# CMSC216: Exceptional Control Flow and Unix Processes

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# Logistics

## Reading: Bryant/O'Hallaron

| Ch | Read? | Topic |
|---|---|---|
| 8 | Finish | See specific section guide from previous slides |
| 10 | READ Except | UNIX File structure, File System structure, I/O functions |
| 10.5 | Opt | Optional: "Robust" I/O library built on top of primitive ops |

## Assignments

- Grading has commenced for P3 / Exam 2, likely to complete late this week
- Lab09 on `fork()` / `wait()` + HW09 on `fork()`
- P4 up later this week

## Goals

- Finish up Process Intro
- C Standard I/O library vs UNIX I/O
- File Descriptors, `open()` / `close()` / `read()` `write()`
- I/O Redirection with `dup2()` / `dup()`
- File Atributes / Permissions `stat()` / `chmod()`
- (Optional) Directory Traversal `opendir()` / `readdir()`

# Announcements

## CS Undergrad Town Hall Mon 21-Apr

- Chance to voice concerns / get attention to issues for CS students
- Nominations for Undergrad rep to Department Council and Education Committee
- Chances to demonstrate service and leadership for those who want those things on their resume
- Food provided

RSVP: `https://go.umd.edu/cstownhall25`

# Detailed Reading from Bryant/O'Hallaron Ch 8

- Textbook has detailed coverage of many aspects of Process basics in Chapter 8 *Exceptional Control Flow*
- Below is a detailed section reading guide for what we will be important for us

| Ch | Read? | Topic |
|---|---|---|
| 8.1 | Skim | Assembly/Hardware mechanisms for "exceptional control flow" |
| 8.2 | READ | Processes as running programs, context switches, user/kernel mode |
| 8.3 | Skim | System call error handling |
| 8.4 | READ | Fundamental process system calls: `fork()` / `waitpid()` / `etc.` |
| 8.5 | Opt | Optional: Software Signals |
| 8.6 | Opt | Optional: Nonlocal jumps via `setjmp()` / `longjmp()` |
| 8.7 | READ | "Tools" (one paragraph, we'll discuss these in more detail in class) |

# Traditional vs Modern Computing Devices

- Old-school computers had a single executing programs which could interact freely with all parts of the computing hardware
- Modern computing devices have different expectations summarized below

| **Traditional** | **Modern** |
|---|---|
| Single program on device | Multiple programs sharing single device |
| No Operating System | OS manages all programs |
| Program access to all hardware | OS controls/coordinates hardware access |
| Single program accesses all memory | OS isolates memories of each program |
| Relatively simple hardware interactions | Complex interactions of many devices |
| Single "user" running programs at once | Multiple users simultaneously on system |
| Apple II: insert disk to run program | Mac OS: Click to start another program |

- New hardware and expectations led to new concepts
- **Operating Systems**: "manager" program that coordinates activities of all programs / users, manages hardware and provides abstraction layer, enforces security and fairness
- **Process**: a running program with its context

# OS Kernel and Kernel Mode

*kernel (noun)*

1. *a softer, usually edible part of a nut, seed, or fruit stone contained within its hard shell.*
2. *the central or most important part of something.*

Operating System code is usually in the **kernel**, a program that starts running when a computing system is powered on

- Kernel sets up handlers for various exceptional control flows such as hardware interrupts and system calls
- Most CPUs have (at least) two modes
  1. **User / Normal** mode
  2. **Kernel / Privileged / Supervisor** mode
- User programs run in user mode, cannot directly manipulate hardware or access certain resources
- Requests OS to perform some operations which jumps to kernel code running in kernel mode

