

Processes in UNIX

SDC, OSW CSE 3541

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Text & Reference Book(s)



Jeri R. Hanly & Elliot B. Koffman

Problem Solving and Program Design in C

Seventh Edition, Pearson Education



Robert Love

LINUX

System Programming

Second Edition, SPD, O'REILLY



Kay A. Robbins & Steve Robbins

Unix™ Systems Programming

Communications, concurrency, and Treads

Pearson Education

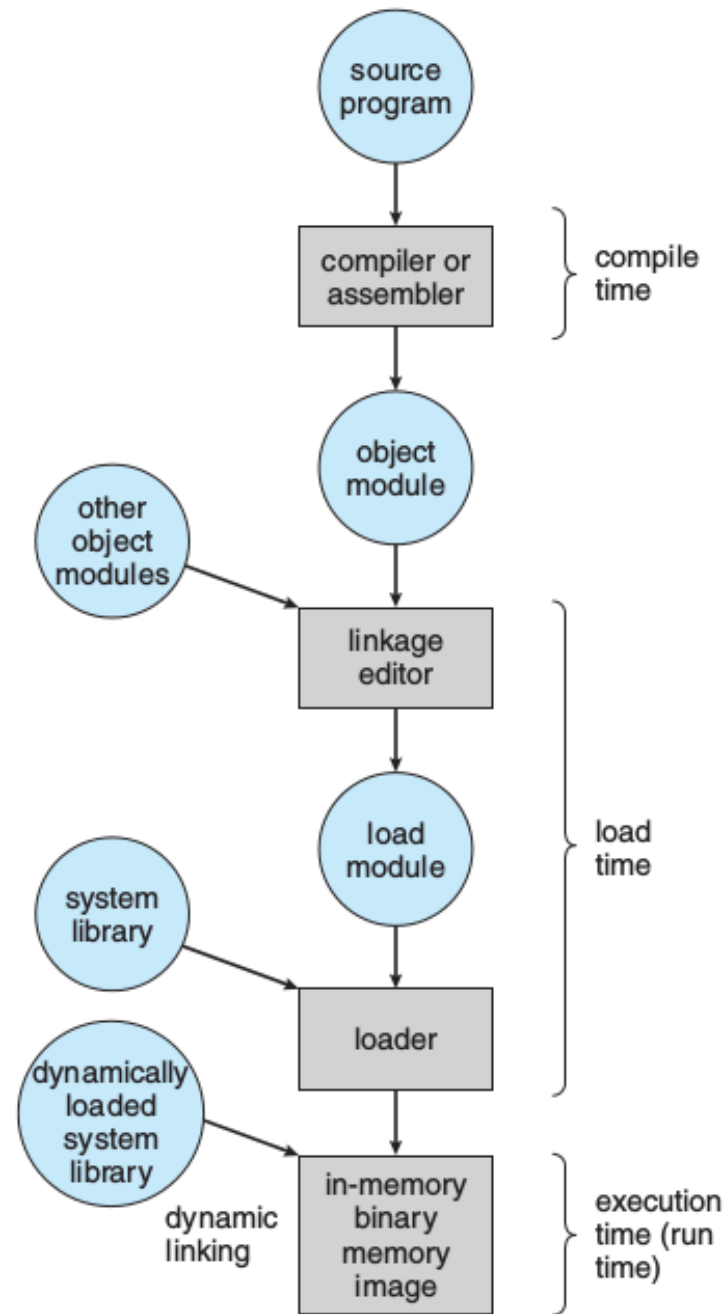
Program

- ☞ A **program** is a prepared sequence of instructions to accomplish a defined task.
- ☞ To write a C source program, a programmer creates **disk files** containing C statements that are organized into functions.
- ☞ An individual C source file may also contain variable and function declarations, type and macro definitions (e.g., **typedef**) and preprocessor commands (e.g., **#ifdef**, **#include**, **#define**).
- ☞ The source program contains exactly one **main** function.

C compiler

- ☞ The C compiler translates each source file into an object file.
- ☞ The compiler then links the individual object files with the necessary libraries to produce an executable module.
- ☞ When a program is run or executed, the operating system copies the executable module into a **program image** in main memory.

Multistage Processing of a User Program



Layout of a Program Image in Main Memory

High address

command-line arguments
and
environment variables

← **argc, argv,**
environment

STACK

← **activation records for
function call**
(return address,
parameters,
saved registers,
automatic variables)



HEAP

← **allocation from
malloc family**

Uninitialized static data(bss)

Initialized static data(data)

Program text(text)

command: \$ size objectfilename

- size utility lists the section sizes and the total size for each of the object in its argument list.
- If none are specified in the filename, the file "a.out" will be used

Low address

Process

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- ☞ A process has an address space (memory it can access) and at least one flow of control called a thread.
- ☞ The variables of a process can either remain in existence for the life of the process (static storage) or be automatically allocated when execution enters a block and deallocated when execution leaves the block (automatic storage).

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- ☞ A thread of execution can be represented by the sequence of instruction addresses assigned to the program counter during the execution of the program's code.

Example-1

Process 1 executes statements 245, 246 and 247 in a loop. Its thread of execution can be represented as $245_1, 246_1, 247_1, 245_1, 246_1, 247_1, 245_1, 246_1, 247_1 \dots$, where the subscripts identify the thread of execution as belonging to process 1.

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Example-2

Process 1 executes its statements 245, 246 and 247 in a loop as in Example 1, and process 2 executes its statements 10, 11, 12 The CPU executes instructions in the order $245_1, 246_1, 247_1, 245_1, 246_1, 247_1, 245_1, 246_1$, [context-switch instructions], $10_2, 11_2, 12_2, 13_2$, [context-switch instructions], $247_1, 245_1, 246_1, 247_1 \dots$. Context switches occur between 246_1 and 10_2 and between 13_2 and 247_1 . The processor sees the threads of execution interleaved, whereas the individual processes see uninterrupted sequences.



Process Identification

- ✎ UNIX identifies processes by a unique integral value called the process ID.
- ✎ Each process also has a parent process ID, which is initially the process ID of the process that created it.
- ✎ If this parent process terminates, the process is adopted by a system process so that the parent process ID always identifies a valid process.

getpid and getppid Function

- ☞ The `getpid` function returns the process ID .
- ☞ The `getppid` function returns the parent process ID.
- ☞ The `pid_t` is an unsigned integer type that represents a process ID.

```
#include <unistd.h>

pid_t getpid(void);

pid_t getppid(void);
```

Neither the `getpid` nor the `getppid` functions can return an error.

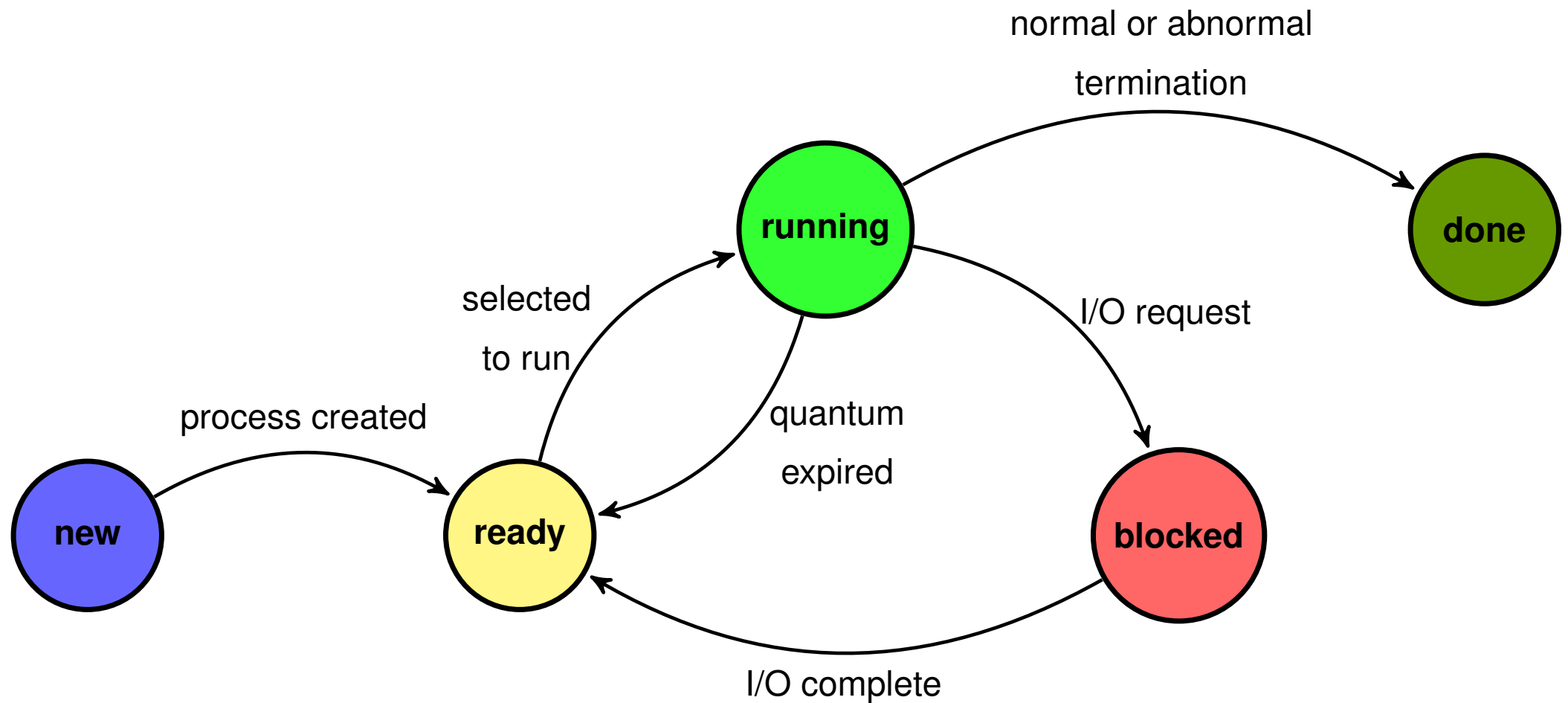
Example

```
#include <stdio.h>
#include <unistd.h>
int main (void) {
    printf("I am process %ld\n", (long)getpid());
    printf("My parent is %ld\n", (long)getppid());
    return 0;
}
```

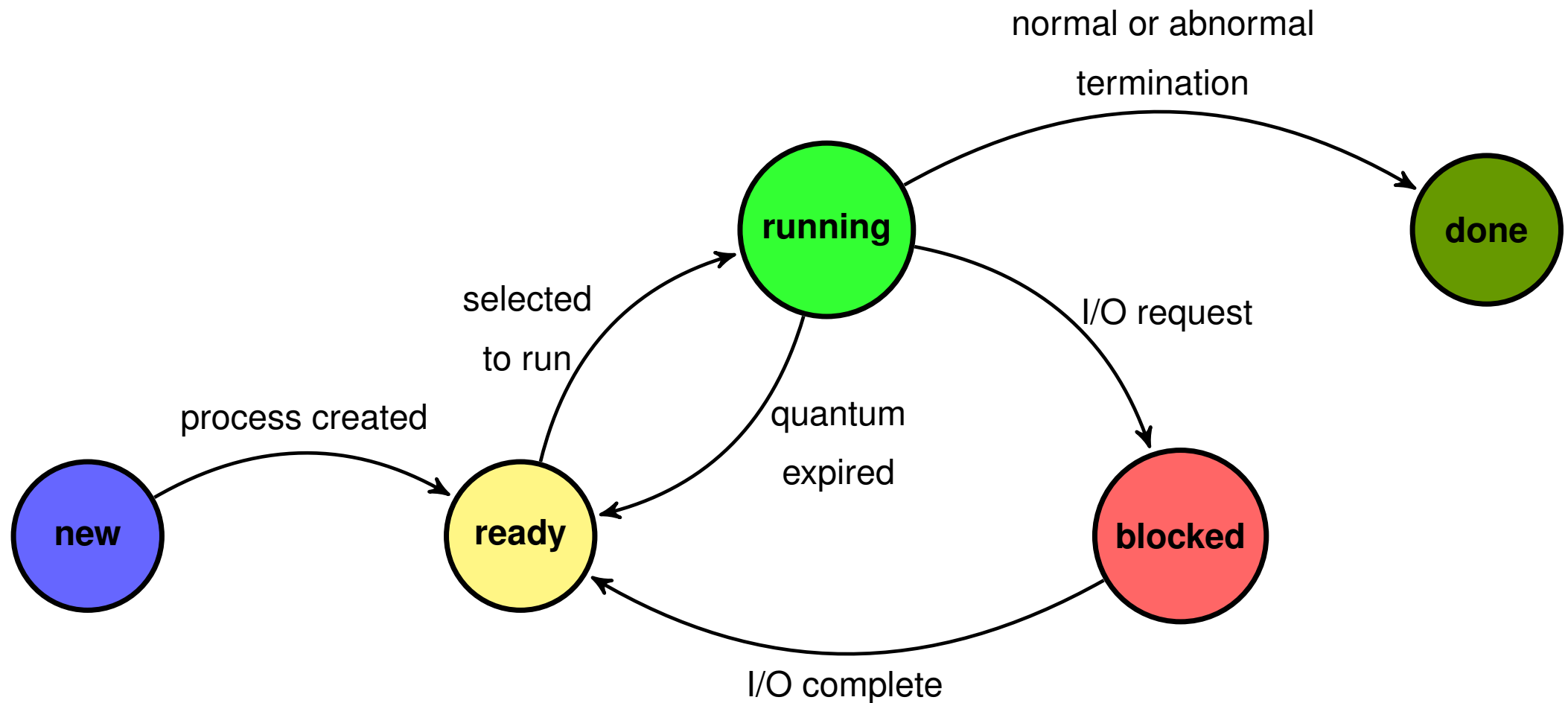


Process State

Process State








Process State



state	meaning
new	being created
ready	waiting to be assigned to a processor
running	instructions are being executed
blocked	waiting for an event such as I/O
done	finished

ps displays information about a selection of the active processes. If you want a repetitive update of the selection and the displayed information, use **top** instead.

