**Chapter 13**

**Simulation and Modeling**

**A Guide to this Instructor’s Manual:**

We have designed this Instructor’s Manual to supplement and enhance your teaching experience through classroom activities and a cohesive chapter summary.

This document is organized chronologically, using the same headings that you see in the textbook. Under the headings you will find: Lecture Notes that summarize the section, Teaching Tips, Class Discussion Topics, and Additional Projects and Resources. Pay special attention to teaching tips and activities geared toward quizzing your students and enhancing their critical thinking skills.

In addition to this Instructor’s Manual, our Instructor’s Resources also contain PowerPoint Presentations, Test Banks, and other supplements to aid in your teaching experience.

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| **At a Glance** |

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**Overview**

Chapter 13 introduces an important area of application for computing: computational modeling for quantitative fields including the sciences, mathematics, engineering, and even social sciences. It introduces the purposes and methods of model building and why computational models can be useful. The chapter describes different features models can have and provides a detailed case study for discrete event simulation, an important kind of computational model. The chapter ends with a discussion of methods for presenting and visualizing quantitative data, particularly when the amount of data becomes difficult to view.

# **Learning Objectives**

* Describe the purpose of modeling in science
* List the benefits of a computational model over a physical model
* Explain the trade-off between accuracy and complexity in models
* Define different types of simulation models, including discrete and continuous, deterministic and stochastic
* Describe how a discrete event simulation works
* Explain the purpose of scientific visualization
* List some common methods of scientific visualization

# **Teaching Tips**

**13.1 Introduction**

1. Discuss past accomplishments like ENIAC and the Enigma code, and Hollerith’s census in 1890.
2. Emphasize how modern computers affect all parts of society, and remind them that scientific applications remain important. Computational modeling is a central aspect of this application.

**13.2 Computational Modeling**

1. Introduce the term **model** and describe its importance as a tool for scientists. Introduce the terms **computational models** and **simulation models**. Emphasize the reasons for building such models: existence, physical realization, safety, speed of construction, time scale, ethical behavior, and ease of modification.
2. Introduce the term **computational steering**, that is, when a designer uses a computational model as part of a design process. Outline the steps by pointing to figure 13.1 and going-over that with students.
3. Introduce the two aspects of a model that must be balanced: accuracy and complexity. The more accurately a system is modeled, the more complex the model becomes. However, too simplistic, the model won’t be predictive.

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| ***Teaching Tip*** | To emphasize the difference between a discrete event simulation and a simulation that updates with every time step, construct an activity where selected students act out the McBurger scenario. First, run through the simulation updating every tick of the clock, and then perform the simulation as a discrete event simulation. Discuss the results. |

1. Introduce the term **continuous model** for a model guided by continuous mathematical equations. Discrete models break the system down into discrete units (of time, of material) for simplicity.
2. Introduce the term **stochastic components** for parts of a model that exhibit random behavior, like flipping a coin or rolling a die.
3. Introduce the term **discrete event simulation** as a popular computational model.
4. An **event** is an activity that changes the state of the system. In discrete event simulation, the model only simulates those time steps when an event takes place, skipping all time steps between events.
5. Introduce the McBurger’s case study. A fast-food owner wants to simulate a restaurant before building it to determine the best number of checkout stations to construct. Events in this model are customers arriving at the store and customers departing after being served. Develop the algorithms for handling events step by step with your students.
6. Introduce the term **statistical distribution**, used to determine the range of random values for a particular event. In the McBurger simulation, a distribution is used to generate varying times each customer will take when being served.
7. Introduce the term **uniform random number** and explain that is one where every possible value is equally likely to occur. Go over how this works with statistical distribution in the McBurger’s example.
8. Introduce the phrase **garbage in, garbage out**. Discuss the meaning: bad data in produces bad data out. Incorrect data regarding the McBurger’s customers provide incorrect analysis.
9. Discuss the data needs of the simulation. Some data are required just to operate the simulation. Other data should be collected to help answer the questions for which the model was constructed. In the McBurger example, the resulting data include the average time a customer spends in the restaurant, the maximum length of the waiting line, and the percentage of time that servers are busy serving customers.

**Quick Quiz 1**

1. A part of a model that exhibits random behavior is called \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_.

Answer: stochastic

1. (True or False) In a model, accuracy and complexity are often working in harmony.

Answer: False

1. (True or False) In a discrete event simulation, not every discrete time step is simulated.

Answer: True

1. When a designer engages in a cycle of creating a computational model, testing it, and refining the model, the process is called \_\_\_\_\_\_\_\_\_\_\_\_.

Answer: computational steering

**13.3 Running the Model and Visualizing the Results**

1. Introduce the term **scientific visualization**: how to display large datasets so as to highlight patterns and important features and to make it easier to interpret.