**Example `hello64.s`:** Linux System Call to write data in x86-64

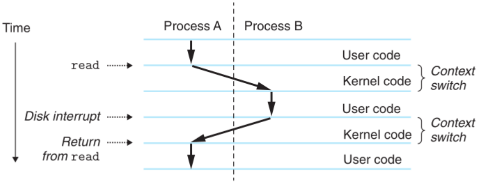
# Processes: Running Programs

- Hardware just executes a stream of instructions
- The OS creates the notion of a **process**: instructions comprising a **running program**
- Processes can be executed for a while, then paused while another process executes
- To accomplish this, OS usually provides...
  1. Bookkeeping info for processes (resources)
  2. Ability to interrupt / pre-empt a running process to allow OS actions to take place
  3. Scheduler that decides which process runs and for how long
- Will discuss these from a **Systems Programming** perspective: control low-level program details to utilize OS Service and Hardware as effectively as possible

# Exceptional Control Flow

- CPUs use "regular" control flow most of the time but support several kinds of **exceptional control flow**
- General idea is as follows:
  1. Something triggers exceptional control flow
  2. Normal program instructions pause
  3. Processor jumps to a designated set of instructions to handle the situation
  4. Typical handling code is in the Operating System Kernel
  5. After the situation is handled control may be returned to the program that was running OR something else may happen
- Flavors of exceptional control flow include interrupts, traps, faults, aborts, and possibly others depending on whose terminology you follow

# Process Context and Context Switches




*Source: Bryan/O'Hallaron Fig 8.14*

- Exceptional Control Flow at hardware level allows high-level behaviors such as changing between processes
- OS Kernel tracks data structures associated with Processes that allows them to be paused and resumed
- **Process Context** includes data such as
  - Values of registers as the process is paused
  - Regions of main memory in use by process
  - Open files and other resources in use by process
- Switching between processes is a **Context Switch**
  - OS saves the context of Process A someplace safe
  - OS loads the context for Process B and starts it running
  - Later A's context can be loaded to resume where it left off

# Exceptional Control Flow Use Cases

## Enable Multiple Processes to Share the CPU

- OS sets a hardware timer
- OS Starts Process A running, A's code runs in user mode
- When timer expires ("rings"), control jumps to the OS
- OS can select Process B to run, resuming A later after B's timer expires
- Selecting a Process to run is part of the **scheduler** code in the OS

## Hiding I/O Latency

- Process A requests to receive data from the Network (e.g. internet search result)
- This Input request is a **System Call**: jumps to OS code
- OS inspects the Network Interface Card (NIC), hardware responsible for network communications, and find data is not yet available for Process A
- Marks Process A as waiting for I/O to complete, starts running Process B
- While Process B is running, data arrives on the NIC which sends an electrical signal to the CPU
- CPU jumps away from Process B to handle the incoming I/O, finds it is a data packet for Process A
- OS marks Process A as ready to run again, then scheduler selects A or B to run

# Inside and Outside of the Kernel

## CMSC216 (This Course)

- Discuss basic OS System Calls that Unix provides
- Create processes, coordinate them simply
- Perform low-level read/write I/O calls
- Understand OS interface at a high level, some ideas about internal data structures maintained by Kernels for processes, files, virtual memory, etc.

## CMSC412 Operating Systems

- Build a small OS Kernel
- Directly implement data structures for processes, files, virtual memory, etc.
- Study tradeoffs in design of these data structures
- Utilize more complex process coordination / communication mechanisms

If you find these things interesting, consider CMSC412 in the future

# Overview of Process Creation/Coordination

The following are the 4 fundamental process creation / coordination primitives provided by UNIX systems including Linux

## `getpid()` / `getppid()`

- Get process ID of the currently running process
- Get parent process ID

## `fork()`

- Create a child process
- Identical to parent EXCEPT for return value of fork() call
- Determines child/parent

## `wait()` / `waitpid()`

- Wait for any child to finish (wait)
- Wait for a specific child to finish (waitpid)
- Get return status of child

## `exec()` family

- Replace currently running process with a different program image
- Process becomes something else losing previous code
- Focus on `execvp()`

# Code: Overview of Process Creation/Coordination

## getpid() / getppid()

```
pid_t my_pid = getpid();
printf("I'm proces %d\n",my_pid);
pid_t par_pid = getppid();
printf("My parent is %d\n",par_pid);
```

