Process

What is a Process?

- Definition: an executable instance of a program
  - A process is the *context* (the information/data) maintained for an executing program
  - How is a program different from a process?
    - a program is a passive collection of instructions;
    - a process is the actual execution of those instructions; each process has a state to keep track of its execution

- Process provides each program with two key abstractions
  - Logical control flow
    - Each program seems to have exclusive use of the CPU
  - Private virtual address space
    - Each program seems to have exclusive use of main memory

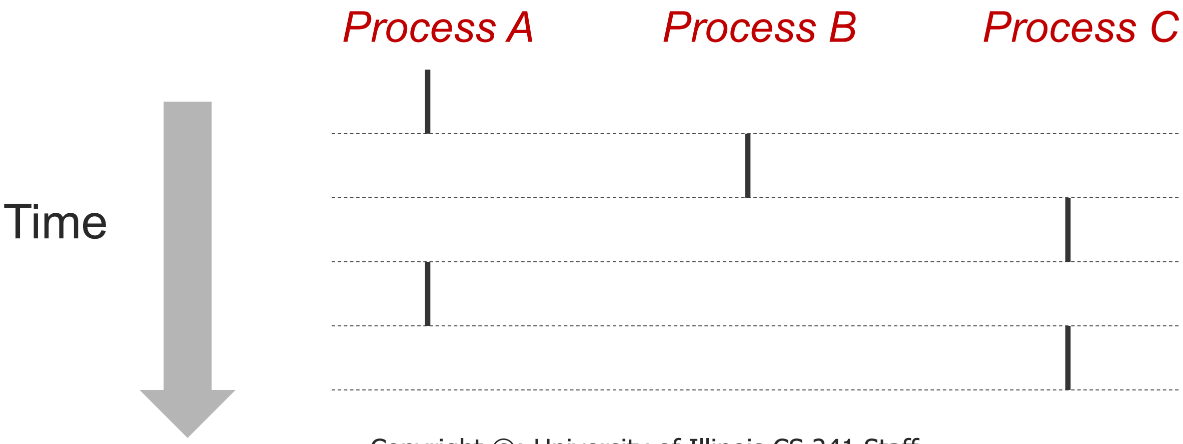
What is a Process?

- How are these illusions maintained?
  - Process executions interleaved (multitasking) or run on separate cores
  - Address spaces managed by virtual memory system

- Unix processes
  - Process #1 is known as the 'init' process (root of the process hierarchy)
  - Each process has a unique identifier

