Computer Systems II

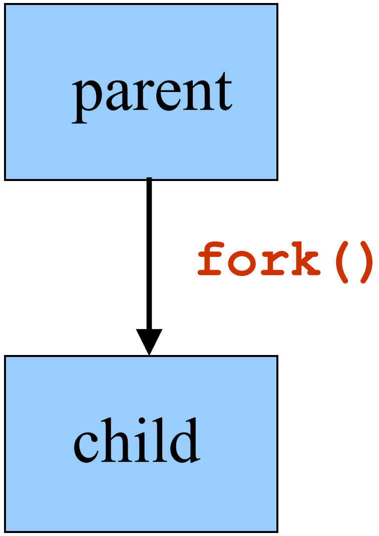
Creating and Executing Processes

Unix system calls

fork( )
wait( )
exit( )

How To Create New Processes?

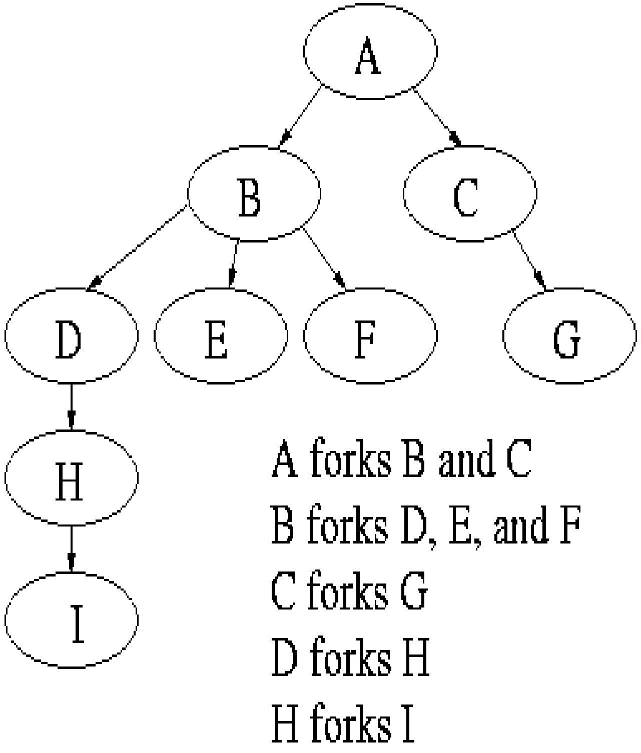
- Underlying mechanism
  - A process runs fork to create a child process
  - Parent and children execute concurrently
  - Child process is a duplicate of the parent process



Process Creation

- After a **fork**, both parent and child keep running, and each can fork off other processes.
- A process tree results. The root of the tree is a special process created by the OS during startup.

- A process can *choose* to wait for children to terminate. For example, if C issued a **wait**() system call, it would block until G finished.



A forks B and C
B forks D, E, and F
C forks G
D forks H
H forks I

Bootstrapping

- When a computer is switched on or reset, there must be an initial program that gets the system running

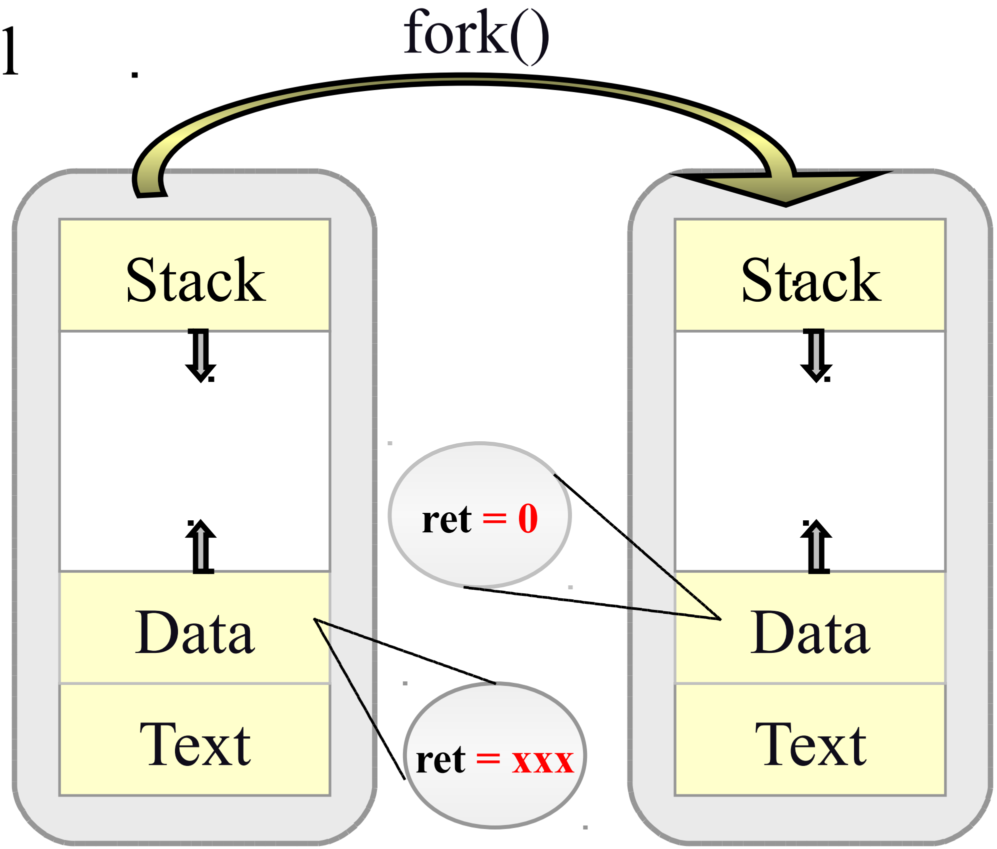
- This is the bootstrap program
  - Initialize CPU registers, device controllers, memory
  - Load the OS into memory
  - Start the OS running

- OS starts the first process (such as “init”)

- OS waits for some event to occur
  - Hardware interrupts or software interrupts (traps)