## fork()

```
pid_t child_pid = fork();
if(child_pid == 0){
  printf("Child!\n");
}
else{
  printf("Parent!\n");
}
```

## wait() / waitpid()

```
int status;
waitpid(child_pid, &status, 0);
printf("Child %d done, status %d\n",
       child_pid, status);
```

## exec() family

```
char *new_argv[] = {"ls","-l",NULL};
char *command = "ls";
printf("Goodbye old code, hello LS!\n");
execvp(command, new_argv);
```

Aside: before the next exercise, compile the `complain.c` program to be named `complain` using GCC (good review)

# Exercise: Putting Child Processes to Work

Explain this program that use `getpid()`, `getppid()`, `fork()`, `execvp()`

```c
// child_labor.c:
#include <stdio.h>
#include <stdlib.h>
#include <sys/wait.h>
#include <unistd.h>

int main(int argc, char* argv){

  char *child_argv[] = {"./complain",NULL};
  char *child_cmd = "complain";

  printf("P: I'm %d, and I really don't feel like '%s'ing\n",
         getpid(),child_cmd);
  printf("P: I have a solution\n");

  pid_t child_pid = fork();

  if(child_pid == 0){
    printf("C: I'm %d My pa '%d' wants me to '%s'. This sucks.\n",
           getpid(), getppid(), child_cmd);

    execvp(child_cmd, child_argv);

    printf("C: I don't feel like myself anymore...\n");
  }
  else{
    printf("P: Great, junior %d is taking care of that\n",
           child_pid);
  }
  return 0;
}
```

# **Answers**: Putting Child Processes to Work

```c
// child_labor.c: demonstrate the basics of fork/exec to launch a
// child process to do "labor"; e.g. run a another program via
// exec. Make sure that the the 'complain' program is compiled first.
#include <stdio.h>
#include <stdlib.h>
#include <sys/wait.h>
#include <unistd.h>

int main(int argc, char* argv[]){

  char *child_argv[] = {"complain",NULL};              // argument array to child, must end with NULL
  char *child_cmd = "complain";                         // actual command to run, must be on path

  printf("P: I'm %d, and I really don't feel like '%s'ing\n",
         getpid(),child_cmd);                           // use of getpid() to get current PID
  printf("P: I have a solution\n");

  pid_t child_pid = fork();                             // clone a child
  // int status;
  // waitpid(child_pid, &status, 0);

  if(child_pid == 0){                                   // child will have a 0 here
    printf("C: I'm %d My pa '%d' wants me to '%s'. This sucks.\n",
           getpid(), getppid(), child_cmd);             // use of getpid() and getppid()

    execvp(child_cmd, child_argv);                      // replace running image with child_cmd

    printf("C: I don't feel like myself anymore...\n"); // unreachable statement
  }
  else{                                                 // parent will see nonzero in child_pid
    int status;
    waitpid(child_pid, &status, 0);
    printf("P: Great, junior %d is taking care of that\n",
           child_pid);
    if(WIFEXITED(status)){
      // get the return value of program
      int retval = WEXITSTATUS(status);
```

# Experiment: Alter Command for exec()

Experiment in `child_labor.c` with altering lines associated with `exec()` arguments

```
char *child_argv[] = {"./complain",NULL};          // argument array to child, must end wit
char *child_cmd = "complain";                      // actual command to run, must be on pat

char *child_argv[] = {"ls","-l","-ah",NULL};       // alternative argv/command swap comment
char *child_cmd = "ls";                            // with above to alter what child does

char *child_argv[] = {"seq","5","2","20",NULL};   // alternative
char *child_cmd = "seq";
```

Note the effects after recompiling and re-running.