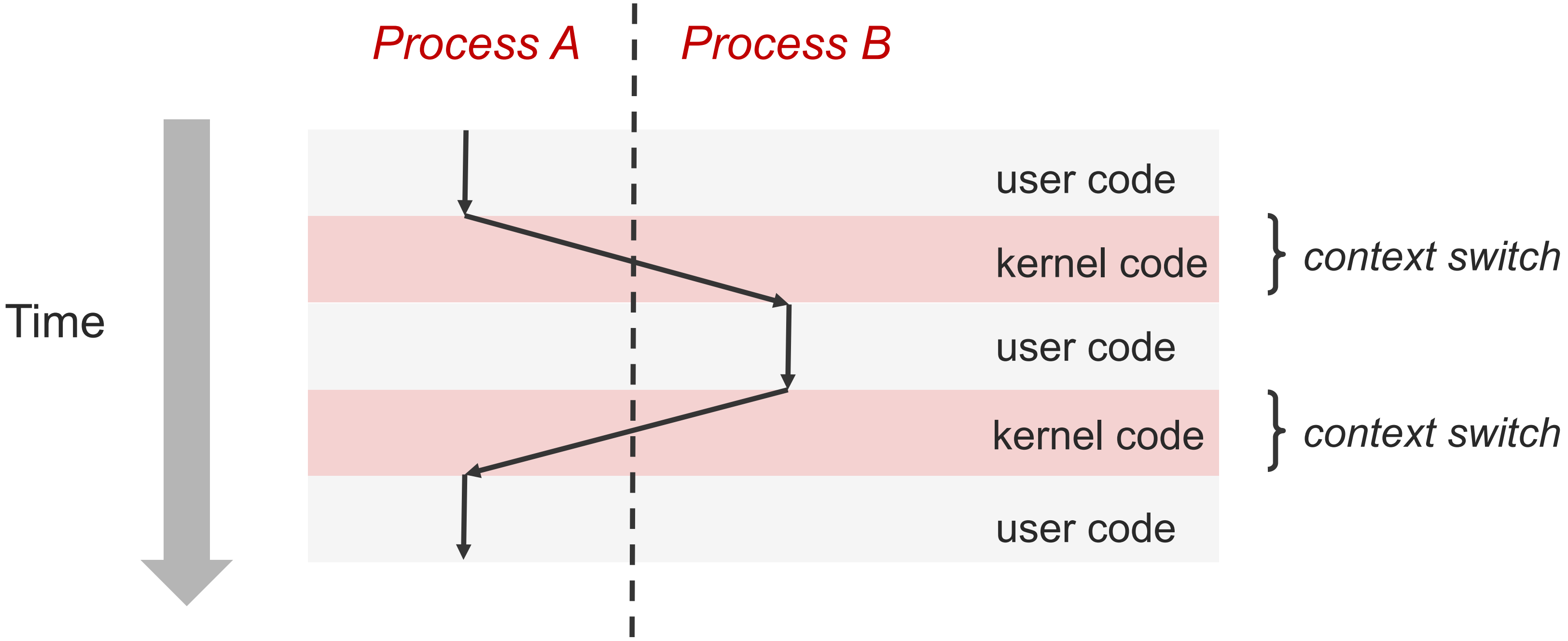
Concurrent Processes

- Two processes run concurrently (are concurrent) if their flows overlap in time
  - Otherwise, they are sequential
- Examples (running on single core)
  - Concurrent: A & B, A & C
  - Sequential: B & C



Context Switching

- Processes are managed by the kernel
- Control passes from one process to another via a context switch



What makes up a process?

- Program code
- Machine registers
- Global data
- Stack
- Open files
- An environment

Process Context

Process ID (`pid`)	unique integer
Parent process ID (`ppid`)	unique integer
Current directory	
File descriptor table	
Environment	
Pointer to program code	
Pointer to data	Mem for global vars
Pointer to stack	Mem for local vars
Pointer to heap	Dynamically allocated memory
Execution priority	
Signal information	

Unix Processes

- Virtual address space
  - The virtual address space is the memory that contains the code to execute as well as the process stack and data

- Process Descriptor: data structure in the kernel to keep track of that process
  - Virtual address space map
  - Current status of the process
  - Execution priority of the process
  - Resource usage of the process
  - Current signal mask
  - Owner of the process

Know your process

- Know your process id

```
pid_t myid = getpid()
```

- Know your parent

```
pid_t myparentid = getppid()
```

Creating a Process – fork()

```
#include <sys/types.h>
#include <unistd.h>
pid_t fork(void);
```

