Modeling and Simulation

CSE Written Qualifying Exam

Fall 2022

Instructions

- Please answer three of the following four questions. All questions are graded on a scale of 10. If you answer all four, all answers will be graded and the three lowest scores will be used in computing your total.
- Please write clearly and concisely, explain your reasoning, and show all work. Points will be awarded for clarity as well as correctness.

1 Problem 1

Georgia Tech would like your help designing a traffic simulator to help improve the flow of pedestrian, bike/scooter, bus, and car traffic on campus. In particular, they want to be able to study a variety of "what-if" scenarios that may involve adding or removing bus routes or adjusting bus frequencies; adding or removing bike lanes; changing some streets from two-way to one-way; adding stop signs; adjusting signal timing (the length of time between changes at stop lights); creating "pedestrian scrambles" (diagonal crossings, like the one at 5th and Spring Streets). Explain how you would approach this simulation project. Start by considering what metric(s) of efficiency might make sense. Then, describe what real-world features you would include and ignore; what kind of conceptual model you would use; what kind of data you might need; and how you would approach validating the simulator.

2 Problem 2

In this problem, you will develop a scheme to avoid the problem of *deadlock* that can occur in a parallel discrete-event simulation.

Recall how deadlock can arise in the basic structure of a simulator consisting of P logical processes (LPs) where any LP may generate remote events for any other. Assume each LP maintains a separate first-in, first-out (FIFO) queue for receiving event messages from every one of the other LPs; and suppose each LP executes the canonical simulation loop shown in Algorithm 2.1. Line 2

Algorithm 2.1 Canonical discrete-event simulation loop, executed by every logical process

Let `now` be the current logical simulation time on the executing LP.

while simulation is not over **do**
    Wait until each incoming FIFO queue has a message event.
    Remove the message event M with the smallest timestamp.
    `now` $:=$ timestamp of M.
    Process event M.

can lead to deadlock: there can be a cycle of waiting among the LPs. While one can use a *null message* synchronization scheme (e.g., Chandy/Misra/Bryant) to avoid deadlock, the performance of such schemes depends strongly on whether the simulation can exploit *lookahead*. (Lookahead refers to whether every LP can reliably estimate a lower bound on the timestamp of the next message that it might send to each of the other LPs.)

Instead of using null messages, suppose you are allowed to use a separate central process to coordinate the action of all LPs. Assume this central process does not otherwise participate in the simulation, i.e., it does not process any events.

a) Suppose this central process can *detect* whether the simulation is in a deadlocked state. In particular, suppose it knows which LP has the event with the smallest timestamp. Explain how it can recover from the deadlock, i.e., enable execution of the simulation to resume.

b) Give a scheme to detect deadlock. You must assume LPs execute *asynchronously*. However, you may assume that each LP has an additional FIFO queue for communicating with the central process.

c) Analyze the tradeoffs of the overall deadlock detection and recovery scheme compared to a null message scheme like CMB.

3 Problem 3

A new insect species has been identified on a remote island. The species is not native to the island and has been preying heavily on native plants, so there is a desire to take steps to eliminate the new species if possible. The insect goes through four life stages: in order, they are egg, larva, pupa, and adult. Only the adults prey on the plants.

Two insect extermination approaches are being considered. One involves setting traps that kill adult insects. The other is application of a toxic spray that is designed to target the larval stage.

Your task is to consider how to develop a mathematical model that could be used to help decide which approach to use.

a) Explain what criterion or criteria should be considered in determining which extermination approach would be better. In other words, what should it mean to be the "better" approach and why?

b) What variables and parameters should be included in an ideal model and why? (If it helps, you may assume that it would be possible to measure any quantity you would like.)

c) Write a *preliminary* mathematical model that could *begin* to answer the question of which approach to use. The goal is not to include every element you think should be in an ideal model, but to develop a reasonable start that is appropriate for the context (this time-constrained exam). Most likely your preliminary model will involve a small subset of the variables and parameters you identified in part (b). Your preliminary model must include some way to determine which extermination approach is "better," although it may not address all criteria that you think a fully developed model should involve. Explain the meanings of all components of your model, including how the model output would be used to determine which extermination approach was a better choice, and explain why you developed your model as you did.

d) List at least three important assumptions that your model makes. Discuss how reasonable these assumptions are. (Because it was already mentioned, you may not list an assumption about the feasibility of measuring any quantities!)

4 Problem 4

The dynamics of a *nonuniform* oscillator can be modeled as

$$\dot{\theta} = \omega - a \sin \theta. \tag{1}$$

where θ is an angle over a circle. If $a = 0$, we recover a uniform oscillator. It turns out that the flashes emitted by fireflies and even the human sleep–wake cycle can be modeled as nonuniform oscillators. Assume $\omega > 0$ and $a \geq 0$ for simplicity.

a) Use linear stability to classify the fixed points of (1) for $a > \omega$.

b) If $a < \omega$, determine the period of oscillation (call it $T(a)$) analytically, and graph what it looks like, roughly, for $0 \leq a \leq \omega$.