Processes, Signals, I/O, Shell lab

15-213: Introduction to Computer Systems
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Agenda

- News
- **Processes**
  - **Overview**
  - **Important functions**
- Signals
  - Overview
  - Important functions
  - Race conditions
- I/O Intro
- Shell Lab Tips

Processes

- An instance of an executing program
- Abstraction provided by the operating system
- Properties
  - Have a process ID(pid) and process group ID(pgid)
  - Private state – memory, registers, etc.
  - Shared state - such as open file table
  - Become zombies when finished running(why?)

Process: fork()

- Prototype:
  pid_t fork(void);
- Clones the current process. The new process gets a new pid, but the same pgid.
- The new process is an exact duplicate of the parent's state. It has its own stack, own registers, etc.
- It has its own file descriptors (but the files themselves are shared).
- Called once, returns twice (once in the parent, once in the child).
- Return value in child is 0, child's pid in parent. (This is how the parent can keep track of who its child is.)
- Returns -1 in case of failure.
- After the fork, we do not know which process will run first, the parent or the child.

Processes

- `int fork(void)`
  - Usually used like:

```
pid_t pid = fork();

if (pid == 0) {
   // pid is 0 so we can detect child
   printf("hello from child\n");
}

else {
   // pid = child's assigned pid
   printf("hello from parent\n");
}
```

Process: execve()

- Prototype:
  *int execve(const char *filename, char *const argv[],*
  *char *const envp[]);*
- Replaces the current process with a new one. The binary corresponding to '*filename*' will be run by current process.
- Called once; does not return (or returns -1 on failure).
- fork() + execve() creates a new process and runs a new binary on it. This is the usual way of running a new process.

Process: exit()

- Prototype:
  void exit(int status);
- Immediately terminates the process that called it. The process goes to Zombie state.
- *status* is normally the return value of main().
- The OS frees the resources (heap, file descriptors, etc.) but not its exit status. It remains in the process table to await its reaping.
- Zombies are reaped when their parents read their exit status. (If the parent is dead, this is done by init.) Then its pid can be reused.

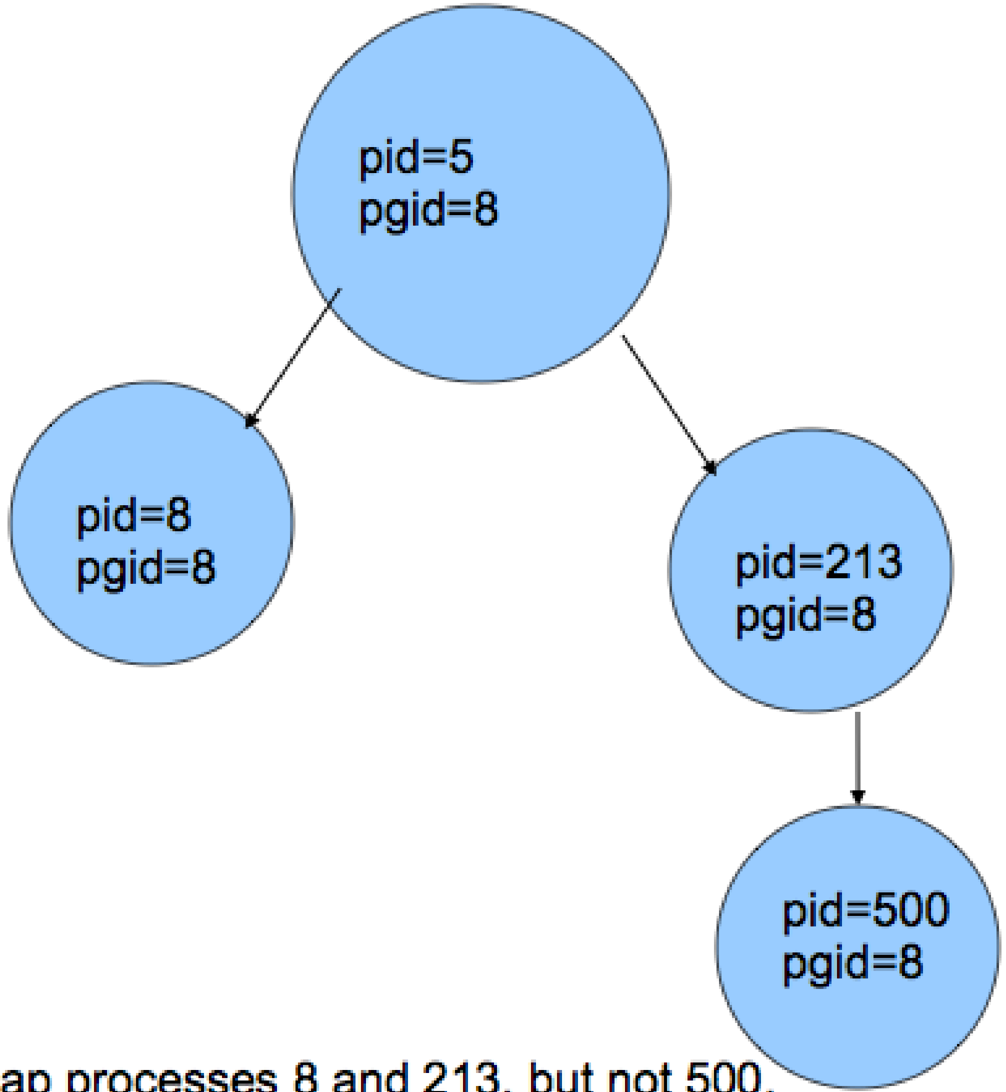
Process: waitpid()