-  \$ **ps** displays information about processes associated with the user.
-  The & **ps -a** option displays information for processes associated with all the terminals.
-  The & **ps -A** option displays information for all processes.
-  & **ps -la** long format
-  Try more

UNIX Process Creation and `fork`

- ✍ A process can create a new process by calling `fork`.
- ✍ The calling process becomes the **parent**, and the created process is called the **child**.
- ✍ The `fork` function copies the parent's memory image so that the new process receives a copy of the address space of the parent.
- ✍ Both processes continue at the instruction after the `fork` statement (executing in their respective memory images).
- ✍ `fork()` prototype

```
#include <unistd.h>

pid_t fork(void);
```

- ✍ `fork()` function returns

- (1) returns 0 to the child
- (2) returns the child's process ID to the parent.
- (3) When `fork` fails, it returns -1 and sets the `errno`.

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Note:: The `fork` function return value is the critical characteristic that allows the parent and the child to distinguish themselves and to execute different code.

More About `fork`

- 👉 If the system does not have the necessary resources to create the child or if limits on the number of processes would be exceeded, `fork` sets `errno` to `EAGAIN`.
- 👉 In case of a failure, the `fork` doesnot create a child.

Find the Output

```
#include <stdio.h>
#include <unistd.h>
int main(void) {
    int x;
    x = 0;
    fork();
    x = 1;
    printf("I am process %ld and my x
           is %d\n", (long)getpid(), x);
    return 0;
}
```

Find the Output

```
#include <stdio.h>
#include <unistd.h>
int main(void) {
    int x;
    x = 0;
    fork();
    x = 1;
    printf("I am process %ld and my x
           is %d\n", (long)getpid(), x);
    return 0;
}
```

In the above program, both parent and child execute the `x = 1` assignment statement after returning from `fork`.

Testing the return value of fork

```
#include <stdio.h>
#include <unistd.h>
#include <sys/types.h>
int main(void) {
    pid_t childpid;
    childpid = fork();
    if (childpid == -1) {
        perror("Failed to fork");
        return 1;
    }
    if (childpid == 0)                /* child code */
        printf("I am child %ld\n", (long)getpid());
    else                             /* parent code */
        printf("I am parent %ld\n", (long)getpid());
    return 0;
}
```


Testing the return value of fork

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#include <stdio.h>
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int main(void) {
    pid_t childpid;
    childpid = fork();
    if (childpid == -1) {
        perror("Failed to fork");
        return 1;
    }
    if (childpid == 0)                /* child code */
        printf("I am child %ld\n", (long)getpid());
    else                             /* parent code */
        printf("I am parent %ld\n", (long)getpid());
    return 0;
}
```

After `fork` in the above program, the parent and child output their respective process IDs.

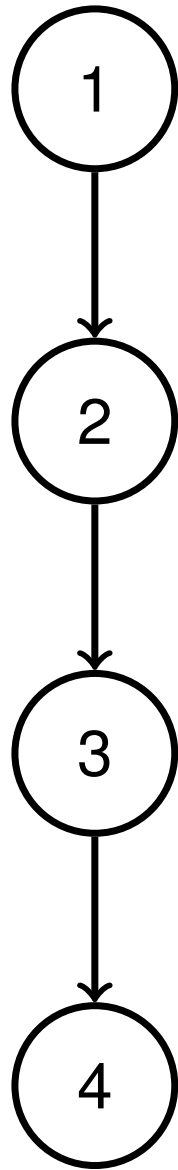
Find the Output

```
#include <stdio.h>
#include <unistd.h>
#include <sys/types.h>
int main(void) {
    pid_t childpid;
    pid_t mypid;
    mypid = getpid();
    childpid = fork();
    if (childpid == -1) {
        perror("Failed to fork");
        return 1;
    }
    if (childpid == 0)                /* child code */
        printf("I am child %ld, ID = %ld\n", (long)
            getpid(), (long)mypid);
    else                             /* parent code */
        printf("I am parent %ld, ID = %ld\n", (long)
            getpid(), (long)mypid);
    return 0;
}
```

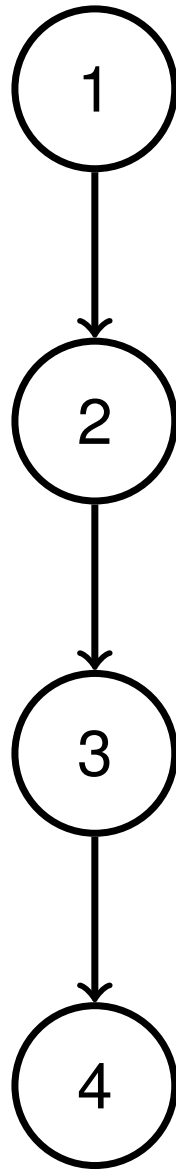
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    childpid = fork();
    if (childpid == -1) {
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        return 1;
    }
    if (childpid == 0)                /* child code */
        printf("I am child %ld, ID = %ld\n", (long)
            getpid(), (long)mypid);
    else                             /* parent code */
        printf("I am parent %ld, ID = %ld\n", (long)
            getpid(), (long)mypid);
    return 0;
}
```

Chain of $n=4$ Processes



Chain of n=4 Processes



- ☞ A graph representing the chain of processes, when n is 4.
- ☞ Each circle represents a process labeled by its value of i when it leaves the loop as per implementation given in next slide.
- ☞ The edges represent the **is-a-parent** relationship.
- ☞ $A \longrightarrow B$ means process A is the parent of process B .

Creating a Chain of n Processes

Create a chain of n processes by calling fork in a loop.

Creating a Chain of n Processes

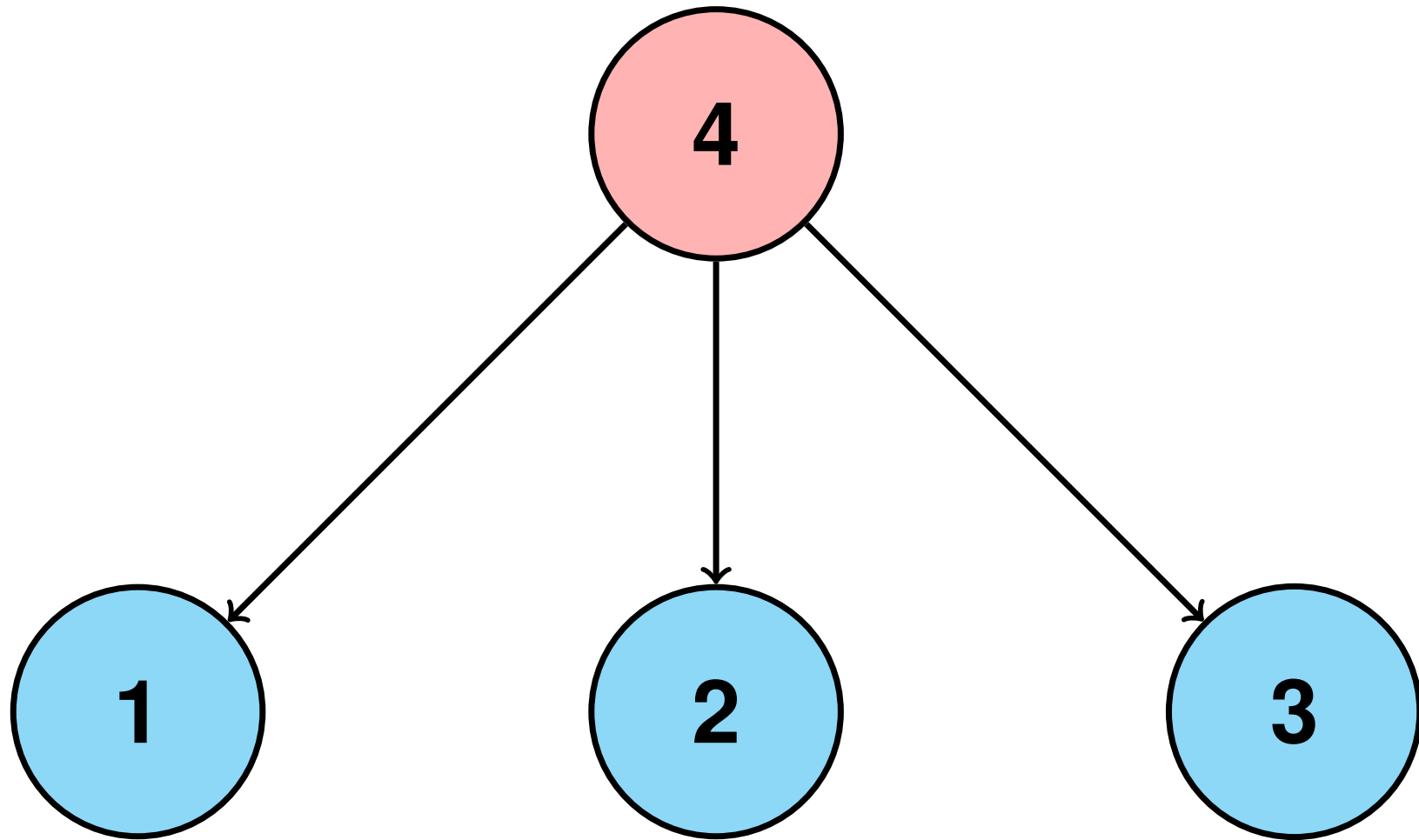
Create a chain of n processes by calling fork in a loop.

```
int main (int argc, char *argv[]) {
    pid_t childpid = 0;
    int i, n;
    if (argc != 2) {/* check for valid number of
        command-line arguments */
        fprintf(stderr, "Usage: %s processes\n", argv
            [0]);
        return 1;
    }
    n = atoi(argv[1]);
    for (i = 1; i < n; i++)
        if (childpid=fork())
            break;
    fprintf(stderr, "i:%d process ID:%ld parent ID:%
        ld child ID:%ld\n", i, (long)getpid(), (long)
        getppid(), (long)childpid);
    return 0;
}
```

Briefing of the Previous Code

- 👉 Creates a chain of n processes by calling **fork** in a loop.
- 👉 On each iteration of the loop, the parent process has a nonzero `childpid` and hence breaks out of the loop.
- 👉 The child process has a zero value of `childpid` and becomes a parent in the next loop iteration.
- 👉 In case of an error, **fork** returns -1 and the calling process breaks out of the loop.

A Fan of $n=4$ Processes



Creating a Fan of n Processes

Creates a fan of n processes by calling `fork` in a loop.

Creating a Fan of n Processes

Creates a fan of n processes by calling `fork` in a loop.

```
int main (int argc, char *argv[]) {
    pid_t childpid = 0;
    int i, n;
    if (argc != 2) {
        /* check for valid number of command-line
           arguments */
        fprintf(stderr, "Usage: %s processes\n", argv
            [0]);
        return 1;
    }
    n = atoi(argv[1]);
    for (i = 1; i < n; i++)
        if ((childpid = fork()) <= 0)
            break;
    fprintf(stderr, "i:%d process ID:%ld parent ID:%
        ld child ID:%ld\n", i, (long)getpid(), (long)
        getppid(), (long)childpid);
    return 0;
}
```

