OS view of networking – Sockets API (an exercise in planning for the future)

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CS162 – Operating Systems and Systems Programming
Lecture 5
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Adjustment on Culler Office Hours:
- Tue 9-10, Wed 2-3, Th 1-2 in 449 Soda

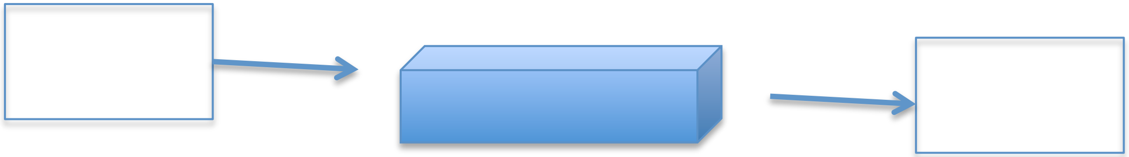
Reading: OSC 2.7, 3.6
HW: 1 is out, due 9/15
Proj:

Real Reading

- Unix Network Programming. The Sockets Networking API, Stevens (et al), Ch 3-5 "Elementary Sockets"
- Lots of on-line tutorials
- This lecture and the code
- http://cs162.eecs.berkeley.edu/static/lectures/code05/eclient.c
- http://cs162.eecs.berkeley.edu/static/lectures/code05/eserver.c
- http://cs162.eecs.berkeley.edu/static/lectures/code05/feserver.c

Communication between processes

```
write(wfd, wbuf, wlen);
```

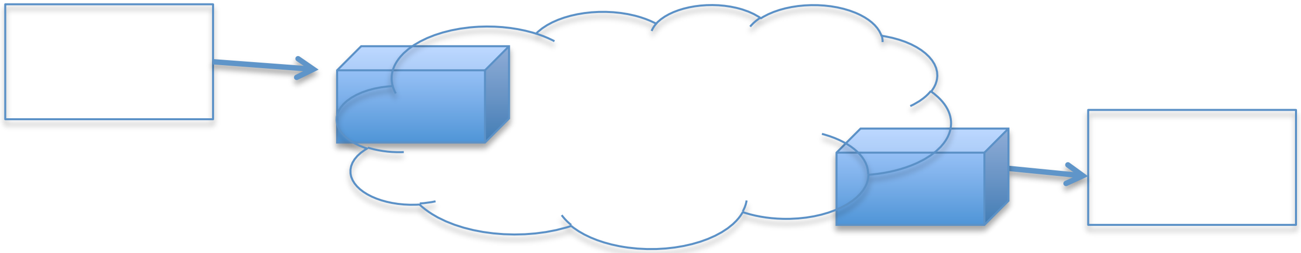


```
n = read(rfd,rbuf,rmax);
```

- Producer and Consumer of a file may be distinct processes
- May be separated in time (or not)

Communication Across the world looks like file IO

```
write(wfd, wbuf, wlen);
```