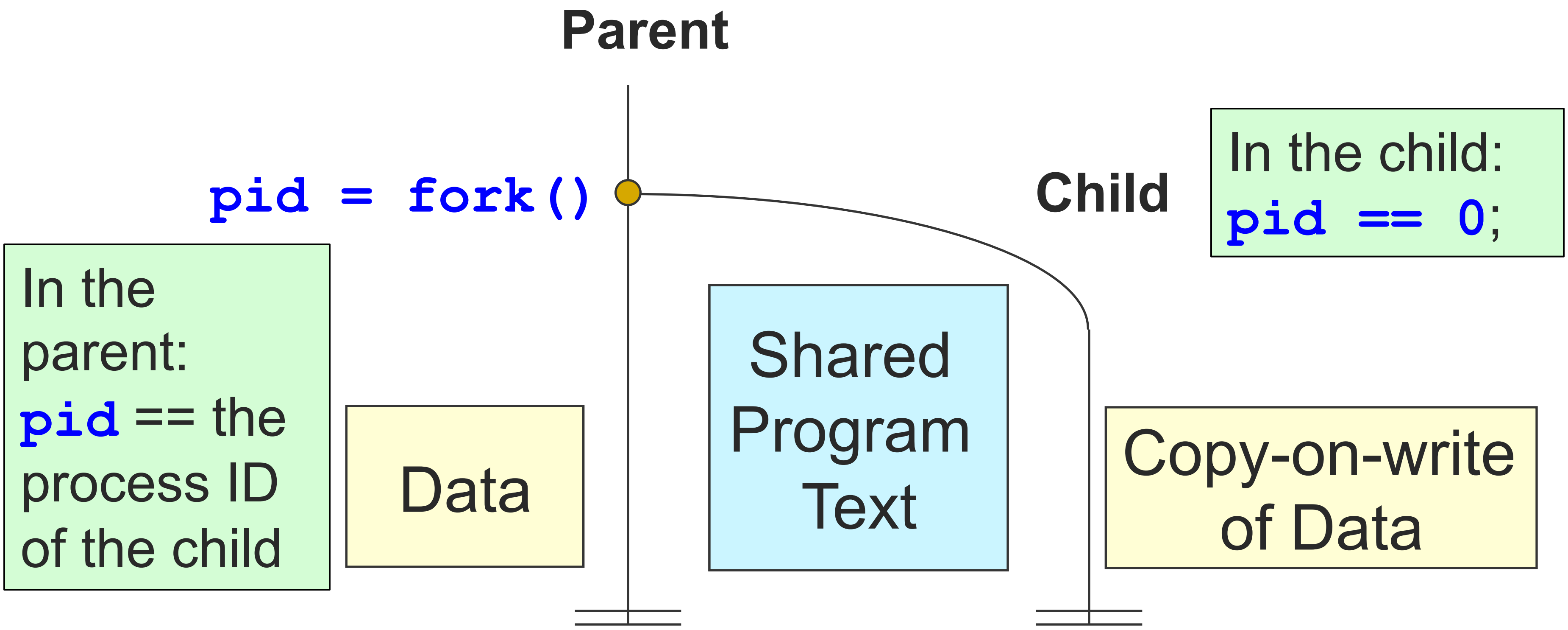
- Create a child process
  - The child is an (almost) exact copy of the parent
  - The new process and the old process both continue in parallel from the statement that follows the `fork()`
- Returns:
  - To child
    - 0 on success
  - To parent
    - process ID of the child process
    - -1 on error, sets `errno`

Understanding fork()

- Fork is interesting (and often confusing) because it is called once but returns twice

```
pid_t pid = fork();
if (pid == 0) {
   printf("hello from child\n");
} else {
   printf("hello from parent\n");
}
```

Creating a Process – `fork()`



Parent

`pid = fork()`

Child

In the child:
`pid == 0`;

In the parent:
`pid` == the process ID of the child

Data

Shared Program Text

Copy-on-write of Data

A program can use this `pid` difference to do different things in the parent and child

An Example

```
#include <stdio.h>
#include <sys/types.h>
#include <unistd.h>

int main() {
    pid_t pid;
    int i;
    pid = fork();
    if( pid > 0 ) {       /* parent */
        for( i=0; i < 1000; i++ )
                printf(“\t\t\t PARENT %d\n”, i);
    } else { /* child */
        for(i=0; i < 1000; i++)
                printf( “CHILD %d\n”, i );
    }
    return 0;
}
```

What will the output be?

An Example

```
#include <stdio.h>
#include <sys/types.h>
#include <unistd.h>

int main() {
    pid_t pid;
    int i;
    pid = fork();
    if( pid > 0 ) {        /* parent */
        for( i=0; i < 1000; i++ )
                printf(“\t\t\t PARENT %d\n”, i);
    } else { /* child */
        for(i=0; i < 1000; i++)
                printf( “CHILD %d\n”, i );
    }
    return 0;
}
```

- Both processes start with same state
  - Each of them has a private virtual address space
  - Including an identical copy of open file descriptors
- Relative ordering of parent/child print statements (and so variable manipulations) is undefined

What will the output be?