Workout Exercise

Explain what happens when you replace the test

```
(childpid = fork()) <= 0
```

of the previous slide program with

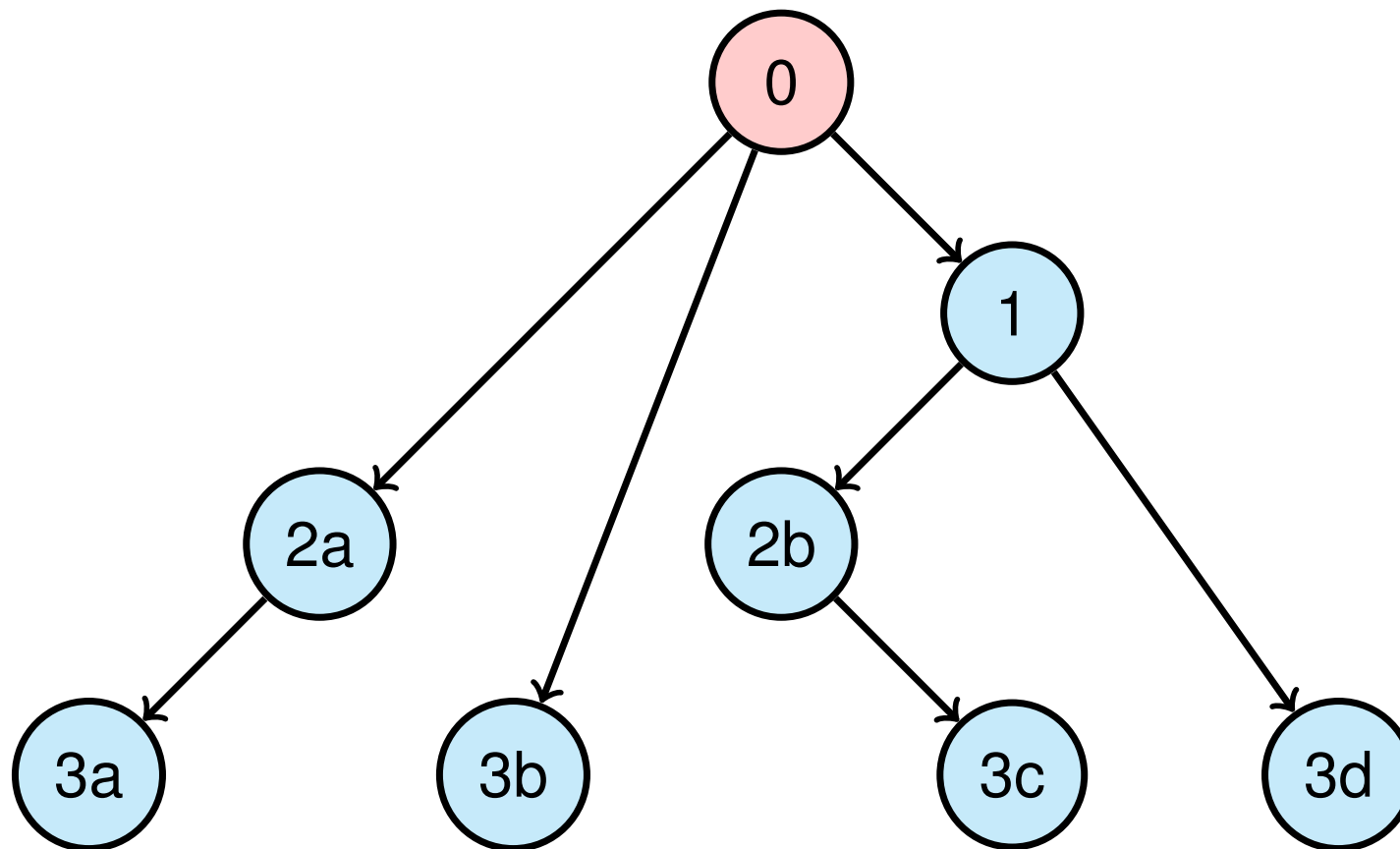
```
(childpid = fork()) == -1
```

Draw a suitable diagram labelling the circles with the actual process.

Solution to Previous Exercise

Tree of processes produced by the modification of the test condition of the Program










```
(childpid = fork()) == -1
```



Parent Vs Child in `fork`

`fork` - create a child process



Description: `fork()` creates a new process by duplicating the calling process. The new process, referred to as the **child**, is an exact duplicate of the calling process, referred to as the **parent**, **except for the following points:**

-  The child has its own unique process ID, and this PID does not match the ID of any existing process group.
-  The child's parent process ID is the same as the parent's process ID.
-  The child does not inherit its parent's memory locks.
-  Process resource utilizations and CPU time counters are reset to zero in the child.
-  The child's set of pending signals is initially empty.
-  The child does not inherit semaphore adjustments from its parent.
-  The child does not inherit record locks from its parent.
-  The child does not inherit timers from its parent.
-  The child does not inherit outstanding asynchronous I/O operations from its parent, nor does it inherit any asynchronous I/O contexts from its parent.

- ✎ The child does not inherit directory change notifications from its parent.
- ✎ **The child does not receive a signal when its parent terminates.**
- ✎ The termination signal of the child is always **SIGCHLD**.
- ✎ The port access permission bits set by **ioperm** (ioperm - set port input/output permissions) are not inherited by the child
- ✎ **The child process is created with a single thread**-the one that called `fork()`. The entire virtual address space of the parent is replicated in the child, including the states of mutexes, condition variables, and other pthreads objects.
- ✎ **The child inherits copies of the parent's set of open file descriptors.** Each file descriptor in the child refers to the same open file description as the corresponding file descriptor in the parent.
- ✎ The child inherits copies of the parent's set of open message queue descriptors.
- ✎ The child inherits copies of the parent's set of open directory streams.

What Does the Parent Do While the Child Executes

It can do two things:

-  Wait to gather the child's exit status.
-  Continue execution without waiting for the child(and pick up the exit status later, if at all)

Two system calls invoked in waiting `wait()` and `waitpid()`

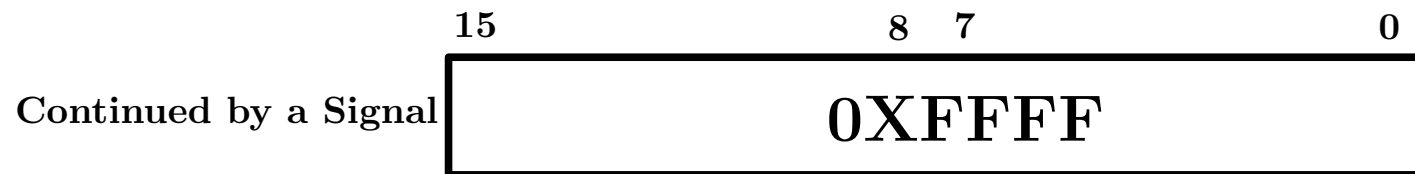
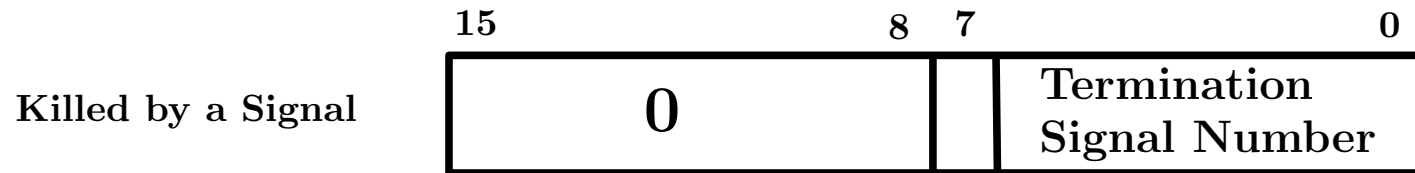
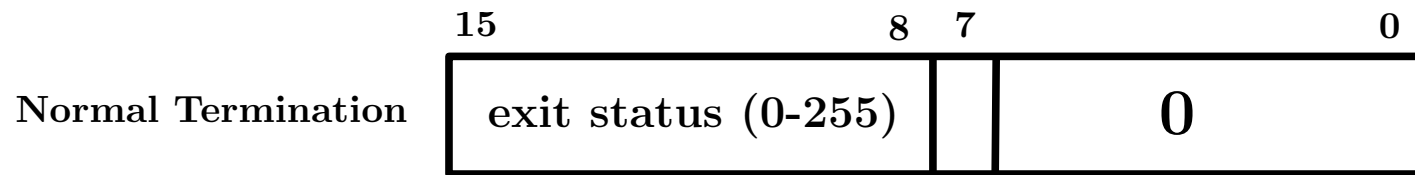
Process Termination

- ✍ When a process terminates, the operating system deallocates the process resources, updates the appropriate statistics and notifies other processes of the demise.
- ✍ The termination can either be **normal** or **abnormal**.
- ✍ The activities performed during process termination:
 - ✍ Canceling pending timers and signals,
 - ✍ Releasing virtual memory resources,
 - ✍ Releasing other process-held system resources such as locks, and closing files that are open.
- ✍ The operating system records the process status and resource usage, notifying the parent in response to a wait function.

Process Termination

- ✎ In UNIX, a process does not completely release its resources after termination until the parent waits for it.
- ✎ If its parent is not waiting when the process terminates, the process becomes a **zombie**.
- ✎ A zombie is an inactive process whose resources are deleted later when its parent **waits** for it.
- ✎ A **normal termination** occurs under the following conditions;
 - ✎ **return** from **main**
 - ✎ Implicit return from main (the main function falls off the end)
 - ✎ Call to **exit**, **_Exit** or **_exit**

Process Termination



7th bit in killed and stopped by a signal is for CORE file

(1) 7th bit=1; Core file generated

(2) 7th bit=0; Core file not generated

ZOMBIE and ORPHAN

Two things can be happened, if the the parent doesnot wait for the child to die.

- ✍ The child dies while the parent is still alive

- ✍ The parent dies while the child is still alive


ZOMBIE

- ✍ If the child dies first, the kernel empties the process address space but retains the process table entry. The child is said to be in a **zombie** state.
- ✍ The zombie is actually not a process at all, so cannot be killed.
- ✍ The only reason for a child to remain in the zombie state is the hope that the parent may eventually call **wait** or **waitpid** to pickup the exit status and clear the process table slot.
- ✍ Type **man ps** to read process state information and locate the state zombie

Example: ZOMBIE

```
int main()
{
    pid_t childpid;
    childpid=fork();
    if(childpid==-1){
        printf("fork error\n");
        return 1;
    }
    else if (childpid==0){
        printf(" I am child my process ID=%ld\n", (long)getpid());
        exit(0);
    }
    else{
        printf("I am parent My PID=%ld\n", (long)getpid());
        sleep(100);
        wait(NULL);
        exit(0);
    }
}
```

How to Identify ZOMBIE ?

- ✎ Open two terminal windows. Run the previous slide code in one terminal. On the other terminal run the command
`(ps -la | grep CMD) ; (ps -la | grep a.out)` 
- ✎ Look into the line that contains **defunct**. It is the Zombie with process state code **Z**
- ✎ After the program terminate, again type the command `ps -la`. Is the ZOMBIE exit or not? If not process terminate.
- ✎ For more `man ps` to read process state information under the heading **PROCESS STATE CODES**

ORPHAN

- ✍ When the parent dies first, the child becomes an **orphan** since the parent is not just there to pickup the child's exit status.
- ✍ The kernel clears the process table slot of the parent, but before doing so, it checks whether there are any process spawned by the parent that are still alive.
- ✍ When it finds one , it makes **init/ systemd** its parent by changing **PPID** field of the child.

Example: ORPHAN

```
int main()
{
    pid_t childpid;
    childpid=fork();
    if(childpid==-1){
        printf("fork error\n");
        return 1;
    }
    else if (childpid==0){
        printf("Child:PID=%ld---PPID=%ld\n", (long) getpid(), (long) getppid());
        sleep(100);
        printf("Child:PID=%ld---PPID=%ld\n", (long) getpid(), (long) getppid());
    }
    else{
        printf("Parent:PID=%ld--PPID=%ld\n", (long) getpid(), (long) getppid());
        exit(0);
    }
}
```

How to Identify ORPHAN ?

- ✎ Open two terminal windows. Run the previous slide code in one terminal. On the other terminal run the command `(ps -le | grep CMD) ; (ps -le | grep <ChildPID>)`
- ✎ Observe the process id (PID) and parent id (PPID) of the child and parent
- ✎ For more `man ps` to read process state information

Prototype of `exit`, `_Exit` and `_exit`

```
#include <stdlib.h>

void exit(int status);

void _Exit(int status);
```

ISO C Version

```
#include <unistd.h>

void _exit(int status);
```

POSIX Version

atexit () Function




```
#include <stdlib.h>
```

```
int atexit(void (*function) (void));
```

ISO C Version

Return value:

- (1) the value 0 **if** successful;
- (2) otherwise it returns a nonzero value.

-  The `atexit()` function registers the given function to be called at normal process termination, either via `exit()` or via return from the program's `main()`
-  Functions so registered are called in the reverse order of their registration; no arguments are passed.
-  The same function may be registered multiple times: it is called once for each registration.

Example: atexit () Function

```
#include<stdio.h>
#include<stdlib.h>
#include<unistd.h>
void display()
{
    printf("function Exit handler\n");
}
int main(void) {
    int i;
    if (atexit(display)) {
        fprintf(stderr, "Failed to install display exit handler\n");
        return 1;
    }
    /* rest of main program goes here */
    for(i=0;i<5;i++){
        sleep(1);
        printf("%d\n",i);
    }
    return 0;
}
```

wait and waitpid System Calls

- ✍ **wait** and **waitpid**: wait for process to change state
- ✍ These system calls are used to wait for state changes in a child of the calling process, and obtain information about the child whose state has changed.
- ✍ A state change is considered to be:
 - ✍ the child terminated: Normal termination (success/unsuccess);
 - ✍ the child was killed by a signal
 - ✍ the child was stopped by a signal; or
 - ✍ the child was resumed (i.e. continued) by a signal.
- ✍ In the case of a terminated child, performing a wait allows the system to release the resources associated with the child; If a wait is not performed, then the terminated child remains in a "zombie" state
- ✍ If a child has already changed state, then these calls return immediately. Otherwise they block until either a child changes state or a signal handler interrupts the call.