- Prototype:
  *pid_t waitpid(pid_t pid, int *status, int options);*
- The wait family of functions allows a parent to know when a child has changed state (e.g., terminated).
- waitpid returns when the process specified by pid terminates.
- *pid* must be a direct child of the invoking process.
- If *pid* = -1, it will wait for any child of the current process.
- Return value: the pid of the child it reaped.
- Writes to *status*: information about the child's status.
- *options* variable: used to modify waitpid's behavior.
  - WNOHANG: keep executing caller until a child terminates.
  - WUNTRACED: report stopped children too.
  - WCONTINUED: report continued children too

Processes – setpgid()

- Prototype:
  setpgid(pid_t pid, pit_t pgid)
  - Sets the process group id(pgid) of the given pid
  - If *pid*=0, setpgid is applied to the calling process
  - If *pgid*=0, setpgid uses pgid=pid of the calling process
  - Children inherit the pgid of their parents by default

Process Group Diagram



process 5 can reap processes 8 and 213, but not 500.
Only process 213 can reap process 500.

Concurrency!

```
pid_t child_pid = fork();

if (child_pid == 0) {
    printf("Child!\n");
    exit(0);

}

else {
    printf("Parent!\n");

}
```

Output?

Concurrency!

```
pid_t child_pid = fork();

if (child_pid == 0) {
    printf("Child!\n");
     exit(0);

}

else {
     printf("Parent!\n");

}
```

Two possible Outcomes:

- Child!
  Parent!

- Parent!
  Child

Concurrency!

```
pid_t child_pid = fork();

if (child_pid == 0) {
     printf("Child!\n");
      exit(0);

}

else {
      printf("Parent!\n");

}
```

Two possible Outcomes:

- Child!
  Parent!

- Parent!
  Child

```
int status;

pid_t child_pid = fork();

if (child_pid == 0) {
     printf("Child!\n");
      exit(0);

}

else {
     waitpid(child_pid,&status, 0);
      printf("Parent!\n");

}
```

Only one possible Outcome:

Child!
Parent!

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- **Signals**
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  - **Important functions**
  - **Race conditions**
- I/O Intro
- Shell Lab Tips

