CS551
Warm-up Project #2

Bill Cheng

http://merlot.usc.edu/cs551-f12

Multi-threading Exercise

- Make sure you are familiar with the *pthreads* library
  - good source is the book by Nichols, Buttlar, and Farrell *"Pthreads Programming"*, O'Rielly & Associates, 1996
  - you must learn how to use mutex and condition variables correctly
    - `pthread_mutex_lock()/pthread_mutex_unlock()`
    - `pthread_cond_wait()/pthread_cond_signal()/ pthread_cond_broadcast()`
  - you must learn how to handle UNIX signals
    - `pthread_sigmask()/sigwait()`
    - `pthread_setcancelstate()`
    - `pthread_setcanceltype()`
    - `pthread_testcancel()`

pthread_sigmask()

- Look at the man pages of `pthread_sigmask()` on nunki and try to understand the example there
  - designate child thread to handler SIGINT
  - parent thread blocks SIGINT

```
#include <pthread.h>
/* #include <thread.h> */

thread_t user_threadID;
sigset_t new;

void *handler(), interrupt();

main( int argc, char *argv[] )  {
    sigemptyset(&new);
    sigaddset(&new, SIGINT);

    pthread_sigmask(SIG_BLOCK, &new, NULL);
    pthread_create(&user_threadID, NULL, handler, argv[1]);
    pthread_join(user_threadID, NULL);

    printf("thread handler, %d exited\n",user_threadID);
    sleep(2);
    printf("main thread, %d is done\n", thr_self());
} /* end main */
```

pthread_sigmask()

- Child thread example
  - child thread unblocks SIGINT

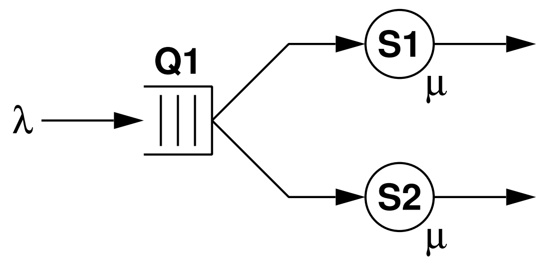
```
struct sigaction act;

void *
handler(char argv1[])
{
    act.sa_handler = interrupt;
    sigaction(SIGINT, &act, NULL);
    pthread_sigmask(SIG_UNBLOCK, &new, NULL);
    printf("\n Press CTRL-C to deliver SIGINT\n");
    sleep(8);  /* give user time to hit CTRL-C */
}

void
interrupt(int sig)
{
    printf("thread %d caught signal %d\n", thr_self(), sig);
}
```

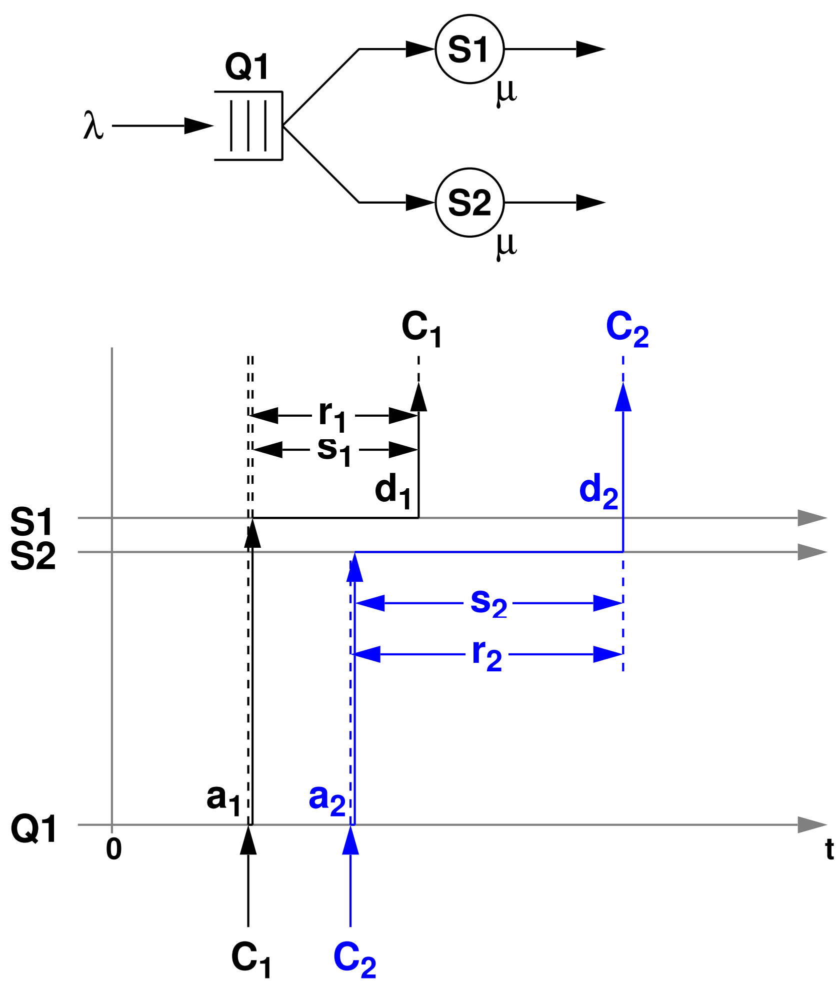
  - child thread is designated to handle SIGINT, no other thread will get SIGINT