The `wait` Function

- ✎ When a process creates a child, both parent and child proceed with execution from the point of the fork.
- ✎ The parent can execute the system calls `wait` or `waitpid` to block until the child finishes.
- ✎ The `wait` function causes the caller to suspend execution until a child's status becomes available or until the caller receives a signal.
- ✎ A process status most commonly becomes available after termination, but it can also be available after the process has been stopped.
- ✎ `wait` synopsis

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

pid_t wait(int *stat_loc);
```

- ✎ If `wait` returns because the status of a child is reported, these functions return the **process ID of that child**.
- ✎ If an error occurs, these functions return -1 and set `errno`.

Wait Example-1

```
#include<stdio.h>
#include<unistd.h>
#include<sys/wait.h>
#include<sys/types.h>
int main(void)
{
    pid_t childpid;
    childpid=fork();
    if (childpid==0) /*child*/
        printf("Inside child \n");
    else{
        wait(NULL);
        printf("In parent\n");
    }
    return 0;
}
```


Wait Example-2

```
int main(void)
{
    pid_t firstCh, secondCh;
    pid_t returnR;
    int sum;
    firstCh=fork();
    if(firstCh>0){
        printf("Parent Section\n");
        returnR= wait(NULL);
        printf("After the child process termination
               wait return value=%ld\n", (long)returnR);
    }
    if(firstCh==0){
        printf("The child process id=%ld\n", (long)
               getpid());
        sum=20+30;
        printf("sum=%d\n", sum);
        printf("Child Completes\n");
    }
    return 0;
}
```

Testing Child's Return Status

- ☞ The `stat_loc` argument of `wait` or `waitpid` is a pointer to an integer variable. If it is not `NULL`, these functions store the return status of the child in this location.
- ☞ The child returns its status by calling `exit`, `_exit`, `_Exit` or `return` from `main`. A zero return value indicates `EXIT_SUCCESS`; any other value indicates `EXIT_FAILURE`.
- ☞ **The parent can only access the 8 least significant bits of the child's return status.**
- ☞ POSIX specifies **six** macros for testing the child's return status. Each takes the status value returned by a child to `wait` or `waitpid` as a parameter.

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

```
WIFEXITED(int stat_val)-----WEXITSTATUS(int stat_val)
WIFSIGNALED(int stat_val)-----WTERMSIG(int stat_val)
WIFSTOPPED(int stat_val)-----WSTOPSIG(int stat_val)
WIFCONTINUED(int stat_val)-----SIGCONT
```

Macro Evaluation

- ✍ The six macros are designed to be used in pairs.
- ✍ The **WIFEXITED** evaluates to a nonzero value when the child terminates normally.
- ✍ If **WIFEXITED** evaluates to a nonzero value, then **WEXITSTATUS** evaluates to the low-order 8 bits returned by the child through `_exit()`, `exit()` or `return` from `main`.
- ✍ The **WIFSIGNALED** evaluates to a nonzero value when the child terminates because of an uncaught signal.
- ✍ If **WIFSIGNALED** evaluates to a nonzero value, then **WTERMSIG** evaluates to the number of the signal that caused the termination.
- ✍ The **WIFSTOPPED** evaluates to a nonzero value if a child is currently stopped.
- ✍ If **WIFSTOPPED** evaluates to a nonzero value, then **WSTOPSIG** evaluates to the number of the signal that caused the child process to stop.

Macros to Evaluate the Termination Status Returned by `wait` and `waitpid`

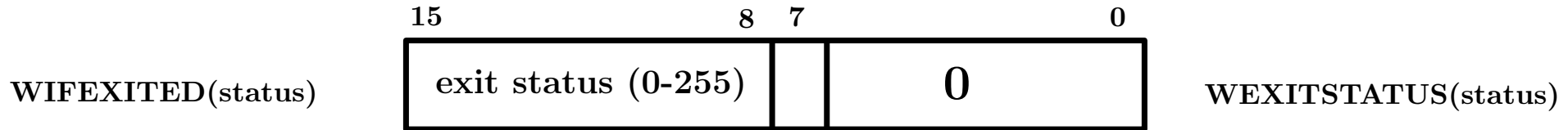
Macro	Description
WIFEXITED (status)	Returns True if the child terminated normally. In this case, execute WEXITSTATUS (status) to fetch the low-order 8 bits of the argument that the child passed to exit , _exit , or _Exit .
WIFSIGNALED (status)	Returns True if the child process was terminated by a signal. In this case, execute WTERMSIG (status) to fetch the signal number that caused the termination. Additionally, some implementations define the macro WCOREDUMP (status) that returns true if a core file of the terminated process was generated.
WIFSTOPPED	Returns True if the child process was stopped by delivery of a signal. In this case, execute WSTOPSIG (status) to fetch the signal number that caused the child to stop.
WIFCONTINUED (status)	Returns True if the child process was resumed by delivery of SIGCONT .

Macro Evaluation

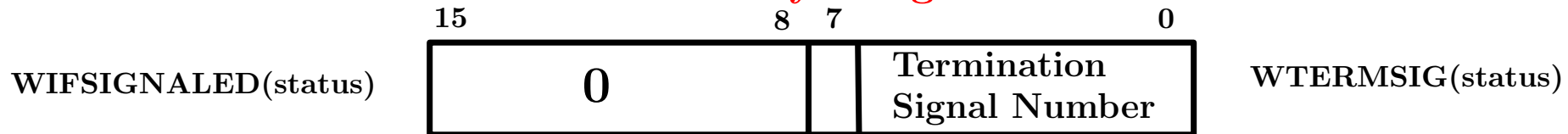
Testing

Normal Termination

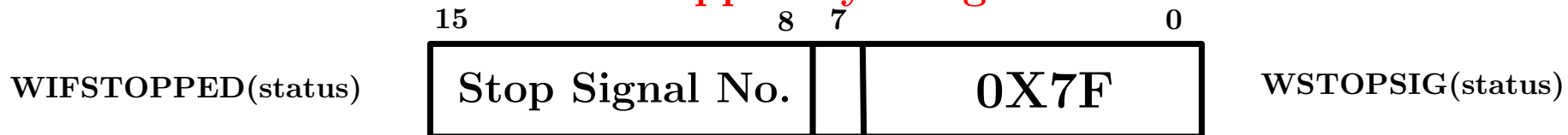
Getting Status



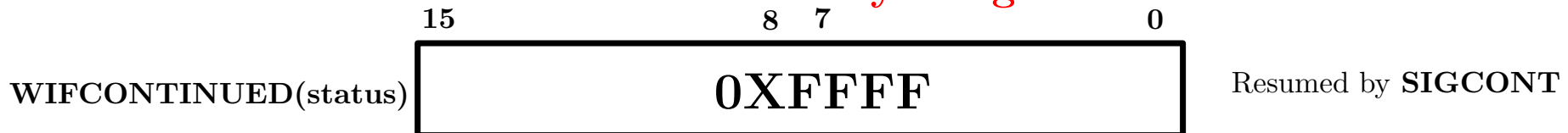
Killed by a Signal



Stopped by a Signal



Continued by a Signal







The parent can only access the 8 least significant bits of the child's return status.

A Sample Code: Macro Evaluation

```
int main(void) {
    pid_t childpid,pid;
    int status;
    pid=fork();
    if(pid==0){
        printf("Child Part Executed!!!!\n");
        exit(0);
    }
    else{
        childpid=wait(&status);
        if (childpid == -1)
            perror("Failed to wait for child\n");
        else if (WIFEXITED(status) && !WEXITSTATUS(status))
            printf("Child %ld terminated normally\n", (long)childpid);
        else if (WIFEXITED(status))
            printf("Child %ld terminated with return status %d\n", (long)childpid
                , WEXITSTATUS(status));
        else if (WIFSIGNALED(status))
            printf("Child %ld terminated due to uncaught signal %d\n", (long)
                childpid, WTERMSIG(status));
        else if (WIFSTOPPED(status))
            printf("Child %ld stopped due to signal %d\n", (long)childpid,
                WSTOPSIG(status));
    }
    return 0; }
```

Limitations of `wait ()` System Call

-  It is not possible for the parent to retrieve the signal number during which the child process has stopped the execution (`SIGSTOP (19)`, `SIGTSTP (20)`).
-  Parent won't be able to get the notification when a stopped child was resumed by the delivery of a signal (`SIGCONT (18)`, `SIGCHLD (17)`).
-  Parent can only wait for first child that terminates. It is not possible to wait for a particular child.
-  It is not possible for a non blocking wait so that if no child has yet terminated, parent get an indication of this fact.

The waitpid Function

- ✎ The waitpid function takes **three** parameters:
 - ✎ a pid,
 - ✎ a pointer to a location for returning the status
 - ✎ a flag specifying options.

✎ waitpid synopsis

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

pid_t waitpid(pid_t pid, int *stat_loc, int options);
```

- ✎ If **waitpid** returns because the status of a child is reported, these functions return the **process ID of that child**.
- ✎ If an error occurs, these functions return -1 and set **errno**.

First Parameter of `waitpid` Function

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

```
pid_t waitpid(pid_t pid, int *stat_loc, int options);
```

- ✎ If `pid = -1`, `waitpid` waits for any child. In this respect, `waitpid` is equivalent to `wait`.
- ✎ If `pid > 0`, `waitpid` waits for the child whose process ID equals `pid`.
- ✎ If `pid = 0`, `waitpid` waits for any child whose process group ID equals that of the calling process.
- ✎ If `pid < -1`, `waitpid` waits for any child whose process group ID equals the absolute value of `pid`.

Third Parameter of `waitpid` Function

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

```
pid_t waitpid(pid_t pid, int *stat_loc, int options);
```

- ✎ The `options` parameter is either **zero** or is constructed from the bitwise OR of the constants: **WNOHANG**, **WUNTRACED**, and **WCONTINUED**
- ✎ The `options = 0` :: The `waitpid` waits until the child change state.
- ✎ The option **WNOHANG** :: The `waitpid` will not block if a child specified by `pid` is not immediately available. In this case, the return value is 0.
- ✎ The option **WUNTRACED** :: The `waitpid` to report the status of un-reported child processes that have been stopped. The **WIFSTOPPED** macro determines whether the return value corresponds to a stopped child process.
- ✎ The **WCONTINUED** :: The `waitpid` returns if a stopped child has been resumed by delivery of the signal **SIGCONT**.

Status Values: `stat_loc` Parameter of `wait`, & `waitpid` Functions

```
pid_t wait(int *stat_loc);
```

```
pid_t waitpid(pid_t pid, int *stat_loc, int options);
```

- ✎ The `stat_loc` argument of `wait` or `waitpid` is a pointer to an integer variable.
- ✎ If it is not **NULL**, these functions store the return status of the child in this location.
- ✎ The child returns its status by calling `exit`, `_exit`, `_Exit` or `return` from `main`.
- ✎ A zero return value indicates **EXIT_SUCCESS**; any other value indicates **EXIT_FAILURE**.
- ✎ The parent can only access the 8 least significant bits of the child's return status.

wait Vs waitpid a case

```
wait(NULL)           or           waitpid(-1, NULL, 0);
```

```
int status;
```

```
wait(&status)        or           waitpid(-1, &status, 0);
```

More Features of `waitpid` than `wait`

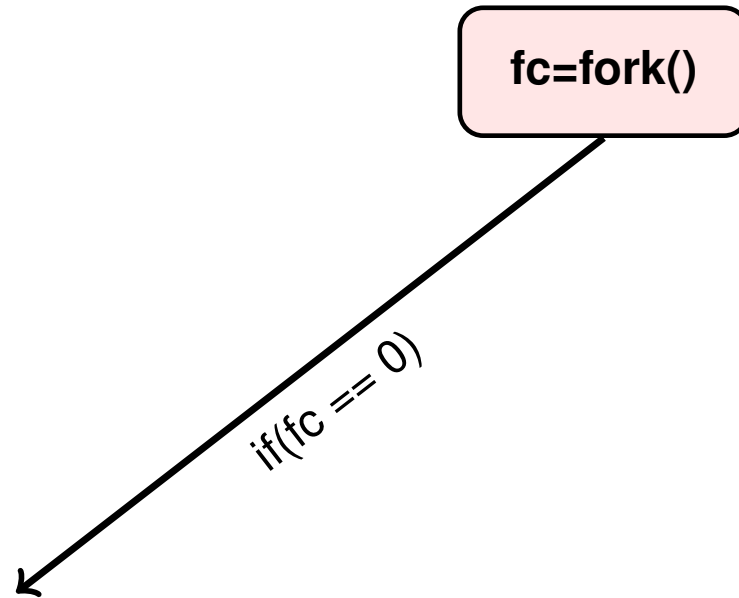
- ✎ The `waitpid` function lets us wait for one particular process, whereas the `wait` function returns the status of any terminated child.
- ✎ The `waitpid` function provides a nonblocking version of `wait`. There are times when we want to fetch a child's status, but we don't want to block.
- ✎ The `waitpid` function provides support for job control with the `WUNTRACED` and `WCONTINUED` options.

