

LEC 05

CONCURRENT TCP SERVER

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- I/O Models
- Concurrent TCP server: one child per client
- Concurrent TCP server: one thread per client

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I/O MODELS

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Review TCP Echo Server

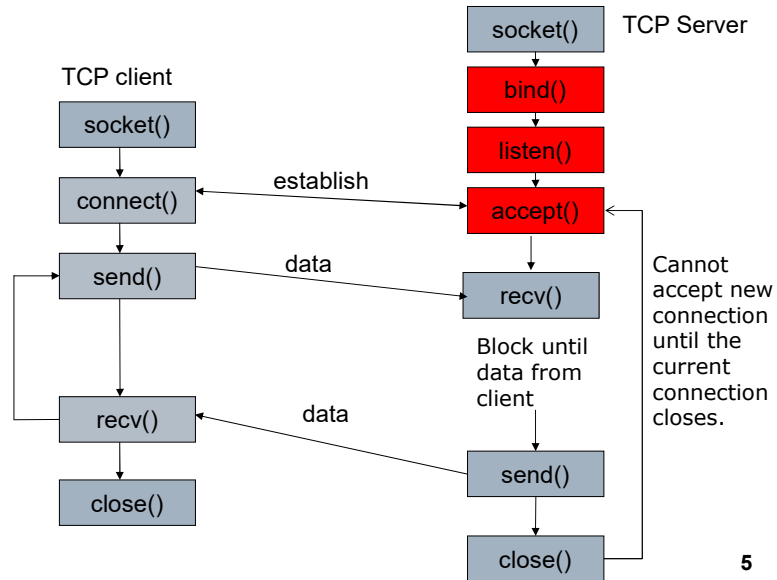
```
while(1){
    //accept request
    connfd = accept(listenfd, (sockaddr *) & clientAddr,
                    &clientAddrLen);

    //receive message from client
    rcvBytes = recv(connfd, buff, BUFF_SIZE, 0);
    if(rcvBytes < 0){
        perror("Error :");
    }
    else{
        buff[rcvBytes] = '\0';
        printf("Receive from client: %s\n",buff);
        //Echo to client
        sendBytes = send(connfd, buff, strlen(buff), 0);
        if(sendBytes < 0)
            perror("Error: ",);
    }
    closesocket(connfd);
} //end while
```

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Blocking I/O Model and TCP server



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I/O Models

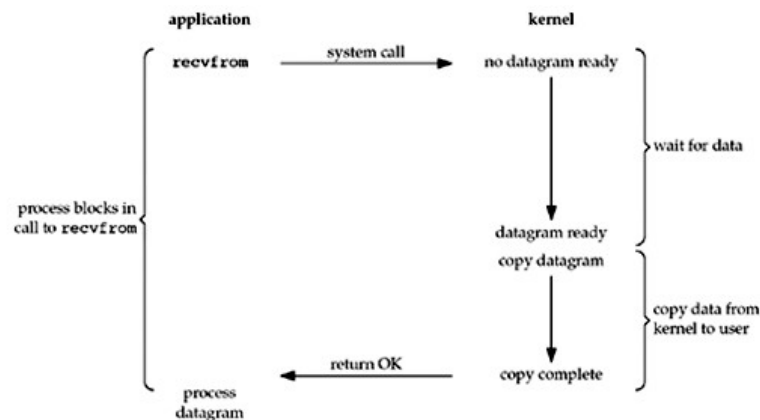
- blocking I/O
- nonblocking I/O
- I/O multiplexing (select and poll)
- signal driven I/O (SIGIO)
- asynchronous I/O (the POSIX aio_functions)

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Blocking I/O Model

- Blocking I/O model: I/O function block process/thread until returning.
- `accept()`, `connect()`, `send()`, `recv()`, ...