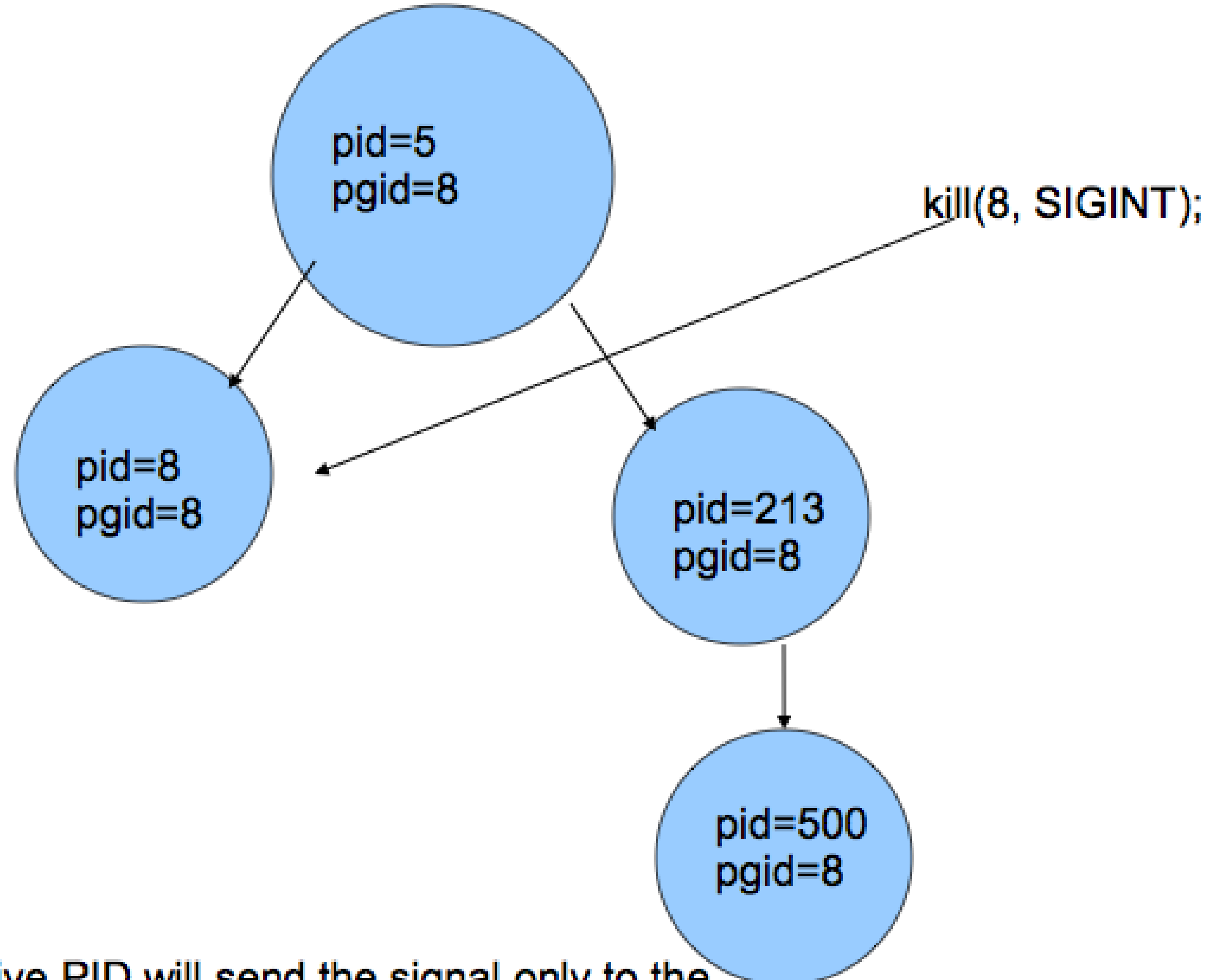
Signals

- Signals are the basic way processes communicate with each other. They notify a process that an event has occurred (for example, that its child has terminated).
- They are sent several ways: Ctrl-C, Ctrl-Z, kill()
- Signals are asynchronous. They aren't necessary received immediately; they're received right after a context switch.
- They are non-queuing.
  - There is only one bit in the context per signal
  - If 100 child processes die and send a SIGCHLD, the parent may still only receive one SIGCHLD
- Three possible ways to react when a signal is received:
  - Ignore the signal (do nothing)
  - Terminate the process (with op7onal core dump)
  - Catch the signal by execu7ng a user-level func7on called signal handler