Possible Output

```
CHILD 0
CHILD 1
CHILD 2
             PARENT 0
             PARENT 1
             PARENT 2
             PARENT 3
CHILD 3
CHILD 4
             PARENT 4
        :
```

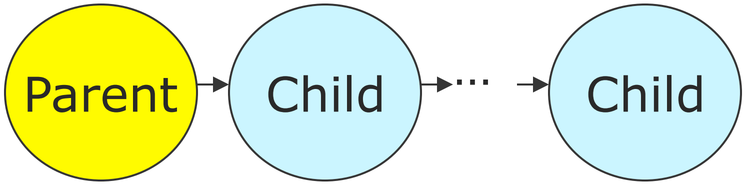
Possible Output

- Switching between parent and child depends on many factors
    - Machine load, OS CPU scheduler
- I/O buffering affects amount of shown output
- Output interleaving is nondeterministic
    - Cannot determine output by looking at code

Chain and Fan

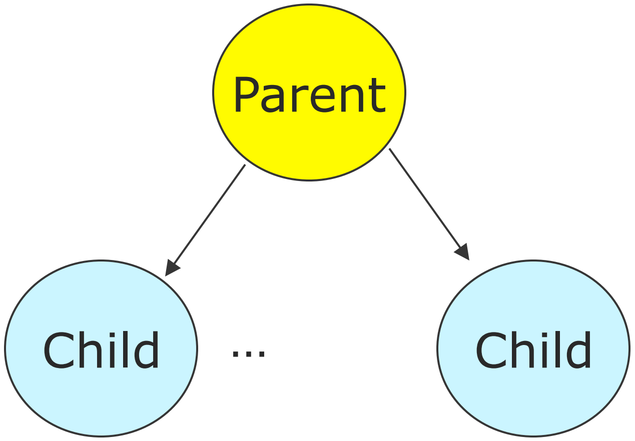
Chain

- Write code to make chain



Fan

- Code to make N children of one parent process

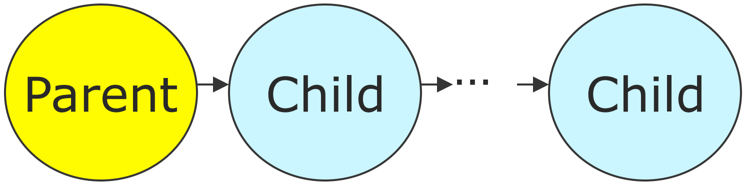


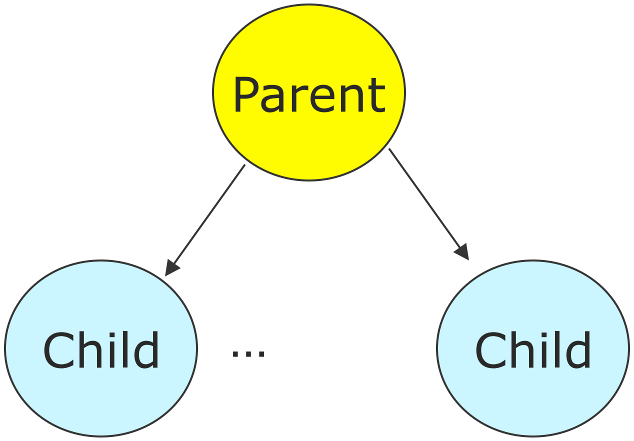
Chain and Fan

Chain

Fan

```
pid_t childpid;
for (i=1;i<n;i++)
  if (childpid = fork())
      break;
```