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| ***Teaching Tip*** | The NASA Scientific Visualization Studio contains a great collection of visualization images: <http://svs.gsfc.nasa.gov/> |

1. Introduce the term **computer graphics**. Point out the important differences between computer graphics and scientific visualization. Scientific visualization emphasizes data presentation, data extraction, and data manipulation, whereas computer graphics focuses on the visual rendering (modeling) of physical objects such as light, water, and grass. Discuss examples of graphing 2D and 3D datasets, such as the tide and water temperature and the forest fire, from the book.
2. Computer graphics can be used to enhance scientific visualization. Virtual 3D models of physical objects can be easier to manipulate in the computer. Color and texture can enhance understanding of data.
3. Introduce the term **image animation**, for the visualization of data through video, rather than images. Animation can show changes over time in a natural, if time-scaled, way.

**13.4 Conclusion**

1. Discuss with students the various aspects of computational modeling.
2. Go over the importance of working with the data in ways that are easy to understand.
3. Discuss some important applications of scientific visualization.

# **Class Discussion Topics**

1. Suppose you wanted to model the behavior of a fire caused by a cigarette tossed in a forest. What essential features of the system would you need to include in the model? What parts of the system would you omit for simplicity? Would the model be continuous or discrete? Would it include stochastic components or be completely deterministic?
2. Name at least three scientific applications of computational modeling or data visualization, other than those discussed in this chapter.
3. Discuss at length the ways in which computational modeling could be of benefit to the healthcare industry.

# **Additional Projects**

1. Suppose you work for a sports stadium. You want to know how many hot dog vendors to hire for sporting events. Design a discrete event simulation for this question. First of all, what data would you want to collect? What would the events be? How would you describe the state of the system, and how an event would change it?
2. Suppose you have information about water temperatures in a river downstream of a power plant. The data were collected at 3-meter intervals from one bank of the river to the other, and every 3 meters for about 90 meters down the river. The collection was repeated every hour for a period of two days. What kind of data visualization would you use to display these kind of data?

# **Additional Resources**

1. Grand Challenges of Engineering, many involve computational modeling: <http://www.engineeringchallenges.org/>
2. “David McCandless: The Beauty of Data Visualization:” <http://www.ted.com/talks/david_mccandless_the_beauty_of_data_visualization.html>
3. “Hans Rosling show the best stats you’ve ever seen:” <http://www.ted.com/talks/hans_rosling_shows_the_best_stats_you_ve_ever_seen.html>

**Key Terms**

* **Computational model**:A model constructed using algorithmic procedures implemented as computer programs.
* **Computational steering**:A procedure for using a computational model to improve the design of an actual system by continually resetting model parameters to improve system performance.
* **Computer graphics**: The field of computer science that examines the technical problems of displaying visual images on a computer screen.
* **Continuous model**: A model of a system using mathematical equations that describe system performance as a continuous function of time *t*.
* **Discrete event simulation**: A computational modeling technique that simulates the behavior of a system only at discrete points in time.
* **Event**: An activity that will cause a change in the state of the system being modeled.
* **Garbage in, garbage out**: The term for the fact that the output coming out of a computer model is only as accurate as the assumption used to build the model.
* **Image animation**: Using multiple images at discrete points in time to produce an animation of a system's behavior over time.
* **Model**: An abstract mathematical, computational, or physical representation of an actual system.
* **Scientific visualization**: The use of images and visualization techniques to make scientific data easier to interpret and understand.
* **Simulation model**: Another term for a computational model.
* **Statistical distribution**: This is a mathematical function that describes the probability of a random quantity taking on certain values.
* **Stochastic components**: Parts of a model that display random behavior.
* **Uniform random number**: Every value in the range from *a* to *b* has the same chance of occurring.

**Solutions to End-of-Chapter Exercises**

**1**. A two-dimensional spreadsheet is a two-dimensional computational model of a system. By entering the appropriate data and formulas, a spreadsheet can be used to model the behavior of a set of entities such as a payroll or a population of animals . It is a form of mathematical model in which the data and the formulae are related to each other by their position in the grid. By changing values within the grid you can begin to answer the “what if” type questions described in this chapter.

**2**. CAD, computer aided design, is a combination of hardware and software that enables engineers and architects to design everything from furniture to airplanes. An engineer can view a design from any angle with the push of a button, and can zoom in or out for close-ups and long-distance views. In addition, the computer keeps track of design dependencies so that when the engineer changes one value, all other values that depend on it are automatically changed accordingly. CAD is related to simulation and modeling because it models real systems, especially in construction.  
CAM, computer aided manufacturing, is a type of computer application that helps automate a factory. Examples of CAM systems include real-time control, robotics, and materials requirements. CAM relates to the ideas in this chapter because applications like real-time controllers keep track of a factory’s behavior, which is like modeling its behavior.

**3**. Provide students with Web-based leads to the topics of SIMULA, GPSS, and Simscript.

**4**. Answers may vary. In addition to the air resistance and the fact that the Earth is not a perfect sphere, additional inaccuracies contained in this mathematical model include outside gravitational forces (for example, from other planets or the moon). These factors shouldn’t be included in the falling body model because their effect is relatively so small that it can be neglected. On the other hand, wind velocity and wind direction, which exerts a horizontal force on the falling object, could be a very significant factor and should not be left out of the model.

