CS 33

Job Control
and
Intro to Storage Allocation

Job Control

```
$ who
```
  - foreground job

```
$ multiprocessProgram
```
  - foreground job

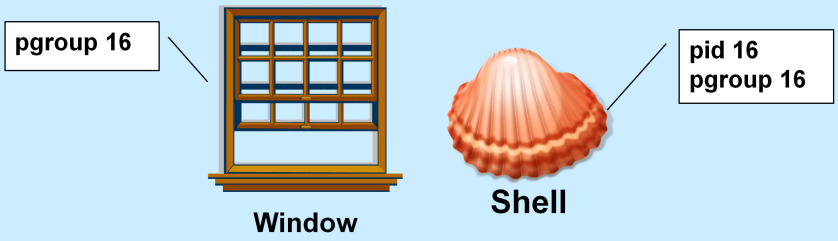
```
^Z
suspended
$ bg
[1] multiprocessProgram &
```
  - multiprocessProgram becomes background job 1

```
$ longRunningProgram &
[2]
$ fg %1
multiprocessProgram
```
  - multiprocessProgram is now the foreground job

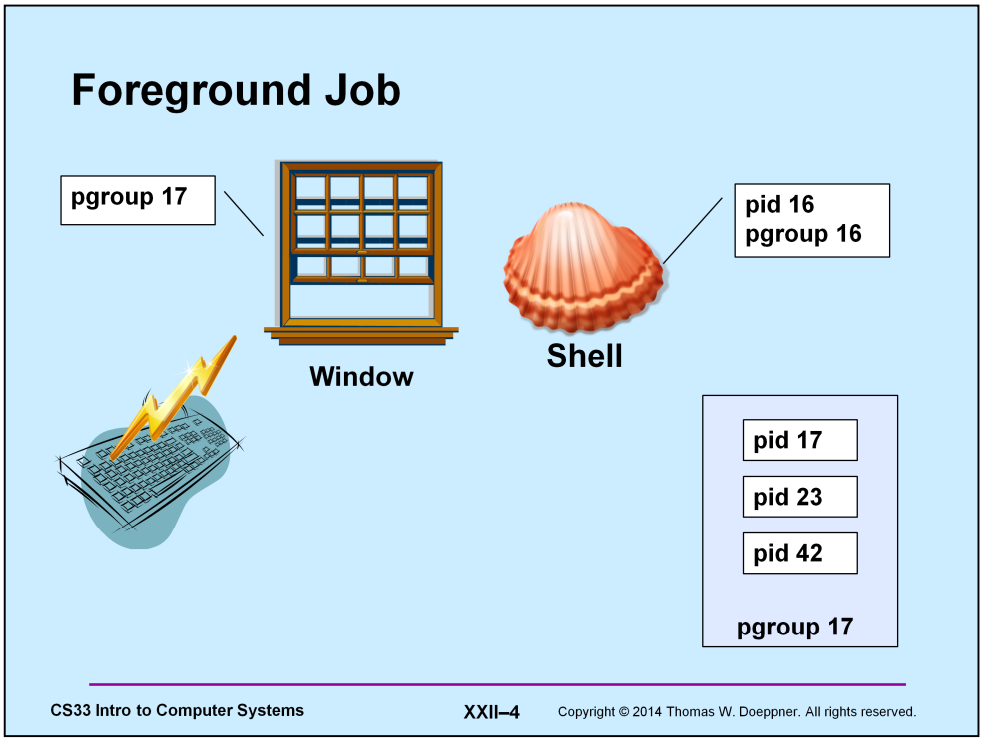
```
^C
$
```

Keyboard-Generated Signals

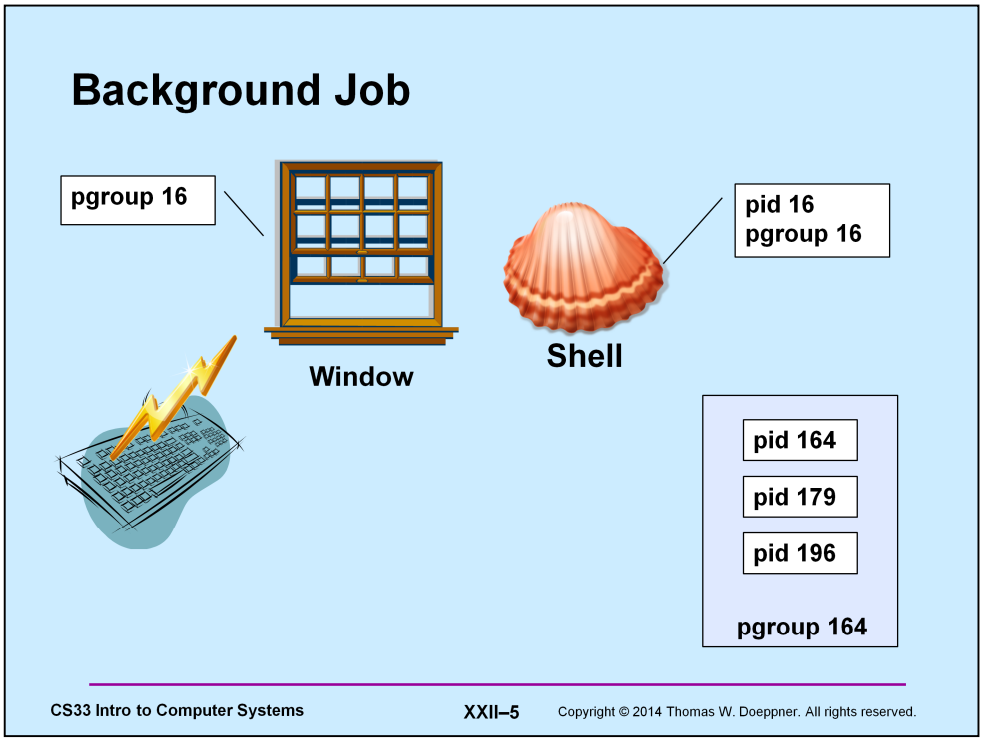
- You type ctrl-C
- How does the system know which process(es) to send the signal to?