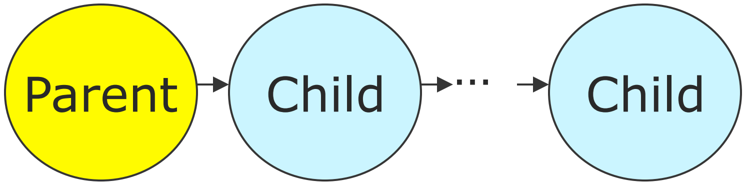
Chain and Fan

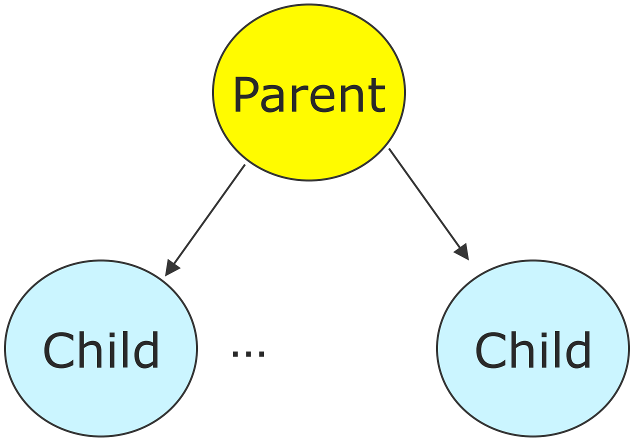
Chain

```
pid_t childpid;
for (i=1;i<n;i++)
  if (childpid = fork())
      break;
```

Fan

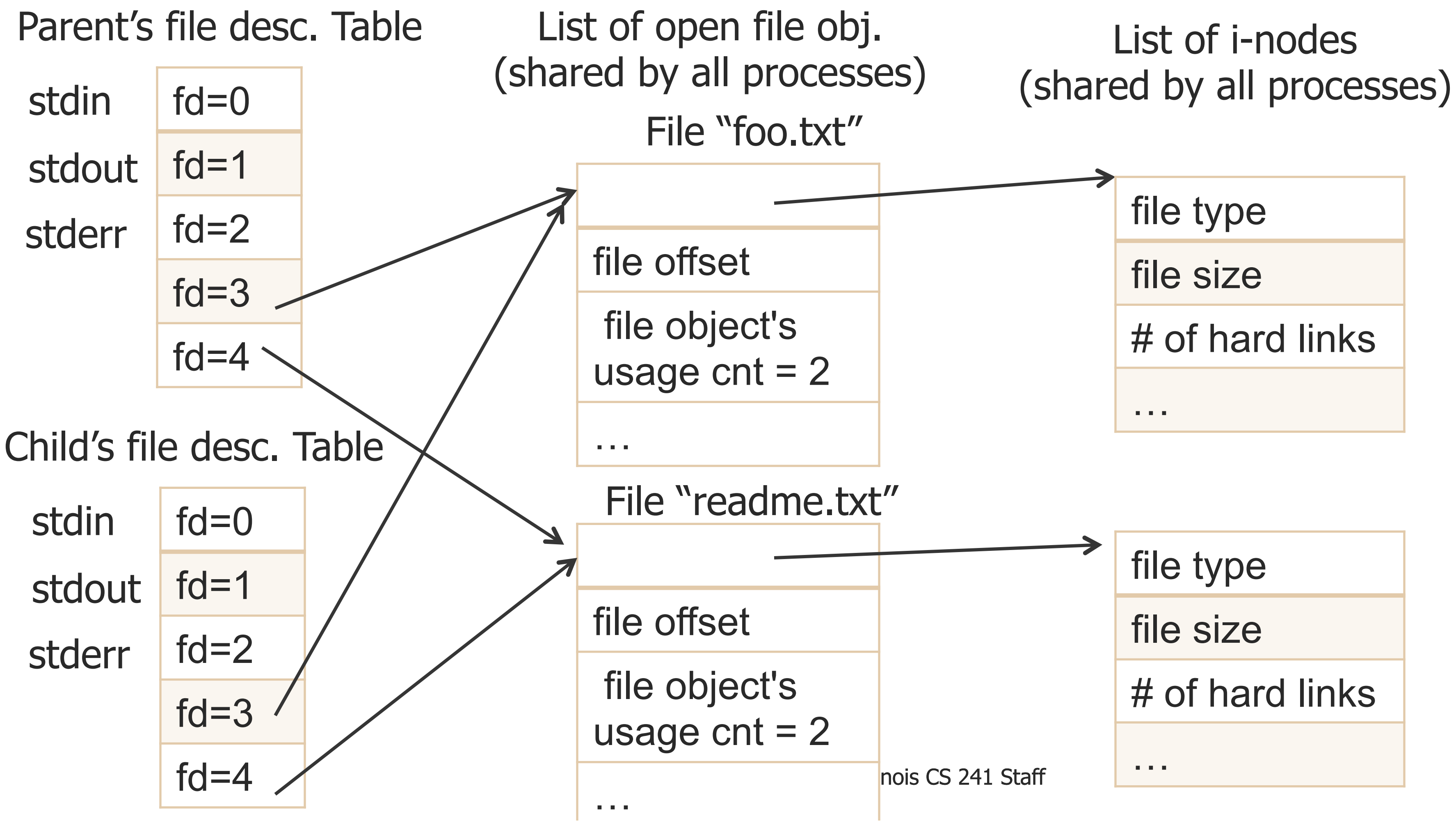
```
pid_t childpid;
for (i=1;i<n;i++)
  if ((childpid=fork()) <=0)
      break;
```