Fork System Call

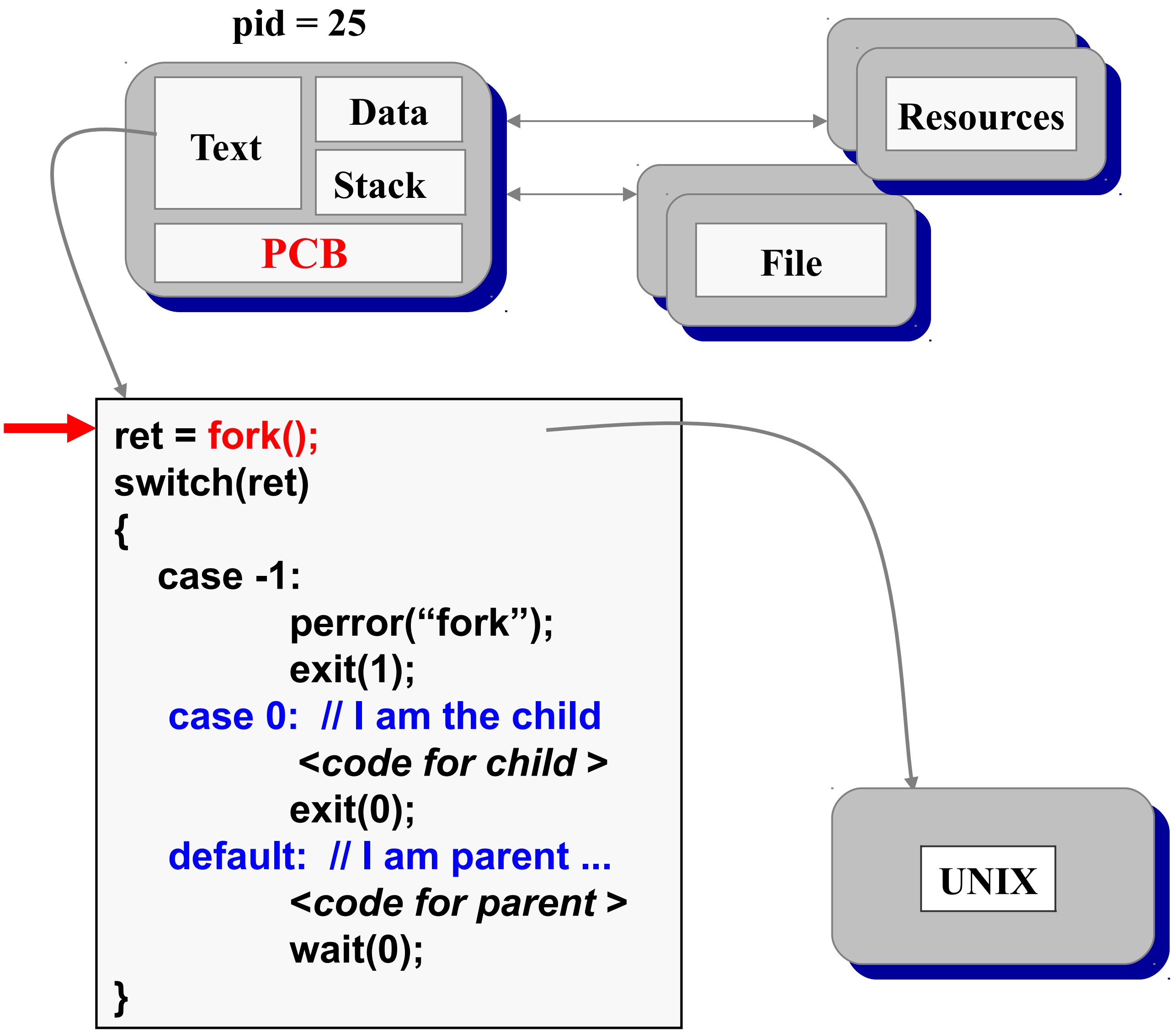
- Current process split into 2 processes: parent, child
- Returns -1 if unsuccessful
- Returns 0 in the child
- Returns the child’s identifier in the parent



Fork System Call

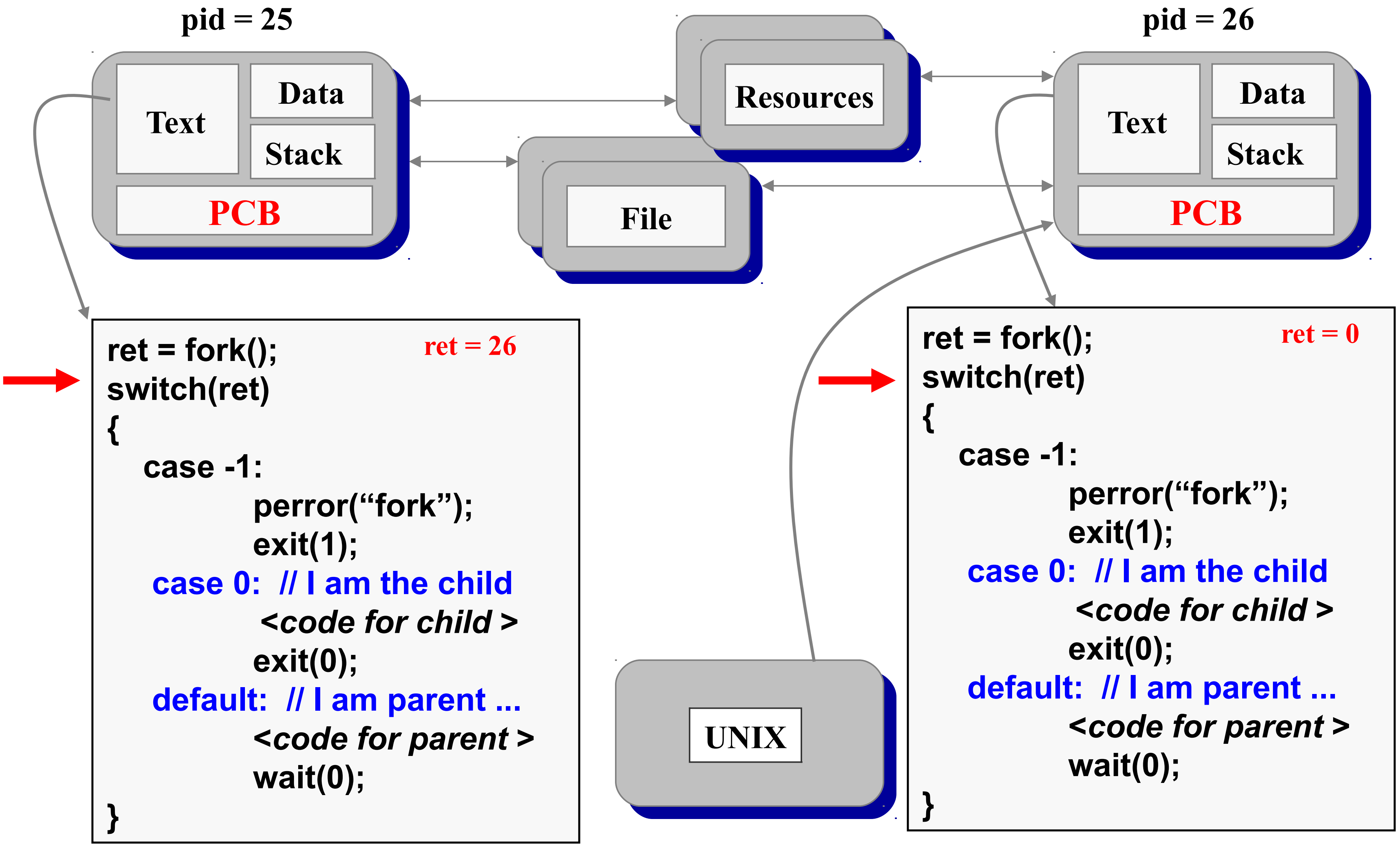
- The child process inherits from parent
  - identical copy of memory
  - CPU registers
  - all files that have been opened by the parent
- Execution proceeds concurrently with the instruction following the fork system call
- The execution context (PCB) for the child process is a copy of the parent's context at the time of the call

