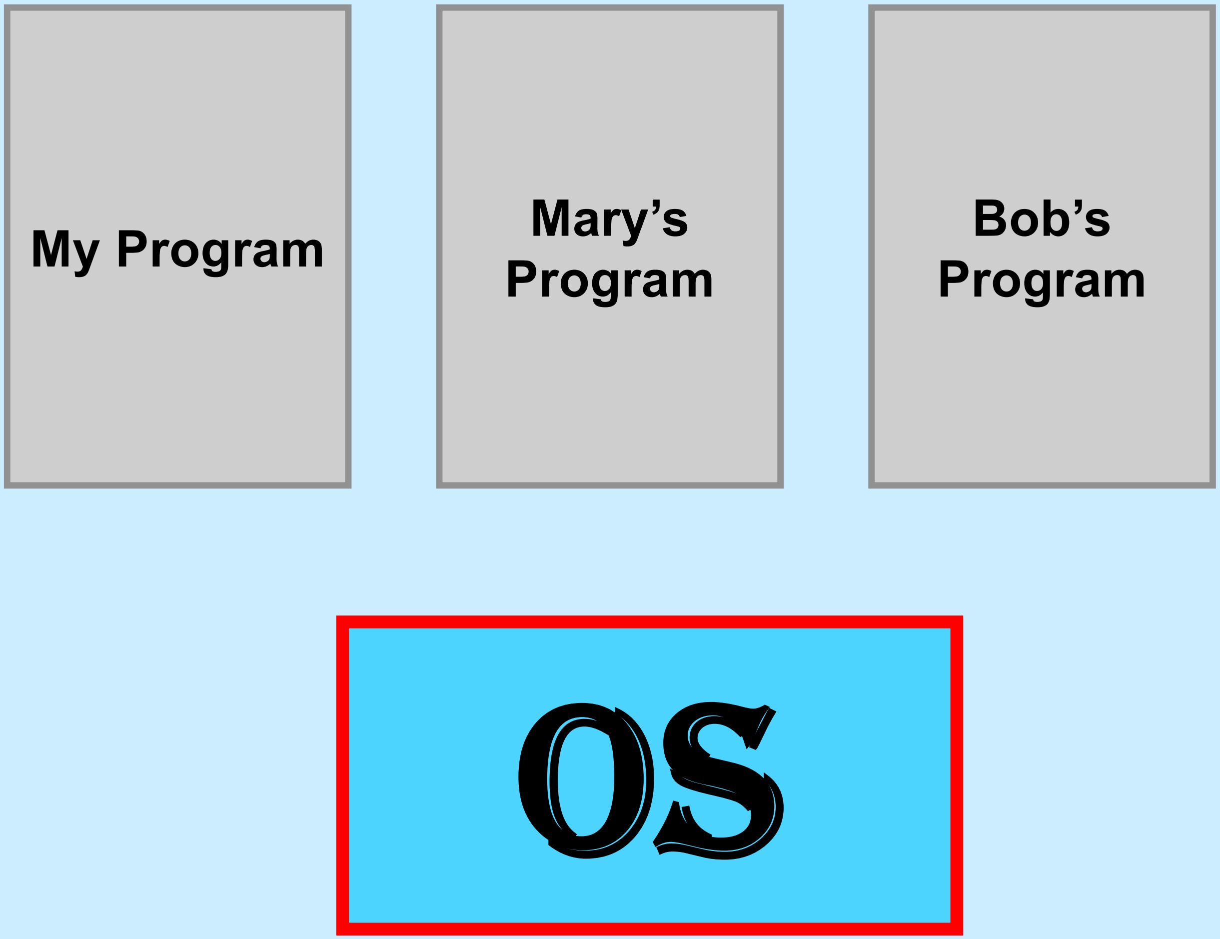
CS 33

Architecture and the OS

The Operating System



Processes

- Containers for programs
  - virtual memory
    - address space
  - scheduling
    - one or more threads of control
  - file references
    - open files
  - and lots more!

Idiot Proof …

```
int main( ) {
  int i;
  int A[1];

  for (i=0; ; i++)
    A[rand()] = i;
}
```

Can I clobber Mary's program?

Mary's Program

Fair Share

```
void runforever( ){
  while(1)
    ;
}

int main( ) {
  runforever();
}
```

Can I prevent Bob's program from running?

Bob's Program

Architectural Support for the OS

- Not all instructions are created equal ...
  - non-privileged instructions
    - » can affect only current program
  - privileged instructions
    - » may affect entire system
- Processor mode
  - user mode
    - » can execute only non-privileged instructions
  - privileged mode
    - » can execute all instructions

Which Instructions Should Be Privileged?