Keyboard-generated signals are sent to all processes in the current window's process group. Unless you do something about it, this group consists of the shell and any of its descendents that have not been moved to other process groups.



When running a foreground job (i.e., a command typed into the shell without an ampersand), its processes are put in a separate process group. The window's process group is changed to that of the job, so that keyboard-generated signals are directed to the processes of the job and not to the shell. A process group's ID is the pid of its first member.



Keyboard-generated signals are not delivered to background jobs (for example, commands that are typed in with ampersands).

Creating a Process Group

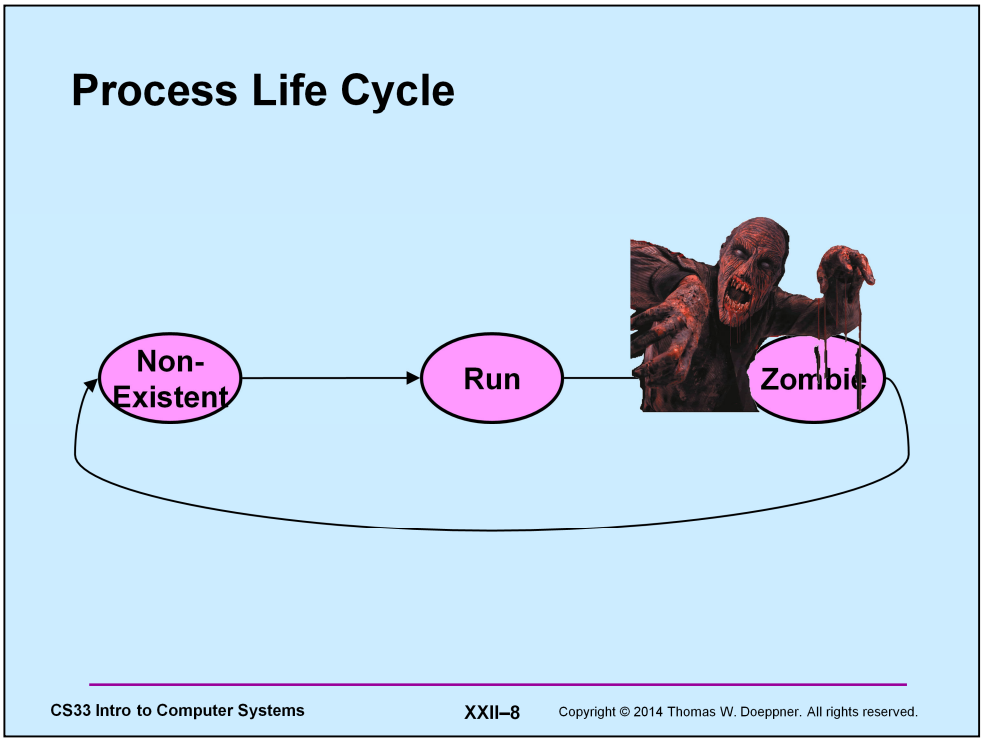
```
if (fork() == 0) {
  // child
  setpgid(0, 0);
     /* puts current process into a
        new process group whose ID is
        the process's pid
     */
  ...
  execv(...);
}
// parent
```


The first argument to setpgid is the process ID of the process whose process group is being changed; 0 means the pid of the calling process. The second argument is the ID of the process group it's being added to. If it's 0, then a new group is created whose ID is that of the calling process. Future children of this process join the new process group.

Setting the Foreground Process Group

```
tcsetpgrp(fd, pgid);
  // sets the process group of the
  // terminal (window) referenced by
  // file descriptor fd to be pgid
```


The tcsetpgrp command sets the process group associated with a terminal (i.e., a window), thus setting that process group to be the foreground process group.



A Unix process is always in one of three states, as shown in the slide. When created, the process is put in the *run* state, meaning that it's active. When a process terminates, its parent might wish to find out and, perhaps, retrieve the exit value. Thus when a process terminates, some information about it must continue to exist until passed on to the parent (via the parent's executing the *wait* or *waitpid* system call). So, when a process calls *exit*, it enters the *zombie* state and its exit code is kept around. Furthermore, the process's ID is preserved so that it cannot be reused by a new process. Once the parent does its *wait*, the exit code and process ID are no longer needed, so the process completely disappears and is marked as being in the *non-existent* state — it doesn't exist anymore.