# Exercise: Coordinating Parent and Child

`child_labor.c` has concurrency issues: Parent/Child output mixed and may occur in an unpredictable order

```
>> ./a.out
P: I'm 53174, and I really don't feel like 'complain'ing
P: I have a solution
P: Great, junior 53175 is taking care of that
C: I'm 53175 My pa '53174' wants me to 'complain'. This sucks.
>> COMPLAIN: God this sucks. On a scale of 0 to 10 I hate pa ...

>> ./a.out
P: I'm 53187, and I really don't feel like 'complain'ing
P: I have a solution
C: I'm 53188 My pa '53187' wants me to 'complain'. This sucks.
COMPLAIN: God this sucks. On a scale of 0 to 10 I hate pa ...
P: Great, junior 53188 is taking care of that

>> ./a.out
P: I'm 53198, and I really don't feel like 'complain'ing
P: I have a solution
C: I'm 53199 My pa '53198' wants me to 'complain'. This sucks.
P: Great, junior 53199 is taking care of that
>> COMPLAIN: God this sucks. On a scale of 0 to 10 I hate pa ...

>>
```

Modify with a call to `wait(somepid)` to ensure Parent output comes AFTER Child output

# **Answers**: `child_wait.c` modification

```c
// child_wait.c: fork/exec plus parent waits for child to
// complete printing befor printing itself.
#include <stdio.h>
#include <stdlib.h>
#include <sys/wait.h>
#include <unistd.h>

int main(int argc, char* argv){

  char *child_argv[] = {"./complain",NULL};          // alternative commands
  char *child_cmd = "complain";

  printf("P: I'm %d, and I really don't feel like '%s'ing\n",
         getpid(),child_cmd);
  printf("P: I have a solution\n");

  pid_t child_pid = fork();

  if(child_pid == 0){
    printf("C: I'm %d My pa '%d' wants me to '%s'. This sucks.\n",
           getpid(), getppid(), child_cmd);
    execvp(child_cmd, child_argv);
    printf("C: I don't feel like myself anymore...\n"); // unreachable
  }
  else{
    int status;
    wait(&status);                                     // wait for any child to finish, collect status
    // wait(NULL);                                     // wait for any child, ignore status
    // waitpid(child_pid, &status);                    // wait for specific child
    // waitpid(-1, NULL);                              // wait for any child, collect status
    printf("P: Great, junior %d is done with that '%s'ing\n",
           child_pid, child_cmd);
  }
  return 0;
}
```

# Effects of fork()

- Single process becomes 2 processes
- Sole difference is return value from fork()
- All other aspects of process are copied

*Before fork(): 1 process*

```
Process 1234

STACK     heap_str | 0x500 |
             myint |     5 |
         child_pid |     ? |
               ... |   ... |
HEAP         0x500 |     h |
             0x501 |     i |
             0x502 |    \0 |
               ... |   ... |
GLOBALS  glob_doub |  1.23 |
               ... |   ... |
TEXT/CODE
int main(){
   char *heap_str = malloc(..);
   int myint = 5;
   glob_doub = 1.23;
>> int child_pid = fork()
   if(child_pid == 0){
     myint = 19;
   }
   printf("myint: %d\n", myint);
   ...
```

*After fork(): 2 processes*

```
Process 1234 (parent)

STACK     heap_str | 0x500 |
             myint |     5 |
         child_pid |  5678 |
               ... |   ... |
HEAP         0x500 |     h |
             0x501 |     i |
             0x502 |    \0 |
               ... |   ... |
GLOBALS  glob_doub |  1.23 |
               ... |   ... |
TEXT/CODE
int main(){
   char *heap_str = malloc(..);
   int myint = 5;
   glob_doub = 1.23;
   int child_pid = fork()
>> if(child_pid == 0){
     myint = 19;
   }
   printf("myint: %d\n", myint);
   ...
```

```
Process 5678 (child)

STACK     heap_str | 0x500 |
             myint |     5 |
         child_pid |     0 |
               ... |   ... |
HEAP         0x500 |     h |
             0x501 |     i |
             0x502 |    \0 |
               ... |   ... |
GLOBALS  glob_doub |  1.23 |
               ... |   ... |
TEXT/CODE
int main(){
   char *heap_str = malloc(..);
   int myint = 5;
   glob_doub = 1.23;
   int child_pid = fork()
>> if(child_pid == 0){
     myint = 19;
   }
   printf("myint: %d\n", myint);
   ...
```

# Effects of exec()

- Entire Memory image of process is replaced/reset
- Original process Text/Code is replaced, begin new `main()`
- Successful `exec()` does not return to original code

