UNIX Networking 3

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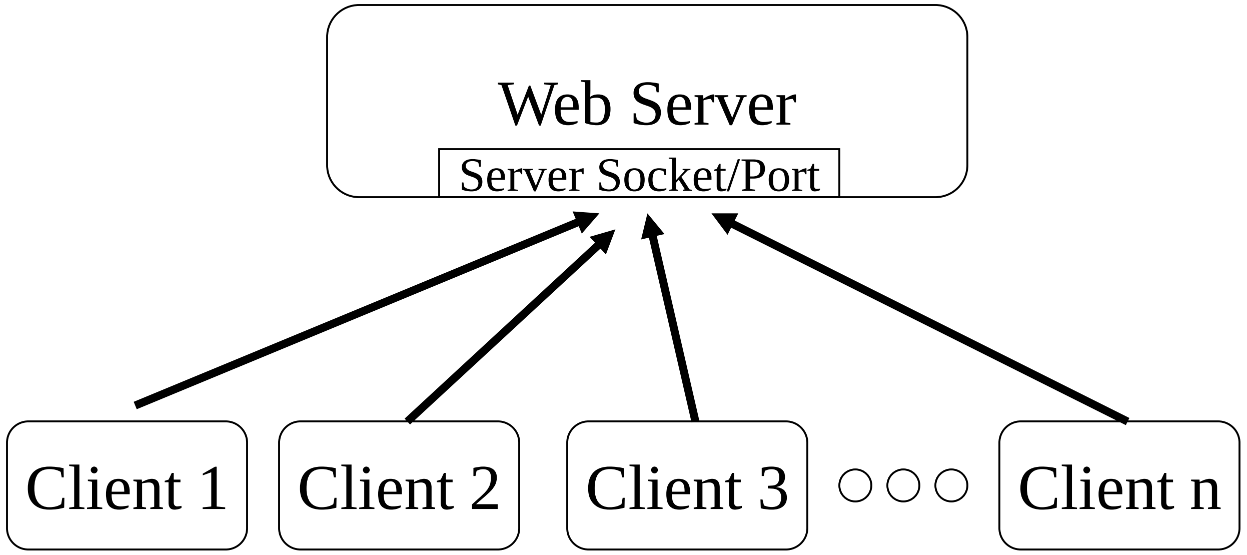
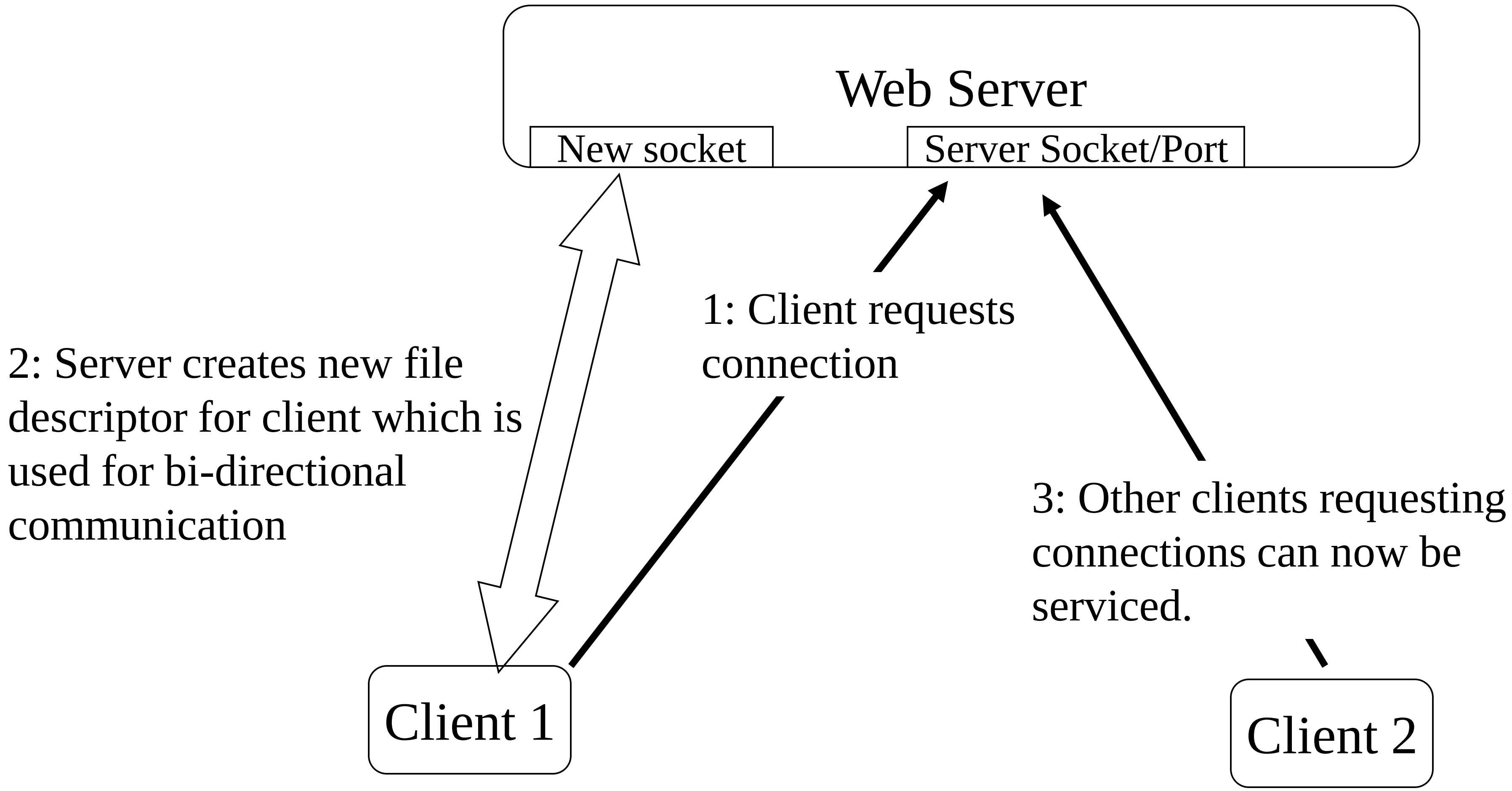
Server Sockets



