Chapter 1 Exercise Hints and Solutions

Agent-based and Individual-Based Modeling: A Practical Introduction, 2nd Edition

Exercise 1

If you are a customer deciding which queue to enter:

- The question your model would address is which queue to select; for most people the decision objective is to minimize the time it takes to check out.
- Entities in the model must include the different queues. The other shoppers waiting in each queue *could* also be treated as explicit entities, possibly with variables for characteristics that affect how long it will take them to check out (how much stuff they are buying, their age, etc.). However, the other shoppers could instead be represented simply as a variable of the queues: each queue has a number representing the expected time it will take for all the shoppers currently in its queue to check out.
- Processes in the model include the customers' decision of which queue to choose, and the checkout process for each customer.

If you are a store manager deciding how to operate the queues:

- The question to model is probably how many staff to assign to the checkout area instead of to other jobs.
- Entities in the model still include the queues but also the store staff that can either work on checkout or at other jobs, and the customers that need to be checked out.
- The key process is checkout of customers. A simple version of the model likely would be built around the calculation of how many queues need to be open, for a certain rate of customers arriving to be checked out (e.g., customers per minute), to keep the number of waiting customers from growing steadily. A more complex version might consider the variability in the times between customers: sometimes it can be several minutes between customers and sometimes many customers arrive within a minute. (This more complex queuing model is a classic example in the "discrete event" simulation literature, which we mention in Chapter 14.)

If you are a store designer deciding how to design the checkout area:

- The question addressed by the model is which alternative type of queue system will process customers most efficiently so that the fewest employees are needed. The most important alternative to the standard grocery store checkout system, in which each checkout stand has its own queue, is the kind used at banks and airline check-in counters: all customers wait in a single queue, and the customer at the front of the queue goes to the next available stand. It is well known that this single-queue system is more efficient when there is high variability in the time it takes customers to be processed: one customer taking 10 times longer than average does not increase the waiting time of the other customers very much.

- Because the relative efficiency of these two queuing systems depends on how variable the checkout time is among customers, the model would include the customers and how the time needed to check out varies among them. Variability in the time between customer *arrivals* at the queue may also be important.

Exercise 2

The main goal of this exercise is to develop the understanding that good models address specific questions, and that the question is the most important factor determining what should be in the model (we discuss other factors in Chapter 18). Answers to these questions should therefore show a clear link between the problem addressed by a model and the things that need to be in it. Part of the exercise is stating whether models need to be agent-based; answers should consider whether key characteristics of agent-based systems—variability among individuals, local interactions, or individual behavior—are important for the question. Here are some things to consider in answers to example questions:

- Question (a): This question is not quite as clear as it needs to be—it does not state what the farmer's objective is. But it is reasonable to assume that the objective is to maximize fruit production in a limited area. Production is increased by planting trees closer together, until the trees are so close that the benefits of closer spacing are outweighed by the costs. There are several negative effects of spacing trees too closely; the most important is probably trees shading each other. If shading is the key process affecting the problem, then the model's variables should include those that determine how much light each tree gets and how much it shades other trees (height; diameter of the leaf-bearing crown; how trees are spaced with respect to each other and the sun), and how much fruit each tree produces. How fruit production depends on shading and light clearly is a critical process. If the size and spacing of trees are relatively uniform (as they typically are in orchards), then variability among trees may not be important and the model need not be agent-based. It could in fact be based on geometric calculations for one typical tree.

- Question (b): It is unstated but safe to assume that the employee's objective is to maximize her probability of having adequate savings at the time she retires. (Note that this is different from maximizing investment return!) Clearly, the model needs to include relevant characteristics of the alternative funds: their expected rate of return, and some measure of their expected volatility (how "safe" they are). But the model also needs to include characteristics of the employee: her decision may depend on how long until she retires, her current savings in her retirement program and elsewhere, etc. This model is not agent-based: it is about a single individual, whereas agent-based models are about systems of multiple individuals.

- Questions (c) and (d) are examples of questions not defined clearly enough to model. How many lanes a road should have can be modeled with a standard traffic model *if* the only consideration is traffic capacity. (Many highway departmens use agent-based traffic models that represent individual vehicles and how they differ from, and interact with, each other.) However, such decisions often also consider land use impacts of road development: what is the cost of paving additional land for a wider road, and how will

the new road's traffic capacity affect regional development? Whether harvesting whales is acceptable depends entirely on who is involved in the decision and what they consider "acceptable". Currently, at least one country has decided that small harvests of some whales are acceptable from both ethical and conservation perspectives, while many people consider whale harvest of any kind unacceptable due to ethical reasons only. For both of these questions, students need to start by narrowing the question down to one specific enough to model.

- Question (g): This is an example of the financial regulatory questions that some now argue must be addressed with agent-based models (e.g.: "Meltdown modelling: Could agent-based computer models prevent another financial crisis?" *Nature*, August 6, 2009, pp 680-682). If we accept that system-level properties such as bank failure rates depend on how individual banks make investment decisions (e.g., whether to buy mortgage-backed securities) and how individual customers behave in response to financial conditions such as bank failure rates (e.g., by withdrawing cash when the rate increases), then agent-based models with these kinds of entities and behaviors are appropriate.