*Before exec(): original code*

```
Process 1234
STACK      heap_str | 0x500 |
              myint |     5 |
           some_var |     ? |
                ... |   ... |
HEAP          0x500 |     h |
              0x501 |     i |
              0x502 |    \0 |
                ... |   ... |
GLOBALS   glob_doub |  1.23 |
                ... |   ... |
TEXT/CODE
int main(){  // my program
   char *heap_str = malloc(..);
   int myint = 5;
   glob_doub = 1.23;
>> exec("ls",...);
   printf("Unreachable!\n");
   some_var = 21;
   ...
```

*After exec(): code replaced*

```
Process 1234
STACK             ?? |    ?? |
                  ?? |    ?? |
                  ?? |    ?? |
                 ... |   ... |
HEAP           0x500 |    ?? |
               0x501 |    ?? |
               0x502 |    ?? |
                 ... |   ... |
GLOBALS           ?? |    ?? |
                 ... |   ... |
TEXT/CODE
int main(...){ // ls program
>> if(argc == 1){
     MODE = SIMPLE_LIST;
   }
   else {
     ...
   }
   ...
```

# Exercise: Child Exit Status

- A successful call to `wait()` sets a status variable with child info:

  ```
  int status;
  wait(&status);
  ```

- Several **macros** are used to parse out this variable

  ```
  // determine if child actually exited
  // other things like signals can cause
  // wait to return
  if(WIFEXITED(status)){

    // get the return value of program
    int retval = WEXITSTATUS(status);
  }
  ```

- **Modify** `child_labor.c` so that parent checks child exit status
- Convention: 0 normal, nonzero error, print something if non-zero

```
# program that returns non-zero
> gcc -o complain complain.c

# EDIT FILE TO HAVE CHILD RUN 'complain'
> gcc child_labor_wait_returnval.c
> ./a.out
I'm 2239, and I really don't feel
like 'complain'ing
I have a solution
   I'm 2240 My pa '2239' wants me to 'complain'.
   This sucks.
COMPLAIN: God this sucks. On a scale of 0 to 10
          I hate pa ...

Great, junior 2240 did that and told me '10'
That little punk gave me a non-zero return.
I'm glad he's dead
>
```

*NOTE: C Macros look a bit like functions with CAPTIAL_NAMES() but are different from normal functions. We will discuss Macros more later.*

# **Answers**: Child Exit Status

```c
// child_wait_returnval.c: fork/exec plus parent waits for child and
// checks their status using macors. If nonzero, parent reports.

#include <stdio.h>
#include <stdlib.h>
#include <sys/wait.h>
#include <unistd.h>

int main(int argc, char* argv[]){
  char *child_argv[] = {"./complain",NULL};            // program returns non-zero
  char *child_cmd = "complain";

  printf("P: I'm %d, and I really don't feel like '%s'ing\n",
         getpid(),child_cmd);
  printf("P: I have a solution\n");

  pid_t child_pid = fork();

  if(child_pid == 0){
    printf("C: I'm %d My pa '%d' wants me to '%s'. This sucks.\n",
           getpid(), getppid(), child_cmd);
    execvp(child_cmd, child_argv);
    printf("C: I don't feel like myself anymore...\n"); // unreachable
  }
  else{
    int status;
    wait(&status);                                     // wait for child to finish, collect status
    if(WIFEXITED(status)){
      int retval = WEXITSTATUS(status);                // decode status to 0-255
      printf("P: Great, junior %d did that and told me '%d'\n",
             child_pid, retval);
      if(retval != 0){                                 // nonzero exit codes usually indicate failure
        printf("P: That little punk gave me a non-zero return. I'm glad he's dead\n");
      }
    }
    else{
      printf("P: Oh no, something happened to the boy!\n");
    }
  }
  return 0;
}
```

# Normal Processes Exit

- Normal exit for a C program results from
  1. `main()` executes `return code;`
  2. Program calls the `exit(code);` standard function
- `WIFEXITED(status)` is "truthy" in parent for such cases
- An "error" may have occurred but the child process detects, handles, and bails "gracefully" in these cases

Alternatively, processes may exit **abnormally**...