- I/O instructions
- Those that affect how memory is mapped
- Halt instruction
- Some others ...

Who Is Privileged?

- **No one**
  - user code always runs in user mode
- **The operating-system kernel runs in privileged mode**
  - nothing else does
  - not even super user on Unix or administrator on Windows

Entering Privileged Mode

- How is OS invoked?
  – very carefully ...
  – strictly in response to interrupts and exceptions
  – (booting is a special case)

Interrupts and Exceptions

- Things don’t always go smoothly ...
  - I/O devices demand attention
  - timers expire
  - programs demand OS services
  - programs demand storage be made accessible
  - programs have problems
- Interrupts
  - demand for attention by external sources
- Exceptions
  - executing program requires attention

Exceptions

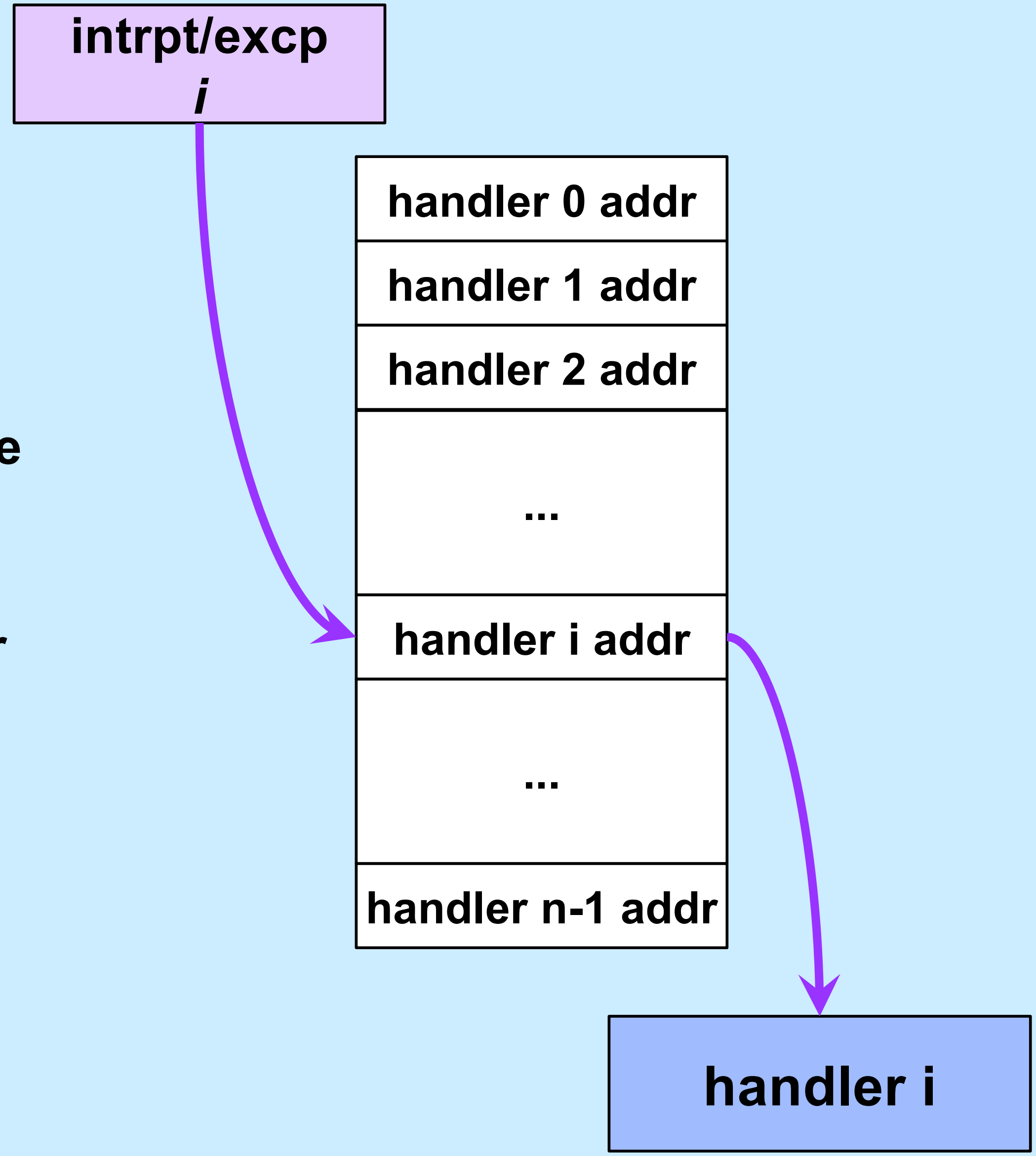
- Traps
  - "intentional" exceptions
    - » execution of special instruction to invoke OS
  - after servicing, execution resumes with next instruction
- Faults
  - a problem condition that is normally corrected
  - after servicing, instruction is re-tried
- Aborts
  - something went dreadfully wrong ...
  - not possible to re-try instruction, nor to go on to next instruction