Queueing Abstraction



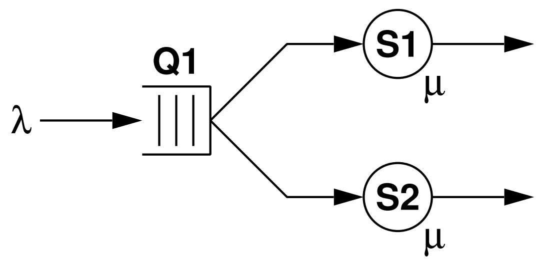
- **Ex:**
  - **line at a bank**
  - **multiprocessor executing jobs from a shared job queue**
  - **ER**

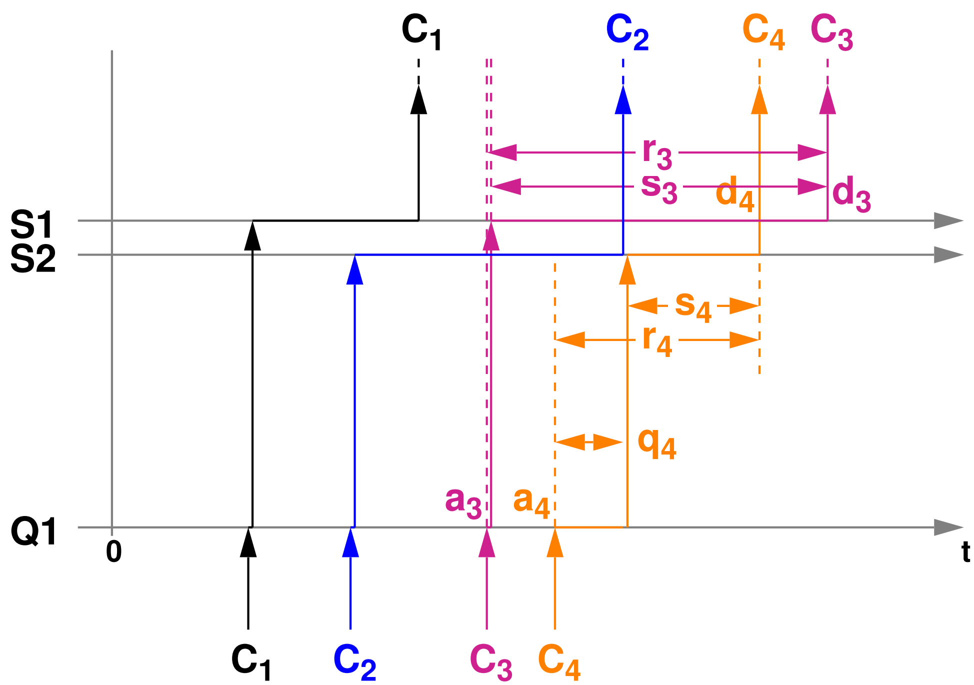
Arrivals & Departures



- a_i : arrival time
- d_i : departure time
- s_i : service time
- r_i : response (system) time
- q_i : queueing time

Arrivals & Departures (Cont...)