How fork Works (1)



```
ret = fork();
switch(ret)
{
    case -1:
                perror("fork");
                exit(1);
     case 0:  // I am the child
                <code for child >
                exit(0);
     default:  // I am parent ...
                <code for parent >
                wait(0);
}
```

How fork Works (2)



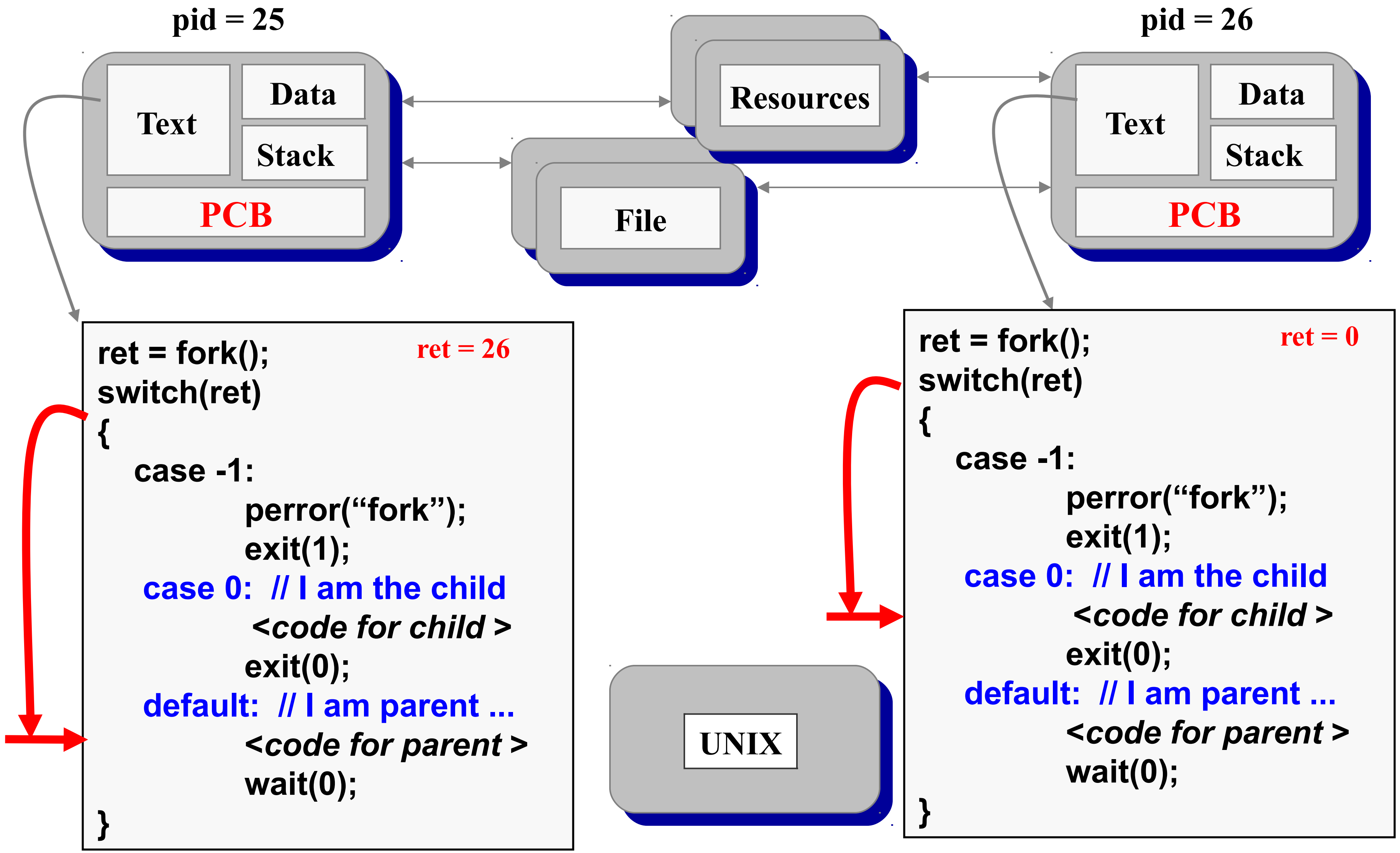
ret = 26

```
ret = fork();
switch(ret)
{
   case -1:
            perror(“fork”);
            exit(1);
   case 0:  // I am the child
             <code for child >
            exit(0);
   default:  // I am parent ...
            <code for parent >
            wait(0);
}
```

ret = 0

```
ret = fork();
switch(ret)
{
   case -1:
            perror(“fork”);
            exit(1);
   case 0:  // I am the child
             <code for child >
            exit(0);
   default:  // I am parent ...
            <code for parent >
            wait(0);
}
```

How fork Works (3)