Actions for Interrupts and Exceptions

- When interrupt or exception occurs
  - processor saves state of current thread/process on stack
  - processor switches to privileged mode (if not already there)
  - invokes handler for interrupt/exception
  - if thread/process is to be resumed (typical action after interrupt)
    - » thread/process state is restored from stack
  - if thread/process is to re-execute current instruction
    - » thread/process state is restored, after backing up instruction pointer
  - if thread/process is to terminate
    - » it's terminated

Interrupt and Exception Handlers

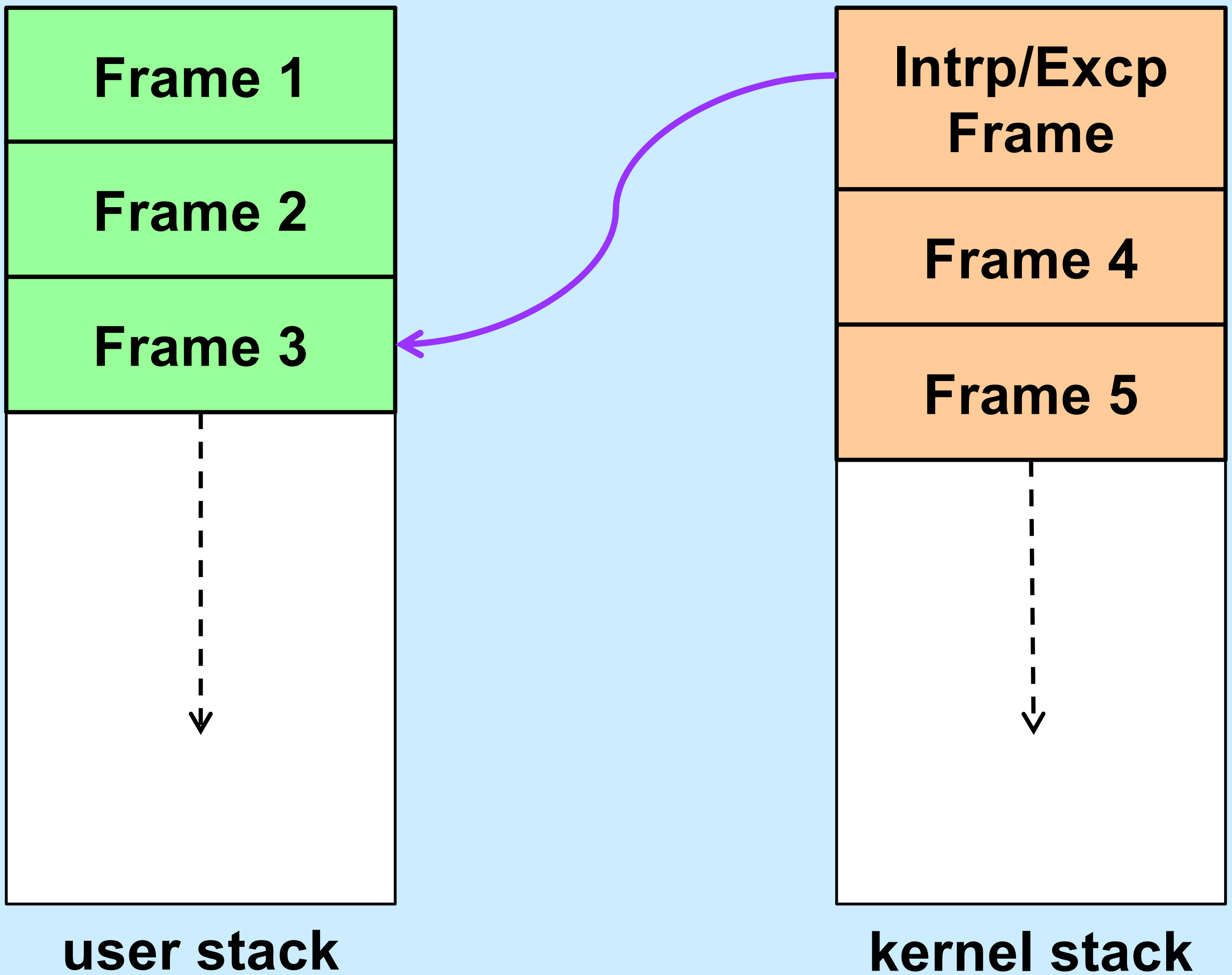
- **Interrupt or exception invokes handler (in OS)**
  - via interrupt and exception vector
    - » one entry for each possible interrupt/exception
      - contains
        - address of handler
  - code executed in privileged mode
    - » but code is part of the OS



Entering and Exiting

- **Entering/exiting interrupt/exception handler more involved than entering/exiting a procedure**
  - must deal with processor mode
    - » switch to privileged mode on entry
    - » switch back to previous mode on exit
  - interrupted process/thread's state is saved on separate kernel stack
  - stack in kernel must be different from stack in user program
    - » why?