- q_1, q_2, q_3 ~ 0
- $q_4 > 0$

Event Driven Simulation

- An *event queue* is a sorted list of events according to timestamps; smallest timestamp at the head of queue
- *Object oriented:* every object has a "next event" (what it will do next if there is no interference), this event is inserted into the event queue
- Execution: remove an event from the head of queue, "execute" the event (notify the corresponding object so it can insert the next event)
- Insert into the event queue according to timestamp of a new event; insertion may cause additional events to be deleted or inserted
- Potentially repeatable runs (if the same seed is used to initialize random number generator)

Event Driven Simulation (Cont...)

- Ex: 4 objects, A (arrival), Q1 (passive object, does not generate events), S1, S2
  - Initially:
    - A : [a_1, create(C_1)]
    - Q1 : empty
    - S1 : NULL
    - S2 : NULL
  - only one event, next event to fire is [a_1, create(C_1)]

    create(C_1), Q1->enqueue(C_1)

    Q1->dequeue(C_1), S1->serve(C_1)
    - A : [a_2, create(C_2)]
    - Q1 : empty
    - S1 : [d_1, destroy(C_1)]
    - S2 : NULL
  - min(a_2, d_1) = a_2, next event to fire is [a_2, create(C_2)]

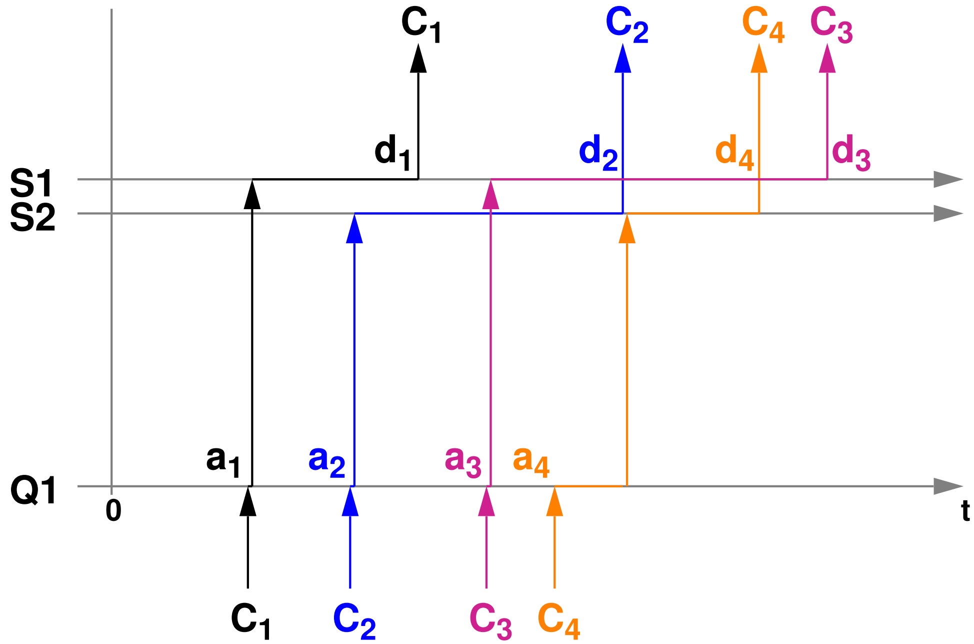
    create(C_2), Q1->enqueue(C_2)

    Q1->dequeue(C_2), S2->serve(C_2)
    - A : [a_3, create(C_3)]
    - Q1 : empty
    - S1 : [d_1, destroy(C_1)]
    - S2 : [d_2, destroy(C_2)]

Event Driven Simulation (Cont...)