Process Ordering Using `wait()` and `fork` return value

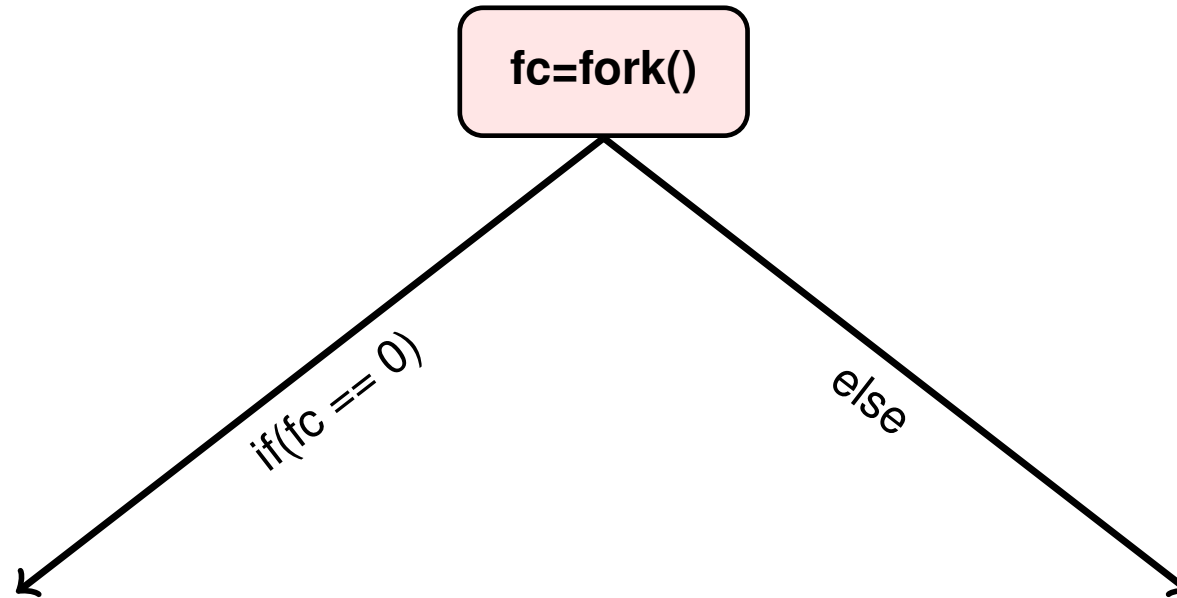
Process Ordering Using `wait()` and `fork` return value

`fc=fork()`

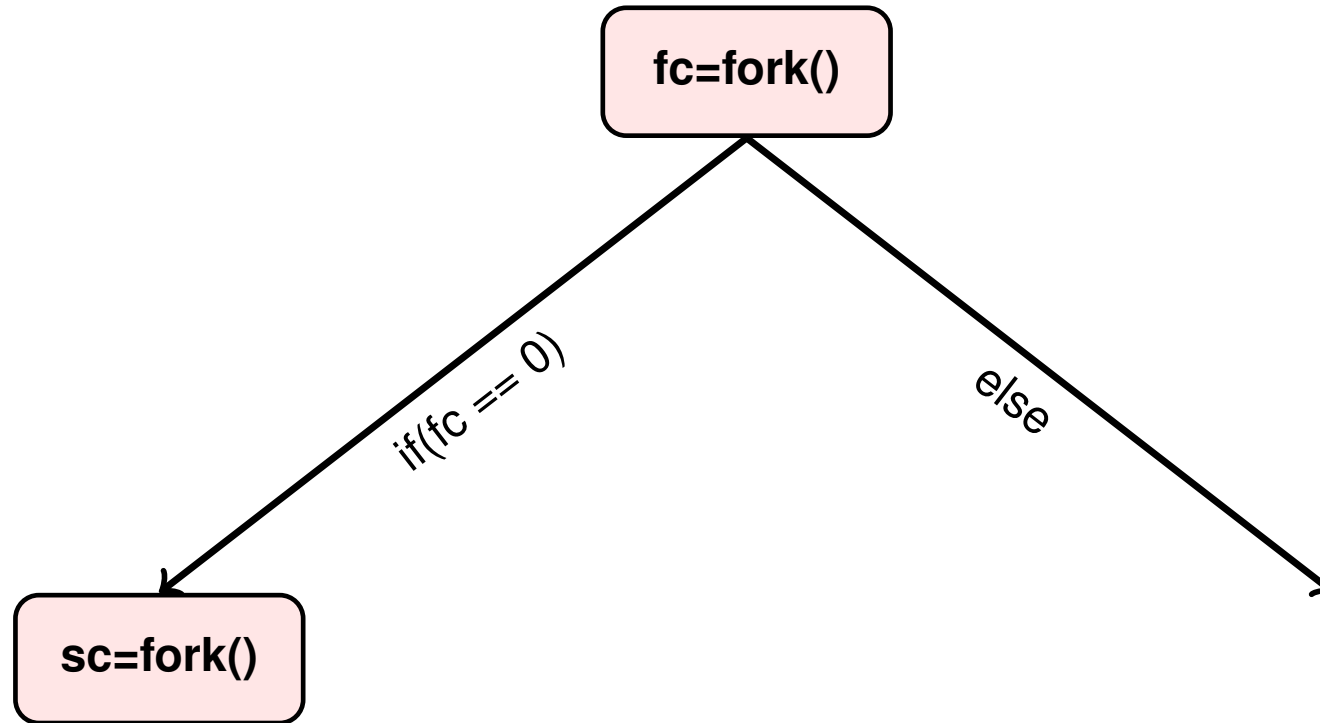
Process Ordering Using `wait()` and `fork` return value



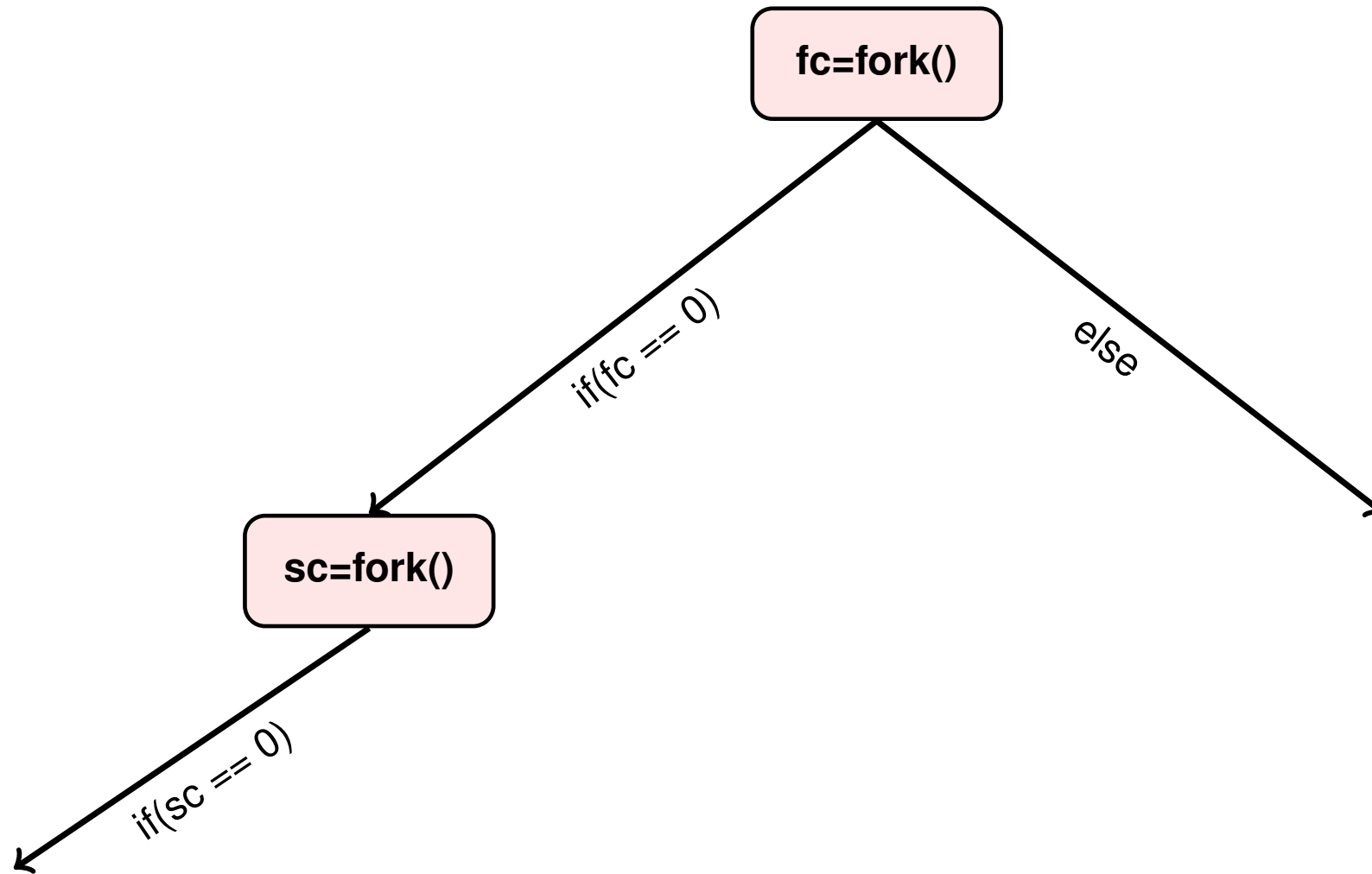
Process Ordering Using `wait()` and `fork` return value



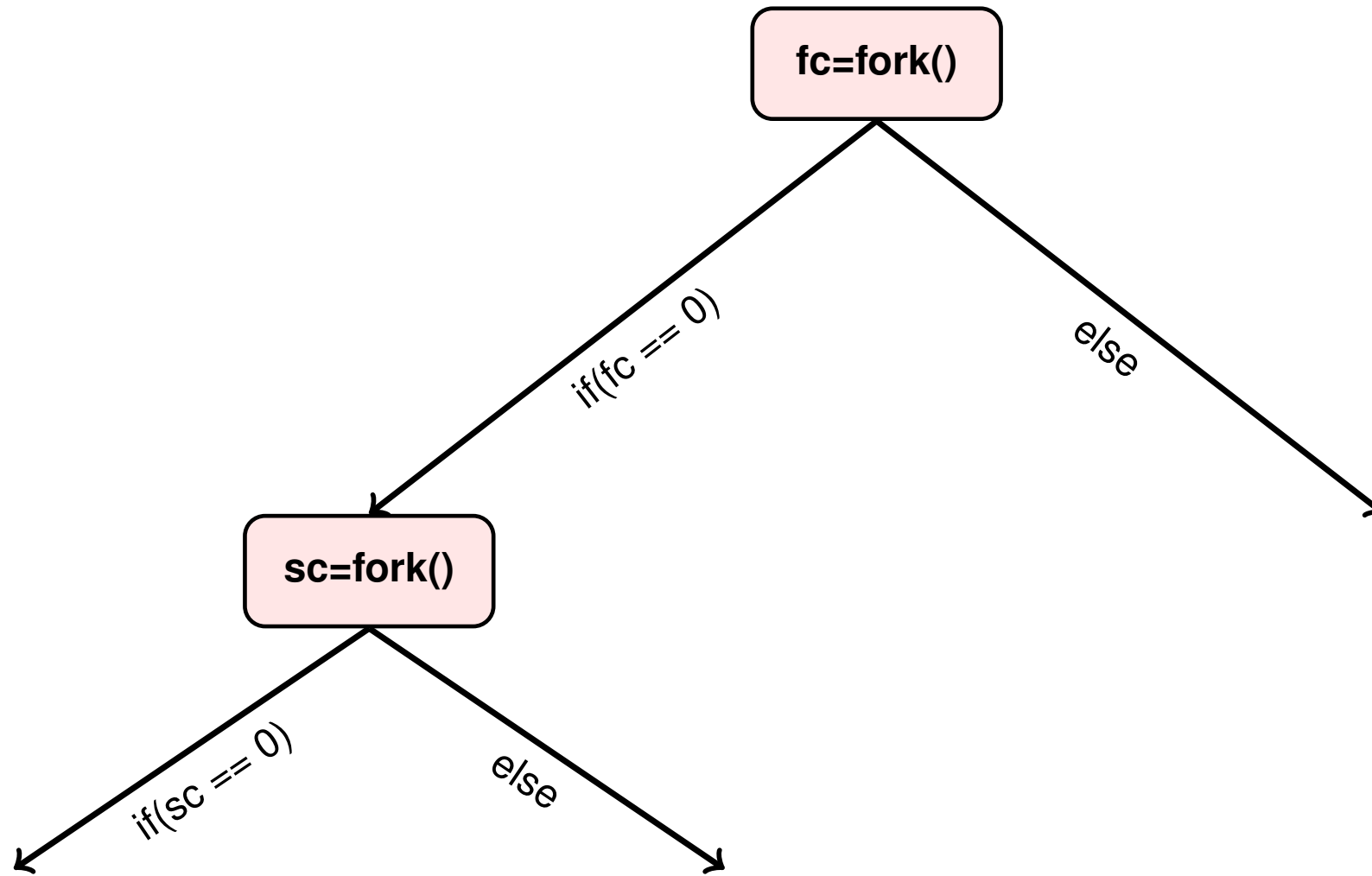
Process Ordering Using `wait()` and `fork` return value