One Stack Per Mode



Quiz 1

If an interrupt occurs, which general-purpose registers must be pushed onto the kernel stack?

a) none

b) callee-save registers

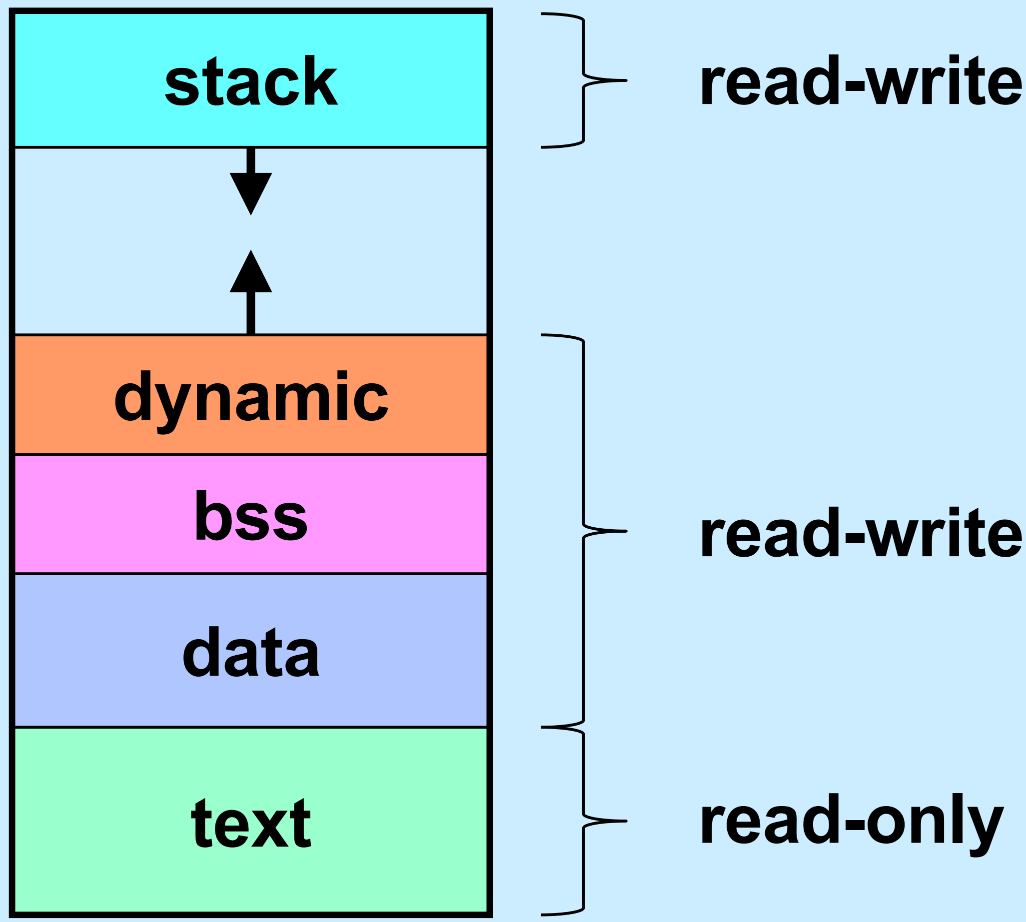
c) caller-save registers

d) all

Back to the x86 ...

- It’s complicated
  - more than it should be, but for historical reasons ...
- Not just privileged and non-privileged modes, but four “privilege levels”
  - level 0
    - » most privileged, used by OS kernel
  - level 1
    - » not normally used
  - level 2
    - » not normally used
  - level 3
    - » least privileged, used by application code