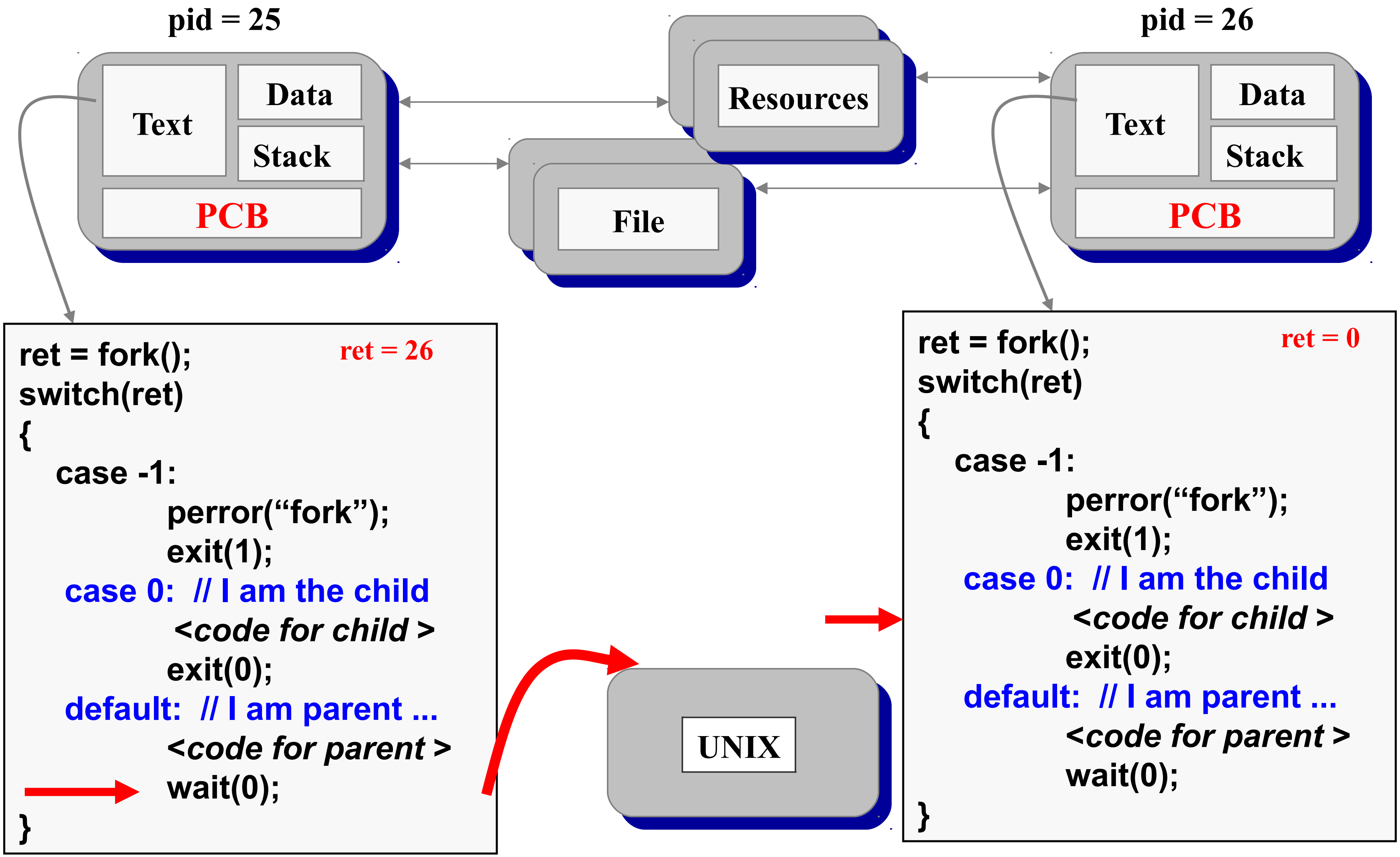
ret = 26

```
ret = fork();
switch(ret)
{
    case -1:
            perror(“fork”);
            exit(1);
    case 0:  // I am the child
            <code for child >
            exit(0);
    default:  // I am parent ...
            <code for parent >
            wait(0);
}
```

ret = 0

```
ret = fork();
switch(ret)
{
    case -1:
            perror(“fork”);
            exit(1);
    case 0:  // I am the child
            <code for child >
            exit(0);
    default:  // I am parent ...
            <code for parent >
            wait(0);
}
```

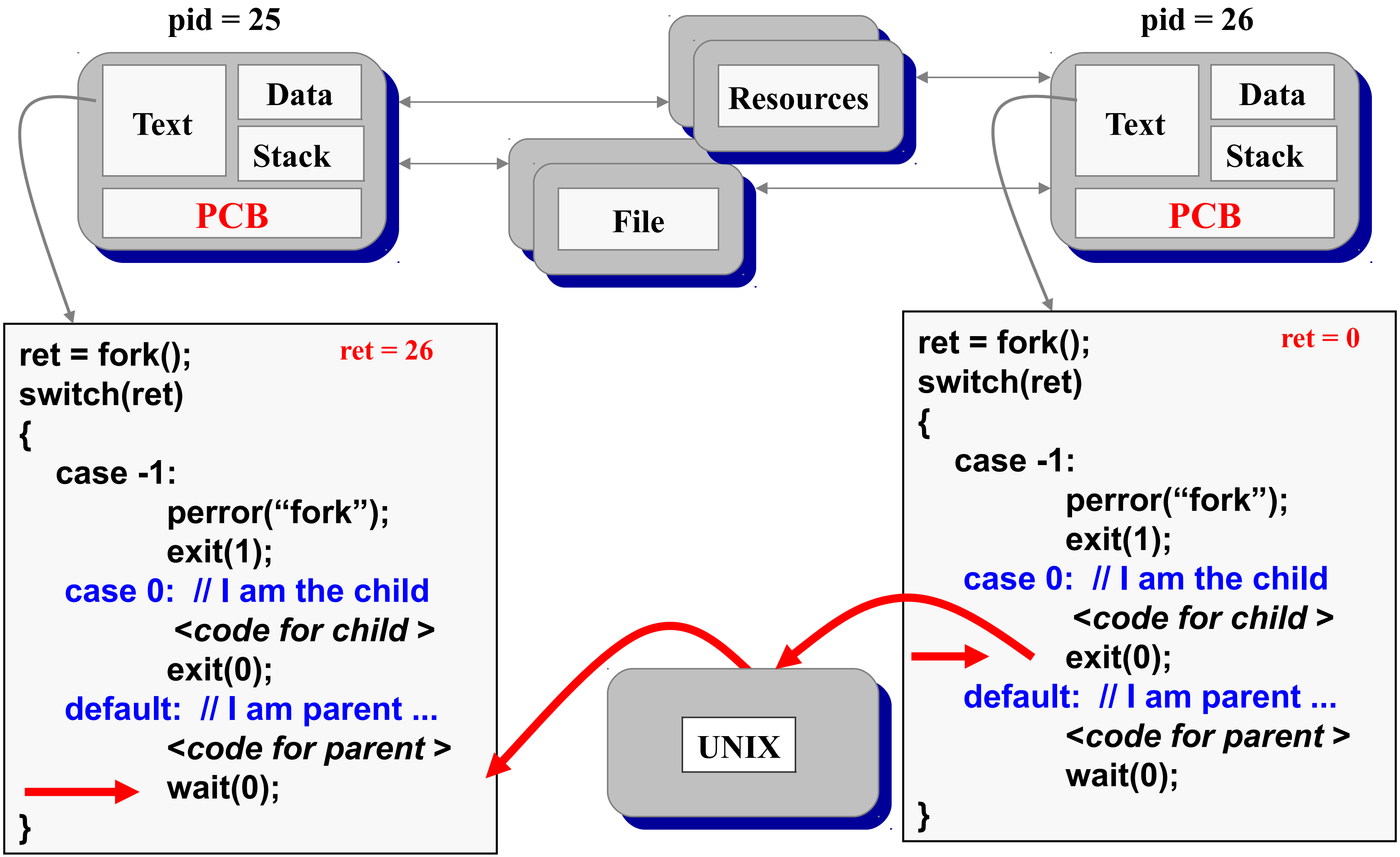
How fork Works (4)



```
ret = fork();
switch(ret)
{
   case -1:
            perror(“fork”);
            exit(1);
    case 0:  // I am the child
             <code for child >
            exit(0);
    default:  // I am parent ...
            <code for parent >
            wait(0);
}
```

```
ret = fork();
switch(ret)
{
   case -1:
            perror(“fork”);
            exit(1);
    case 0:  // I am the child
             <code for child >
            exit(0);
    default:  // I am parent ...
            <code for parent >
            wait(0);
}
```