Child process inherits parent's open files

- Parent forks **after** opening files foo.txt and readme.txt



Parent's file desc. Table

stdin fd=0

stdout fd=1

stderr fd=2

fd=3

fd=4

Child's file desc. Table

stdin fd=0

stdout fd=1

stderr fd=2

fd=3

fd=4

List of open file obj.
(shared by all processes)

File "foo.txt"

file offset

file object's usage cnt = 2

…

File "readme.txt"

file offset

file object's usage cnt = 2

…

List of i-nodes
(shared by all processes)

file type

file size

# of hard links

…

file type

file size

# of hard links

…

When a process terminates

- When a child process terminates:
  - Open files are flushed and closed
  - Child’s resources are de-allocated
    - File descriptors, memory, semaphores, file locks, …
  - Parent process is notified via signal SIGCHLD
  - Exit status is available to parent via wait()

Process Termination

- Voluntary termination
  - Normal exit
    - return zero from `main()`
    - `exit(0)`
  - Error exit
    - `exit(1)`
- Involuntary termination
  - Fatal error
    - Divide by 0, core dump / seg fault
  - Killed by another process
    - `kill` procID, end task

exit() Example

void exit(int status)

- Exits a process
- Normally return with status 0

atexit()

- Registers functions to be executed upon exit

```
void cleanup(void) {
        printf("cleaning up\n");
}

int main() {
        atexit(cleanup);
        fork();
        exit(0);
}
```

Zombies

- What happens on termination?
  - When process terminates, still consumes system resources
  - Entries in various tables & info maintained by OS
- Called a “zombie”
  - Living corpse, half alive and half dead

Zombies

- Reaping
  - Performed by parent on terminated child (using `wait` or `waitpid`)
  - Parent is given exit status information
  - Kernel discards process
- What if parent doesn't reap?
  - If any parent terminates without reaping a child, then child will be reaped by `init` process (`pid == 1`)
  - So, only need explicit reaping in long-running processes
    - e.g., shells and servers

Zombie Example

```
void forktest() {
    if (fork() == 0) {
        /* Child */
        printf("Terminating Child, PID = %d\n",
                getpid());
        exit(0);
    } else {
        printf("Running Parent, PID = %d\n",
                getpid());
        while (1); /* Infinite loop */
    }
}
```

Zombie Example

```
void forktest() {
    if (fork() == 0) {
        /* Child */
        printf("Terminating C
               getpid());
        exit(0);
    } else {
        printf("Running Paren
               getpid());
        while (1); /* Infinit
    }
}
```

```
Linux> ./forktest 7 &
[1] 8992
Terminating Child, PID = 8993
Running Parent, PID = 8992
Linux> ps
  PID TTY          TIME CMD
 8992 pts/1    00:00:06 forktest
 8993 pts/1    00:00:00 forktest <defunct>
 8994 pts/1    00:00:00 ps
29160 pts/1    00:00:00 bash
Linux> kill 8992
[1]+  Terminated              ./forktest
Linux> ps
  PID TTY          TIME CMD
 9004 pts/1    00:00:00 ps
29160 pts/1    00:00:00 bash
```

- `ps` shows child process as "defunct"
- Killing parent allows child to be reaped by `init`