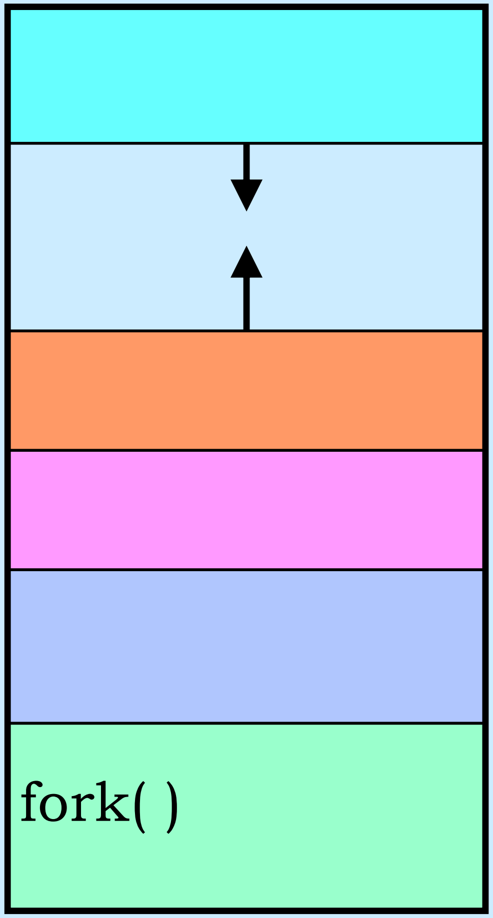
The Unix Address Space



Creating Your Own Processes

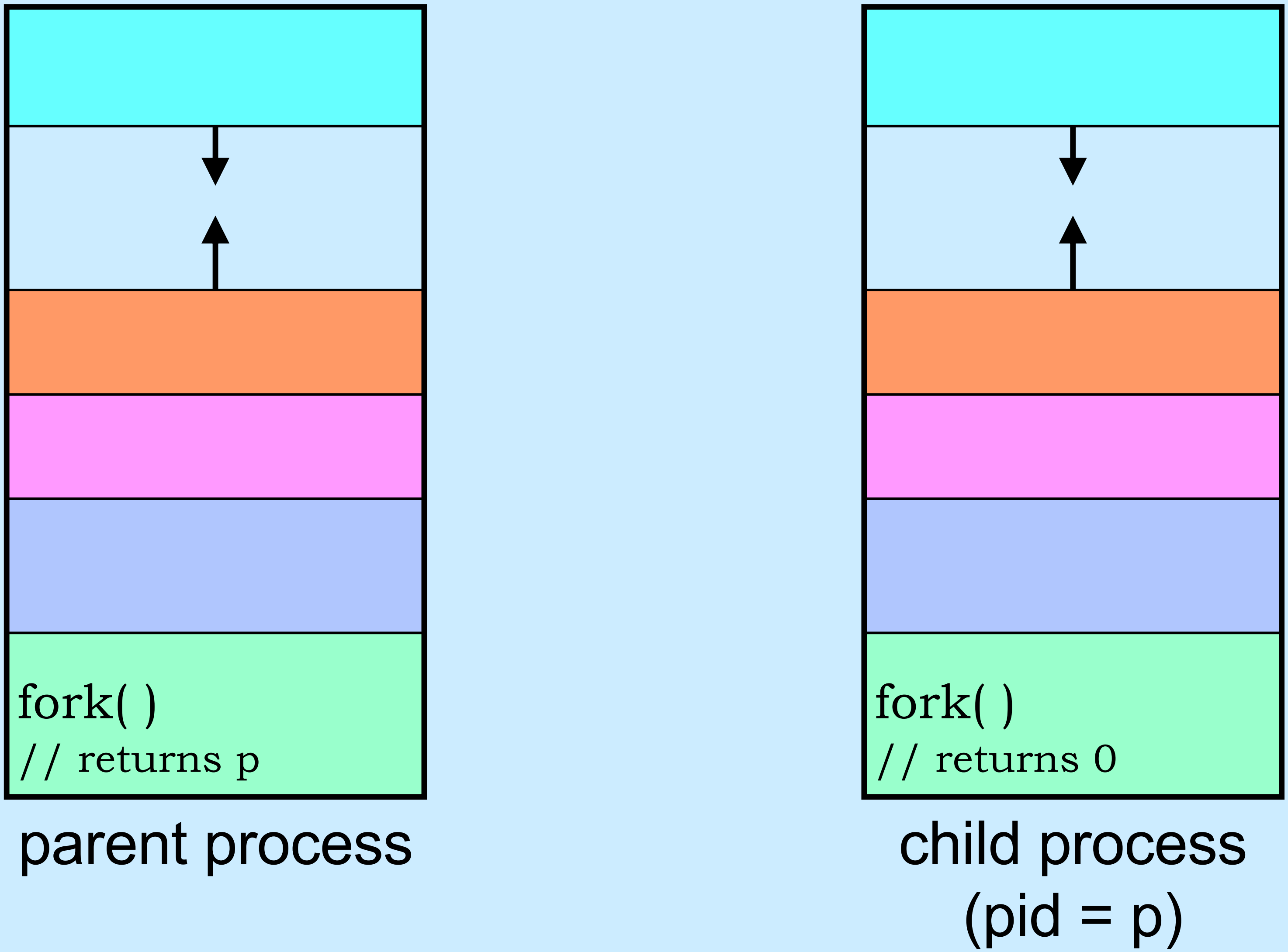
```
#include <unistd.h>
int main( ) {
  pid_t pid;
  if ((pid = fork()) == 0) {
       /* new process starts
          running here */
  }
  /* old process continues
     here */
}
```