Reaping: Zombie Elimination

- **Shell must call `waitpid` on each child**
  - **easy for foreground processes**
  - **what about background?**

```
pid_t waitpid(pid_t pid, int *status, int options);
```

  - ***pid* options:**

< −1	**any child process whose process group is |pid|**
−1	**any child process**
0	**any child process whose process group is that of caller**
>0	**process whose ID is equal to pid**

  - `wait(&status)` **is equivalent to** `waitpid(-1, &status, 0)`

(continued)

```
pid_t waitpid(pid_t pid, int *status, int options);
```

- *options* are some combination of the following
  - » WNOHANG
    - return immediately if no child has exited (returns 0)
  - » WUNTRACED
    - also return if a child has stopped (been suspended)
  - » WCONTINUED
    - also return if a child has been continued (resumed)

When to Call `waitpid`

- Shell reports status only when it is about to display its prompt
  - thus sufficient to check on background jobs just before displaying prompt

`waitpid` status

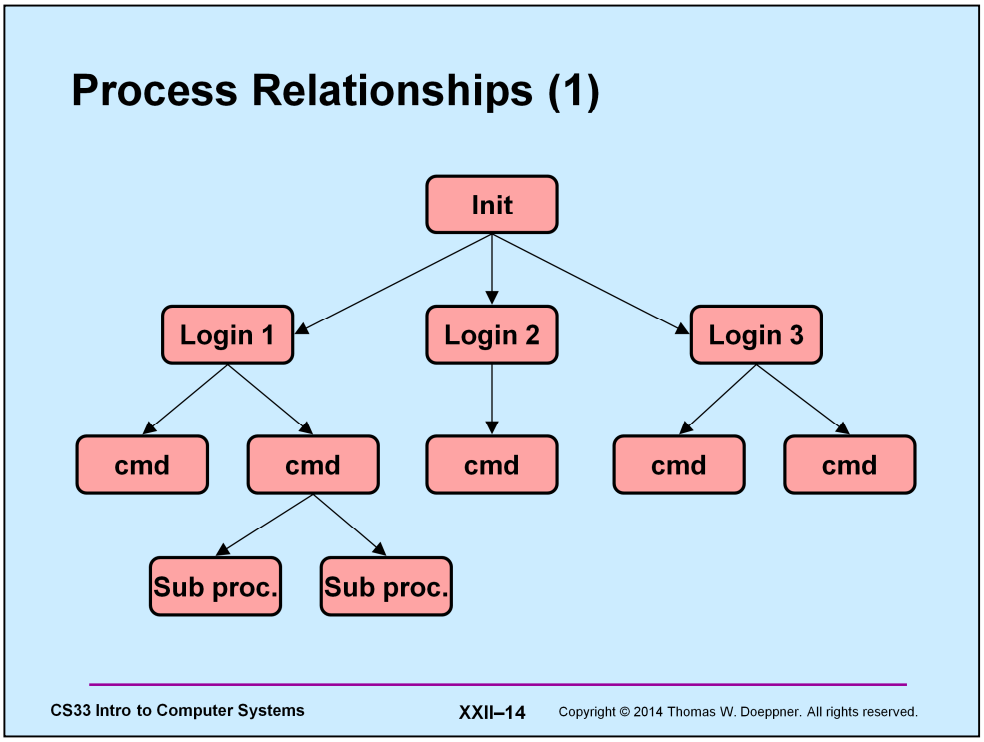
- WIFEXITED(*status): 1 if the process terminated normally and 0 otherwise
- WEXITSTATUS(*status): argument to exit
- WIFSIGNALED(*status): 1 if the process was terminated by a signal and 0 otherwise
- WTERMSIG(*status): the signal which terminated the process if it terminated by a signal
- WIFSTOPPED(*status): 1 if the process was stopped by a signal
- WSTOPSIG(*status): the signal which stopped the process if it was stopped by a signal
- WIFCONTINUED(*status): 1 if the process was resumed by SIGCONT and 0 otherwise

These are macros that can be applied to the status output argument of waitpid. Note that “terminated normally” means that the process terminated by calling exit. Otherwise it was terminated because it received a signal, which it neither ignored nor had a handler for, whose default action was termination.

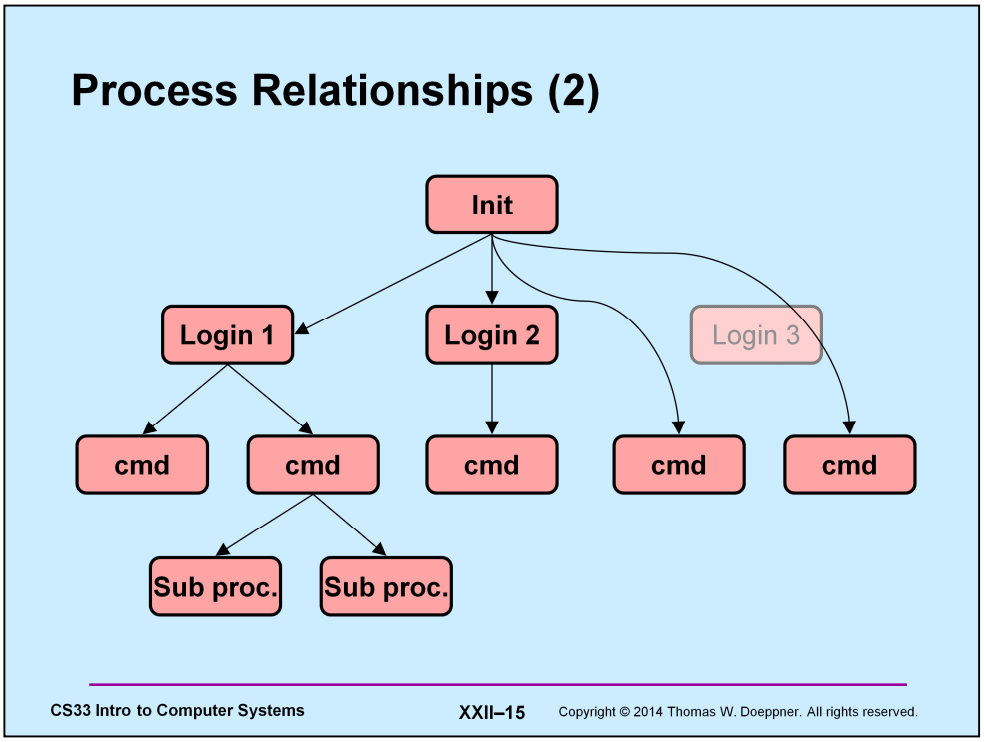
Example (in Shell)

```
int wret, status;
while ((wret = waitpid(-1, &wstatus, WNOHANG|WUNTRACED)) > 0){
  // examine all children who've terminated or stopped
  if (WIFEXITED(wstatus)) {
    // terminated normally
    ...
  }
  if (WIFSIGNALED(wstatus)) {
    // terminated by a signal
    ...
  }
  if (WIFSTOPPED(wstatus)) {
    // stopped
    ...
  }
}
```


