Lecture Overview

- What is a Model?
- Uses of Modeling
- The Modeling Process
  - Pose the Question
  - Define the Abstractions
  - Create the Model
  - Analyze the Data
- Model Representations

What Is a Model?

- A representation of a system that is
  - *simpler than the actual system*
  - *captures the "essential characteristics"*
  - *can be evaluated for a property of interest*
- *Examples*
  - A hardware system as a block diagram.
  - An operating system as a network of queues and servers.
  - A software system as an object model.
  - A parallel computer as a Petri net.
  - A communication protocol as a set of interacting state machines.

"Simpler"

- Easier to construct than the actual system
  - *server utilization = .005 * #users*
  - *Performance in 1 year can be estimated by running a workload generator on the current system*
- "Simpler" often means "has fewer parameters"
  - Example: Computational Complexity (O(•) notation):

  captures almost no details of any real hardware or implementation, yet provides useful information.

"Simpler" almost always means a more abstract representation than the representation of the actual system.

- Example: A resource allocator as a queue/server pair.

"Captures the essential Characteristics"

- Include only those characteristics that affect the property to the level of accuracy desired for the question that has been posed
  - *My web server needs more disk capacity. Can I just add disks or must I add servers?*
  - ** Do you model file buffer space effects or not?*
- Deciding whether or not a model captures the essential characteristics is subjective
- I probably tend to err on the side of simplicity.

  Your initial inclination will probably be to include too much detail.

"Can be evaluated"

Values of metrics for the property of interest can be evaluated from the model.

- **Example: Performance of a web server**
  - **What is metric for performance of a web server?**
  - **What kind of model will yield the desired metrics?**
  - **What are the available evaluation methods for the model representation?**
  - **How will I know the accuracy of the values of the metrics?**
  - **Validation?**
  - **Verification?**

What Is a Model?

- **A representation of a system that is**
  - ***simpler* than the actual system**
  - ***captures the essential* characteristics**
  - ***can be evaluated***
- **There is always an interaction among these three properties of a model.**
  - **Faithfulness versus effort.**
  - **Accuracy of evaluation versus effort.**
- **The ultimate model is a measurable implementation of the system.**

Uses of Modeling

- **System Planning**
  - **Requirements**
  - **Constraints**
- **System Design**
  - **Choice of Components**
  - **Relationships among components**
  - **Performance**
  - **Availability**
  - **Correctness**
- **System Evaluation**
  - **Performance**
    - **Capacity Planning**
    - **System Tuning**
    - **Application Design**

The Modeling Process for an existing system.

1. **Pose the Questions**
2. **Define the Abstractions, Metrics and Parameters.**
3. **Create the Model**
4. **Gather and Analyze the Data**
5. **Measure the system and parameterize the Model**
6. **Verification/Validation**
7. **Explore the Parameter/Metric Space.**

Modeling Process Example:

- **Imagine we have a parallel application running on a dual processor and want to project performance on larger machines**
- **Pose the Question/Define the Metric and the Parameters**
  - **What will the speedup be on 8 processors?**
    - **Metric - Speedup**
    - **Parameters - Number of Processors**
    - **Are there hidden parameters?**
- **Create the Model - Amdahl's Law**
  - **S(f,N) = 1 / (f + (1-f)/N)**
  - **f is the serial fraction of the computation.**
  - **N is the number of processors**

Modeling Process Example Continued:

- **Measure the system and parameterize the Model**
  - **Suppose measured S(2) = 1.79. Then we deduce that f =0.12.**
- **Verification/Validation**
  - **Evaluation is not a problem.**
  - **How good is the model?**
    - **What factors are overlooked in Amdahl's Law?**
- **Evaluate the Model for cases of interest**
  - **N = 8**
  - **S(8) = 1 / (0.12 + .88/8) = 4.35**
- **Sensitivity Analysis**
  - **What is sensitivity of model to f?**

Pose the Question

- **This is a surprisingly difficult step**
- **One criterion: *Is the answer the model is going to give obvious from the problem statement and the model structure?***
  - **E.g., "Is response time better on a system with a faster CPU?" when the model contains representations of only the workload and the CPU itself**
- **Clearly, the answer is "yes"**
  - **In this case, either problem statement or the model should be changed**

Pose the Question

- **The question posed strongly affects the kind of accuracy required**
  - ***What will the response time be if the server is upgraded from a 500 MHz PII to a 933MHz PII?***
- **Must give a single number to within X% of true value**

  - ***How much faster will the 933 MHz system be than the current system?***
- **If model underestimates response time by 20% on both the original and the projected systems, answer will still be exact**

Pose the Question

∗ **Is the 933 MHz system faster than the original?**

• **Suppose the model says "yes" and real system in fact has response times that are 80% of the original system. Let α be the modeling error in the modified system and β be the modeling error in the existing system.**

Modeled performance system projected

---------- < 1

Modeled performance system existing

$(\alpha * 0.8) / \beta < 1$

$\alpha / \beta < 1.25$

Pose the Question

• **As a rule, comparing several alternatives to each other is much easier than other sorts of questions.**

• **On the other hand, you don't know what the true answers are, and your confidence that the model is behaving accurately in a comparative sense typically decreases as your suspicion about the absolute error grows.**

Create the Model

• ***"How is the model represented?"*** **versus**
"How is the model evaluated?"