Creating a Process: Before



parent process

Creating a Process: After



Quiz 2

The following program

a) runs forever

b) terminates quickly

```
int flag;
int main() {
  while (flag == 0) {
    if (fork() == 0) {
      // in child process
      flag = 1;
      exit(0);  // causes process to terminate
    }
  }
}
```

Process IDs

```
int main( ) {
  pid_t pid;
  pid_t ParentPid = getpid();

  if ((pid = fork()) == 0) {
      printf("%d, %d, %d\n",
             pid, ParentPid, getpid());
      return 0;
  }
  printf("%d, %d, %d\n",
             pid, ParentPid, getpid());
  return 0;
}
```

```
parent prints:
  27355, 27342, 27342

child prints:
  0, 27342, 27355
```

Putting Programs into Processes

```
 .
 .
 .

if (fork() == 0){
  execv("prog", argv);
}

 .
 .
 .
```

fork

execv

```
/* prog */

int main() {

 .
 .
 .

}
```

Exec

- **Family of related system functions**
  - **we concentrate on one:**
    - » **execv(program, argv)**

```
char *argv[] = {"MyProg", "12", (void *)0};
if (fork() == 0) {
  execv("./MyProg", argv);
}
```

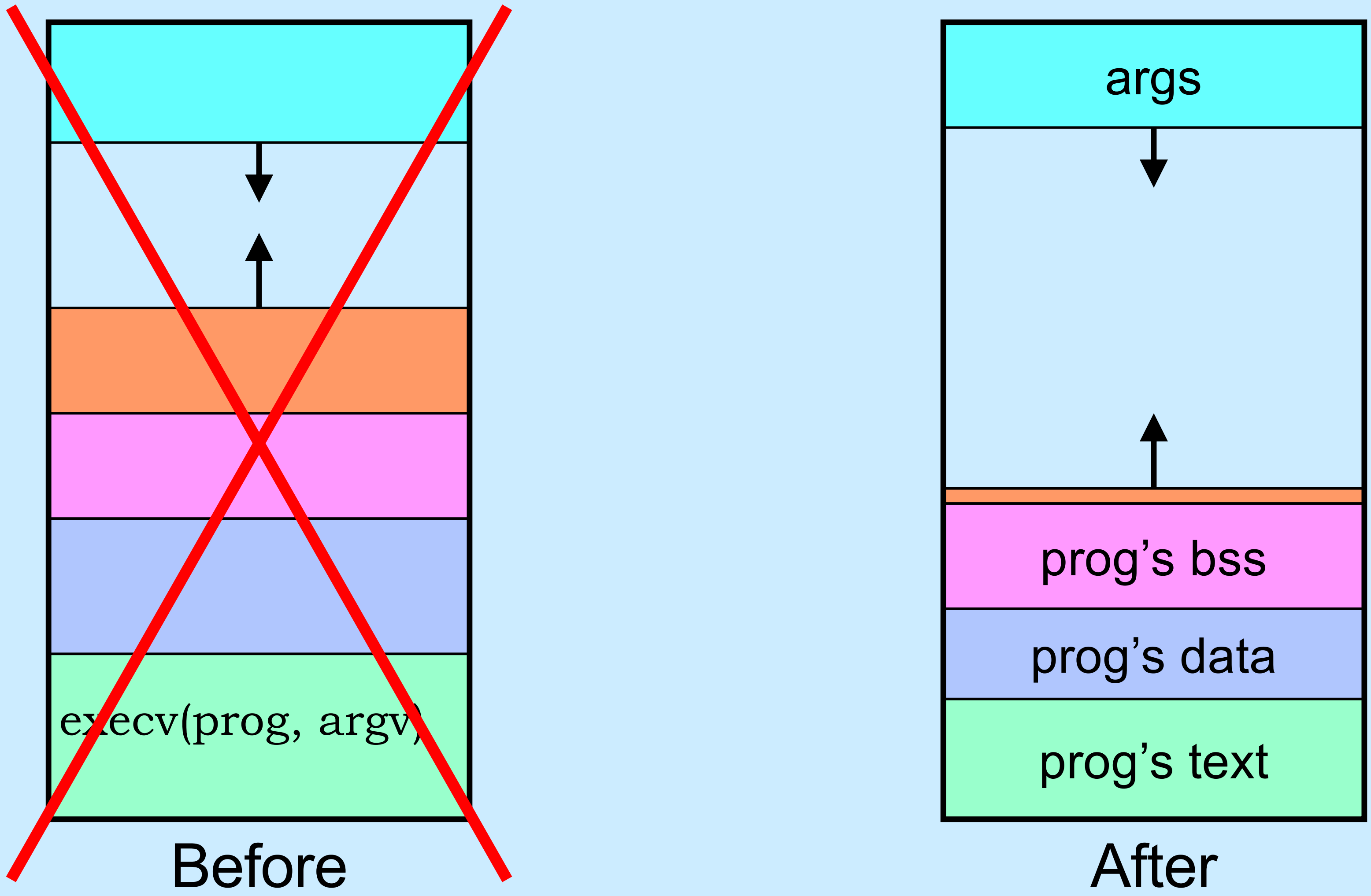
First “real” argument

End of list

Name of the file that contains the program

argv[0] is the name of the program

Loading a New Image



A Random Program ...

```
int main(int argc, char *argv[]) {
 if (argc != 2) {
    fprintf(stderr, "Usage: random count\n");
    exit(1);
  }
  int stop = atoi(argv[1]);
  for (int i = 0; i < stop; i++)
    printf("%d\n", rand());
  return 0;
}
```


Passing It Arguments

- **From the shell**