This code might be executed by a shell just before it displays its prompt. The loop iterates through all child processes that have either terminated or stopped. The WNOHANG option causes waitpid to return 0 (rather than waiting) if the caller has extant children, but there are no more that have either terminated or stopped. If the caller has no children, then waitpid returns -1.

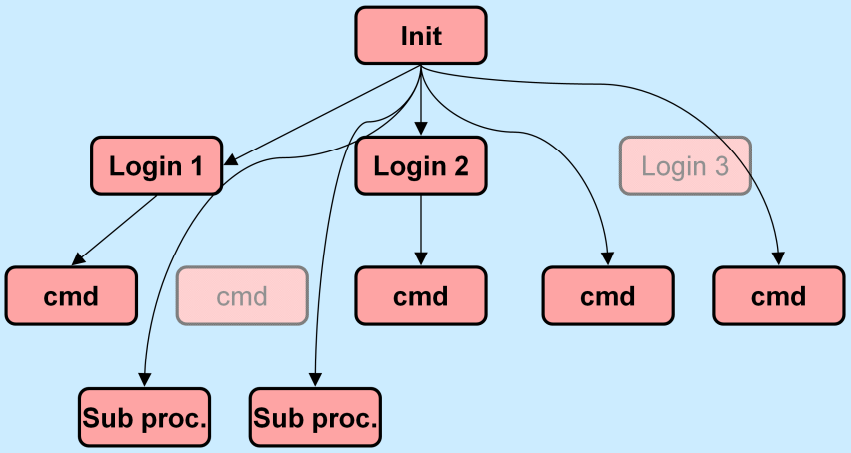


The init process is the common ancestor of all other processes in the system. It continues to exist while the system is running. It starts things going soon after the system is booted by forking child processes that exec the login code. These login processes then exec the shell. Note that, since only the parent may wait for a child's termination, only parent-child relationships are maintained between processes.



When a process terminates, all of its children are inherited by the *init* process, process number 1.

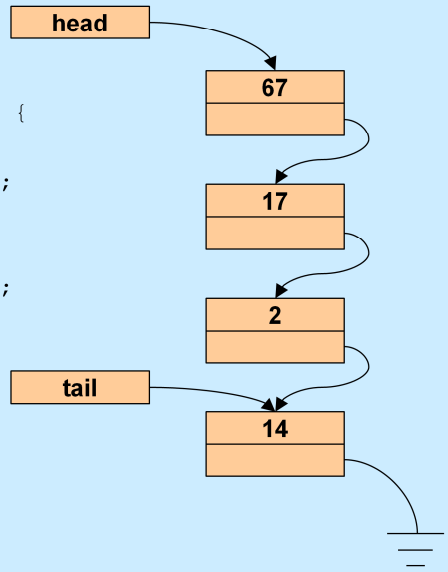
Process Relationships (3)



A Queue

```
typedef struct list_element {
  int value;
  struct list_element *next;
} list_element_t;

list_element_t *head, *tail;
```



malloc and free

```
void *malloc(size_t size)
```

- allocate *size* bytes of storage and return a pointer to it
- returns 0 (NULL) if the requested storage isn't available

```
void free(void *ptr)
```

- free the storage pointed to by *ptr*
- *ptr* must have previously been returned by *malloc* (or other storage-allocation routine — *calloc* and *realloc*)

Enqueue

```
int enqueue(int value) {
  list_element_t *newle
      = (list_element_t *)malloc(sizeof(list_element_t));
  if (newle == 0)
    return 0;
  newle->value = value;
  newle->next = 0;
  if (head == 0) {
    // list was empty
    assert(tail == 0);
    head = newle;
  } else {
    tail->next = newle;
  }
  tail = newle;
  return 1;
}
```


Dequeue

```
int dequeue(int *value) {
  list_element_t *first;
  if (head == 0) {
    // list is empty
    return 0;
  }
  *value = head->value;
  first = head;
  head = head->next;
  if (tail == first)
    assert(head == 0);
    tail = 0;
  }
  free(first);
  return 1;
}
```


realloc

```
void *realloc(void *ptr, size_t size)
```

- change the size of the storage pointed to by *ptr*
- the contents, up to the minimum of the old size and new size, will not be changed
- ptr must have been returned by a previous call to malloc, realloc, or calloc
- it may be necessary to allocate a completely new area and copy from the old to the new
  - » thus the return value may be different from *ptr*
  - » if copying is done the old area is freed
- returns 0 if the operation cannot be done

