

A computer system consists of three networked service facilities: Macintosh, NeXTstation, and LaserJet Printer. Three groups of personal computer (PC) users remotely dial-in by using a modem and send batch computer jobs to the system for processing. When a job arrives from a PC user, it enters a queue in front of the Macintosh facility and waits for processing. All of the queues in the system are handled in arrival order (First-Come First-Served). After the job is processed on the Macintosh, it enters the queue in front of the NeXTstation. Then, after the job is executed on the NeXTstation, it joins the queue in front of the LaserJet printer. No limit exists on the number of jobs waiting in the queue in front of Macintosh or NeXTstation. But there is a limit of 10 jobs allowed on the LaserJet printing facility due to its memory capacity. If ten jobs are already at the printer (9 in the queue and 1 in processing), then any subsequent arrivals to the printer are diverted to another printer which is excluded from the system definition.

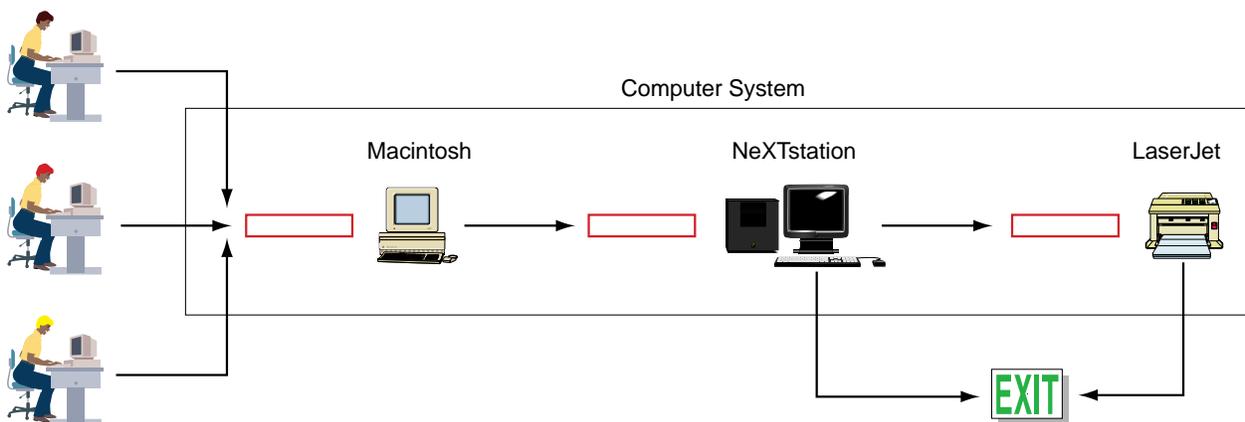


Figure 1. The Computer System

The probability distributions and corresponding parameters for job interarrival times are given in Table 1 below. All values are given in seconds.

Table 1. Interarrival Times of Jobs

Source	Interarrival Times	Mean
PC Users Group 1	Exponential	20 seconds
PC Users Group 2	Exponential	40 seconds
PC Users Group 3	Exponential	12.5 seconds

The probability distributions and corresponding parameters for job execution times are given in Table 2 below. All values are given in seconds.

Table 2. Execution Times of Jobs

Facility	Job Execution Times	Mean
Macintosh	Exponential	4.5 seconds
NeXTstation	Exponential	5 seconds
LaserJet	Exponential	5.8 seconds

Use the Method of Replications technique for data collection, assume that the simulation model reaches the steady-state conditions after **1000** jobs executed, simulate the system for **10,000** jobs executed in steady state, replicate the simulation run **30** times under different conditions, and estimate the average for the following performance measures of interest:

Performance Measures

1. Macintosh utilization (ρ^{Mac})
2. NeXTstation utilization (ρ^{NeXT})
3. LaserJet printer utilization (ρ^{LaserJet})
4. Average time a job (which completes service at all three facilities) spends in the whole system (W) [*Those jobs finding 10 or more at the printer will be excluded.*]
5. Average number of jobs in the whole system (L)