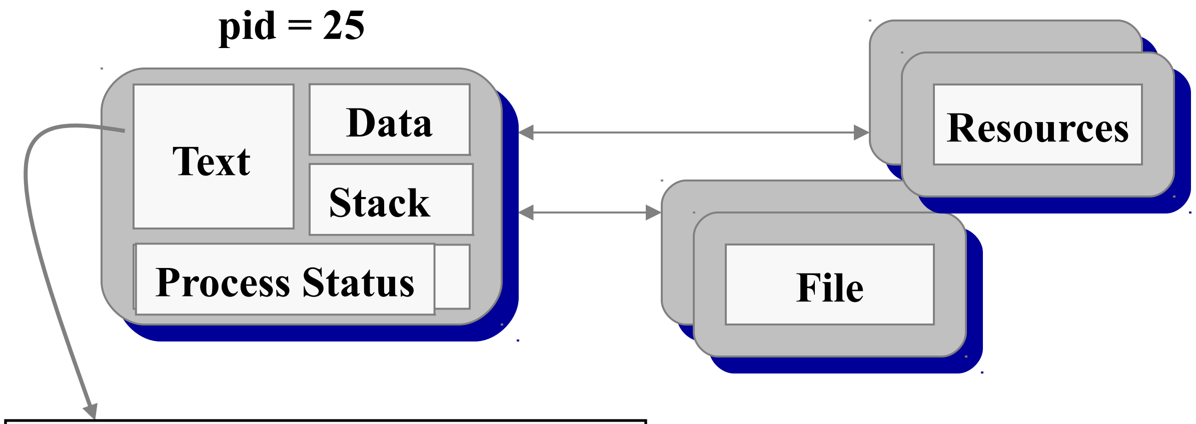
How fork Works (5)



```
ret = fork();
switch(ret)
{
   case -1:
            perror("fork");
            exit(1);
   case 0:  // I am the child
            <code for child >
            exit(0);
   default:  // I am parent ...
            <code for parent >
            wait(0);
}
```

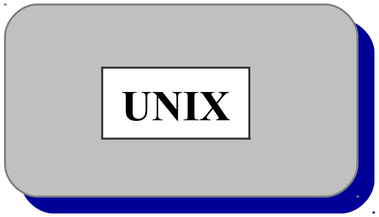
```
ret = fork();
switch(ret)
{
   case -1:
            perror("fork");
            exit(1);
   case 0:  // I am the child
            <code for child >
            exit(0);
   default:  // I am parent ...
            <code for parent >
            wait(0);
}
```

How fork Works (6)



ret = 26

```
ret = fork();
switch(ret)
{
   case -1:
            perror(“fork”);
            exit(1);
    case 0:  // I am the child
             <code for child >
            exit(0);
    default:  // I am parent ...
            <code for parent >
            wait(0);
→           < … >
```



Orderly Termination: exit()

- To finish execution, a child may call exit(*number*)

- This system call:
  - Saves result = argument of exit
  - Closes all open files, connections
  - Deallocates memory
  - Checks if parent is alive
  - If parent is alive, holds the result value until the parent requests it (with wait); in this case, the child process does not really die, but it enters a zombie/defunct state
  - If parent is not alive, the child terminates (dies)

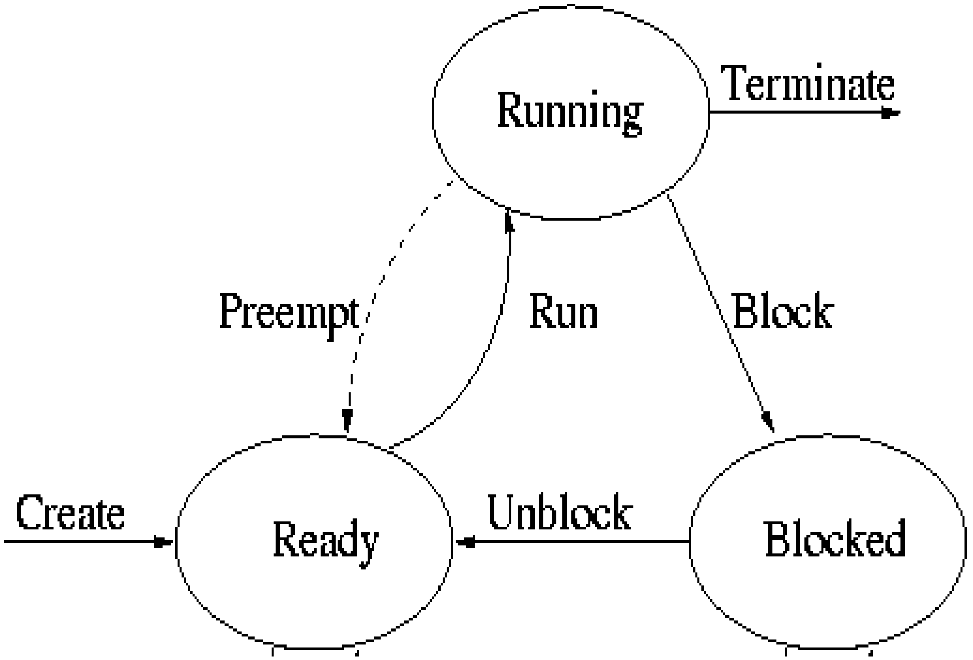
Waiting for the Child to Finish

- Parent may want to wait for children to finish
  - Example: a shell waiting for operations to complete
- Waiting for any some child to terminate: wait()
  - Blocks until some child terminates
  - Returns the process ID of the child process
  - Or returns -1 if no children exist (i.e., already exited)
- Waiting for a specific child to terminate: waitpid()
  - Blocks till a child with particular process ID terminates

```
#include <sys/types.h>
#include <sys/wait.h>

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

State Transition on wait and exit Calls



Other useful system calls: `getpid, getppid`

- getpid returns the identifier of the calling process. Example call (pid is an integer):

```
pid = getpid();
```

- getppid returns the identifier of the parent.
- Note:
  - Zombies can be noticed by running the '**ps**' command (shows the process list); you will see the string "<**defunct**>" as their command name:

```
ps -ef
ps -ef | grep mdamian
```

Fork Example 1: What Output?

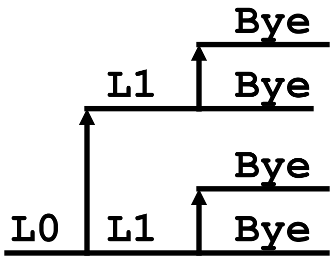
```
int main()
{
   pid_t pid;
   int x = 1;

   pid = fork();
   if (pid != 0) {
     printf(“parent: x = %d\n”, --x);
     exit(0);
   } else {
     printf(“child: x = %d\n”, ++x);
     exit(0);
   }
}
```

Fork Example 2

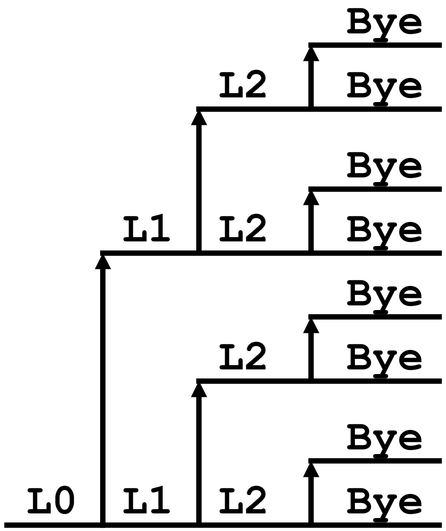
- Key Points
  - Both parent and child can continue forking