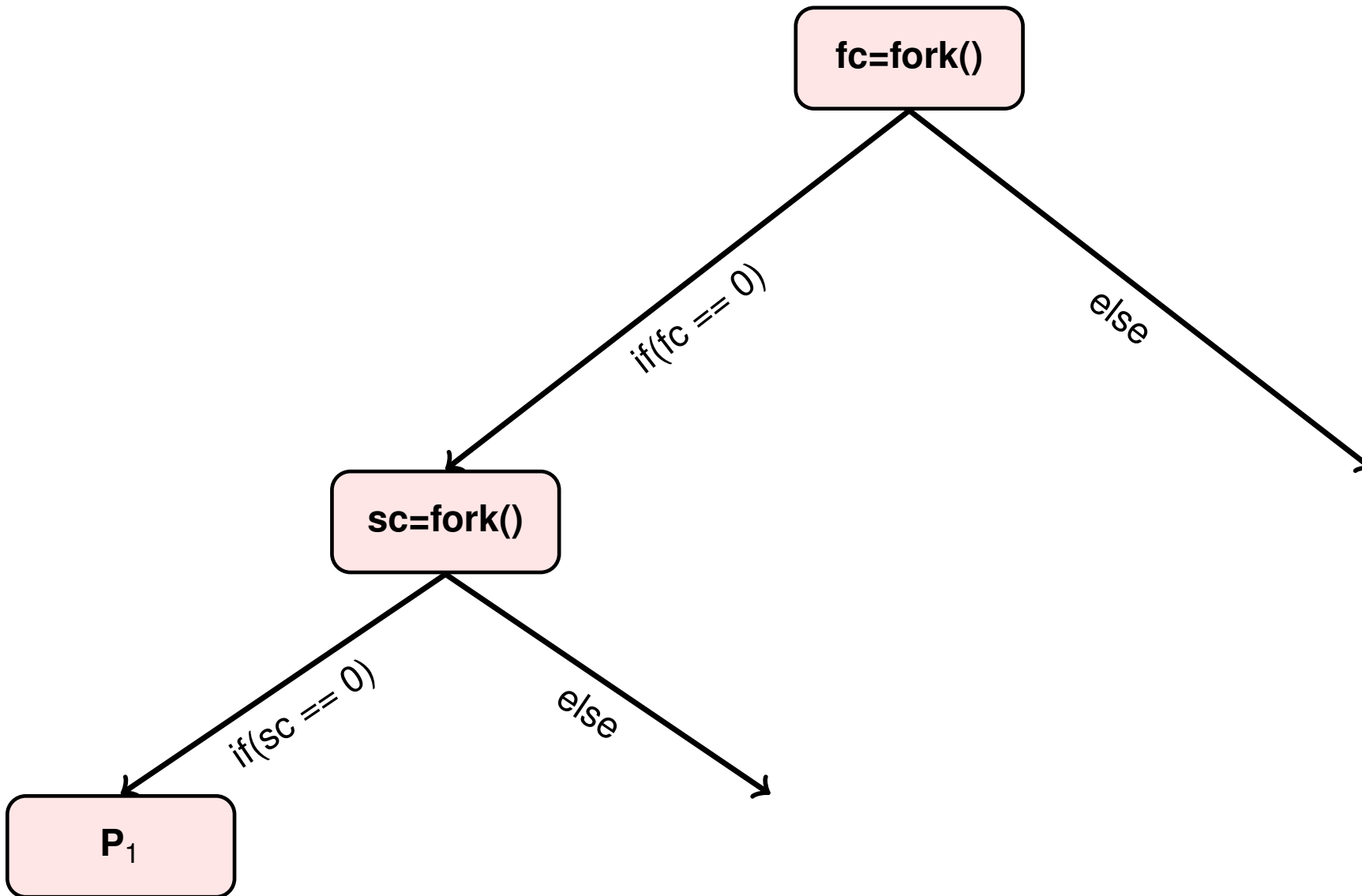
Process Ordering Using `wait()` and `fork` return value



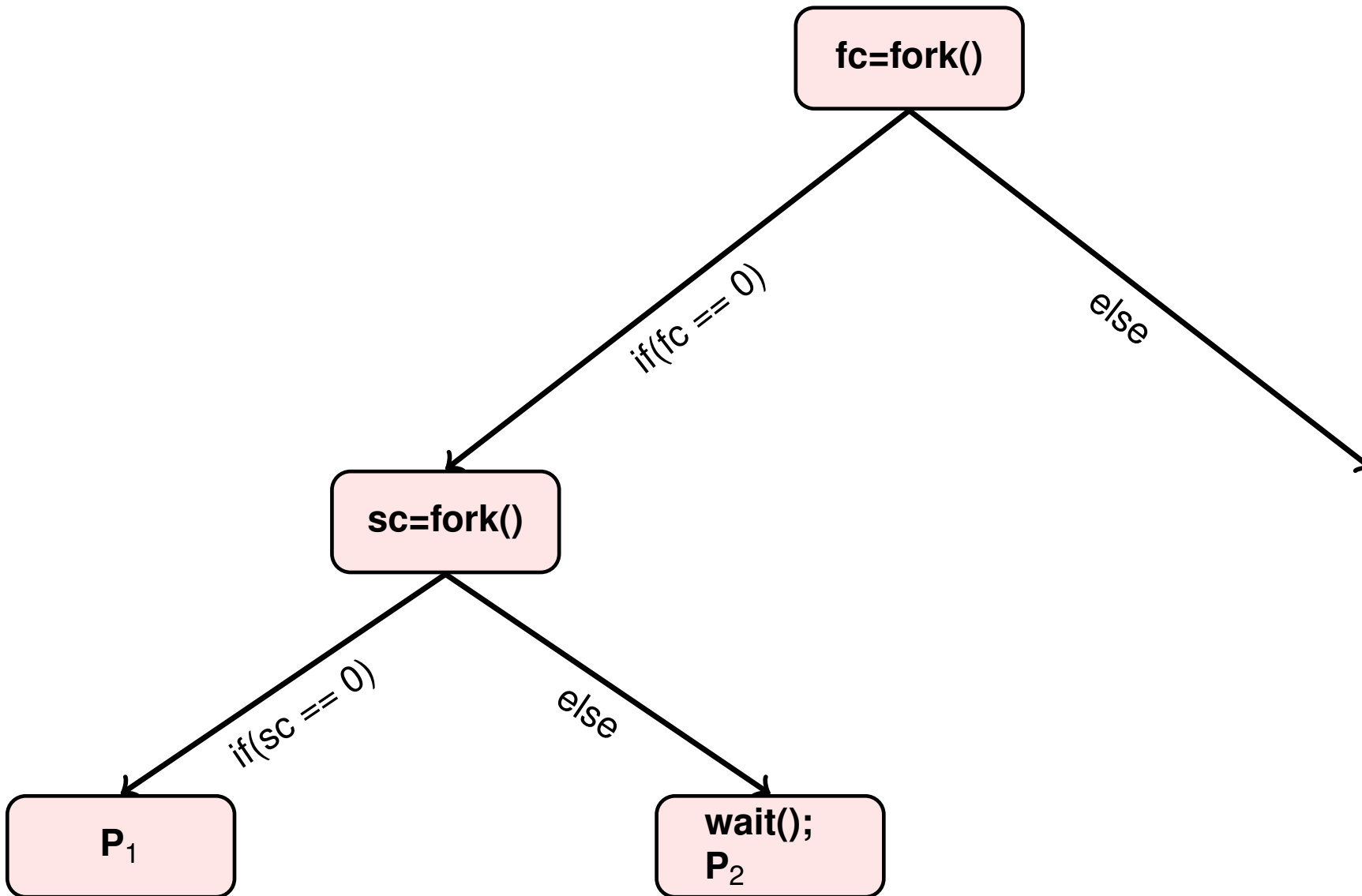
Process Ordering Using `wait()` and `fork` return value



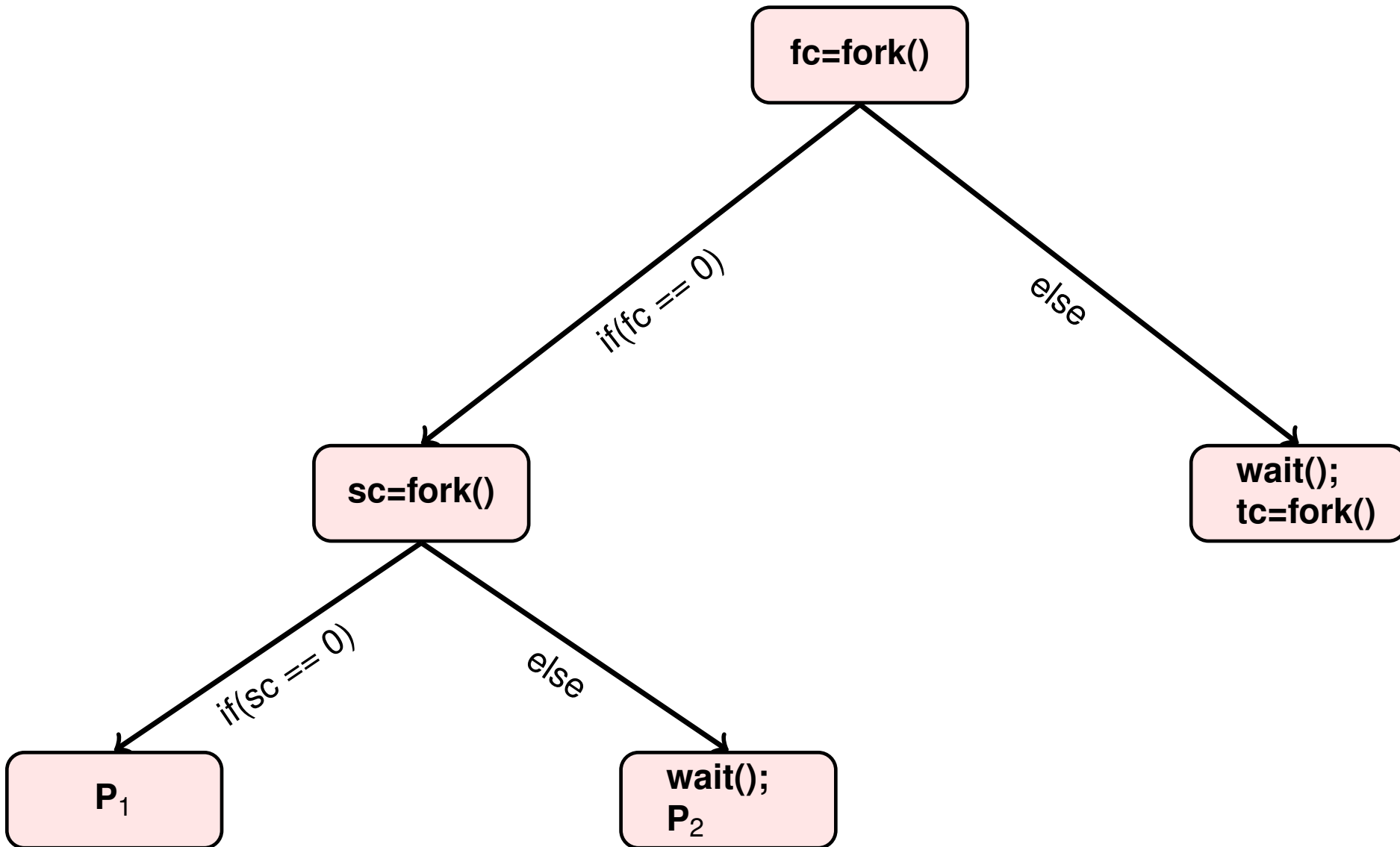
Process Ordering Using `wait()` and `fork` return value



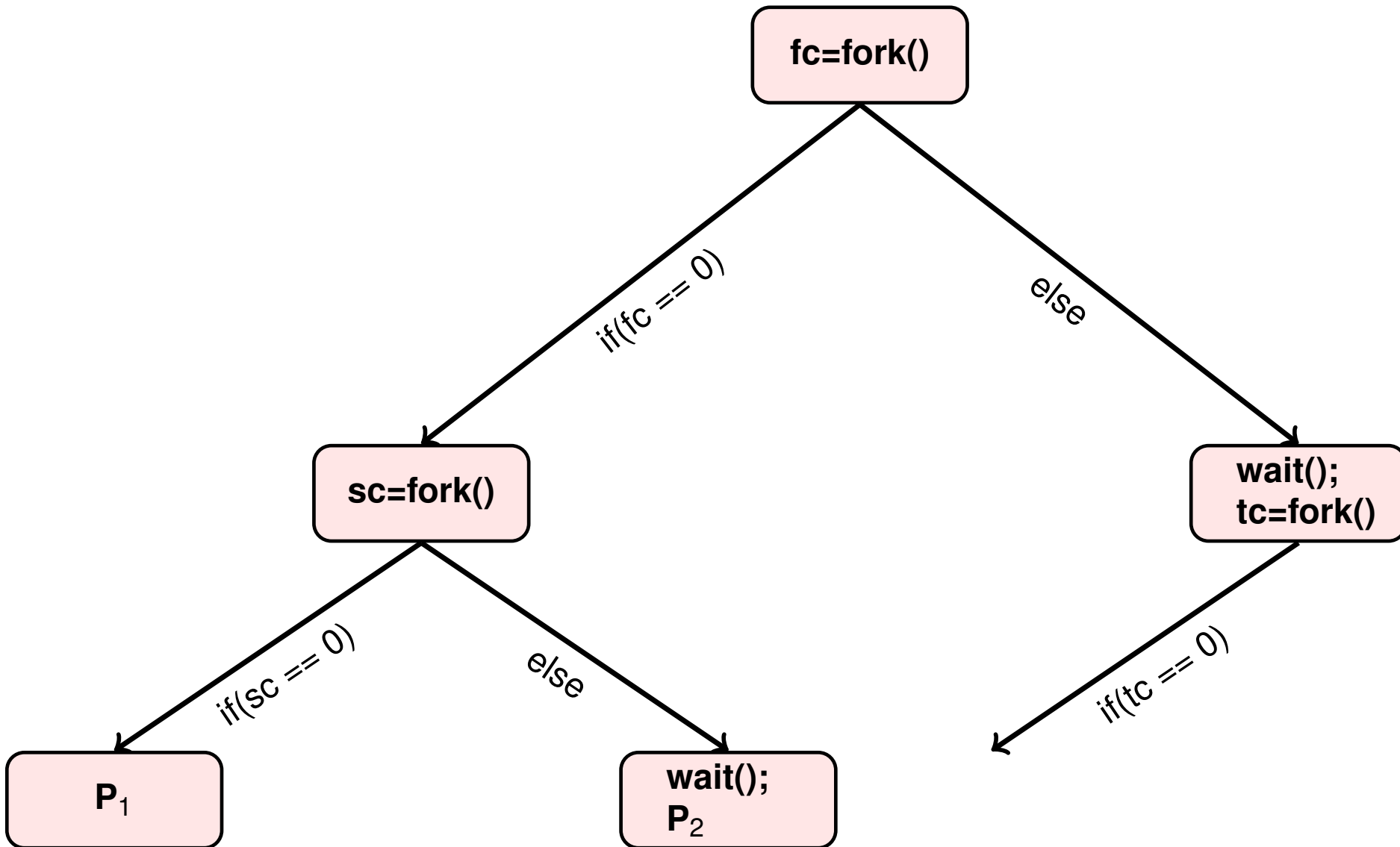
Process Ordering Using `wait()` and `fork` return value