Sending a signal

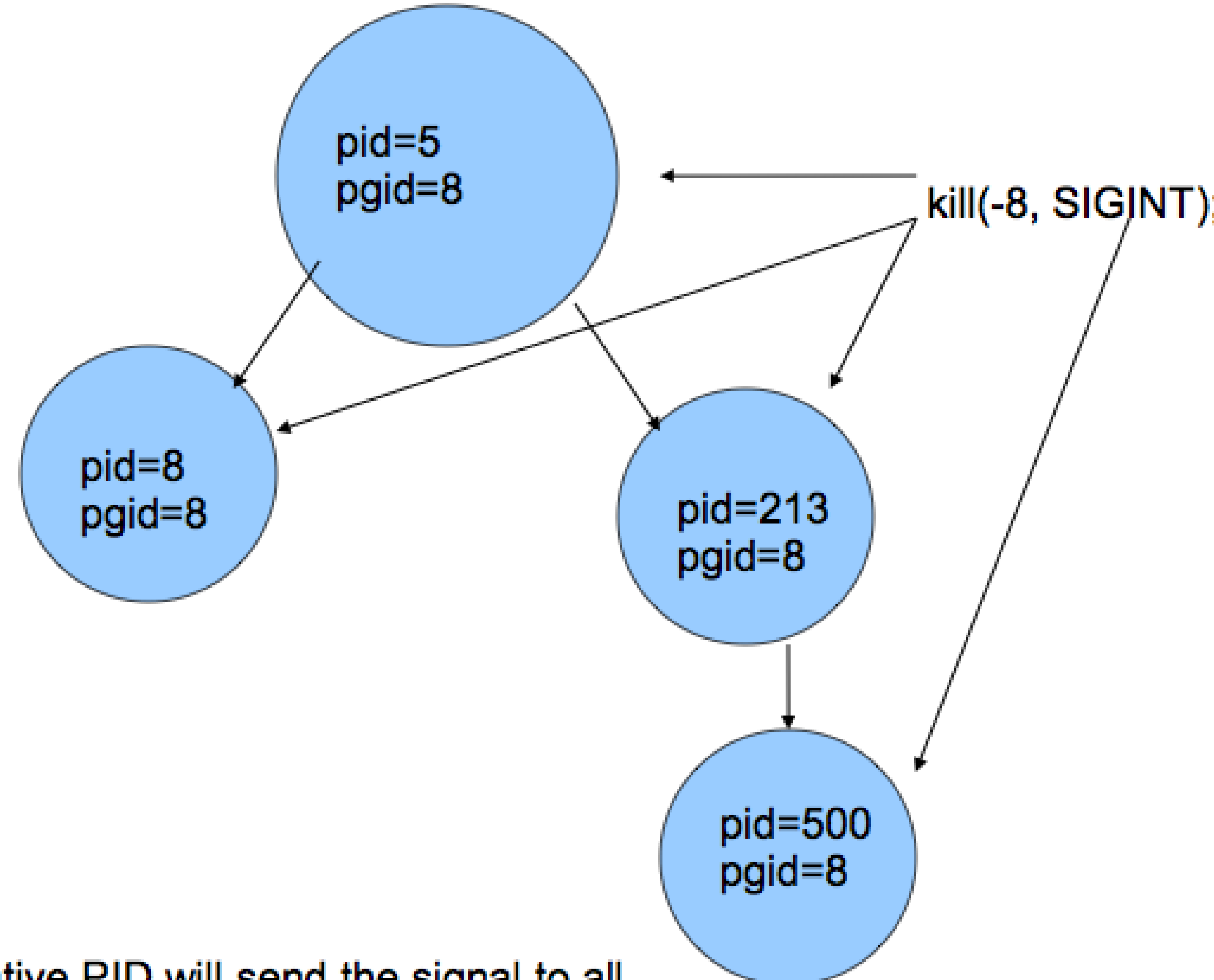
- kill(pid_t id, int sig)
  - If id positive, sends signal sig to process with pid=id
  - If id negative, sends signal sig to all processes with with pgid=-id

Kill - Process



kill() with a positive PID will send the signal only to the process with that ID.

Kill – Process Group



kill() with a negative PID will send the signal to all processes with that group ID.

Handling signals

- signal(int signum, sighandler_t handler)
  - Specifies a handler function to run when signum is received
  - sighandler_t means a function which takes in one int argument and is void (returns nothing)
  - When a signal is caught using the handler,its default behavior is ignored
  - The handler can interrupt the process at any time, even while either it or another signal handler is running
  - Control flow of the main program is restored once it's finished running
  - SIGKILL,SIGSTOP cannot be caught

Caveat

- Remember Signals are received asynchronously.
- Signal handlers can be called anytime when the program is running.
- Concurrency bug?
  - What if main() and signal_handler() access a common data?
  - A typical scenario in your shell lab
- Solution: Block Signals

Signals (contd..)