```
void fork2()
{
    printf("L0\n");
    fork();
    printf("L1\n");
    fork();
    printf("Bye\n");
}
```



Fork Example 3

```
void fork3()
{
    printf("L0\n");
    fork();
    printf("L1\n");
    fork();
    printf("L2\n");
    fork();
    printf("Bye\n");
}
```



Fork Example 4

```
void fork4()
{
    printf("L0\n");
    if (fork() != 0) {
       printf("L1\n");
       if (fork() != 0) {
           printf("L2\n");
           fork();
       }
    }
    printf("Bye\n");
}
```

Fork Example 5

```
void fork5()
{
    printf("L0\n");
    if (fork() == 0) {
       printf("L1\n");
       if (fork() == 0) {
           printf("L2\n");
           fork();
       }
    }
    printf("Bye\n");
}
```

Summary

- Fork
  - Creates a duplicate of the calling process
  - The result is two processes: parent and child
  - Both continue executing from the same point on
- Exit
  - Orderly program termination
  - Unblocks waiting parent
- Wait
  - Used by parent
  - Waits for child to finish execution

Unix system calls

execv
execl

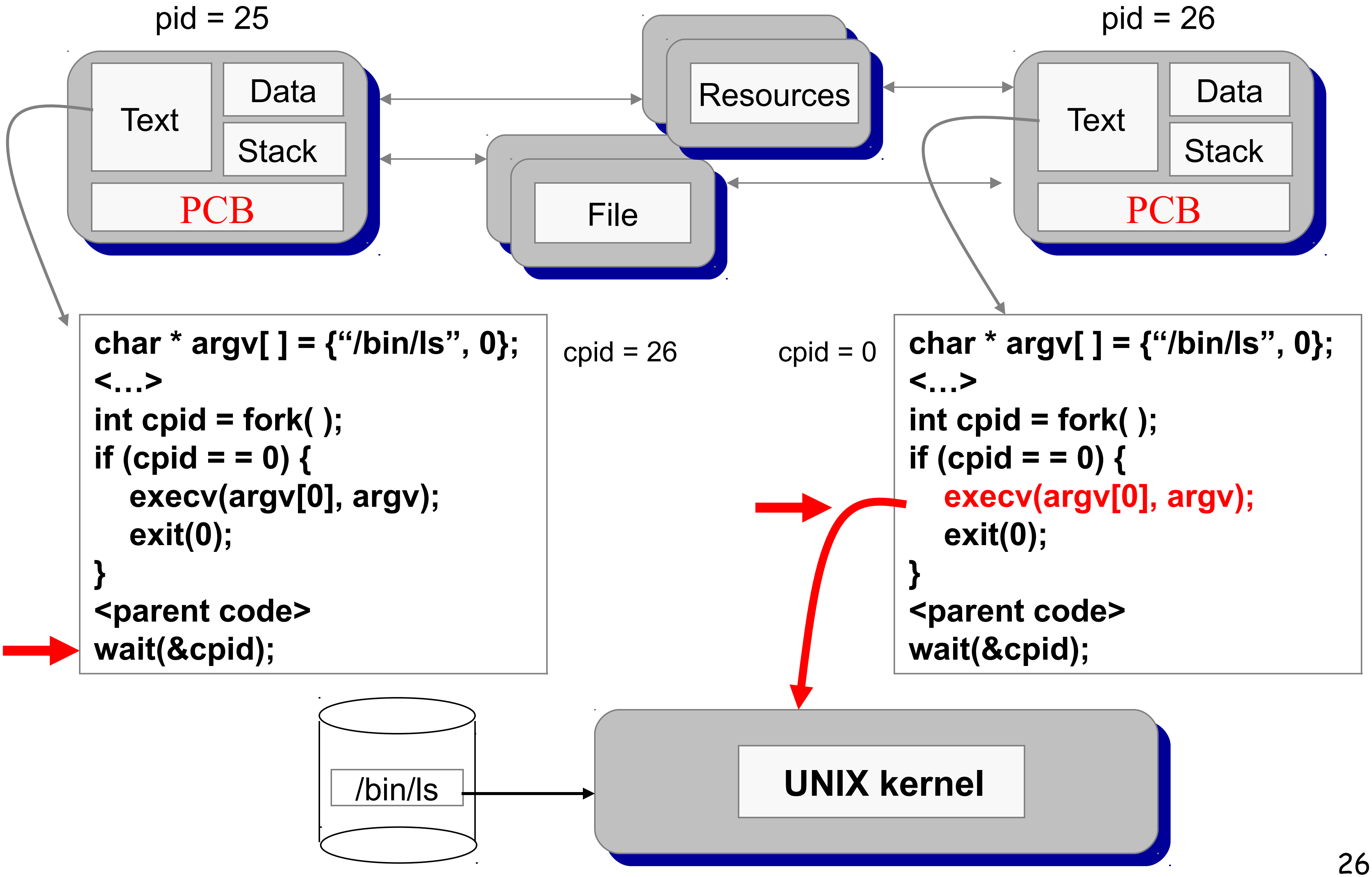
Unix’s execv

- The system call `execv` executes a file, transforming the calling process into a new process. After a successful **`execv`**, there is no return to the calling process.