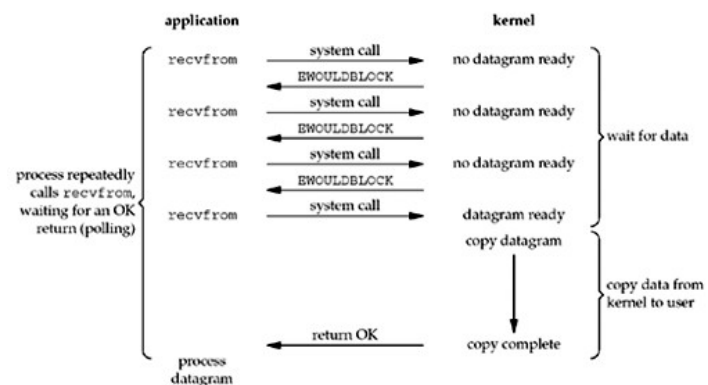


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Non-blocking I/O Model

- Non-blocking I/O model: I/O function returns immediately
- If there is no data to return, so the kernel immediately returns an error of `EWOULDBLOCK` instead

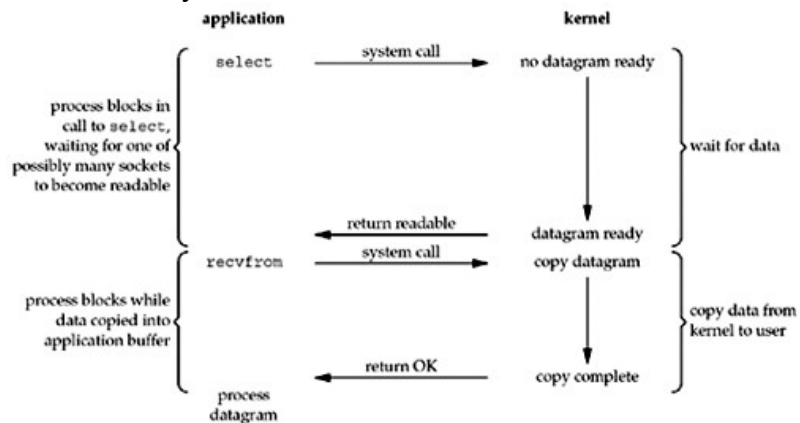


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I/O Multiplexing Model

- With I/O multiplexing, we call select or poll and block in one of these two system calls, instead of blocking in the actual I/O system call

