LEC 05

# CONCURRENT TCP SERVER

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## Content

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

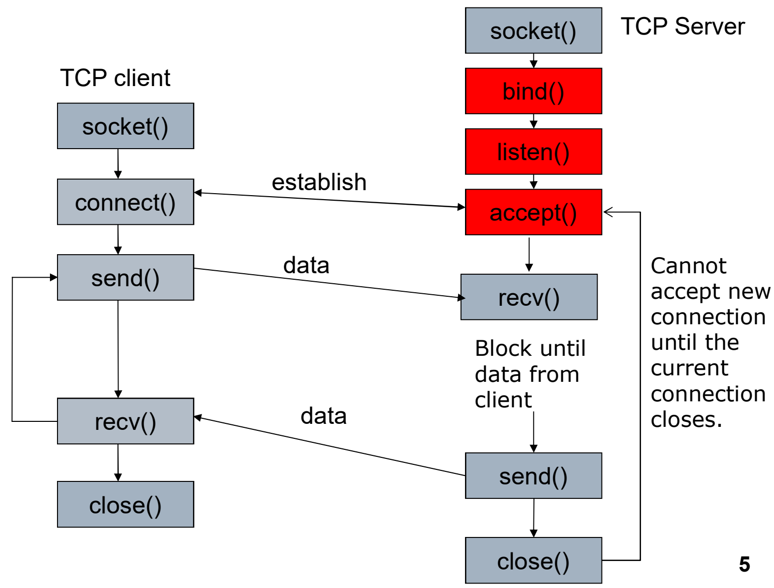
# I/O MODELS



## 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
```

## 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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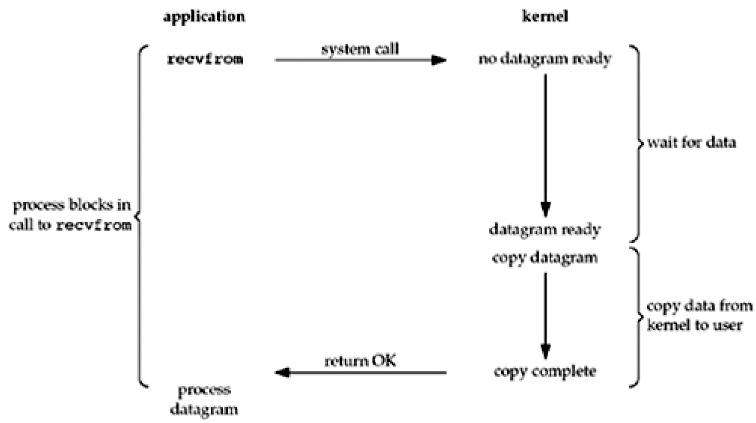
# Blocking I/O Model

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

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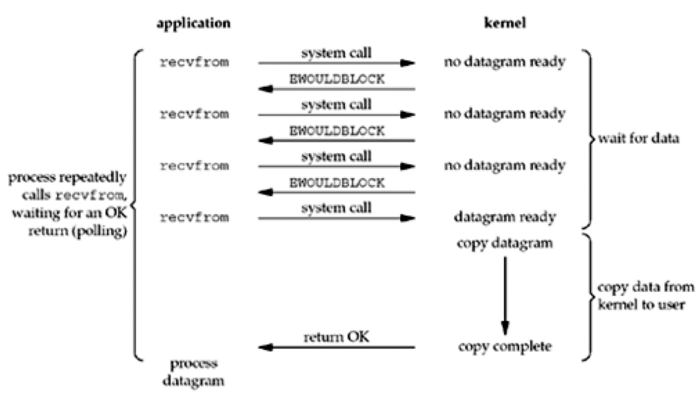
# Non-blocking I/O Model

- 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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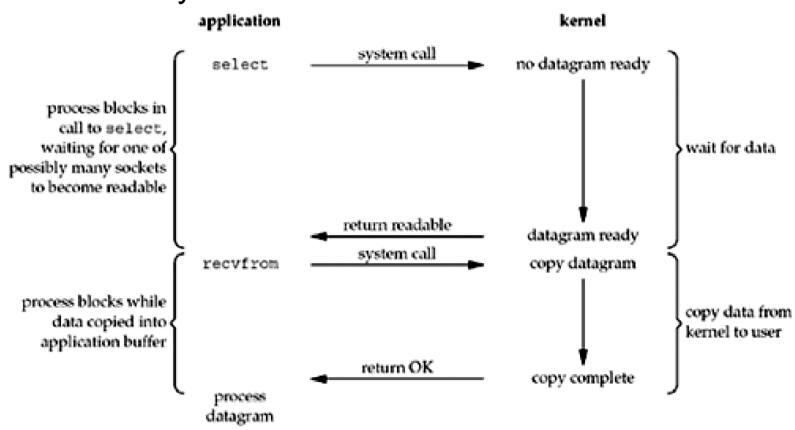