# Abnormal Process Exit

- Abnormal exit can happen for a variety of reasons including
  1. Attempts to access out-of-bounds memory causing a segmentation fault or memory bus error
  2. Divides an integer by 0 triggering a floating point exception[1]
  3. Executes an illegal instruction
  4. ...
- `WIFEXITED(status)` is "falsey" in parent process in these cases
- Usually `WIFSIGNALLED(status)` is "truthy" in parent process

[1] This is among the **worst** named errors as a "floating point exception" or "SIGFPE" is almost always integer division by 0; modern floating point units allow for division by 0.0 which gives either `Inf` or `NaN` results as dictated by the IEEE-754 standard

# Abnormal Exits and Software Signals

- Unix systems usually **signal** a running process when severe errors such as a Segmentation Fault occurs
- Signals also allow for a limited form of communication between processes but...
- Signal handling is beyond the scope of this course
- Our only use:
  **Parent processes can determine the cause of death when a child is killed by the OS using signals**

Examine: `dumb_kid.c` and `dumb_kid_parent.c`

- Common abnormal exits (`dumb_kid.c`)
- Diagnosing abnormal exits with `WIFSIGNALLED()` and `WTERMSIGNAL()`

# Return Value for `wait()` family

- Return value for `wait()` and `waitpid()` is the PID of the child that finished
- Makes a lot of sense for `wait()` as multiple children can be started and `wait()` reports which finished
- One `wait()` per child process is typical

## Examine: `faster_child.c`

Demonstrates determining which child finished based on the return value of `wait()`

```c
// parent waits for each child
for(int i=0; i<3; i++){
  int status;
  int child_pid = wait(&status);
  if(WIFEXITED(status)){
    int retval = WEXITSTATUS(status);
    printf("PARENT: Finished child proc %d, retval: %d\n",
           child_pid, retval);
  }
}
```

# Blocking vs. Nonblocking Activities

## Blocking

- A call to `wait()` and `waitpid()` may cause calling process to **block** (hang, stall, pause, suspend, so many names…)
- Blocking is associated with other activities as well
  - I/O, obtain a lock, get a signal, etc.
- Generally creates **synchronous** situations: waiting for something to finish means the next action *always* happens.. next (e.g. print after `wait()` returns)

```
// BLOCKING VERSION
int pid = waitpid(child_pid, &status, 0);
```

## Non-blocking

- Contrast with **non-blocking** (asynchronous) activities: calling process goes ahead even if something isn't finished yet
- `wait()` is always blocking
- `waitpid()` can be blocking or non-blocking

# Non-Blocking waitpid()

- Use the `WNOHANG` option
- Returns immediately regardless of the child's status

```
int child_pid = fork();
int status;

// NON-BLOCKING
int pid = waitpid(child_pid, &status, WNOHANG); // specific child
OR                                    |||||||
int pid = waitpid(       -1, &status, WNOHANG); // any child
```

Returned `pid` is

| Returned | Means |
|---|---|
| `child_pid` | status of child that changed / exited |
| 0 | there is no status change for child / none exited |
| -1 | an error |

Examine `impatient_parent.c`

# impatient_parent.c

```c
// impatient_parent.c: demonstrate non-blocking waitpid(),

#include <stdio.h>
#include <stdlib.h>
#include <sys/wait.h>
#include <unistd.h>

int main(int argc, char* argv){
  char *child_argv[] = {"./complain",NULL};
  char *child_cmd = "complain";
  printf("PARENT: Junior is about to '%s', I'll keep an eye on him\n",
         child_cmd);
  pid_t child_pid = fork();

  // CHILD CODE
  if(child_pid == 0){
    printf("CHILD: I'm %d and I'm about to '%s'\n",
           getpid(), child_cmd);
    execvp(child_cmd, child_argv);
  }

  // PARENT CODE
  int status;
  int retcode = waitpid(child_pid, &status, WNOHANG);   // non-blocking wait
  if(retcode == 0){                                     // 0 means child has not exited/changed status
    printf("PARENT: 0? The kid's not done yet. I'm bored\n");
  }
  else{                                                 // child has changed status / exited
    printf("PARENT: Something happend to junior!\n");
    if(WIFEXITED(status)){
      printf("Ah, he Exited with code %d\n", WEXITSTATUS(status));
    }
    else{
      printf("Junior didn't exit, what happened to him?\n");
    }
  }
  return 0;
}
```