```
execv(const char * path, char * const argv[])
```

  - `path` is the full path for the file to be executed
  - `argv` is the array of arguments for the program to execute
    - each argument is a null-terminated string
    - the first argument is the name of the program
    - the last entry in argv is NULL

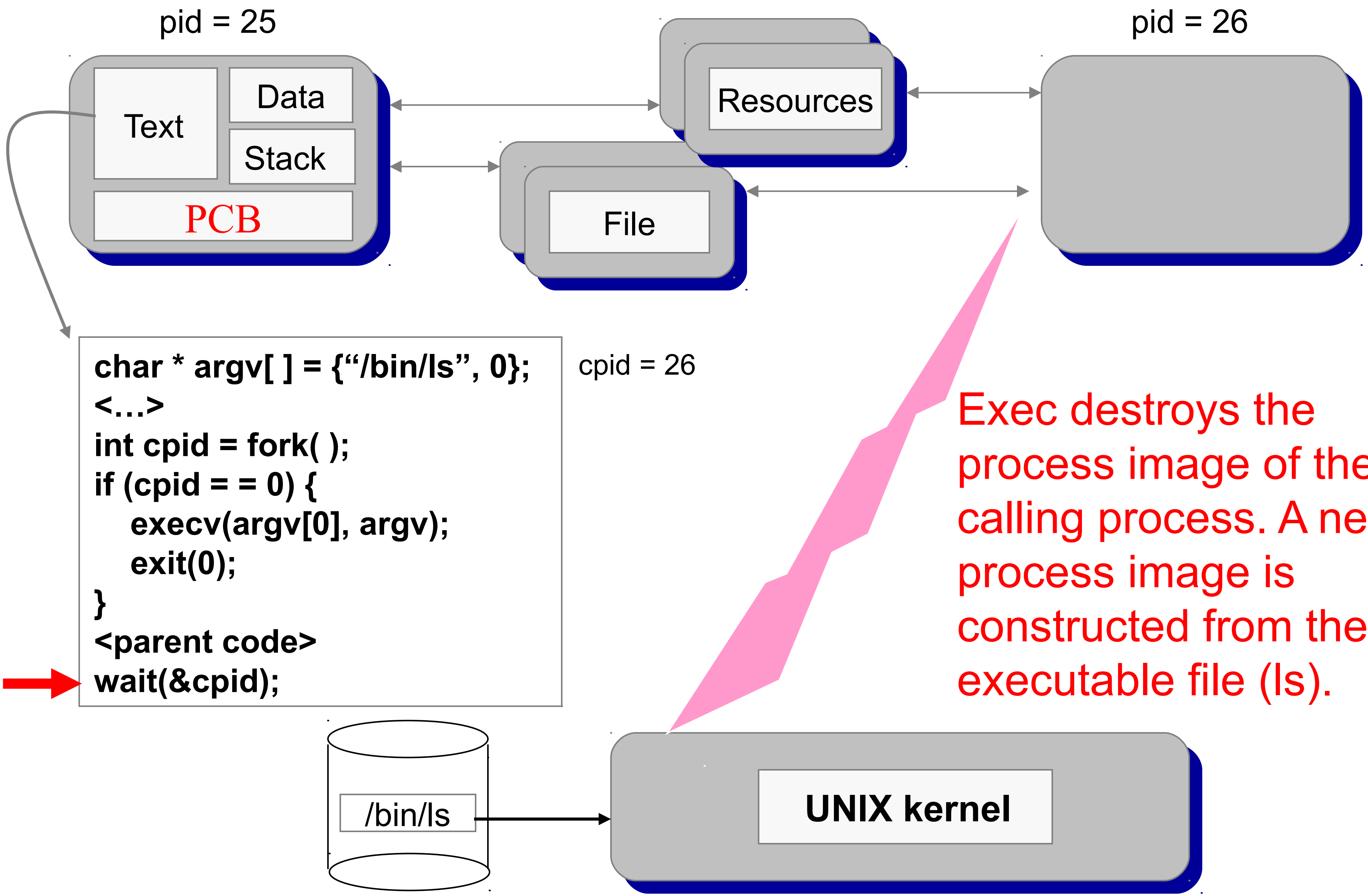
How execv Works (1)



```
char * argv[ ] = {“/bin/ls”, 0};
<…>
int cpid = fork( );
if (cpid = = 0) {
    execv(argv[0], argv);
    exit(0);
}
<parent code>
wait(&cpid);
```

```
char * argv[ ] = {“/bin/ls”, 0};
<…>
int cpid = fork( );
if (cpid = = 0) {
    execv(argv[0], argv);
    exit(0);
}
<parent code>
wait(&cpid);
```

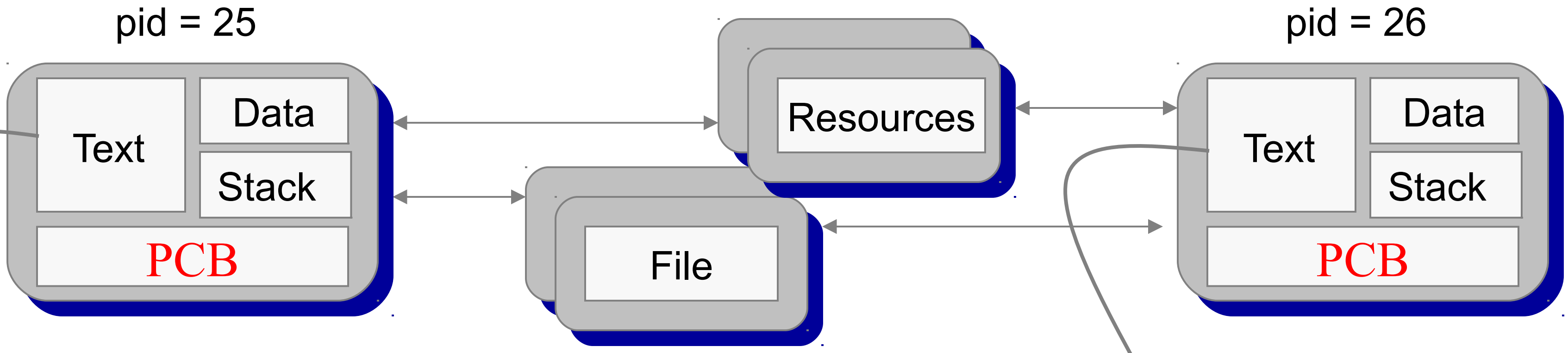
How execv Works (2)



```
char * argv[ ] = {"/bin/ls", 0};
<…>
int cpid = fork( );
if (cpid = = 0) {
    execv(argv[0], argv);
    exit(0);
}
<parent code>
wait(&cpid);
```

Exec destroys the process image of the calling process. A new process image is constructed from the executable file (ls).

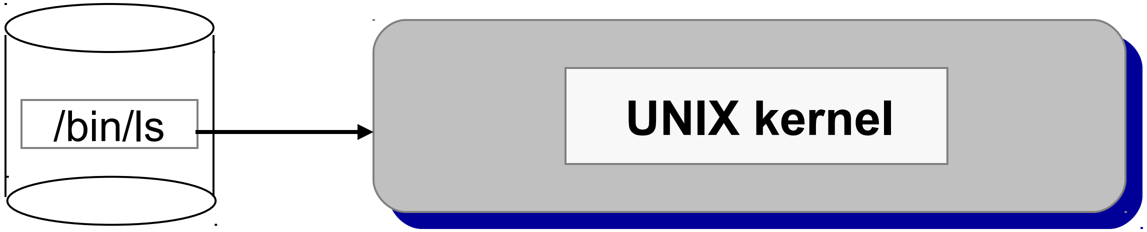
How execv Works (3)