Get (contiguous) Input (1)

```
char *getinput() {
  int alloc_size = 4;  // start small
  int read_size = 4;   // max number of bytes to read
  int next_read = 0;   // index in buf of next read
  int bytes_read;      // number of bytes read
  char *buf = (char *)malloc(alloc_size);
  char *newbuf;

  if (buf == 0) {
    // no memory
    return 0;
  }
```


In this example, we're to read a line of input. However, we have no upper bound on its length. So we start by allocating four bytes of storage for the line. If that's not enough (the four bytes read in don't end with a '\n'), we then double our allocation and read in more up to the end of the new allocation, if that's not enough, we double the allocation again, and so forth. When we're finished, we reduce the allocation, giving back to the system that portion we didn't need.

Get (contiguous) Input (2)

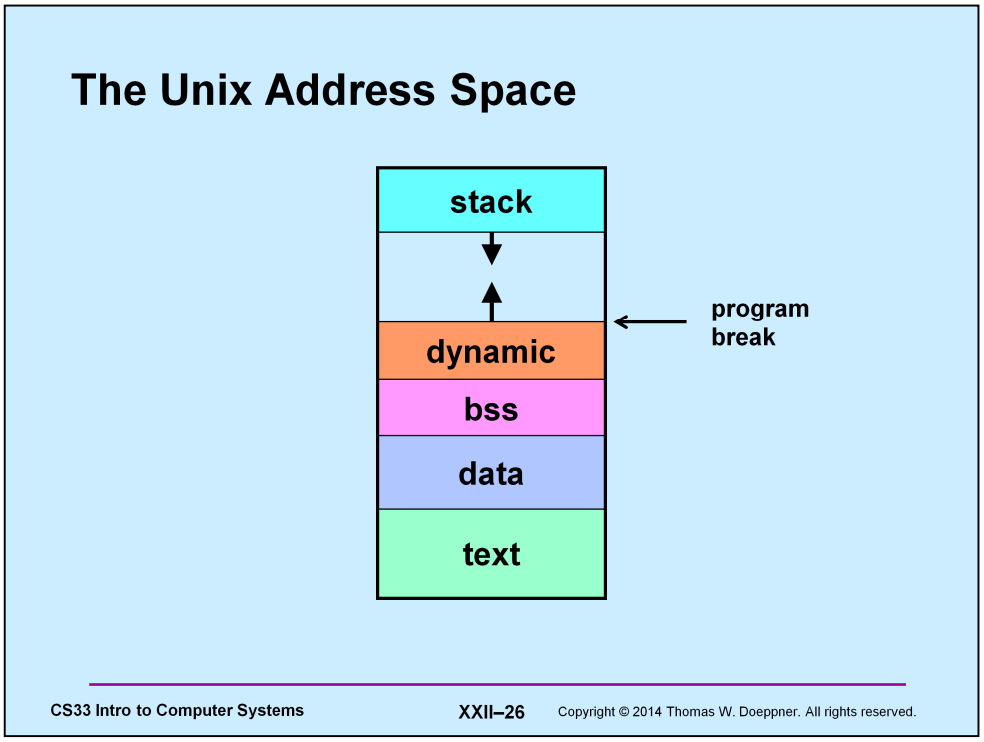
```
while (1) {
  if ((bytes_read
        = read(0, buf+next_read, read_size)) == -1) {
    perror("getinput");
    return 0;
  }
  if (bytes_read == 0) {
    // eof, possibly premature
    return buf;
  }
  if ((buf+next_read)[bytes_read-1] == '\n') {
    // end of line
    break;
  }
```


Get (contiguous) Input (3)

```
    next_read += read_size;
    read_size = alloc_size;
    alloc_size *= 2;
    newbuf = (char *)realloc(buf, alloc_size);
    if (newbuf == 0) {
      // realloc failed: not enough memory.
      // Free the storage allocated previously and report
      // failure
      free(buf);
      return 0;
    }
    buf = newbuf;
  }
```


Get (contiguous) Input (4)

```
  // reduce buffer size to the minimum necessary
  newbuf = (char *)realloc(buf,
      alloc_size - (read_size - bytes_read));
  if (newbuf == 0) {
    // couldn't allocate smaller buf
    return buf;
  }
  return newbuf;
}
```



The program break is the upper limit of the currently allocated dynamic region.

sbrk System Call

```
void *sbrk(intptr_t increment)
```

- moves the program break by an amount equal to *increment*
- returns the previous program break
- *intptr_t* is typedef'd to be a *long*