- min(a_3, d_1, d_2) = d_1, next event to fire is [d_1, destroy(C_1)]
  - destroy(C_1)
  - A : [a_3, create(C_3)]
  - S1 : NULL
  - Q1 : empty
  - S2 : [d_2, destroy(C_2)]
- min(a_3, d_2) = a_3, next event to fire is [a_3, create(C_3)]
  - create(C_3), Q1->enqueue(C_3)
  - Q1->dequeue(C_3), S1->serve(C_3)
  - A : [a_4, create(C_4)]
  - S1 : [d_3, destroy(C_3)]
  - Q1 : empty
  - S2 : [d_2, destroy(C_2)]
- min(a_4, d_2, d_3) = a_4, next event to fire is [a_4, create(C_4)]
  - create(C_4), Q1->enqueue(C_4)
  - A : [a_5, create(C_5)]
  - S1 : [d_3, destroy(C_3)]
  - Q1 : C_4
  - S2 : [d_2, destroy(C_2)]
- etc.

Event Driven Simulation (Cont...)



Time Driven Simulation

- **Every active object is a thread**
  - **a customer is a passive object, it gets passed around**
- **To execute a job for x msec, the thread sleeps for x msec**
  - **nunki.usc.edu does not run a realtime OS**
  - **it may not get woken up more than x msec later, and sometimes, *a lot more* than x msec later**
    - **you need to decide if the extra delay is reasonable or it is due to a bug in your code**
- **Let your machine decide which thread to run next (irreproducible results)**
- **Compete for resources (such as Q1), must use mutex**

Time Driven Simulation (Cont...)

- You will need to implement 3 threads (or 1 main thread and 3 child threads)
  - the *arrival thread* sits in a loop
    - sleeps for an interval, trying to match a given interarrival time (from trace or coin flip)
    - wakes up, creates a customer object, enqueues the customer to Q1, and goes back to sleep
    - if the Q1 was empty before, need to *signal* or *broadcast* a *queue-not-empty condition*
  - two *server threads*
    - initially blocked, *waiting* for the *queue-not-empty condition* to be *signaled*
    - (cont...)

Time Driven Simulation (Cont...)

- two *server threads* (cont...)
  - when it is unblocked, if Q1 is not empty, dequeues a customer, sleeps for an interval matching the service time of the customer, eject the customer from the system, check if Q1 is empty, etc.
  - if there is no work to perform, go wait for the queue-not-empty condition to be signaled

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- arrival thread will stop generating customers and terminate
  - the arrival thread needs to clear out Q1
- server threads must finish serving its current customer
- must print statistics for all customer seen

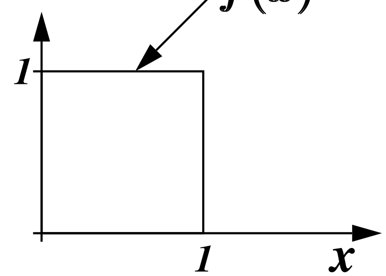
Time Driven Simulation (Cont...)

- Notation: α_i : inter-arrival time for customer i $(a_i - a_{i-1})$, $a_0 = 0$
  β_i : service time of customer i
  - Initially:
    - A : sleep($\alpha_1 = a_1$)
    - Q1 : empty
    - S1 : idle
    - S2 : idle
  - A wakes up at a_1: create(C_1), Q1->enqueue(C_1)
    Q1->dequeue(C_1), S1->serve(C_1)
    - A : sleep(α_2)
    - Q1 : empty
    - S1 : sleep(β_1)
    - S2 : idle
  - A wakes up at $a_1 + \alpha_2$: create(C_2), Q1->enqueue(C_2)
    Q1->dequeue(C_2), S2->serve(C_2)
    - A : sleep(α_3)
    - Q1 : empty
    - S1 : sleeping...
    - S2 : sleep(β_2)
  - etc.