# Runs of `impatient_parent.c`

```
> gcc impatient_parent.c
> a.out
PARENT: Junior is about to 'complain', I'll keep an eye on him
PARENT: 0? The kid's not done yet. I'm bored
CHILD: I'm 1863 and I'm about to 'complain'
> COMPLAIN: God this sucks. On a scale of 0 to 10 I hate pa ...

> a.out
PARENT: Junior is about to 'complain', I'll keep an eye on him
PARENT: 0? The kid's not done yet. I'm bored
CHILD: I'm 1865 and I'm about to 'complain'
> COMPLAIN: God this sucks. On a scale of 0 to 10 I hate pa ...
```

# Exercise: Helicopter Parent

©Zits Partnership

- Modify `impatient_parent.c` to `helicopter_parent.c`
- Checks continuously on child process
- Will need a loop for this. . .

```
> gcc helicopter_parent.c
> a.out
PARENT: Junior is about to 'complain', I'll keep an eye on him
Oh, junior's taking so long. Is he among the 50% of people that are below average?
Oh, junior's taking so long. Is he among the 50% of people that are below average?
...
Oh, junior's taking so long. Is he among the 50% of people that are below average?
Oh, junior's taking so long. Is he among the 50% of people that are below average?
CHILD: I'm 21789 and I'm about to 'complain'
Oh, junior's taking so long. Is he among the 50% of people that are below average?
...
Oh, junior's taking so long. Is he among the 50% of people that are below average?
Oh, junior's taking so long. Is he among the 50% of people that are below average?
COMPLAIN: God this sucks. On a scale of 0 to 10 I hate pa ...
Oh, junior's taking so long. Is he among the 50% of people that are below average?
Oh, junior's taking so long. Is he among the 50% of people that are below average?
...
PARENT: Good job junior. I only checked on you 226 times.
```

# **Answers**: Helicopter Parent

```c
// helicopter_parent.c: demonstrate non-blocking waitpid() in excess
#include <stdio.h>
#include <stdlib.h>
#include <sys/wait.h>
#include <unistd.h>

int main(int argc, char* argv){

  char *child_argv[] = {"./complain",NULL};
  char *child_cmd = "complain";

  printf("PARENT: Junior is about to '%s', I'll keep an eye on him\n",
         child_cmd);

  pid_t child_pid = fork();

  // CHILD CODE
  if(child_pid == 0){
    printf("CHILD: I'm %d and I'm about to '%s'\n",
           getpid(), child_cmd);
    execvp(child_cmd, child_argv);
  }

  // PARENT CODE
  int status;
  int checked = 0;
  while(1){
    int cpid = waitpid(child_pid,&status,WNOHANG); // Check if child done, but don't actually wait
    if(cpid == child_pid){                         // Child did finish
      break;
    }
    printf("Oh, junior's taking so long. Is he among the 50%% of people that are below average?\n");
    checked++;
  }
  printf("PARENT: Good job junior. I only checked on you %d times.\n",checked);
  return 0;
}
```

# Polling vs Interrupts

- `helicopter_parent.c` is an example of **polling**: checking on something repeatedly until it achieves a ready state
- Easy to program, generally inefficient
- Alternative: **interrupt** style is closer to `wait()` and `waitpid()` *without* `WNOHANG`: rest until notified of a change
- Usually requires cooperation with OS/hardware which must wake up process when stuff is ready
- Both polling-style and interrupt-style programming have uses
- Projects may use one or the other of these so it's good to be aware of them

# Zombies Processes

- Parent creates a child
- Child completes
- Child becomes a **zombie** (!!!)
- Parent waits for child
- Child reaped

*All we want is the attention of a loving parent...*

## Zombie Process

A process that has finished, but has not been `wait()`'ed for by its parent yet so cannot be (entirely) eliminated from the system. OS can reclaim child resources like memory once parent `wait()`'s.