```
$ random 12
```

- **From a C program**

```
if (fork() == 0) {
  char *argv[] = {"random", "12", (void *)0};
  execv("./random", argv);
}
```

Quiz 3

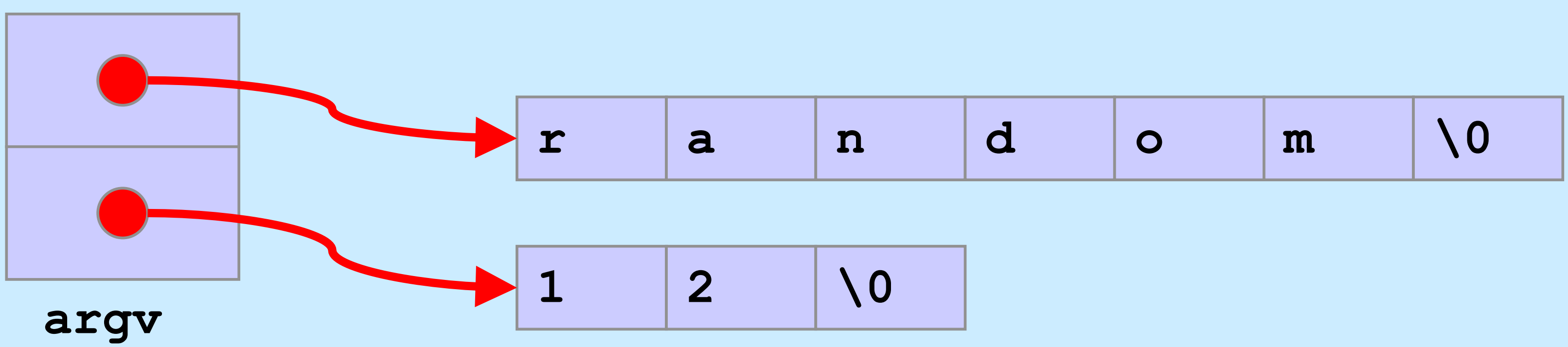
```
if (fork() == 0) {
  char *argv[] = {"random", "12", (void *)0};
  execv("./random", argv);
  printf("random done\n");
}
```

The *printf* statement will be executed

a) only if execv fails
b) only if execv succeeds
c) always

Receiving Arguments

```
int main(int argc, char *argv[]) {
  if (argc != 2) {
    fprintf(stderr, "Usage: random count\n");
    exit(1);
  }
  int stop = atoi(argv[1]);
  for (int i = 0; i < stop; i++)
    printf("%d\n", rand());

  return 0;
}
```



Not So Fast …

- **How does the shell invoke your program?**

```
if (fork() == 0) {
   char *argv = {"random", "12", (void *)0};
   execv("./random", argv);
}
/* what does the shell do here??? */
```

Wait

```
#include <unistd.h>
#include <sys/wait.h>
…
  pid_t pid;
  int status;
  …
  if ((pid = fork()) == 0) {
    char *argv[] = {"random", "12", (void *)0};
    execv("./random", argv);
  }
  waitpid(pid, &status, 0);
```

Exit

```
#include <unistd.h>
#include <stdlib.h>
#include <sys/wait.h>
int main( ) {
  pid_t pid;
  int status;
  if ((pid = fork()) == 0) {
    if (do_work() == 1)
      exit(0); /* success! */
    else
      exit(1); /* failure … */
  }
  waitpid(pid, &status, 0);
  /* low-order byte of status contains exit code.
     WEXITSTATUS(status) extracts it */
```

exit code

Shell: To Wait or Not To Wait ...