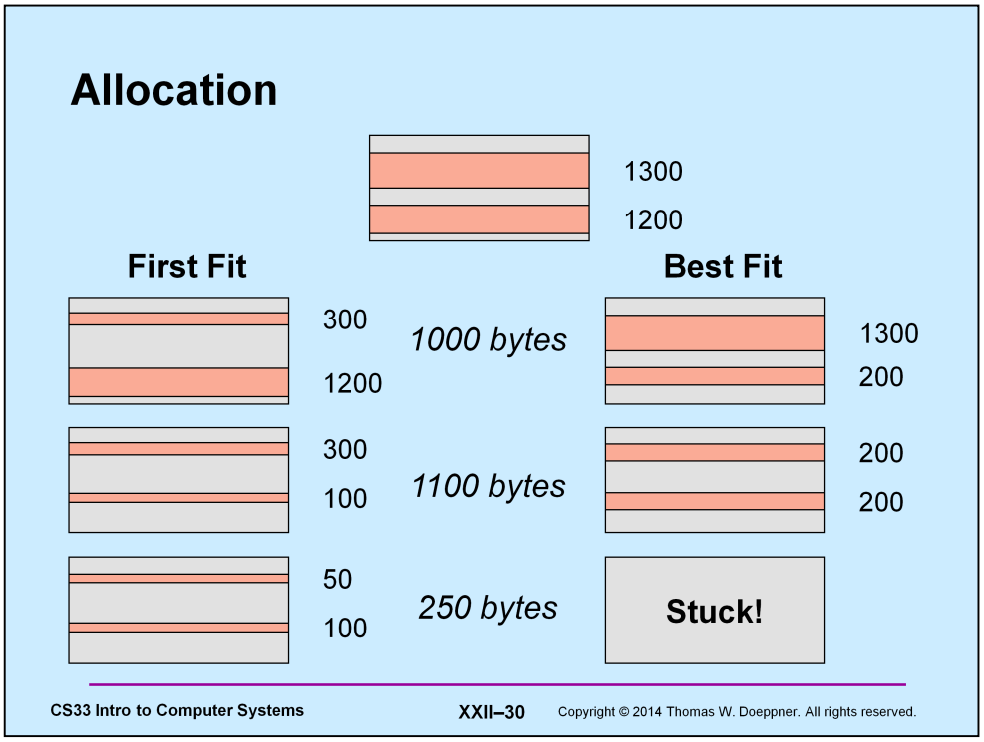
Managing Dynamic Storage

- Strategy
  - get a "chunk" of memory from the OS using *sbrk*
    - » pool of available storage, aka the "heap"
  - *malloc*, *calloc*, *realloc*, and *free* use this storage if possible
    - » they manage the heap
  - if not possible, get more storage from OS
    - » heap is made larger (by calling sbrk)
- Important note:
  - when process terminates, all storage is given back to the system
    - » all memory-related sins are forgotten!

Dynamic Storage Allocation Overview

- Goal: allow dynamic creation and destruction of data structures
- Concerns:
  - efficient use of heap
  - efficient use of processor time
- Example:
  - first-fit vs. best-fit allocation

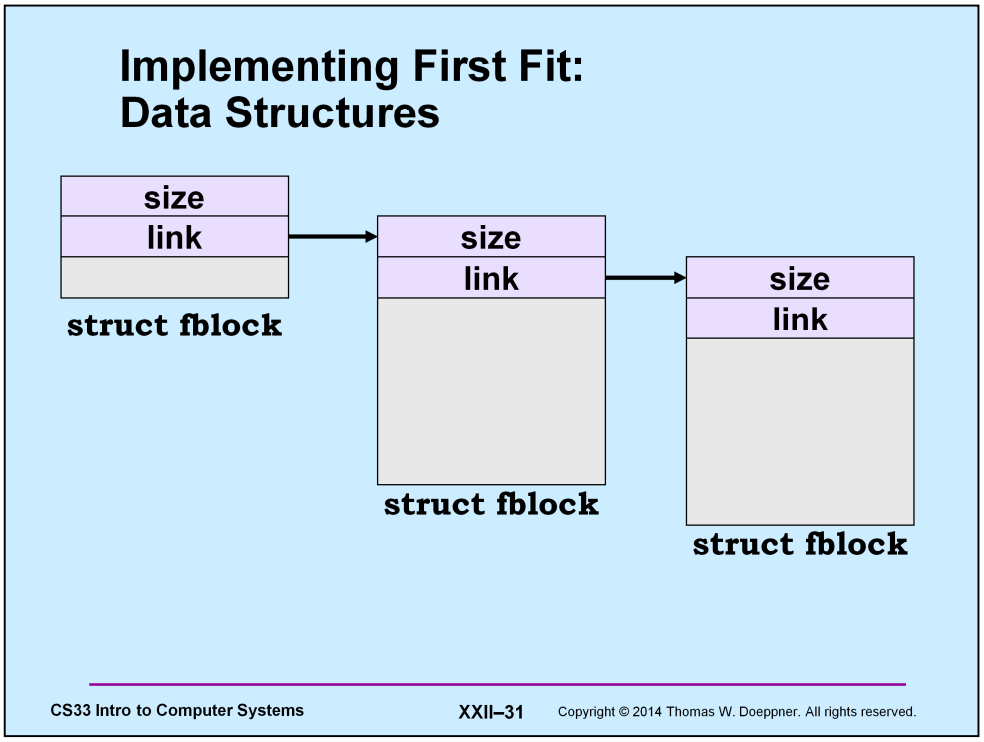
Much of the material in this and the next few slides is taken from *The Art of Computer Programming, Vol. 1: Fundamental Algorithms*, by D. Knuth.



Consider the situation in which we have one large pool of memory from which we will allocate (and to which we will liberate) variable-sized pieces of memory. Assume that we are currently in the situation shown at the top of the picture: two unallocated areas of memory are left in the pool—one of size 1300 bytes, the other of size 1200 bytes. We wish to process a series of allocation requests, and will try out two different algorithms. The first is known as *first fit*—an allocation request is taken from the first area of memory that is large enough to satisfy the request. The second is known as *best fit*—the request is taken from the smallest area of memory that is large enough to satisfy the request. On the principle that whatever requires the most work must work the best, one might think that best fit would be the algorithm of choice.