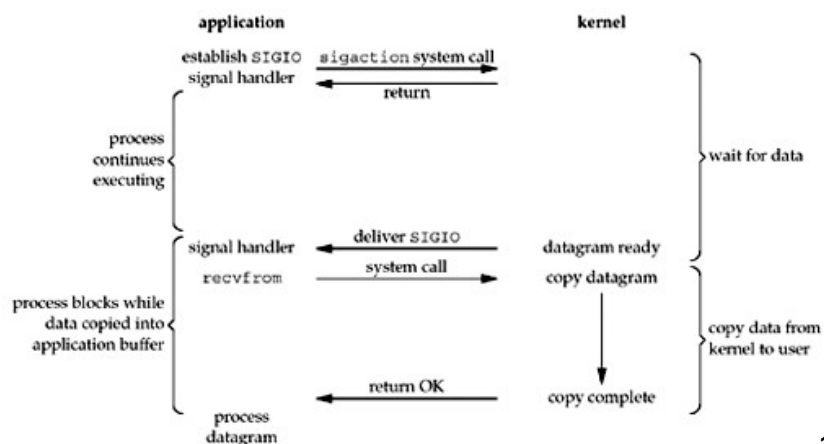


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Signal-Driven I/O Model

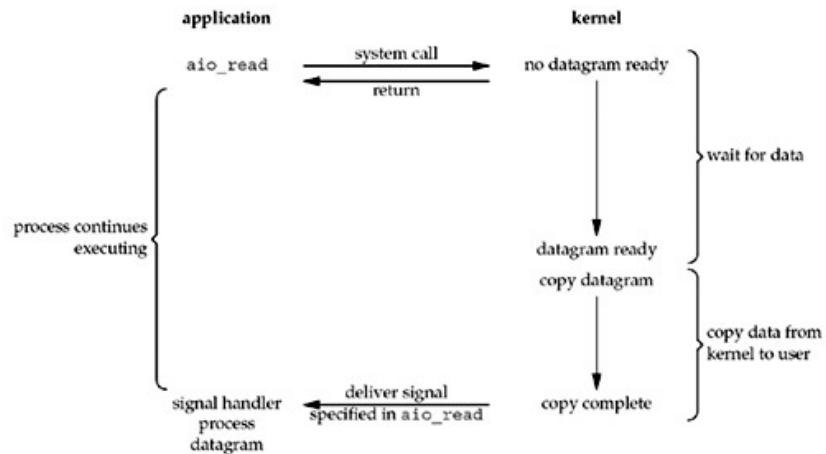
- Use signals, telling the kernel to notify app with the SIGIO signal when the descriptor is ready



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Asynchronous I/O Model



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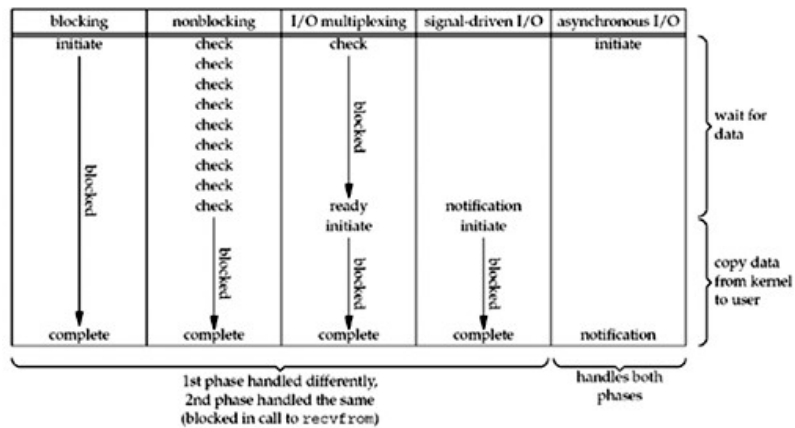
Asynchronous I/O Model (2)

- App calls `aio_read` (the POSIX asynchronous I/O functions begin with `aio_`)
- Pass the kernel
 - the descriptor
 - buffer pointer
 - buffer size (the same three arguments for `read`)
 - buffer offset (similar to `lseek`)
 - how to notify us when the entire operation is complete
- This system call returns immediately and our process is not blocked while waiting for the I/O to complete.

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Comparison of the I/O Models



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Iterating server

- Simple server
- But when a client request can take longer to service, we can't handle other clients
- Use a *concurrent server*
- One child per client: `fork()` function spawns one child process to handle each client
- One thread per client: `pthread_create()` creates one thread to handle each client

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MULTI-PROCESS SERVER

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fork()

```
#include <unistd.h>
pid_t fork(void);
```

- Create a new process by copying itself.
- Returns twice:
 - Once in the calling process (called the parent) with a return value that is the process ID of the newly created process (the child).
 - Once in the child, with a return value of 0
- All descriptors open in the parent before the call to fork are shared with the child after fork returns

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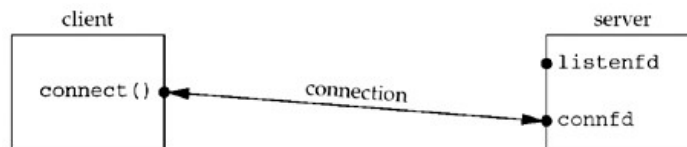
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One child per client

(1) LISTENING



(2) accept()