Assumptions

- The service facilities, i.e., Macintosh, NeXTstation, and LaserJet, process each job one at a time from start to completion. (No multiprocessing)
- After a job leaves the system, its owner is not notified.
- First-Come First-Served queue discipline is used for all waiting lines.
- Constant execution rate (μ)
- Constant arrival rate (λ)

Instructions

- [1] Using C, C++, Java, or C# programming language of your choice, write a computer program to simulate the behavior of the computer system. **Your program must implement one of the four conceptual frameworks for simulation programming described in class.**
- [2] Replicate the simulation model execution 30 times under different experimental conditions by changing the seed value of the random number generator. Compute the average for each performance measure using the 30 independent values obtained.
- [3] Use the following **pseudo random number generator** on a 32-bit computer:

```
/**
 * 32-bit Multiplicative Congruential Pseudo Random Number Generator
 * Microsoft Visual C++ Version
 */

#include <math.h>

/**
 * The seed used by randomNumberGenerator.
 */
long         gv_lRandomNumberSeed;

/**
 * Returns a random number between 0.0 and 1.0.
 * plSeed - Pointer to the seed value to use.
 */
double randomNumberGenerator( long* plSeed ) {
    double    dZ;
    double    dQuot;
    long      lQuot;

    dZ = ( *plSeed ) * 16807;
    dQuot = dZ / 2147483647;
    lQuot = ( long ) floor( dQuot );
    dZ -= lQuot * 2147483647;
    ( *plSeed ) = ( long ) floor( dZ );

    return ( dZ / 2147483647 );
}
```

- [4] Use the following **Exponential** random variate generator:

```
/**
 * Returns a random variate from an exponential probability
 * distribution with the given mean value of dMean.
 */
double exponentialRVG( double dMean ) {
    return ( -dMean * log( randomNumberGenerator( &gv_lRandomNumberSeed
) ) );
}
```

Requirements:

1. You can write your program using: **C, C++, Objective C, Java, or C# programming language**.
2. **Compatibility:** It is your responsibility to make sure that your program compiles and runs under an environment your GTA can compile and run your program. You must provide **detailed** instructions for the GTA about how to compile and run your program.
3. **Documentation** is an integral part of your computer program and you will be graded for it. Inline documentation, procedure/method documentation, class documentation, and overall program documentation are all required. Your up-front documentation must clearly show your full name and describe how to compile and execute your program.
4. Your program must be your own work and the Virginia Tech **Honor Code** is in effect fully. All work is to be done under the provisions of the [Virginia Tech Honor System](#).

What to submit in class on the due date:

(Failure to submit a hard copy will result in a grade of zero. The lateness policy is applied depending on the hard copy submission time.)

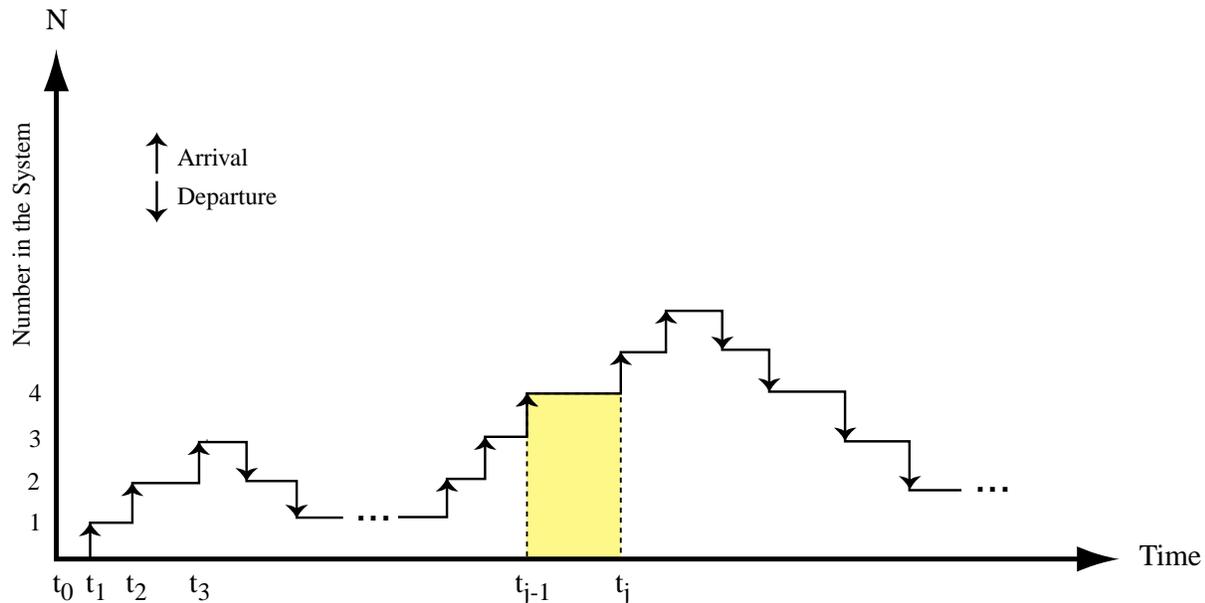
1. A hard-copy printout of your well documented source code.
2. A hard-copy printout of the execution results of your program in the following format:

	ρ Mac	ρ NeXT	ρ LaserJet	W Avg. Time	L Avg. Number
Run 1					
Run 2					
Run 3					
:					
Run 30					
Average					

What to email to the GTA before the due date: (See the lateness policy on the course website.)

1. Create a folder named *YourLastName*. Include all of your source code files, related files, and the output file created by the execution of your program into this folder.
2. Compress the folder. Name the compressed file *YourLastName.zip*. Make sure that your “zipping” preserves the folder structure.
3. E-mail your *YourLastName.zip* file to your GTA before the due date.

Computation of the Average Number of Jobs in the Computer System (L):



$Area_j = (\text{Previous } N \text{ at } t_{j-1}) * [(\text{The current time } t_j \text{ at which } N \text{ is changed}) - (\text{The last time } t_{j-1} \text{ at which } N \text{ was changed})]$

Total Area = Sum of $Area_j$ during the course of simulation in steady state

Average Number in the System = $L = \text{Total Area} / \text{Simulation Duration in Steady State}$

INSTRUCTIONS FOR PROGRAM DOCUMENTATION

Here are the guidelines my GTA will use for grading your **program documentation**:

1. **(5 points)** Top-level documentation describing student name, how to compile and execute the program, and overall conceptual framework documentation.
2. **(5 points)** Documentation header describing the **Initializations** section of your program.
3. **(5 points)** Documentation header describing the **Data Structures** (e.g., event list, condition list, objects list) of your program.
4. **(5 points)** Documentation header describing the **Time Flow Mechanism / Clock Update** section of your program.
5. **(5 points)** Documentation header describing **Each Event / Activity Action / Object Scan Routine** of your program. (Take 5 points off for each.)
6. **(5 points)** Documentation header describing the **Random Number Generator** of your program.
7. **(5 points)** Documentation header describing the **Exponential Random Variate Generator** of your program.
8. **(5 points)** Documentation header describing the **Output** section of your program.

ANALYTIC SOLUTION

(to use for Verification and Validation of your Simulation Model)

Performance Measures

True Value

- | | |
|--|-----------|
| 1. Macintosh utilization (ρ^{Mac}) | 0.6975 |
| 2. NeXTstation utilization (ρ^{NeXT}) | 0.775 |
| 3. LaserJet printer utilization (ρ^{LaserJet}) | 0.8536 |
| 4. Average time a job (which completes service at all three facilities) spends in the whole system (W) | 63.997951 |
| 5. Average number of jobs in the whole system (L) | 9.709233 |

Analytic Solution and Grading:

	ρ^{Mac}	ρ^{NeXT}	ρ^{LaserJet}	W	L
Mean Value	0.6975	0.775	0.8536	63.997951	9.709233
Acceptable Range	[0.677, 0.717]	[0.755, 0.795]	[0.833, 0.873]	[58, 70]	[8.7, 10.7]
Points Off	10	10	10	10	10