- A server socket listens on a given port
- Many different clients may be connecting to that port
- Ideally, you would like a separate file descriptor for each client connection

Server Sockets:


Web Server
New socket
Server Socket/Port
1: Client requests connection
2: Server creates new file descriptor for client which is used for bi-directional communication
3: Other clients requesting connections can now be serviced.
Client 1
Client 2

Server Sockets

- How to use the socket API to listen for and accept connections
- Lets start by describing a non-concurrent implementation of a server (only one thread of executation)
- Procedure
  - Create network endpoint with socket()
  - Bind socket to a port - bind()
  - Start listening for connections - listen()
  - Loop and accept connections - accept()
  - Read and write data to client - send(), recv(), read(), write()

Creating the Socket

`socket()` creates an endpoint for network communication

```
int socket(int domain, int type, int protocol);
```

For IP, use AF_INET

Returns file descriptor or -1

For TCP, use SOCK_STREAM
For UDP, use SOCK_DGRAM

For IP, 0

```
if ((sockfd = socket(AF_INET,SOCK_STREAM, 0)) == -1)
{
      perror("socket");
      exit(1);
}
```

Bind the Socket to a Port

- Ports allow multiple network processes on a machine with a single address
- A server has to choose a port where clients can contact it
- bind() associates the chosen port with a socket already created with the socket() command

Binding the socket

bind() connects a server socket to a port

```
int bind(int sockfd, struct sockaddr *address,
  size_t add_len);
```

0 on success
or -1 on error

Size of address structure

Network address structure
identifying port to listen on

```
if (bind(sockfd, (struct sockaddr *) &server, sizeof(SERVER)) == -1)
{
   perror("bind call failed");
   exit(1);
}
```

Setting up an address

- Server accepting connections:

```
struct sockaddr_in server;

server.sin_family = AF_INET;
server.sin_port = htons(7000);
server.sin_addr.s_addr = INADDR_ANY;
```

Listening for Connections

- The server will ignore any connection attempts until you tell the socket() to start listening
- This is done with listen()

Listen

```
int listen(int sockfd, int queue_size);
```

Maximum numbers of connections to queue up

0 on success or -1 on error

```
if (listen(sockfd, 5) == -1)
{
   perror("listen call failed");
   exit(1);
}
```

Loop and Accept

- Servers generally run continually, waiting for clients to contact them
- Thus a server has an "infinite loop" that continually processes connections from clients
- The accept() function takes the next connection off of the listen queue or blocks the process until a connection arrives

Accept

accept() returns the next client connection

```
int accept(int sockfd, struct sockaddr *address,
           size_t &add_len);
```

Returns file descriptor or -1

Network address structure identifying client. This can be NULL pointer

Pointer to variable containing size of address structure, can be NULL

```
while (1) {
   client_sockfd = accept(sockfd, NULL, NULL);
   if (client_sockfd == -1) {
      perror("accept call failed");
      /* Here you may want to continue or exit - depends */
   }
}
```

Concurrency Definitions

- Iterative
  - One process
  - Handling one connection at a time

- Concurrent
  - One or more processes
  - Handling multiple connections concurrently

Iterative Servers

- Non-preemptive
  - Client must wait for all previous requests to complete
- Easy to design, implement, and maintain
- Best when
  - request processing time is short
  - No I/O is needed by server

Server Concurrency

- Many clients may connect “at once”
- Want to minimize:
  - Response time
  - Complexity
- Want to maximize
  - Throughput (connections serviced / second)
  - Hardware utilization (%CPU usage)
- Tradeoffs
  - Response time vs. throughput vs. hardware utilization vs. complexity