## I/O Multiplexing Model

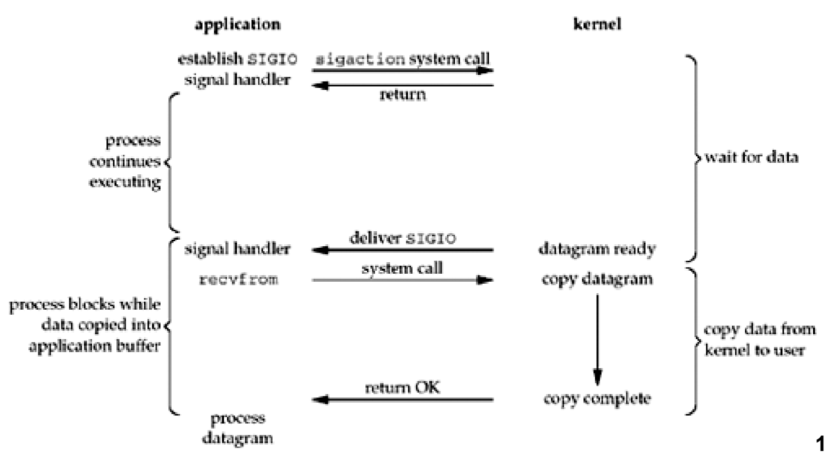
- With I/O multiplexing, we call select or poll and block in one of these two system calls, instead of blocking in the actual I/O system call



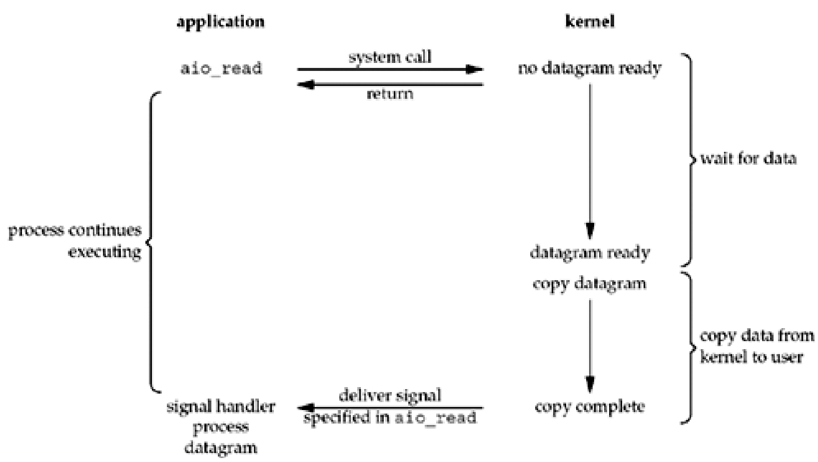



## Signal-Driven I/O Model

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



## Asynchronous I/O Model

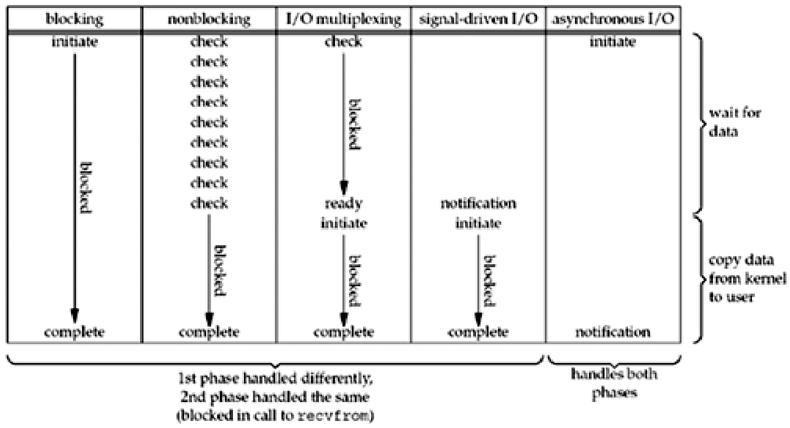





## Asynchronous I/O Model (2)

- 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.

## 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()` a child process to handle each client
- One thread per client: create a thread to handle each client by using `pthread_create()`

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# MULTI-PROCESS SERVER

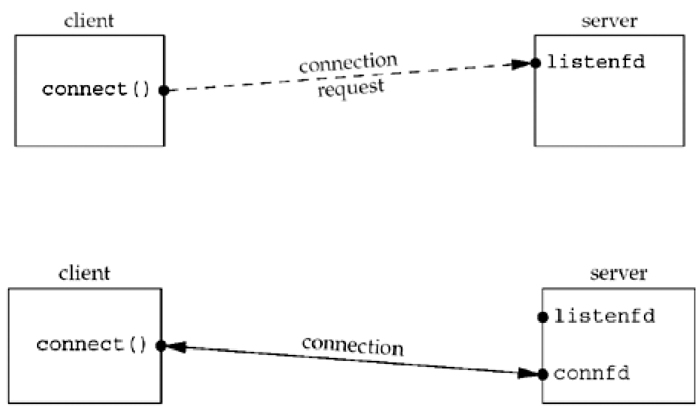


## fork()

