

Outline of the course

- ◆ Introduction to Simulation.
- ◆ Hand Simulation.
- ◆ Review of basic Probability Theory.
- ◆ Random Number Generation
- ◆ Generation of Random Varieties.
- ◆ Analysis of Output.
- ◆ Elementary Queuing Models

Modeling and Simulation

Model

- It is a simplification of the reality
- A (usually miniature) representation of an actual system; an example for imitation or emulation
- A description of observed behavior, simplified by ignoring certain details.
- Models allow complex systems to be understood and their behavior predicted within the scope of the model
- A model can be **Analytical** (Queuing Theory) or by Simulation.

Queuing Theory

- Queuing is the study of waiting lines, or queues.
- The objective of queuing analysis is to design systems that enable organizations to perform optimally according to some criterion.
- That require a clear understanding of the appropriate service measurement.
- Possible service measurements
 - Average time a customer spends in line.
 - Average length of the waiting line.
 - The probability that an arriving customer must wait for service.

Applications of Queuing Theory

- Telecommunications
- Computer Networks
- Predicting computer performance
- Health services (eg. control of hospital bed assignments)
- Airport traffic, airline ticket sales
- Layout of manufacturing systems.

Discrete-Event Simulation

- Discrete Event System
 - a system whose *state* changes at discrete points in time due to the occurrence of asynchronous *events*
- Example: M/M/1 queuing system
 - State
 - number of customers in system
 - Events
 - customer arrival
 - customer departure

5

Queuing System

- A Queuing system is determined by three basic components
 - Arrival characteristics: Customers arrive according to some arrival pattern.
 - Service facility characteristics: Customers receive service and leave the system.
 - Queue characteristics: Arriving customers may have to wait in one or more queues for service.

Arrival Characteristics

- Size of the arrival population – either infinite or limited
- Arrival distribution:
 - Either fixed or random, The random process is more common in businesses.
 - measured by time between consecutive arrivals, or arrival rate
 - The **Poisson distribution** is often used for random arrivals

Arrival Characteristics

- Under three conditions the arrivals can be modeled as a Poisson process
 - ***Orderliness***: one customer, at most, will arrive during a predefined time interval.
 - ***Stationarity***: for a given time frame, the probability of arrivals within a certain time interval is the same for all time intervals of equal length.
 - ***Independence***: the arrival of one customer has no influence on the arrival of another.

Service facility characteristics

1. Configuration of service facility
 - Number of servers
2. Service distribution
 - The time it takes to serve 1 arrival
 - Can be fixed or random
 - Exponential distribution is often used

Queue Configuration

- A single service queue.
- Multiple service queue with single waiting line.
- Multiple service queue with multiple waiting lines.
- Multistage service system.

Queue Characteristics

- Queue length (max possible queue length)
 - either limited or unlimited
- There are several commonly used rules:
 - First come first served (FCFS - FIFO).
 - Last come first served (LCFS - LIFO).
 - Estimated service time.
 - Random selection of customers for service.

The Waiting Line Characteristics

- Factors that influence the modeling of queues
 - Line configuration
 - Balking
 - Reneging
 - Jockeying

Balking, Reneging, Jockeying

- Balking occurs if customers avoid joining the line when they perceive the line to be too long
- Reneging occurs when customers abandon the waiting line before getting served
- Jockeying (switching) occurs when customers switch lines once they perceived that another line is moving faster

13

M/M/1 System

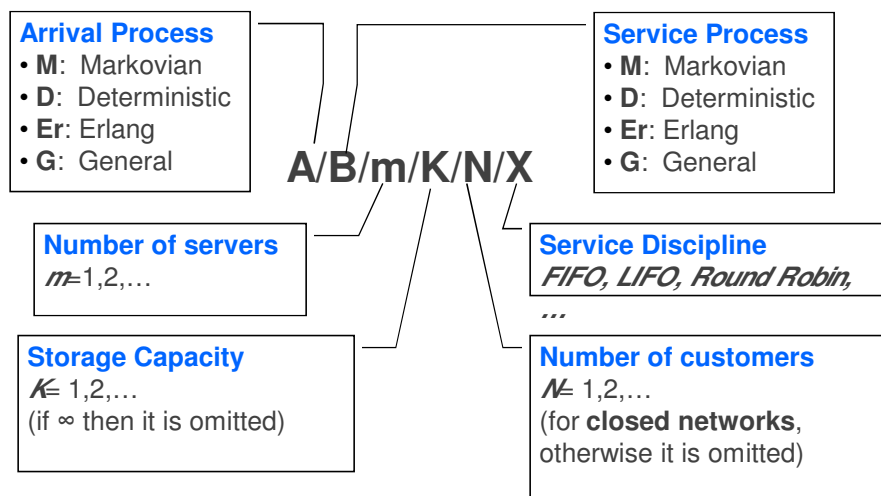
- M stands for “Memoryless” (a property of the exponential distribution)
 - M/M/1 stands for Poisson arrival process (which is memoryless)
 - M/M/1 stands for exponentially distributed transmission times
 - M/M/1 stands for one server
- “M/M/1” is a special case of more general (Kendall notation)
- Example of packet :
 - Arrival process is Poisson with rate λ
 - Processing times are exponentially distributed with mean $1/\mu$
 - One server
 - Independent interarrival times and processing times

The Exponential Distribution - Characteristics

- The memoryless property (Markov)
 - No additional information about the time left for the completion of a service, is gained by recording the time elapsed since the service started.
 - $P(T \geq s+t \mid T \geq s) = P(T \geq t)$
- The Exponential and the Poisson distributions are related to one another.
 - If customer arrivals follow a **Poisson distribution with mean rate λ** , their interarrival times are **exponentially distributed with mean time $1/\lambda$** .

15

Kendall Notation



Kendall Notation

- **M/M/1 Queue** Poisson arrivals (*exponential inter-arrival*), and exponential service, 1 server, infinite capacity and population, FCFS (FIFO). The most basic and important queuing model -Was the subject of our course
- **M/M/m Queue** *Same, but m servers*
- **M/M/m/k Queue** system Same as M/M/m, but there is buffer space for at most k packets. Packets arriving at a full buffer are dropped, k is omitted when $k = \infty$
- **M/D/1 Queue** Poisson arrivals and CONSTANT service times, 1 server, infinite capacity and population, FIFO.

Name (Kendall Notation)	Example
Simple system (M / M / 1)	Customer service desk in a store
Multiple server (M / M / s)	Airline ticket counter
Constant service (M / D / 1)	Automated car wash
General service (M / G / 1)	Auto repair shop
General service G/G/3/20/1500/SPF	3 servers, <u>17 queues</u> (20-3), 1500 total jobs, Shortest Packet First