- Blocking Signals
  - Processes can choose to block signals using a signal mask
  - While a signal is blocked, the signal will be still delivered to the process but keep it pending
  - No action will be taken until the signal is unblocked
  - Implemented using sigprocmask()
- Waiting for Signals
  - Sometimes, a process needs to wait for a signal to be received.
  - Implemented using sigsuspend()

Blocking Signals – sigprocmask()

- sigprocmask(int option, const sigset_t* set, sigset_t *oldSet)
  - Updates the mask of blocked/unblocked signals using the handler signal set
  - Blocked signals are ignored until unblocked
    - Process only tracks whether it has received a blocked signal, not the count
    - Getting SIGCHILD 20 times while blocked then unblocking will only run its handler once
  - option: SIG_BLOCK,SIG_UNBLOCK,SIG_SETMASK
  - Signal mask's old value is written into oldSet

Waiting for Signals – sigsuspend()

- sigsuspend(sigset_t *tempMask)
  - Temporarily replaces the signal mask of the process with tempMask
  - Sigsuspend will return once it receives an unblocked signal (and after its handler has run)
  - Good to stop code execution until receiving a signal
  - Once sigsuspend returns, it automatically reverts the process signal mask to its old value

Signals – sigsetops

- A family of functions used to create and modify sets of signals. E.g.,
  - *int sigemptyset(sigset_t *set);*
  - *int sigfillset(sigset_t *set)*
  - *int sigaddset(sigset_t *set, int signum);*
  - *int sigdelset(sigset_t *set, int signum);*
- These sets can then be used in other functions.
- http://linux.die.net/man/3/sigsetops
- Remember to pass in the address of the sets, not the sets themselves

Race Conditions

- Race conditions occur when sequence or timing of events are random or unknown
- Signal handlers will interrupt currently running code
- When forking, child or parent may run in different order
- If something can go wrong, it will
  - Must reason carefully about the possible sequence of events in concurrent programs

Race Conditions

```
// sigchld handler installed
pid_t child_pid = fork();
if (child_pid == 0){
  /* child comes here */
  execve(......);
}
else{
  add_job(child_pid);
}
```

```
void sigchld_handler(int signum)
{
   int status;
   pid_t child_pid =
    waitpid(-1, &status, WNOHANG);
   if (WIFEXITED(status))
     remove_job(child_pid);
}
```

- Does add_job() or remove_job() come first?
- Where can signals be blocked to ensure correctness?

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Unix I/O

- All Unix I/O, from network sockets to text files, are based on one interface.
- A file descriptor is what's returned by open().
  int fd = open("/path/to/file", O_RDONLY);
- It's just an int, but you can think of it as a pointer into the file descriptor table.
- Every process starts with three file descriptors by default:
  - 0: STDIN
  - 1: STDOUT
  - 2: STDERR.
- Every process gets its own file descriptor table, but processes share the open file table and v-node table.

Unix I/O – dup2()

- Prototype:
  int dup2(int oldfd, int newfd);

- *newfd* becomes a copy of *oldfd*;
- Read/write on *newfd* will access the file corresponding to *oldfd*.
- This is handy for implementing I/O redirection in shelllab.

Unix I/O – Practice Problem

```
int main()
{
    int fd = open("ab.txt", O_RDONLY);
    char c;
    fork();
    read(fd,&c,1); //Read one character from the file
    printf("%c\n",c); //Print the character
}
```

- Assume the file ab.txt contains "ab"
- What do the file tables look like?
- What's the output?
- What if the process forked before opening the file?

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Shell Lab Tips

- There's a lot of starter code
  - Look over it so you don't needlessly repeat work
- Use the reference shell to figure out the shell's behavior
  - For instance, the format of the output when a job is stopped
- Use sigsuspend, not waitpid, to wait for foreground jobs
  - You will lose points for using tight loops (while(1) {}), sleeps to wait for the foreground

Shell Lab Tips

- Shell requires SIGINT and SIGSTP to be fowarded to the foreground job (and all its descendants) of the shell
  - How could process groups be useful?
- dup2 is a handy function for the last section, I/O redirection
- SIGCHILD handler may have to reap multiple children per call
- Try actually using your shell and seeing if/where it fails
  - Can be easier than looking at the driver output

Questions?