Coin Flipping

- **Uniform distribution**
  - **probability mass function (pmf), denoted by *f(x)***

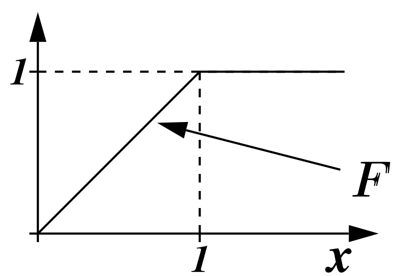
$$f(x) = \begin{cases} 1 & 0 \le x \le 1 \\ 0 & \text{otherwise} \end{cases}$$



$$\int_{-\infty}^{\infty} f(x)dx = 1$$

  - **Probability Distribution Function (PDF), denoted by *F(x)***

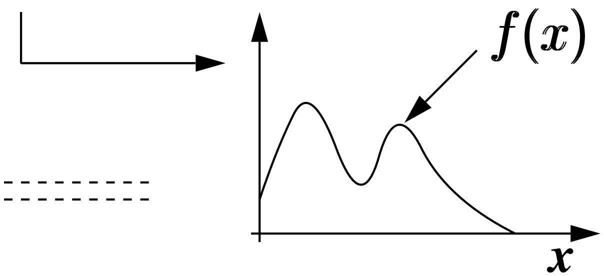
$$F(x) = \int_{-\infty}^{x} f(w)dw$$



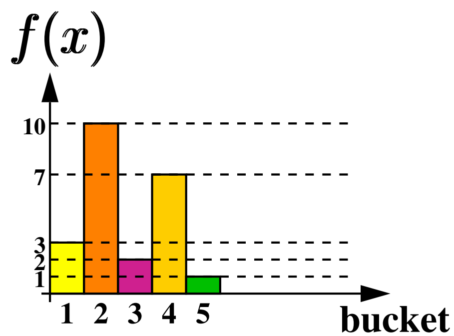
$$F(x) = \begin{cases} 0 & x < 0 \\ x & 0 \le x \le 1 \\ 1 & x > 1 \end{cases}$$

Coin Flipping (Cont...)

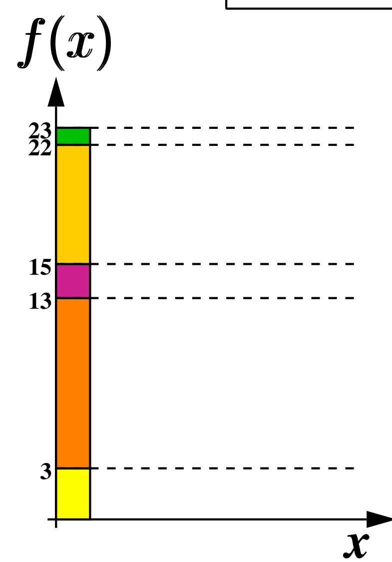
- How do you flip a coin according to this distribution?



- Think about discrete case:

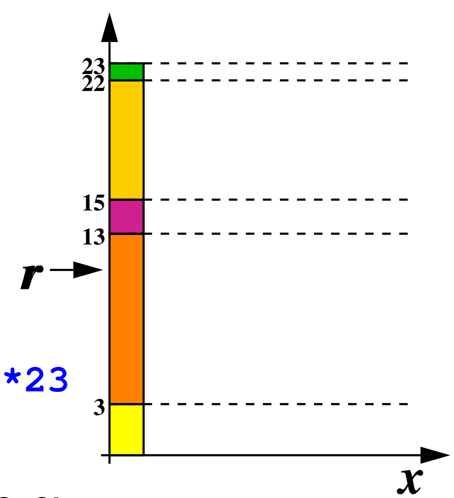


Add them up:



Flip a coin between 0 and 23

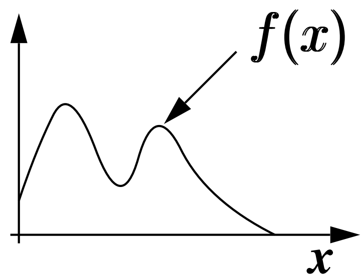
r = `drand48()*23`



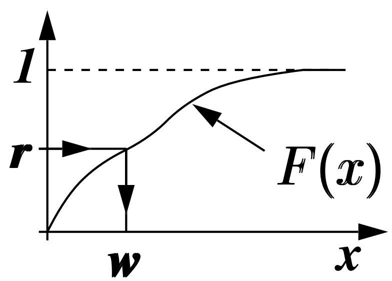
- r lies between 3 and 13, so we have randomly chosen bucket #2

Coin Flipping (Cont...)