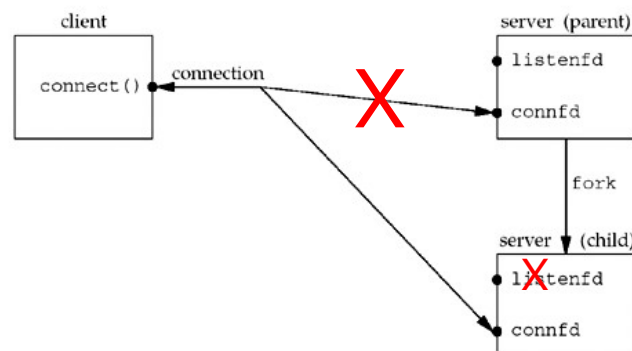


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One child per client

(3) fork()



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Use fork()

```
pid_t pid;
int listenfd, connfd;
//Step 1: Construct socket
//Step 2: Bind address to socket
//Step 3: Listen request from client

//Step 4: Communicate with client
while (1) {
    connfd = accept (listenfd, ... );
    if( (pid = fork()) == 0) { // process in child
        close(listenfd); // child closes listening socket
        doit(connfd);    // process the request
        close(connfd);   // done with this client
        exit(0);         // child terminates
    }
    close(connfd); // parent closes connected socket
}
```

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Handling SIGCHLD Signals

- When a child process ends, it sends the **SIGCHLD** signal to the parent
 - Information about the child process is still maintained in “process table” in order to allow its parent to read the child exit status afterward.
- If we ignore the **SIGCHLD**, the child process will enter the zombie state
- We need to wait and handle **SIGCHLD** signal

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Signaling

- A signal is a notification to a process that an event has occurred.
- Signals are sometimes called software interrupts.
- Signals usually occur asynchronously. By this we mean that a process doesn't know ahead of time exactly when a signal will occur.
- Signals can be sent
 - By one process to another process (or to itself)
 - By the kernel to a process

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Signal (cont.)

- Typing certain key combinations at the controlling terminal of a running process causes the system to send it certain signals:
 - Ctrl-C sends an INT signal ("interrupt", SIGINT)
 - Ctrl-Z sends a TSTP signal ("terminal stop", SIGTSTP)
 - Ctrl-\ sends a QUIT signal (SIGQUIT)
- SIGHUP is sent to a process when its controlling terminal is closed (a hangup)
- SIGTERM is sent to a process to request its termination.
 - Unlike the SIGKILL signal, it can be caught and interpreted or ignored by the process.

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Handling SIGCHLD Signals

- The purpose of the zombie state is to maintain information about the child for the parent to fetch at some later time.
- They take up space in the kernel and eventually we can run out of processes
- Whenever we *fork* children, we must *wait* for them to prevent them from becoming zombies → establish a signal handler to catch *SIGCHLD*, and within the handler, we call *wait*
- Establish the signal handler by adding the function call :
signal (SIGCHLD, handler);

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wait() and waitpid()

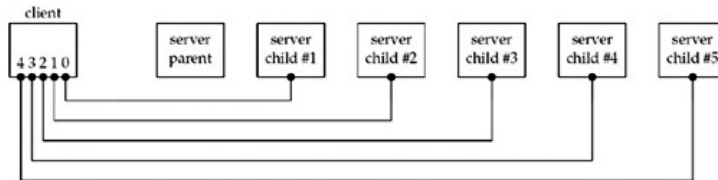
```
#include <sys/wait.h>
pid_t wait (int *statloc);
pid_t waitpid (pid_t pid, int *statloc, int options);
```

- Wait for the status change of a process.
- Use to handle the terminated child
- Both return two values:
 - The return value of the function:
 - the process ID of the terminated child
 - 0 or -1 if error
 - The termination status of the child (an integer) is returned through the *statloc* pointer.