```
char * argv[ ] = {“/bin/ls”, 0};
<…>
int cpid = fork( );
if (cpid = = 0) {
    execv(argv[0], argv);
    exit(0);
}
<parent code>
wait(&cpid);
```

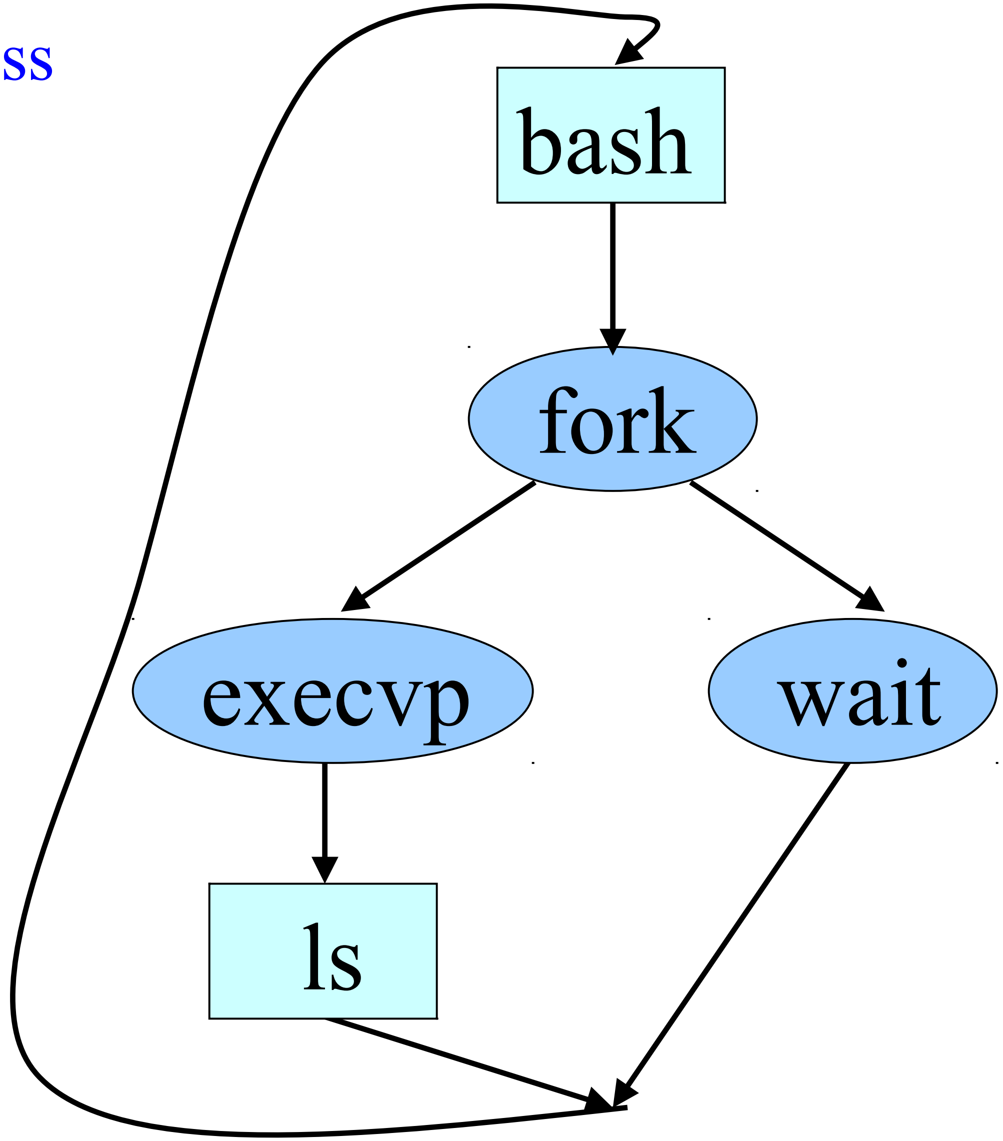
cpid = 26

```
<first line of ls>
<…>
<…>
<…>
exit(0);
```



Example: A Simple Shell

- Shell is the parent process
  - E.g., bash
- Parses command line
  - E.g., “ls –l”
- Invokes child process
  - Fork, execvp
- Waits for child
  - Wait



execv Example

```
#include <stdio.h>
#include <unistd.h>

char * argv[] = {“/bin/ls”, “-l”, 0};
int main()
{
   int pid, status;

   if ( (pid = fork() ) < 0 )
   {
       printf(“Fork error \n”);
       exit(1);
   }
   if(pid == 0)  { /* Child executes here */
       execv(argv[0], argv);
       printf(“Exec error \n”);
       exit(1);
   } else      /* Parent executes here */
       wait(&status);
   printf("Hello there! \n”);
   return 0;
}
```

Note the NULL string at the end

execv Example – Sample Output

- Sample output:

```
total 282
drwxr-xr-x  2 mdamian  faculty  512 Jan 29 14:02 assignments
-rw-r--r--    1 mdamian  faculty  3404 Jan 29 14:05 index.html
drwxr-xr-x  2 mdamian  faculty  512 Jan 28 15:02 notes

Hello there!
```

execl

- Same as execv, but takes the arguments of the new program as a list, not a vector:
- Example:

```
execl(“/bin/ls”, “/bin/ls”, “-l”, 0);
```

- Is equivalent to

Note the NULL string at the end

```
char * argv[] = {“/bin/ls”, “-l”, 0};
execv(argv[0], argv);
```

- execl is mainly used when the number of arguments is known in advance

General purpose process creation

- In the parent process:

```
int childPid;
char * const argv[ ] = {…};

main {
    childPid = fork();
    if(childPid == 0)
    {
          // I am child ...
          // Do some cleaning, close files
          execv(argv[0], argv);
    }
    else
    {
          // I am parent ...
          <code for parent process>
        wait(0);
    }
}
```

Combined fork/exec/wait

- Common combination of operations
  - Fork to create a new child process
  - Exec to invoke new program in child process
  - Wait in the parent process for the child to complete
- Single call that combines all three
  - int system(const char *cmd);
- Example

```
int main()
{
   system(“echo Hello world”);
}
```

Properties of fork / exec sequence

- In 99% of the time, we call execv(…) after fork()
  - the memory copying during fork() is useless
  - the child process will likely close open files and connections
  - overhead is therefore high
  - might as well combine both in one call (OS/2)

- vfork()
  - a system call that creates a process without creating an identical memory image
  - sometimes called “lightweight” fork
  - child process is understood to call execv() almost immediately

Variations of execv

- execv
  - Program arguments passed as an array of strings
- execvp
  - Extension of execv
  - Searches for the program name in the PATH environment
- execl
  - Program arguments passed directly as a list
- execlp
  - Extension of execv
  - Searches for the program name in the PATH environment

Summary

- exec(v,vp,l,lp)
  - Does NOT create a new process
  - Loads a new program in the image of the calling process
  - The first argument is the program name (or full path)
  - Program arguments are passed as a vector (v,vp) or list (l,lp)
  - Commonly called by a forked child

- system:
  - combines fork, wait, and exec all in one