```
#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

## One child per client

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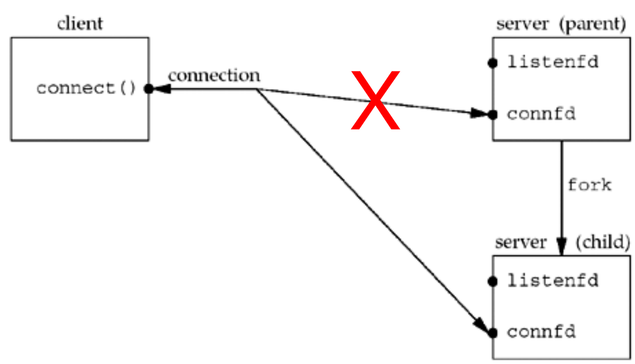
## One child per client

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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);*

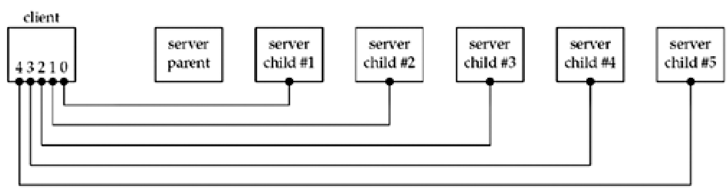


## wait() and waitpid()

```
#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.

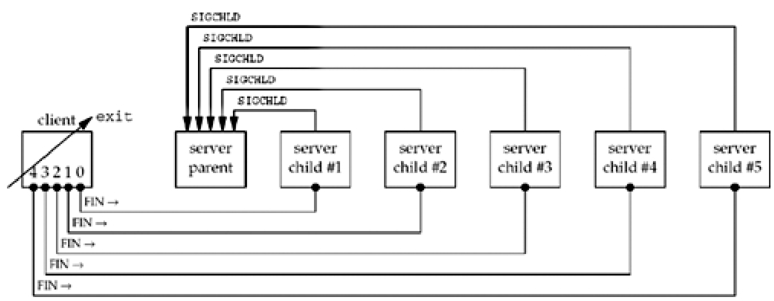
## wait()




- 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



## waitpid()




- 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()*

# 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.



# void sig_chld(int signo)

```
void sig_chld(int signo)
{
        pid_t pid;
        int stat;
        pid = waitpid(-1, &stat, WNOHANG );
        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.

## 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
}
```



## 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: ");
}
```

## 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*



## 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

## 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 incontrollable, and/or
  - The process crash
- Synchronize threads so that only one thread can access shared meory:
  - Inter-lock
  - Semaphore
  - Mutex



# 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);
//...
}
```

## `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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