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`wait()`

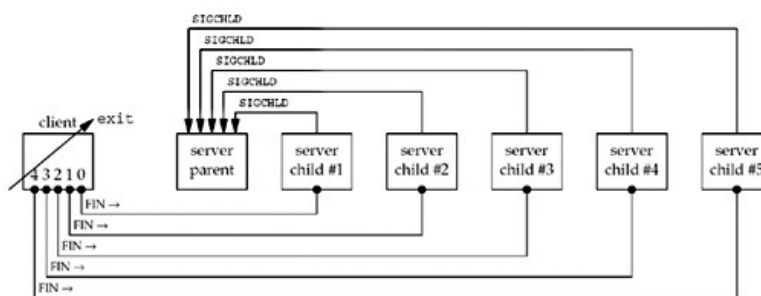


- Create 5 connections from a client to a forking server
- When the client terminates, all open descriptors are closed automatically by the kernel → five connections ended simultaneous

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`wait()`



- Client terminates, closing all five connections, terminating all five children → four children are zombies
- It can happen when many users connect to a server
- → we have to use `waitpid()`

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waitpid()

pid_t waitpid (pid_t pid, int *statloc, int options);

- pid < 0: wait for any child process whose process group ID is equal to the absolute value of *pid*.
- **pid = -1**: wait for any child process.
- pid = 0: wait for any child process whose process group ID is equal to that of the calling process
- pid > 0: wait for the child whose process ID is equal to the value of *pid*
- Without option WNOHANG, waitpid blocks until the status change
- With option WNOHANG, waitpid returns immediately
- Return
 - pid of the child whose state has changed
 - with option WNOHANG, return 0 if the specified process has not changed status.

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void sig_chld(int signo)

```
void sig_chld(int signo)
{
    pid_t pid;
    int stat;
    while((pid = waitpid(-1, &stat, WNOHANG))>0)
        printf("child %d terminated\\", pid);
}
```

- WNOHANG: waitpid() does not block
- while loop: waitpid() repeatedly until there is no child process change status, i.e until waitpid returns 0.

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Forking server

```
pid_t pid;
int listenfd, connfd;
//Step 1: Construct socket
//Step 2: Bind address to socket
//Step 3: Listen request from client

// wait for a child process to stop
signal(SIGCHLD, sig_chld);
//Step 4: Communicate with client
while (1) {
    connfd = accept (listenfd, ... );
    if( (pid = fork()) == 0) { // process in child
        close(listenfd); // child closes listening socket
        doit(connfd);    // process the request
        close(connfd);   // done with this client
        exit(0);         // child terminates
    }
    close(connfd); // parent closes connected socket
}
```

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Handling EINTR Errors

- When a process is blocked in a **slow system call** and the process catches a signal and the signal handler returns, the system call can return an error of EINTR.
- Slow system call: connect, accept, send, recv...
- Not all kernels automatically restart some interrupted system calls
- We must rewrite function to handle EINTR error

```
while(1)
    if ((connfd = accept (listenfd...)) < 0) {
        if (errno == EINTR)
            continue;          /* back to for () */
        else
            perror ("Error: ");
    }
```

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Other problems

- Connection abort before *accept* return
- Termination of server process
- Crashing of sever host
- Crashing and Reboot of server host

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MULTI-THREAD SERVER

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pthread_create()

```
#include <pthread.h>
int pthread_create(pthread_t *tid, const pthread_attr_t *attr,
                  void *(*routine) (void *), void *arg);
```

- Create a new thread
- Parameters:
 - [OUT] tid: points to ID of the new thread
 - [IN] attr: points to structure whose contents are used to determine attributes for the new thread
 - [IN] routine: the new thread starts execution by invoking routine()
 - [IN] arg: points to the argument is passed as the sole argument of routine()
- Return:
 - On success, returns 0
 - On error, returns an error number
- **Compile and link with -pthread**

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pthread_create()