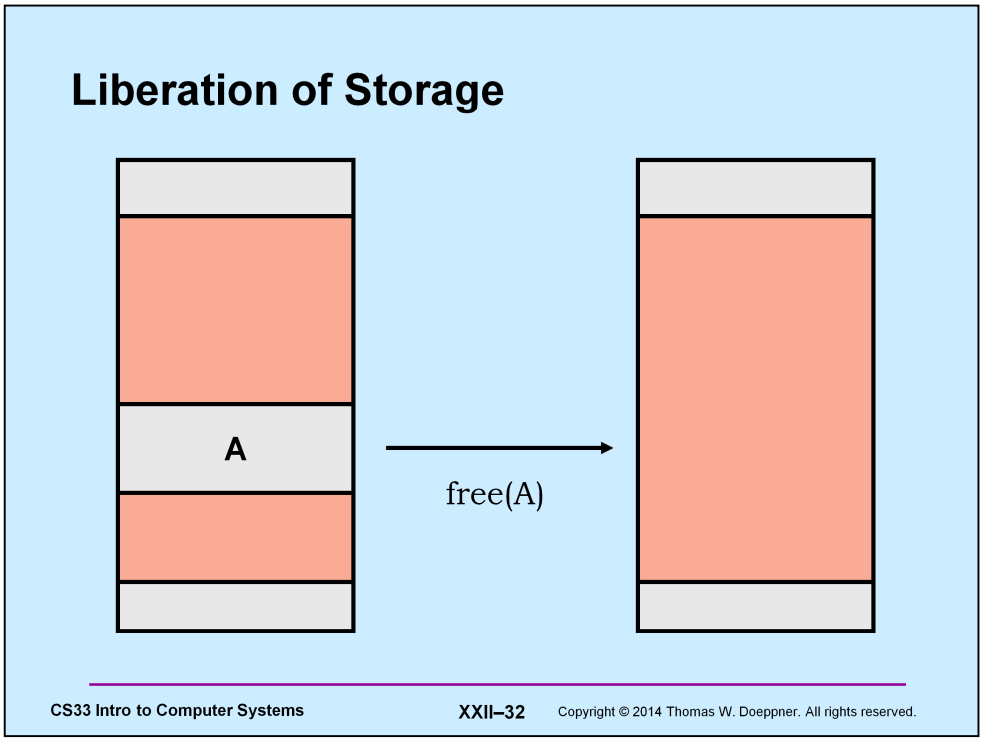
The picture illustrates a case in which first fit behaves better than best fit. We first allocate 1000 bytes. Under the first-fit approach (shown on the left side), this allocation is taken from the topmost region of free memory, leaving behind a region of 300 bytes of still unallocated memory. With the best-fit approach (shown on the right side), this allocation is taken from the bottommost region of free memory, leaving behind a region of 200 bytes of still-unallocated memory. The next allocation is for 1100 bytes. Under first fit, we now have two regions of 300 bytes and 100 bytes. Under best fit, we have two regions of 200 bytes. Finally, there is an allocation of 250 bytes. Under first fit this leaves behind two regions of 50 bytes and 100 bytes, but the allocation cannot be handled under best fit—neither remaining region is large enough.

Clearly, one could come up with examples in which best fit performs better. However, simulation studies performed by Knuth have shown that, on the average, first fit works best. Intuitively, the reason for this is that best fit tends to leave behind a large number of regions of memory that are too small to be of any use.