• **These two are often intimately intertwined (or confused)**

Representation	***Evaluation***
System similar to the projected system	***Measurement*** **or** ***Benchmarking***
Arbitrary set of equations.	***Analytic model***
Arbitrary software description of system behavior (state changes).	***Simulation model***

Create the Model

• **Higher-level description languages can be useful**
- ∗ **More convenient expression**
- ∗ **Provide some structure for thinking about how to model the system**
- ∗ **Determine what needs to be measured**
- ∗ **"canned evaluations"**

• **As always, there is a trade-off between convenience and generality: the more tailored a model description language is to the environment, the easier it is to apply there, but the more difficult it is to use for anything else**

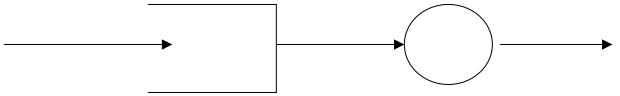
Model Description Representations

- **We're going to look at two abstract representations of systems - Petri nets and queueing models.**

- **Only the briefest introductions here - just enough to have some common vocabulary until we look at these topics in more detail**

Queueing Model Overview

- The basic component is the *service center*

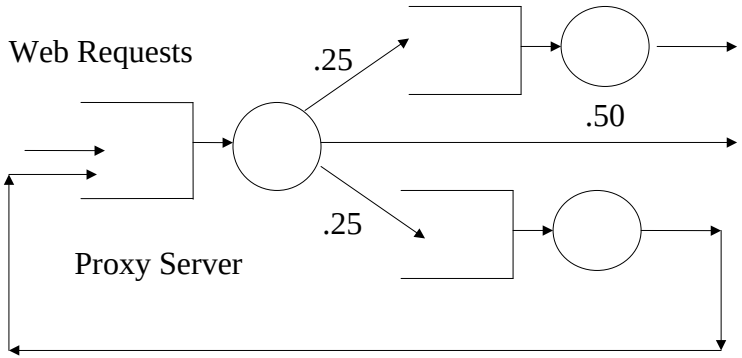


Customer Arrivals | Queue | Server | Service Center | Customer Departures

- Parameters
  - Customer arrival rate
  - Average service time
  - Scheduling discipline
  - ...

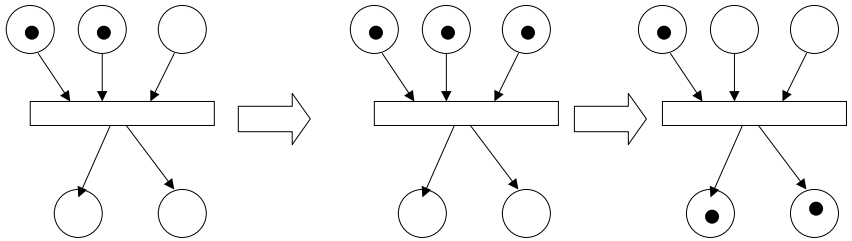
Queueing Model Overview

- We can construct networks of service centers



Petri Net Overview

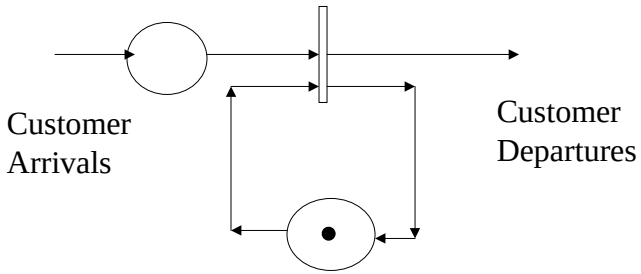
- Basic components are *place*s, *transition*s, and *tokens*



Token Arrives

Transition Occurs

Modeling a Service Center as a Petri Net



Principles of Abstraction

Hierarchical Abstraction

Collapse Events/Actions into more abstract events/actions.

Stochastic Abstraction

Map specific behaviors into generically defined behaviors.

The execution time of each action is represented as the average of the execution times of all events.

The execution time of each action is chosen from a distribution derived from the execution times of the individual actions.