- ***Q:*** **What were we doing when we "added them up"?**
  - ***A:*** **We were doing "integration"**



- **Hint:** $0 \le F(x) \le 1 \quad \text{for any } x$

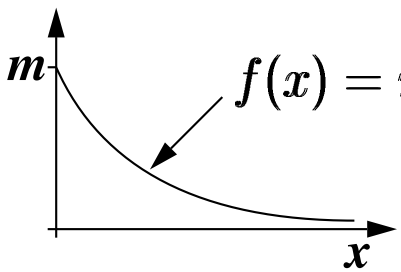


r = `drand48()`
w = ?

  - **can *numerically* compute** w

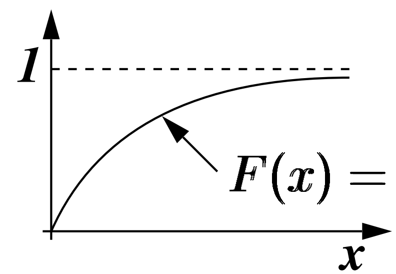
Coin Flipping (Cont...)

Exponential distribution

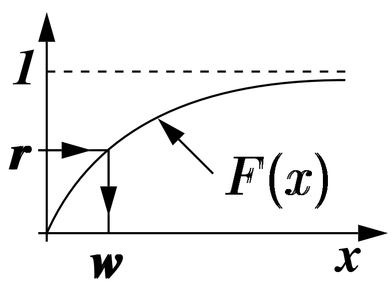


$$f(x) = me^{-mx}$$

Note: inter-arrival time of a Poisson process is Exponentially distributed



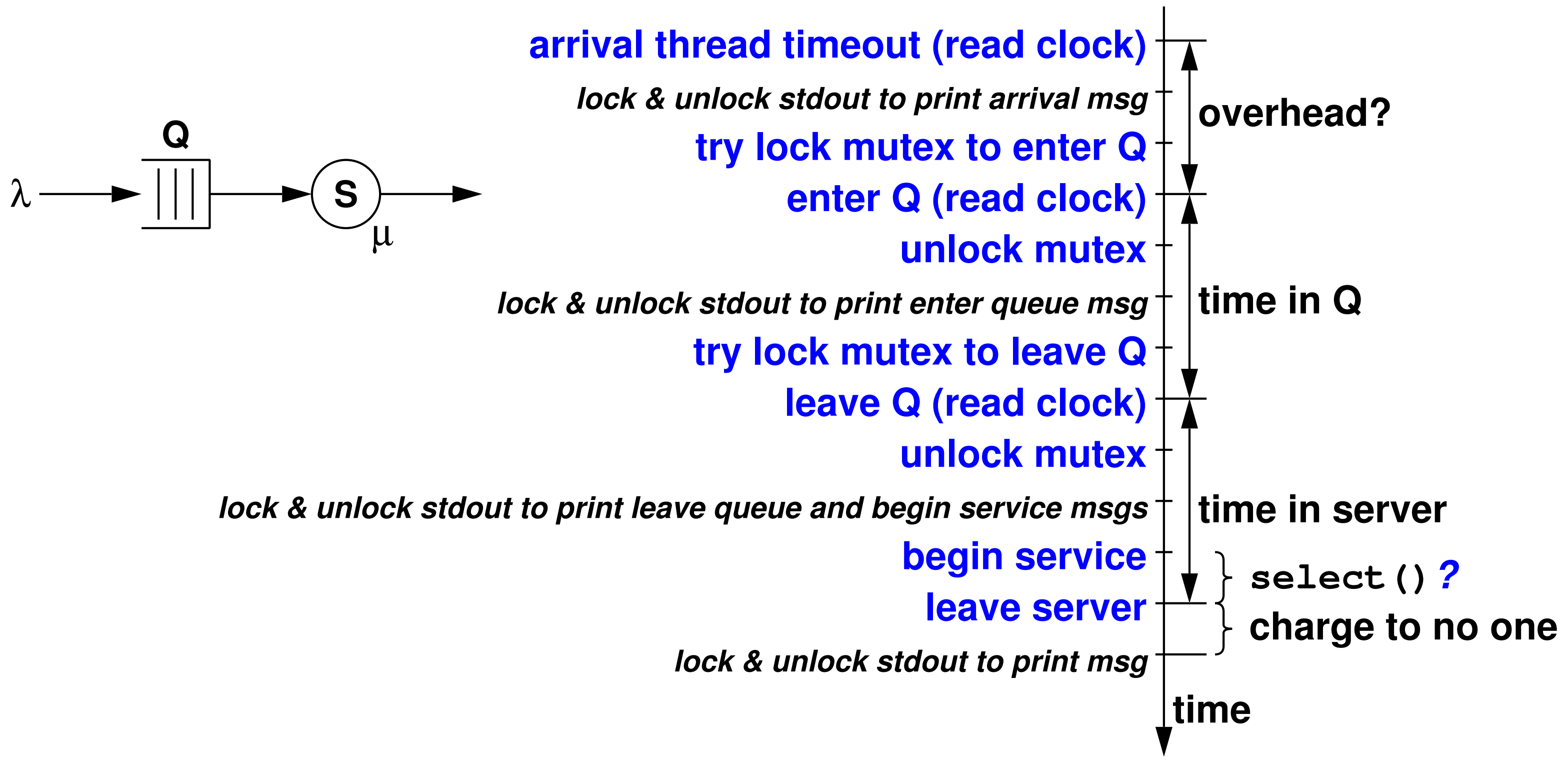
$$F(x) = \int_0^x f(y)dy = 1 - e^{-mx}$$