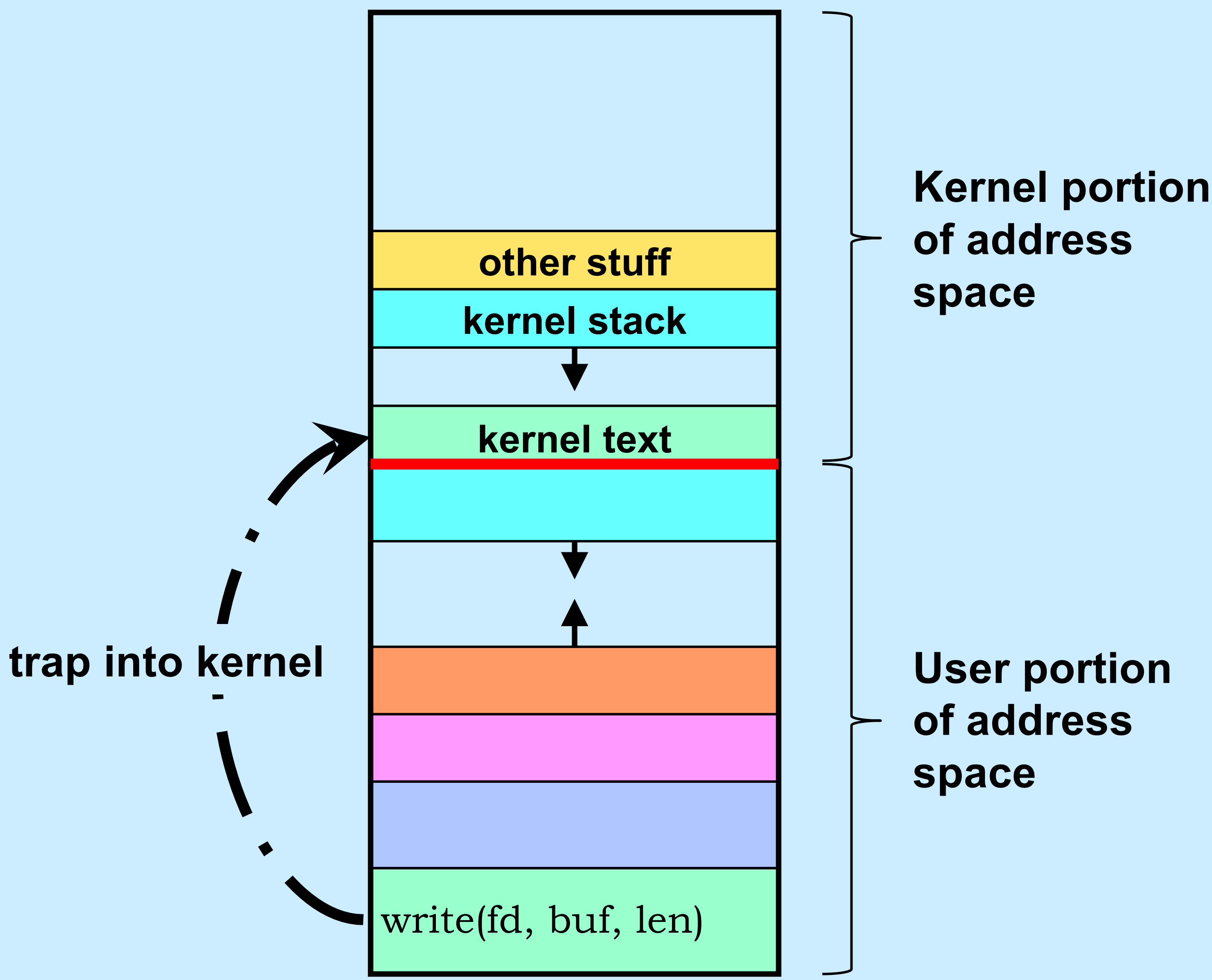
```
$ who
    if ((pid = fork()) == 0) {
        char *argv[] = {"who", 0};
        execv("who", argv);
    }
    waitpid(pid, &status, 0);
    …

$ who &
    if ((pid = fork()) == 0) {
        char *argv[] = {"who", 0};
        execv("who", argv);
    }
    …
```

System Calls

- **Sole direct interface between user and kernel**
- **Implemented as library function that execute *trap* instructions to enter kernel**
- **Errors indicated by returns of –1; error code is in global variable *errno***

```
if (write(fd, buffer, bufsize) == -1) {
   // error!
   printf("error %d\n", errno);
   // see perror
}
```

System Calls



Multiple Processes