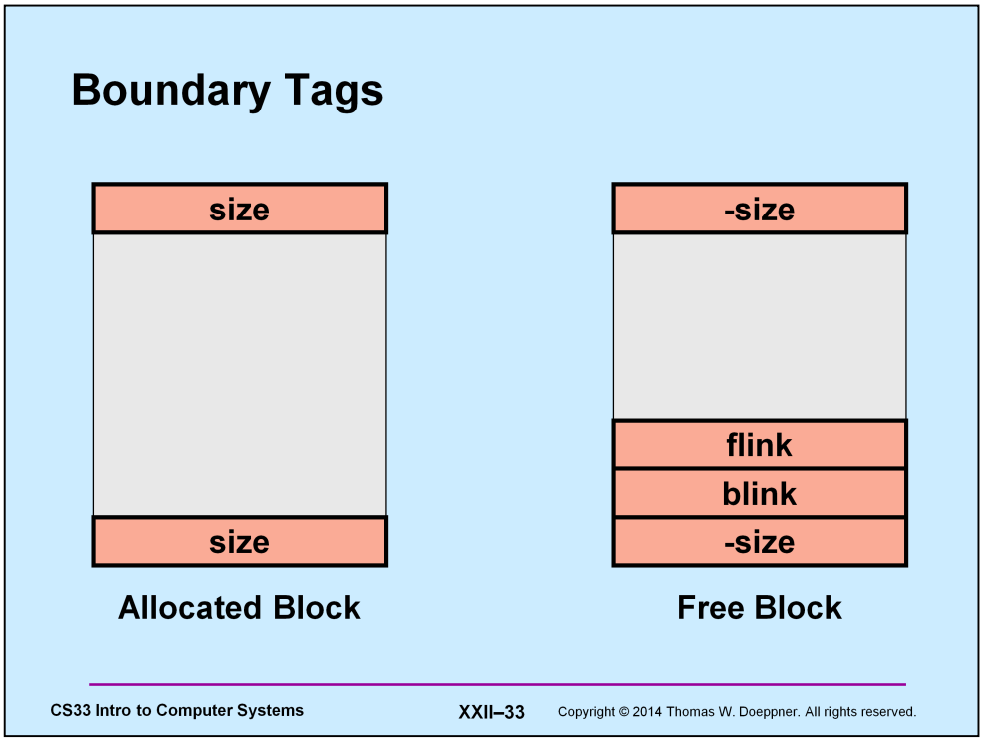


We now look at an implementation of the first-fit allocation algorithm. We need a data structure—*struct fblock*—to represent an unallocated region of memory. Since these regions are of variable size, the data structure has a *size* field. We need to link the unallocated regions together, and thus the data structure has a *link* field. Conceptually, the data structure represents the entire region of unallocated memory, but, since C has no natural ability to represent variable-sized structures, we define names for only the *size* and *link* fields.

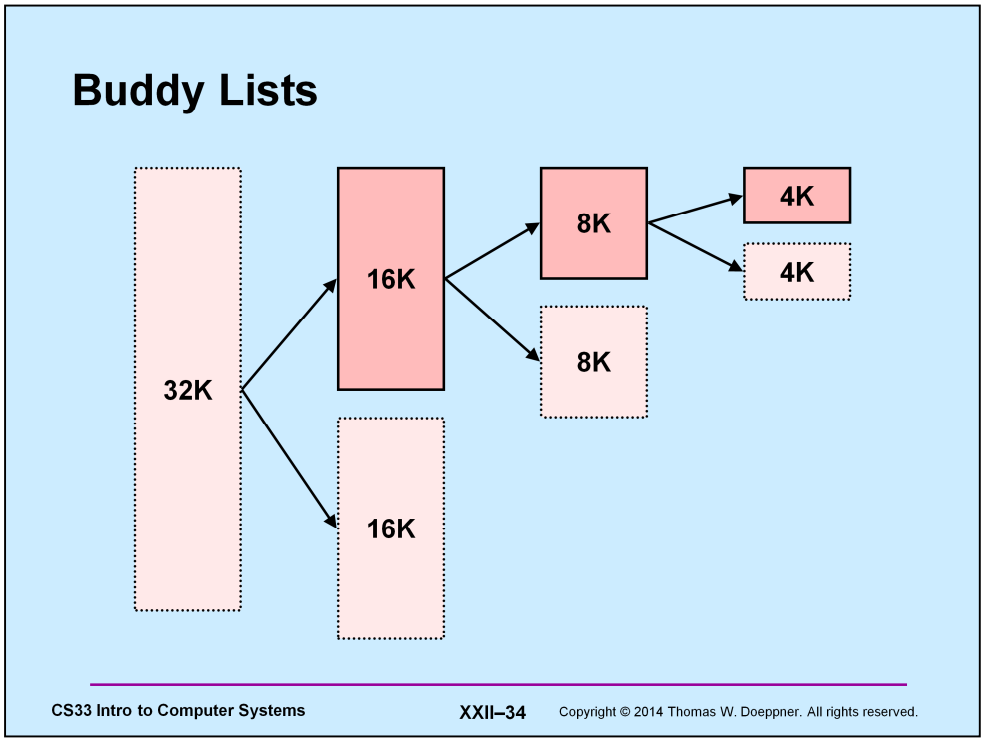
All of the fblocks are singly linked into a free list or avail list. The header for this list is also a *struct fblock*.



The liberation of storage is more difficult than its allocation, for the reason shown in the picture. Here the shaded regions are unallocated memory. The region of storage, A, separating the two unallocated regions is about to be liberated. The effect of doing this should be to produce one large region of unallocated storage rather three adjacent smaller regions. Thus the liberation algorithm must be able to handle this sort of situation.



A simple method for implementing storage liberation is to use a technique known as *boundary tags*. The idea is that each region of memory, whether allocated or unallocated, has a boundary tag at each end indicating its size and whether it is allocated or not. (A positive size means allocated, a negative size means unallocated.) Thus, when we liberate a region of memory, we can quickly check the adjacent regions to determine if they too are free. Free regions are linked into a doubly linked list; thus free blocks also contain two link fields—a forward link (*flink*) and a backward link (*blink*). We call the structure representing a free block a *struct block*. (In the picture, storage addresses increase towards the top of the page, so that a pointer to a *struct block* points to the bottom of the free block.)



The buddy system is a simple dynamic storage allocation scheme that works surprisingly well. Storage is maintained in blocks whose sizes are powers of two. Requests are rounded up to the smallest such power greater than the request size. If a block of that size is free, it's taken, otherwise the smallest free block greater than the desired size is found and split in half — the two halves are called buddies. If the size of either buddy is what's needed, one of them is allocated (the other remains free). Otherwise one of the buddies is split in half. This splitting continues until the appropriate size is reached.

Liberating a block now is easy: if the block's buddy is free, you join the block being liberated with its buddy, forming a larger free block. If this block's buddy is free, you join the two of them, and so forth until the largest free block possible is formed.

One bit in each block, say in its first or last byte, is used as a tag to indicate whether the block is free (this portion of each block can clearly not be used for data and thus is overhead). Determining the address of a block's buddy is simple. If the block is of size 2^k, then the least significant k-1 bits of its address are zeros. The next bit (to the left) is zero in one buddy and one in the other; so you simply complement that bit to get the buddy's address.