$$F(x)$$

r = `drand48()`
w = ?

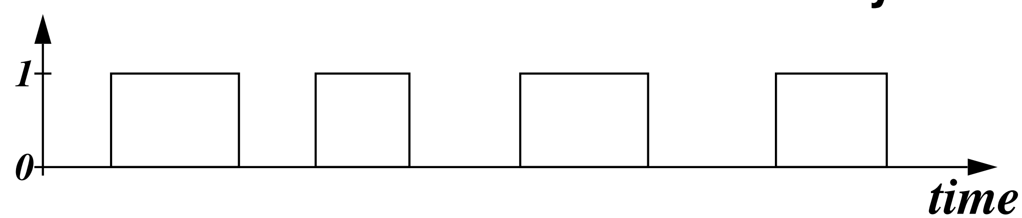
Calculating Statistics



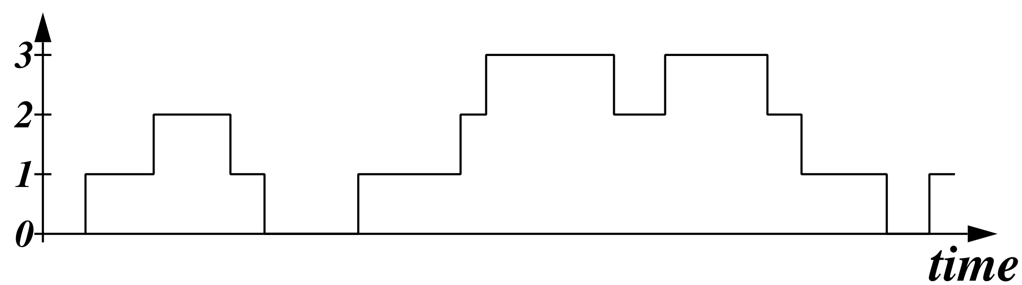
- time between **begin service** and **leave server** is the amount of time in `select()`

Mean and Standard Deviation

- **Average time**
  - **for *n* samples, add up all the time and divide by *n***
- **Average number of customer at a server**
  - **same a fraction of time the server is busy**



- **Average number of customer at Q1**



- **Standard deviation is the squareroot of variance**
  - $Var[X] = E[X^2] - (E[X])^2$