how big are the oscillations?



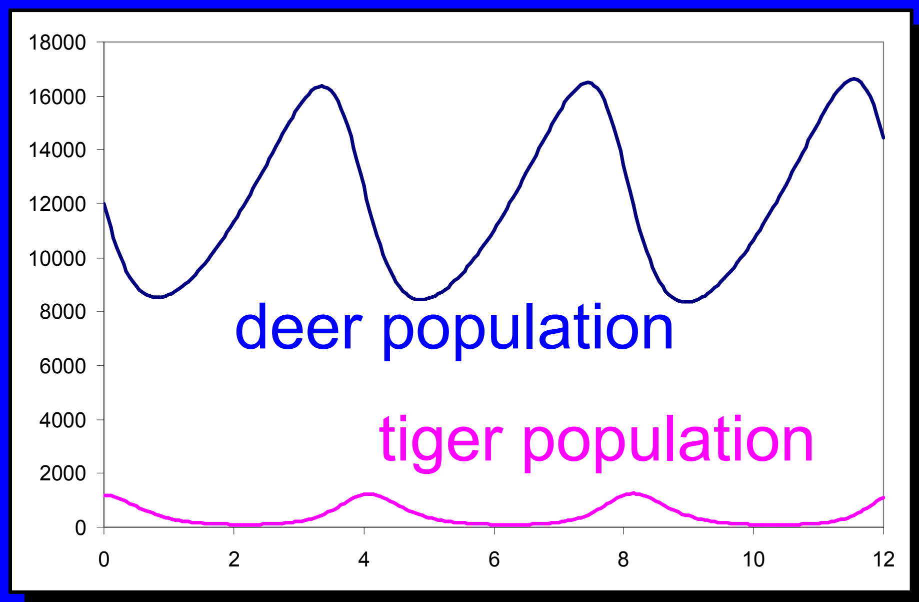
- Randomness does not play a crucial role

System Dynamics

- Often "socio-economic" systems are investigated by this methodology

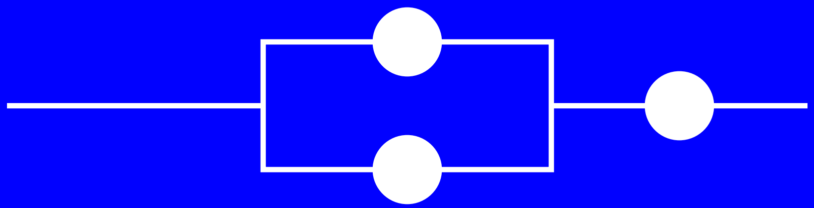
$$\frac{dx(t)}{dt} = \frac{9}{20}x(t) - \frac{1}{1000}x(t)y(t)$$

$$\frac{dy(t)}{dt} = -6y(t) + \frac{5}{10000}x(t)y(t)$$



Reliability Analysis

- Considers a system composed of many components interaction in different fashion
- Given the probability that each component is functional, what is the probability that the system is functional?
- Given the probability distributions for the lifetimes of the components, what is the probability distribution for the lifetime of the system?



Network Reliability

- Comes into play when passing messages between different components of a complex system
  - How to transmit packages between different components so that the transmission delay is minimized?
  - How to design a system so that the system continues to function even if a number of links fail?

Optimization

- There is a conflict between transmission capacity and reliability

- Setting up a network with minimum cost that satisfies transmission delay and reliability requirements

Decision-Making under Uncertainty

- Deals with decision-making situations under limited or probabilistic information
  - What is the best decision to take?
  - How much is additional information worth?

- Launching a product under limited information on whether the product will be successful
  - Carrying out a test market study to obtain additional information about the probability of success

Decision-Making under Uncertainty

- Jobs arrive at a server asking for processing capacity
  - The jobs are of different types and the type of the job is indicated by a header
  - Some jobs try to cheat the server by carrying out a false header
  - All we know is the conditional probabilities of the form

    $$P\{\text{ job is of type } i \mid \text{head is of type } j \} = p_{ij}$$
  - Should we accept a job that claims to be type i?
  - What is the value of investing in better means to assess the type of the job?

	1	2	3
1	0.90	0.05	0.05
2	0.02	0.92	0.06
3	0.04	0.08	0.88