- By default, the new thread is joinable:
 - Not automatically cleaned up by GNU/Linux when it terminates
 - the thread's exit state hangs around in the system until another thread calls pthread_join() to obtain its return value
- Detached thread is cleaned up automatically when it terminates
 - Another thread may not obtain its return value
- Detach a thread: `int pthread_detach(pthread_t tid)`
 - On success, returns 0
 - On error, returns an error number

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```
main(){
    pthread_create(tid,...);
    pthread_join(tid);
    return 0;
}
```

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Multi-thread TCP Echo Server

```
pthread_t tid;
int listenfd, *connfd;
//Step 1: Construct socket
//Step 2: Bind address to socket
//Step 3: Listen request from client

//Step 4: Communicate with client
while (1) {
    connfd = malloc(sizeof(int));
    *connfd = accept (listenfd, ... );
    pthread_create(&tid, NULL, &client_handler, connfd);
}

close(listenfd);
return 0;
```

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Multi-thread TCP Echo Server(cont.)

```
void *client_handler(void *arg){
    int connfd;
    int sendBytes, rcvBytes;
    char buff[BUFF_SIZE + 1];

    pthread_detach(pthread_self());
    connfd = *((int *) arg);
    while(1){
        rcvBytes = recv(connfd, buff, BUFF_SIZE, 0);
        if (rcvBytes <= 0)
            break;

        sendBytes = send(connfd, buff, rcvBytes, 0);
        if (sendBytes <= 0)
            break;
    }
    close(connfd);
}
```

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Synchronize threads

- Since multiple threads can be running concurrently, accessing the shared variables:
 - The order of the accessing shared memory is unpredictable, so
 - The processing flow of the thread may be uncontrollable, and/or
 - The process crash
- Synchronize threads so that only one thread can access shared memory:
 - Mutex
 - Condition variable
 - Inter-lock

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Mutex

```
#include <pthread.h>
int pthread_mutex_lock(pthread_mutex_t * mptr);
int pthread_mutex_unlock(pthread_mutex_t * mptr);
```

- The thread can access the shared variable only when it hold the mutex
- `pthread_mutex_lock()`: lock a mutex
- `pthread_mutex_unlock()`: unlock a mutex
- If the thread try to lock a mutex that is already locked by some other thread, it is blocked until the mutex is unlocked.

```
void *routine(void *arg) {
    //...
    pthread_mutex_lock(mptr);
    // access shared memory
    pthread_mutex_unlock(mptr);
    //...
}
```

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Condition variable

- Mutexes are for **locking** and cannot be used for **waiting**
- Condition variable can be used to **waiting**

```
#include <pthread.h>
int pthread_cond_wait(pthread_cond_t *cond,
                      pthread_mutex_t *mutex);
int pthread_cond_signal(pthread_cond_t *cond);
```

- `pthread_cond_wait()`: wait on a condition
- `pthread_cond_signal()`: signal a condition

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Mutex + Condition variables template

```
struct {  
    pthread_mutex_t mutex;  
    pthread_cond_t cond;  
    whatever variables maintain the condition  
} var = (PTHREAD_MUTEX_INITIALIZER, PTHREAD_COND_INITIALIZER);
```

```
/* on signal thread */  
pthread_mutex_lock(&var.mutex);  
set condition true  
pthread_cond_signal(&var.cond);  
pthread_mutex_unlock(&var.mutex)
```

```
/* on waiting thread */  
pthread_mutex_lock(&var.mutex);  
while (condition is false)  
    pthread_cond_wait(&var.cond, &var.mutex);  
modify condition  
pthread_mutex_unlock(&var.mutex)
```

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fork() VS pthread_create()

fork()

- Heavy-weight
- Passing information from the parent to the child before the fork is easy
- Returning information from the child to the parent takes more work
- Needn't synchronize processes
- Greater isolation between the parent and the child

pthread_create()

- Light-weight
- Passing information from a thread to the others is easy
- Don't need signal-driven processing when the threads ends.
- May synchronize threads
- If a thread crashes, process may crash

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