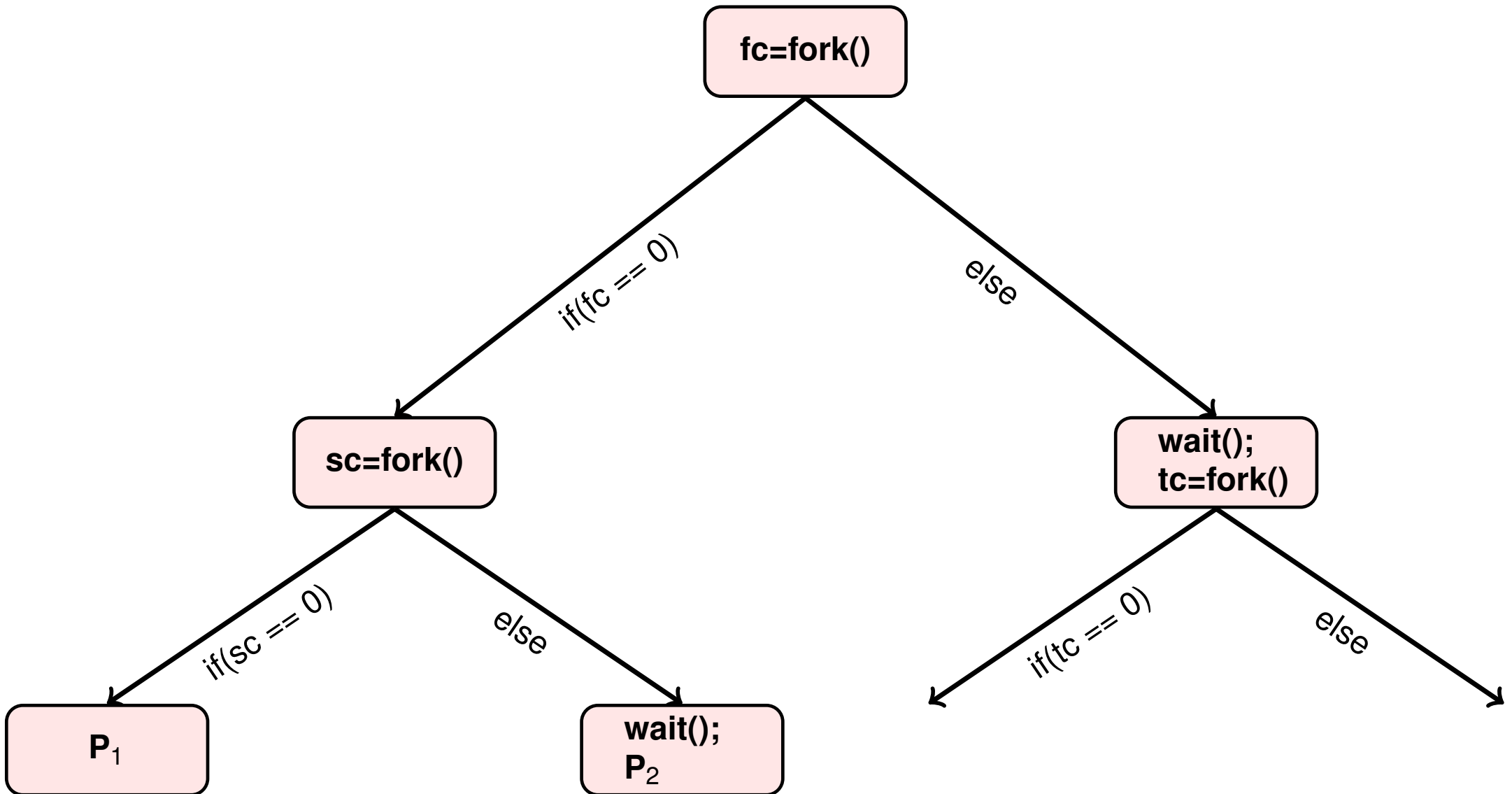
Process Ordering Using `wait()` and `fork` return value



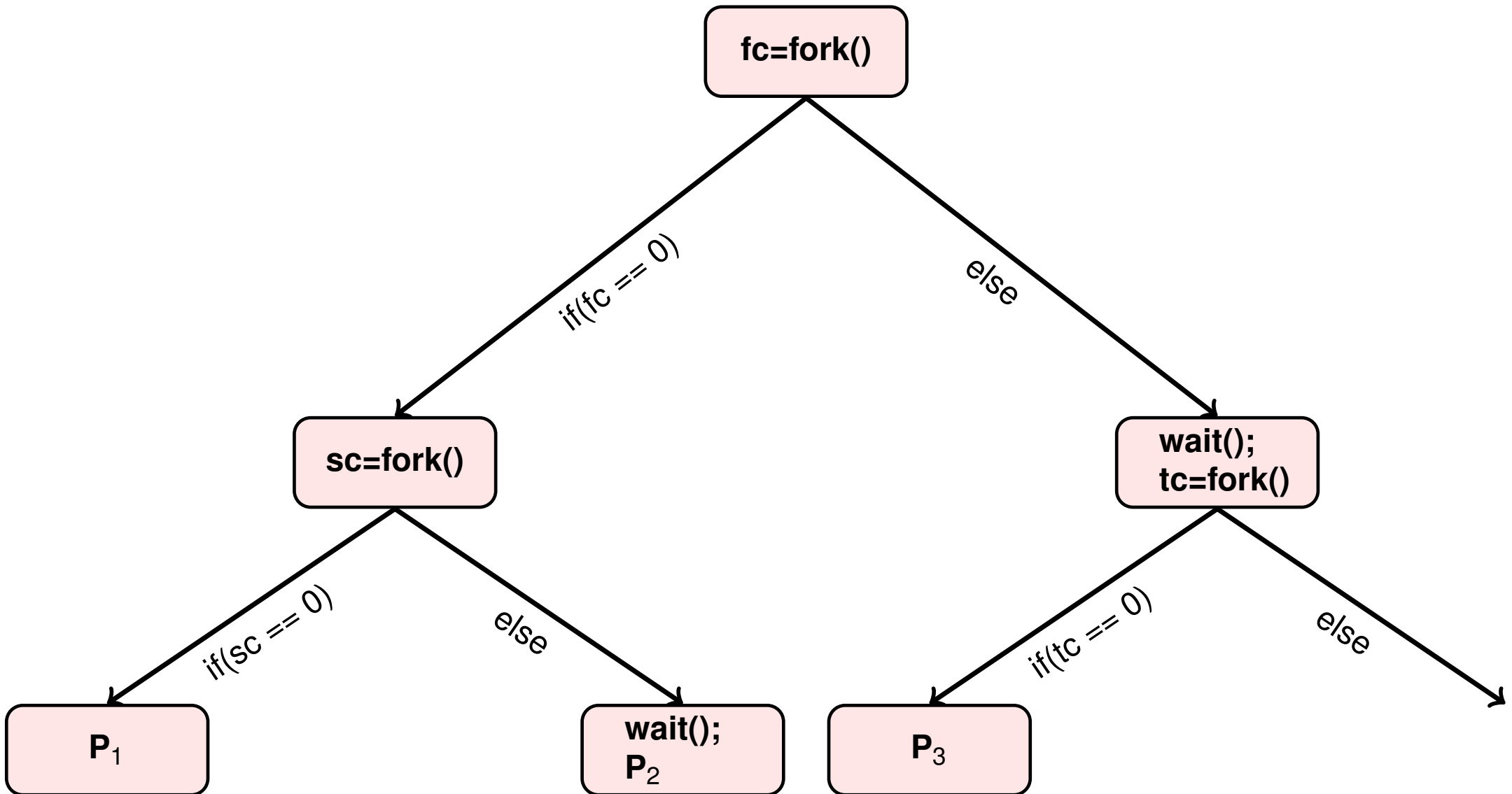
Process Ordering Using `wait()` and `fork` return value



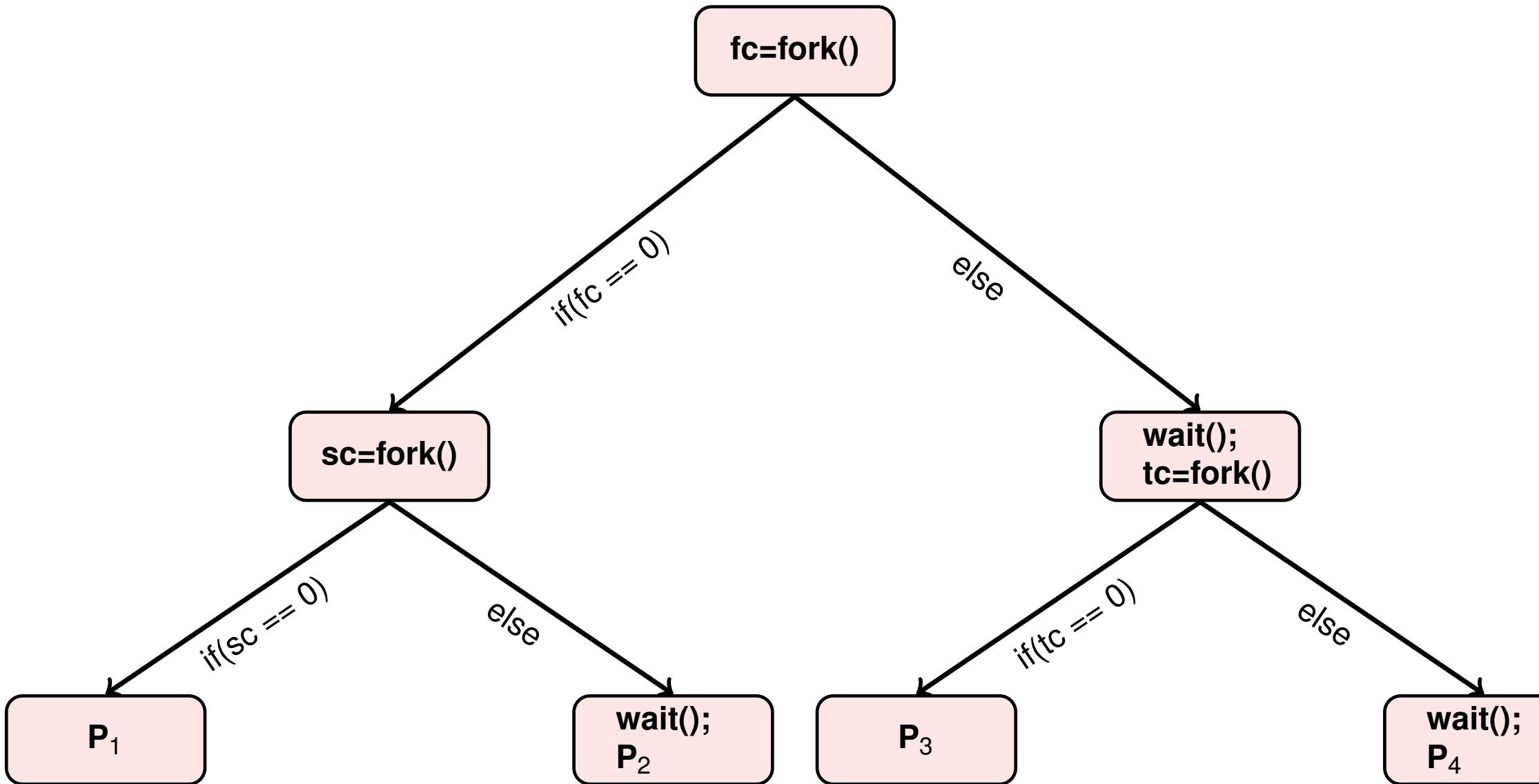
Process Ordering Using `wait()` and `fork` return value