Concurrent Server

- Concurrency can be provided in two ways
  - Apparent concurrency
    - A single thread of execution, using the `select()` command and non-blocking I/O
  - Real concurrency
    - Multiple threads of execution
      - Could be multiple processes, each with one thread
    - OS preempts thread/process after each quantum

More on `select` later

Apparent Concurrency

- Only one thread, no preemption, using non-blocking I/O
- Whenever an I/O request would block
  - Switch to another connection
- Up to a certain number of connections:
  - Maximizes CPU utilization
  - Increases throughput
- Less programming/debugging problems than true concurrency
- Code is more complicated
- Works well (only) if requests are short

Real Concurrency Using Threads

- Preemptive
  - Response time not dependent on length of previous client’s request
- Harder to design, implement, and maintain
- Up to a certain number of connections
  - Maximizes CPU utilization
  - Maximizes response time
  - Increases throughput
- After too many concurrent connections
  - Everything gets worse -> server eventually hangs
  - Need to put limits on concurrent connections

More Real Concurrency

- Four different methods
  - Create process per client connection
  - A pool of available processes
  - One process, create one thread per connection
  - One process, a pool of available threads

Fork Solution #1

- One process per client connection
  - Fork a new process to handle every connection
  - Advantages:
    - Simple: minimal shared state to manage
  - Disadvantages:
    - Process creation (fork) is slow
    - Context-switching between procs is also slow (minor compared to fork)

Fork Solution #2

- Pool of available processes
  - Maintain a pool of iterative processes to handle connections
  - Advantages:
    - No longer have to fork
    - Have rapid response as long as there is an idle process available
    - Can set the pool size, so that you don't overload the hardware
  - Disadvantages:
    - Still have process context switching

Threads Solution

- Threads allow multiple concurrent execution contexts within a single process
  - Shared address space, shared code, shared data, etc.
- Can implement a web server as a single process with multiple threads
  - Either one thread per connection or a pool of threads
- Advantages:
  - Can sometimes avoid context-switches (user-level threads)
  - Can share data easily
- Disadvantages:
  - Code must be thread-safe (AKA *re-entrant*)
  - Must always worry about inadvertent data-sharing

`select()`

- `select()` is designed for server-like applications that have many communication channels open at once
  - Data or space may become available at any time on any of the channels
  - You want to minimize the delay between when data/space becomes available and your process takes action (calls `read()` or `write()`)
- You give select a list of file descriptors, and `select()` returns when any one of those selectors becomes readable or writable

select()

```
int select(
    int nfds,           // number of fds of interest
    fd_set *readfds,    // input fds of interest
    fd_set *writefds,   // output fds of interest
    fd_set *errorfds,   // fds where exception has occurred
   struct timeval *timeout  //when to time out
)
```

select()

```
int select(
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    fd_set *errorfds,     // fds where exception has
   occurred
   struct timeval *timeout  //when to time out
)
```

- nfds: This should be larger than the number of file descriptors you are interested in
  - FD_SETSIZE - max number of file descriptors
  - Probably more efficient if you pass the exact number of file descriptors you are interested in

File descriptor sets

- The three parameters `readfds`, `writefds`, and `errorfds` are bit masks
  - Each bit of the number refers to one file descriptor
  - Bit 0 -> file descriptor 0, Bit 1 -> file descriptor 1, etc.
- UNIX provides you with functions to manipulate bit masks for the select() system call
  - FD_ZERO - set all bits to 0
  - FD_SET   - set one specific bit to 1
  - FD_ISSET - determine if a specific bit is set to 1
  - FD_CLR   - set one specific bit to 0

```
int fd1, fd2;
fd_set readset;
fd1 = open("file1", O_RDONLY);
fd2 = open("file2", O_RDONLY);

FD_ZERO(&readset);
FD_SET(fd1, &readset);
FD_SET(fd2, &readset);

switch (select(2, &readset, NULL, NULL, NULL))
{
      // do shtuff
}
```

Return value of select()

- -1 upon error
- 0 if time out
  - no events occurred
- Otherwise, the return value is the number of interesting file descriptors:
  - file descriptors where something happened

Waiting on lots of pipes

- What if you have lots of pipes open, and you are waiting for events on all of them?
  - ie you are waiting for data to become available on any of the pipes you have open
- You obviously don't want blocking reads/writes
  - You might end up blocking on fdA when there is data available on fdB
- However, you don't want to spend all of your time looping through your open pipes looking for data
- The answer: `select()`

Where did events occur?

- `select()` reuses the masks that you passed in.
- If a file descriptor became readable, the bit is set in the `readfds`
- If a file descriptor became writable, the bit is set in the `writefds`
- If an error or exceptional event occurred, the bit is set in the `errorfds`
- NOTE: it overwrites your mask, so you probably want to keep a copy of the original mask

Where did events occur?

- You need to loop through your file descriptors of interest to determine which ones the event occurred on

```
for (i = 0; i < 3; i++)
{
   if (FD_ISSET(i, &readset))
   {
      // Say there's data to read on descriptor I…
      read(i, …)
   }
}
```