## Demonstrate

Requires a process monitoring with `top/ps` but can see zombies created using `spawn_undead.c`

# Tree of Processes

```
> pstree
systemd-+-NetworkManager---2*[{NetworkManager}]
        |-accounts-daemon---2*[{accounts-daemon}]
        |-colord---2*[{colord}]
        |-csd-printer---2*[{csd-printer}]
        |-cupsd
        |-dbus-daemon
        |-drjava---java-+-java---27*[{java}]
        |               `-37*[{java}]
        |-dropbox---106*[{dropbox}]
        |-emacs-+-aspell
        |       |-bash---pstree
        |       |-evince---4*[{evince}]
        |       |-idn
        |       `-3*[{emacs}]
        |-gdm-+-gdm-session-wor-+-gdm-wayland-ses-+-gnome-session-b-+-gnome-shell-+-Xwayland---14*[{Xwayland}]
        ...       ...
        |         |-gnome-terminal--+-bash-+-chromium-+-chrome-sandbox---chromium---chromium-+-8*[chromium---12*[{chromium}]]
        |         |                 |      |          |                                      |-chromium---11*[{chromium}]
        |         |                 |      |          |                                      |-chromium---14*[{chromium}]
        |         |                 |      |          |                                      |-chromium---15*[{chromium}]
        |         |                 |      |          |                                      `-chromium---18*[{chromium}]
        |         |                 |      |          |-chromium---9*[{chromium}]
        |         |                 |      |          `-42*[{chromium}]
        |         |                 |      `-cinnamon---21*[{cinnamon}]
        |         |                 |-bash---ssh
        |         |                 `-3*[{gnome-terminal-}]
```

- Processes exist in a tree: see with shell command `pstree`
- Children can be **orphaned** by parents: parent exits without `wait()`'ing for child
- Orphans are adopted by the root process (PID==1)
  - `init` traditionally
  - `systemd` in many modern systems
- Root process occasionally `wait()`'s to "reap" zombies

# Orphans are always Adopted

- Parent exits without `wait()`'ing, leaving them orphaned.
- Adopted by root process with PID=1

Examine: `baudelair_orphans.c`

Demonstrates what happens to orphan processes: adopted by the "root" process #1

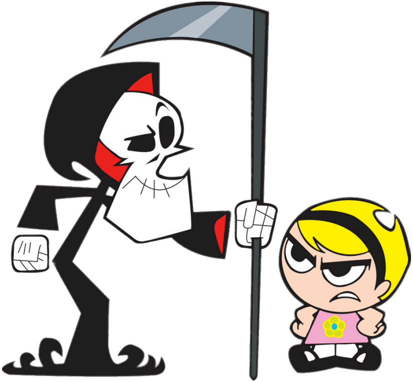
```
> gcc baudelaire_orphans.c

> ./a.out
1754593: I am Klaus and my parent is 1754592
1754594: I amm Violet and my parent is 1754592
1754596: (Sunny blows raspberry) 1754592
1754593: My original parent was 1754592, my current parent is 1754592
> 1754594: My original parent was 1754592, my current parent is 1
1754594: I have been orphaned. How Unforunate.
1754596: My original parent was 1754592, my current parent is 1
1754596: I have been orphaned. How Unforunate.
```

# Reapers and the Subreapers

- Process X creates many children, Orphans them
- Children of X complete, become Zombies until…
- Newly assigned Parent `wait()`'s for them
- Adoptive parent like Process 1 sometimes referred to as a **Reaper** process: "reaps the dead processes"
- System may designate a Subreaper to do this per user so orphans NOT re-parented to process ID 1

- Graphical Login on Ubuntu Linux systems usually designates a Subreaper for each user



Source: Cartoongoodies.com
*Reaper and Orphan? More like Subreaper…*