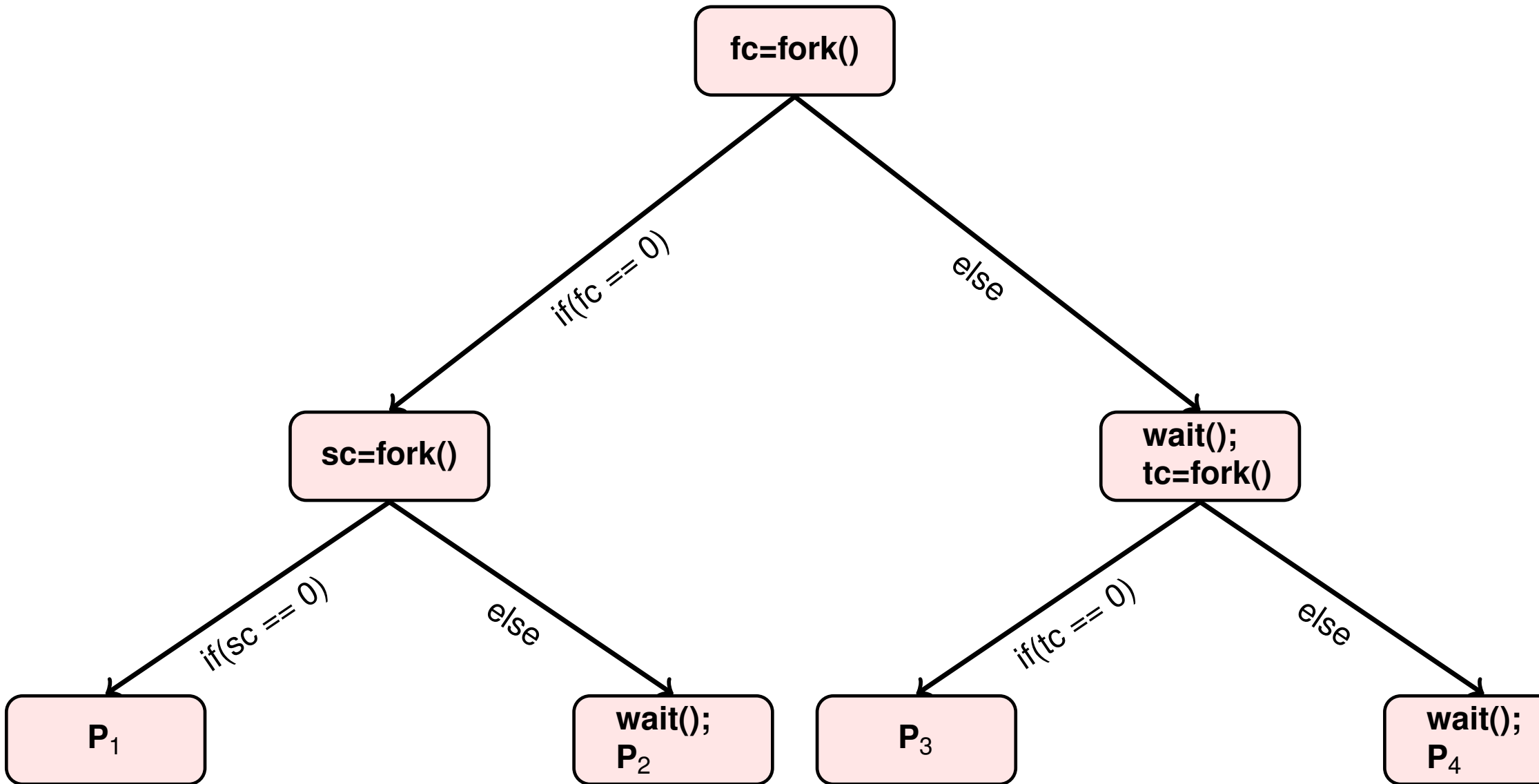
Process Ordering Using `wait()` and `fork` return value



Process Ordering Using `wait()` and `fork` return value



Process Ordering Using `wait()` and `fork` return value



Sample Code









```
int main(void) {
    pid_t fc,sc,tc;
    fc=fork();
    if(fc==0){
        sc=fork();
        if(sc==0)
            printf("Process 1\n");
        else{
            wait(NULL);
            printf("Process 2\n");
        }
    }
    else{
        wait(NULL);
        tc=fork();
        if(tc==0)
            printf("Process 3\n");
        else{
            wait(NULL);
            printf("Process 4\n");
        }
    }
    return 0;
}
```

Sample Code

```
int main(void) {
    pid_t fc, sc, tc;
    fc=fork();
    if(fc==0) {
        sc=fork();
        if(sc==0)
            printf("Process 1\n");
        else{
            wait(NULL);
            printf("Process 2\n");
        }
    }
    else{
        wait(NULL);
        tc=fork();
        if(tc==0)
            printf("Process 3\n");
        else{
            wait(NULL);
            printf("Process 4\n");
        }
    }
    return 0;
}
```

- ✎ Extend the code:
- ✎ To test **fork** return value for -1.
- ✎ Under P_1 perform addition of two numbers, under P_2 for multiplication of two numbers, under P_3 perform sum of digits of a number, and under P_4 make the reverse of a number.
- ✎ Generalize for n processes if required.

The **exec** Family of System Calls

-  The **exec** family of functions replaces the current process image with a new process image.
-  The **fork** function creates a copy of the calling process, but many applications require the child process to execute code that is different from that of the parent.
-  The **exec** family of functions provides a facility for overlaying the process image of the calling process with a new image.
-  The **exec** operation replaces the entire address space(text, data, and stack) with that of the new process.
-  Since the stack is also replaced, the call to **exec** family of functions donot return unless it results in an error.
-  The child executes (with an **exec** function) the new program while the parent continues to execute the original code.
-  All **exec** functions return -1 and set **errno** if unsuccessful.
-  If any of these functions return at all, the call was unsuccessful.

The exec Family Series

 The **exec: 1** series: 1 - a fixed list of arguments

 `execl(argument list)`

 `execle(argument list)`

 `execlp(argument list`

 The **exec: v** series: v - a variable number of arguments

 `execv(argument list)`

 `execve(argument list)`

 `execvp(argument list)`

The exec Family System Call Prototype

```
#include <unistd.h>
extern char **environ;

int execl(const char *path, const char *arg0, ... /*, char *(0) */);

int execl_e (const char *path, const char *arg0, ... /*, char *(0), char *const
    envp[] */);

int execlp (const char *file, const char *arg0, ... /*, char *(0) */);

int execl_v(const char *path, char *const argv[]);

int execl_ve (const char *path, char *const argv[], char *const envp[]);

int execl_vp (const char *file, char *const argv[]);
```

Variations of the **exec** functions

- ✎ The six variations of the **exec** function differ in the way command-line arguments and the environment are passed.
- ✎ They also differ in whether a full pathname must be given for the executable.
- ✎ The **exec1** (**exec1**, **exec1p** and **exec1e**) functions pass the command-line arguments in an explicit list and are useful if the number of command-line arguments are known at compile time.
- ✎ The **execv** (**execv**, **execvp** and **execve**) functions pass the command-line arguments in an argument array.
- ✎ The **arg_i** parameter represents a pointer to a string.
- ✎ **argv** and **envp** represent **NULL**-terminated arrays of pointers to strings.
- ✎ The **path** parameter to **exec1** is the pathname of a process image file specified either as a fully qualified pathname or relative to the current directory.
- ✎ The individual command-line arguments are then listed, followed by a (**char ***) 0 pointer (a **NULL** pointer).

The exec1 System Call

```
#include <unistd.h>

int exec1(const char *path, const char *arg0, ... /*, char *(0) */);

return -1 if unsuccessful
on successful no return to the calling process
```

Example: `exec1`

A program that creates a child process to run `ls -l`.

```
int main(void) {
    pid_t childpid;
    childpid = fork();
    if (childpid == -1) {
        perror("Failed to fork");
        return 1;
    }
    if (childpid == 0) {                /* child code */
        execl("/bin/ls", "ls", "-l", NULL);
        perror("Child failed to exec ls");
        return 1;
    }
    if (childpid != wait(NULL)) {       /* parent code */
        perror("Parent failed to wait due to signal or error");
        return 1;
    }
    return 0;
}
```

The execle System Call

```
#include <unistd.h>

int execle (const char *path, const char *arg0, ... /*, char *(0),
            char *const envp[] */);

return -1 if unsuccessful
on successful no return to the calling process
```

Example: execle

A program that creates a child process to run `wc`.

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

int main(void)
{
    int err;
    err=execle("/usr/bin/wc", "wc", "execldemo.c", NULL, NULL) ;
    if(err==-1) {
        perror("Execle Failed\n");
    }
    return 0;
}
```

The exec1p System Call




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

```
int exec1p (const char *file, const char *arg0, ... /*, char *(0) */  
            );
```

return -1 if unsuccessful

on successful no return to the calling process

NOTE: The `exec1p` System Call

-  The first parameter is the name of the executable; **file**.
-  **exec1p** uses the `PATH` environment variable to search for the executable.
(It is the similar way, how the shell tries to locate the executable file in one of the directories specified by the `PATH` variable when a user enters a command.)
-  If the first parameter (**file**) contains a slash, then **exec1p** treats file as a **pathname** and behaves like **exec1**.

Example: `exec1p`

A program that creates a child process to run `echo`.

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

int main(void)
{
    char *temp1,*temp2;
    temp1="Funny"; temp2="world";
    pid_t pid;
    pid=fork();
    if(pid==0){
        execlp("echo","echo",temp1,temp2,NULL);
        printf("Error");
        return 1;
    }
    else{
        /* Parent code */
    }
    return 0;
}
```

The `execv` System Call

- ✎ The **`execv`** function takes exactly two parameters, a pathname for the executable and an argument array.
- ✎ Used to run a command or executable with any number of arguments.
- ✎ Use an **`execv`** function with an argument array constructed at run time.
- ✎ The **`execve`** and **`execvp`** are variations on **`execv`**; they are similar in structure to `execle` and `execlp`, respectively.
- ✎ SYNOPSIS:

```
#include <unistd.h>

int execv(const char *path, char *const argv[]);

return -1 if unsuccessful
on successful no return to the calling process
```

Example: `execv`

A program that creates a child process to run `ls -l`.

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

int main(void)
{
    char *cmdargs[]={ "ls", "-l", NULL};
    pid_t pid;
    pid=fork();
    if(pid==0){
        execv("/bin/ls", cmdargs);
    }
    else{
        wait(NULL);
        printf("child terminate\n");
    }
    return 0;
}
```

A Sample to Create 2nd Argument of `execv`

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

int main(int argc, char *argv[])
{
    int i;
    char *cmdarg[20];
    for(i=1; argv[i] != NULL; i++) {
        cmdarg[i-1] = argv[i];
    }
    cmdarg[i-1] = NULL;
    execv("/bin/ls", cmdarg);
    return 0;
}
```

 To run `./a.out ls`

 To run `./a.out ls -l`

The execvp System Call

```
#include <unistd.h>

int execvp (const char *file, char *const argv[]);

return -1 if unsuccessful
on successful no return to the calling process
```

Example: execvp

A program that creates a child process to run `ls -l`.

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

int main(void)
{
    char *cmdargs[]={ "ls", "-l", NULL};
    pid_t pid;
    pid=fork();
    if(pid==0){
        execvp("ls", cmdargs);
    }
    else{
        wait(NULL);
        printf("child terminate\n");
    }
    return 0;
}
```

execvp to take arguments from Commandline

A program that creates a child process to run `ls -l`.

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

int main(int argc, char *argv[])
{
    pid_t pid;
    pid=fork();
    if(pid==0){
        execvp("ls",&argv[1]);
    }
    else{
        wait(NULL);
        printf("child terminate\n");
    }
    return 0;
}
```

execvp to take arguments from Commandline

A program that creates a child process to run `ls -l`.

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

int main(int argc, char *argv[])
{
    pid_t pid;
    pid=fork();
    if(pid==0){
        execvp(argv[1], &argv[1]);
    }
    else{
        wait(NULL);
        printf("child terminate\n");
    }
    return 0;
}
```


The execve System Call

```
#include <unistd.h>

int execve (const char *path, char *const argv[],
            char *const envp[]);

return -1 if unsuccessful
on successful no return to the calling process
```

Example: `execve`

A program that creates a child process to run `ls -l`.

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

int main(void)
{
    char *cmdargs[]={ "ls", "-l", NULL};
    pid_t pid;
    pid=fork();
    if(pid==0){
        execve("/bin/ls", cmdargs, NULL);
    }
    else{
        wait(NULL);
        printf("child terminate\n");
    }
    return 0;
}
```

Process Environment

- ✎ An *environment list* consists of an array of pointers to strings of the form **name = value**.
- ✎ The **name** specifies an environment variable, and the **value** specifies a string value associated with the environment variable.
- ✎ The last entry of the array is **NULL**.
- ✎ The **external** variable **environ** points to the process environment list when the process begins executing. The strings in the process environment list can appear in any order.
- ✎ SYNOPSIS:

```
#include<stdio.h>

extern char **environ;
```

NOTE::

- ✎ If the process is initiated by **execl**, **execlp**, **execv** or **execvp**, then the process inherits the environment list of the process just before the execution of **exec**.
- ✎ The **execl** and **execve** functions specifically set the environment list.







Program to Print Environment List

```
#include <stdio.h>



extern char **environ;

int main(void) {
    int i;
    printf("The environment list follows:\n");
    for(i = 0; environ[i] != NULL; i++){
        sleep(2);
        printf("environ[%d]: %s\n", i, environ[i]);
    }
    return 0;
}
```

Background Processes and Daemons

-  The shell is a command interpreter that prompts for commands, reads the commands from standard input, forks children to execute the commands and waits for the children to finish.
-  When standard input and output come from a terminal type of device, a user can terminate an executing command by entering the interrupt character(CTRL+C).
-  Most shells interpret a line ending with & as a command that should be executed by a background process.
-  When a shell creates a background process, it does not wait for the process to complete before issuing a prompt and accepting additional commands.

Daemon

-  A daemon is a background process that normally runs indefinitely.
-  The UNIX operating system relies on many daemon processes to perform routine tasks.