**5**. Provide students with leads to sources about random number generators. Often random number generators use functions based on the computer clock’s current time since midnight measured in milliseconds. The likelihood that the random number generator would be started at the exact (to the millisecond) time of day on two different days is near zero, so the numbers generated in each case would be different.

**6**. This may be a good approximation to the statistical distribution of service times, but it will not be completely accurate. Many factors determine the time of service, such as the time of day (breakfast orders can be filled faster than lunch orders?), the skill level of the workers, the number of customers being served (may have to wait for the next batch of french fries), etc. Because this distribution is an assumption in the model, the more inaccurate it is, the less reliance we should place on the conclusions of the model. Just as the garbage-in-garbage-out principle says, the model is only as good as the information one puts into it.

**7.** a. If instead of a single waiting line, we have N waiting lines, one for each of the N servers, then we would need to keep track of the number of customers in each waiting line.

Customer arrival algorithm: If all servers are busy, then put this customer at the end of the shortest waiting line and increase the length of that line by 1.

Customer departure algorithm: Take the next customer out of the corresponding server’s line and decrease that line size by 1

Main simulation: Set all N waiting line sizes to zero on initialization instead of just the single line.

b. If the waiting line had a maximum length of MAX

Customer arrival algorithm:   
 If waiting line size = MAX, then  
 New customer departs

Else

If everyone is busy…

Customer departure algorithm: unchanged

Main simulation: unchanged

c. If the priority system is used

Customer arrival algorithm: when the new customer first arrives, assign a priority number to the customer. If everyone is busy, begin at the end of the waiting line and go forward to the first person with an equal or higher priority than new customer. Insert new customer into line behind this person.

Customer departure algorithm: unchanged

Main simulation: unchanged

**8.** No, this is not a realistic assumption. As any restaurant owner knows, arrivals peak at certain times of the day (e.g., lunch, dinner, after theater) and slows dramatically at other times. To implement this behavior we could use the current value of the simulation clock. We might use one statistical distribution from time T = 0.0 minutes to 240.0 minutes (7AM to 11AM) which models a relatively low arrival rate. Then when T passes 240 we could switch to a completely different statistical distribution that models the higher arrival rate we might see during the lunch hour.

**9.** a. Yes, age could be a factor as people of different ages might order

quite different amounts of food, thus affecting the service time of each

customer

b. Possibly. Male and female customers might order different amounts of

food, which would have an effect on service time. However, this would have

to be examined closely to see if that assumption is valid and should be

included.

c. No. Height would not have any effect on customer waiting or service time.

**10.** As in the case of the fast-food restaurant, one could make observations over a few days' time at the bus station. Or one could examine past records of bus ticket sales. In any case the desired outcome would be something of the form

23% of passengers travel to B

16% of passengers travel to C

39% of passengers travel to D

22% of passengers travel to E

**11.** Most likely it would be a continuous model. There are two reasons: First, the mathematical and physical laws governing how particles are created and destroyed during collisions as a function of their speed, energy, and atomic structure is reasonably well understood. Most likely it could be described as a set of formal mathematical equations.

Second, the number of distinct events that occur in a high-speed particle accelerator is so massive, it would be enormously time consuming, in a computational sense, to try and simulate each and every event in the same way we did with the McBurgers model.

**12.** a. One day of activity in the model would take three million seconds to simulate, since 1014 computations are needed for an hour of activity and, assuming a 24-hour day, 24×1014 instructions need to be computed. On a machine with a computation speed of 800 MIPS (which is 800×106) instructions per second,

(24×1014 instructions) / (800×106 instructions/second) = 3,000,000 seconds

which is nearly 35 days! It takes longer to run the simulation than the actual

amount of time being simulated.

b. We would need a computer that can process 8 million MIPS. To find this, we use algebra. We know that 5 minutes is 5×60 = 300 seconds. The algebraic problem, then, is

(24×1014 instructions) / (x instructions/second) = 300 seconds

Solving for x, we get x = 8×1012 instructions / second = 8,000,000 MIPS, or about 8 teraflops.

**13**. Answers will vary. In addition to color and scale to enhance and highlight aspects of data sets being studied, one could use animation, pie charts, bar graphs, three-dimensionality, sorting, and slideshows to visually enhance the output of a model to help clarify its interpretation.

**14.** Provide leads to sources about the social sciences, humanities, anthropology, sociology, and political science. For example, Jay W. Forrester’s work on modeling the dynamics of complex systems, including populations, economies, and ecological systems, may be a good place to start.

**15**. Answers will vary according to what field the student is in. Sources should be provided to simulation models being used in both science fields and humanities fields.

**Challenge Work**

The objects in this model include departing planes and arriving planes. The state of the system includes the number of planes waiting to take off and the number of planes waiting to land. The events are plane arrivals and plane departures, which are really requests for landing and requests for takeoff. Assume a known distribution for arrivals and departures, plus a fixed time for landing a plane and a fixed time for a plane to take off. The model must take into account the fact that only one plane may use the runway at a time, and should keep track of the time a plane waits for arrival or departure. Also note that arrivals and departures, unlike the McBurgers simulation, are unrelated events, that is, an arrival does not trigger a later departure, and planes can arrive while other planes are departing.