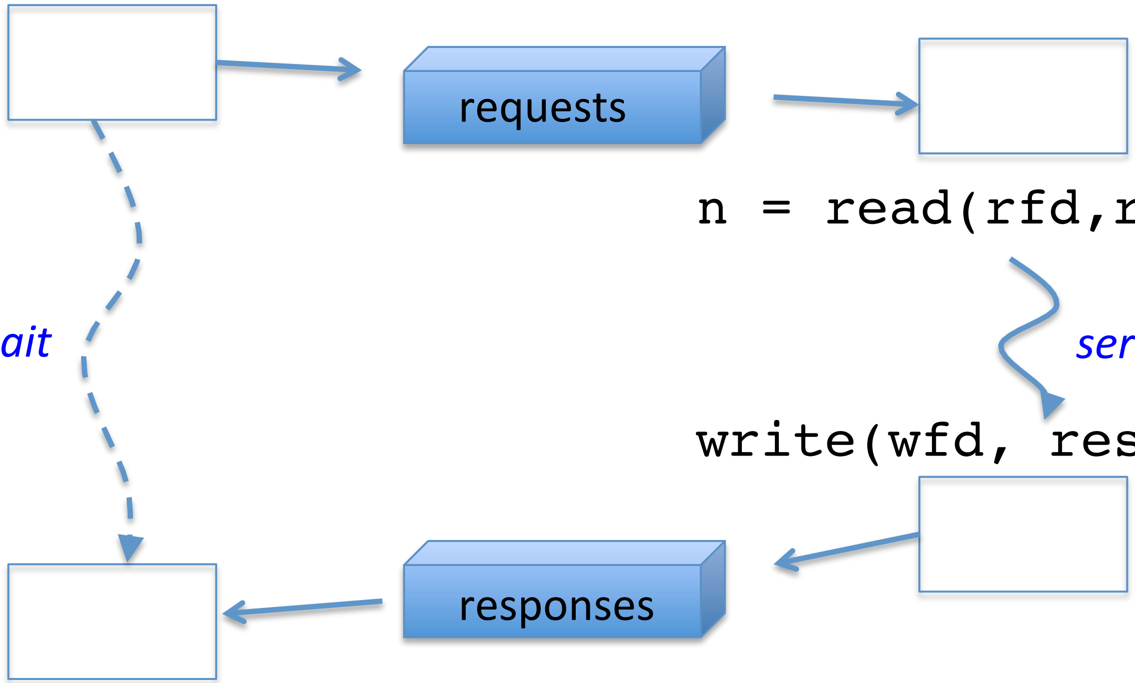
```
n = read(rfd,rbuf,rmax);
```

- But what’s the analog of open?
- What is the namespace?
- How are they connected in time?

Request Response Protocol

Client (issues requests)

Server (performs operations)



```
write(rqfd, rqbuf, buflen);
```

```
n = read(rfd,rbuf,rmax);
```

```
write(wfd, respbuf, len);
```

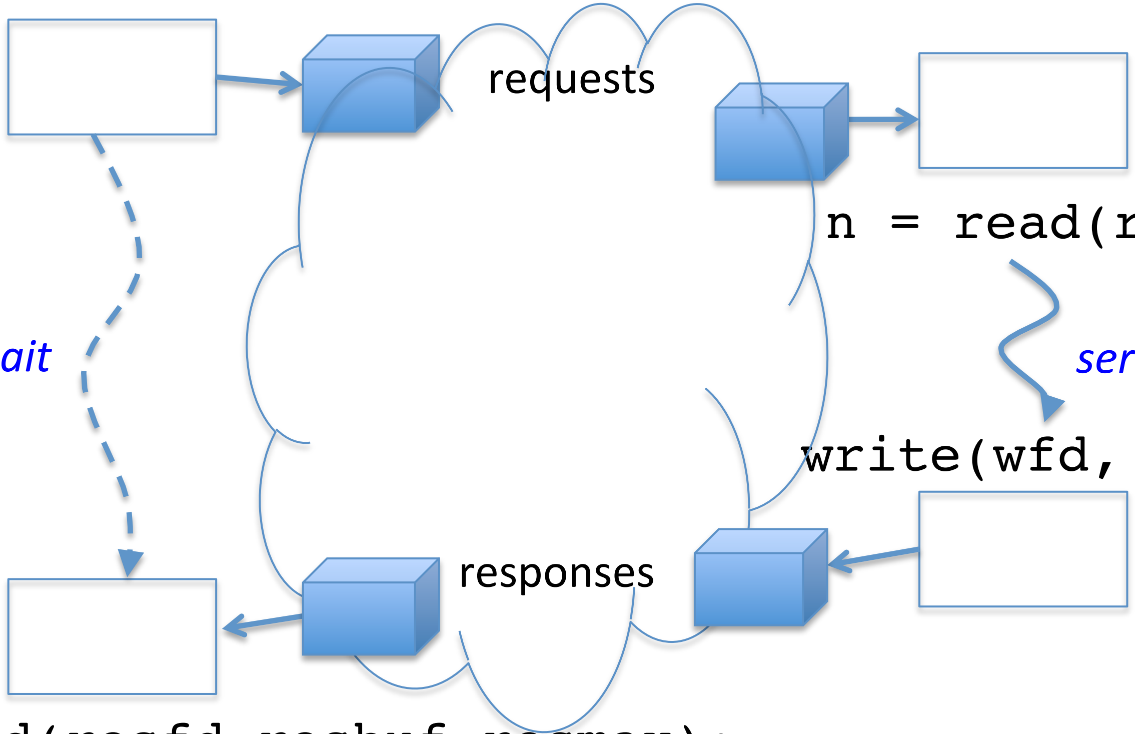
```
n = read(resfd,resbuf,resmax);
```

Request Response Protocol

Client (issues requests)

Server (performs operations)

```
write(rqfd, rqbuf, buflen);
```

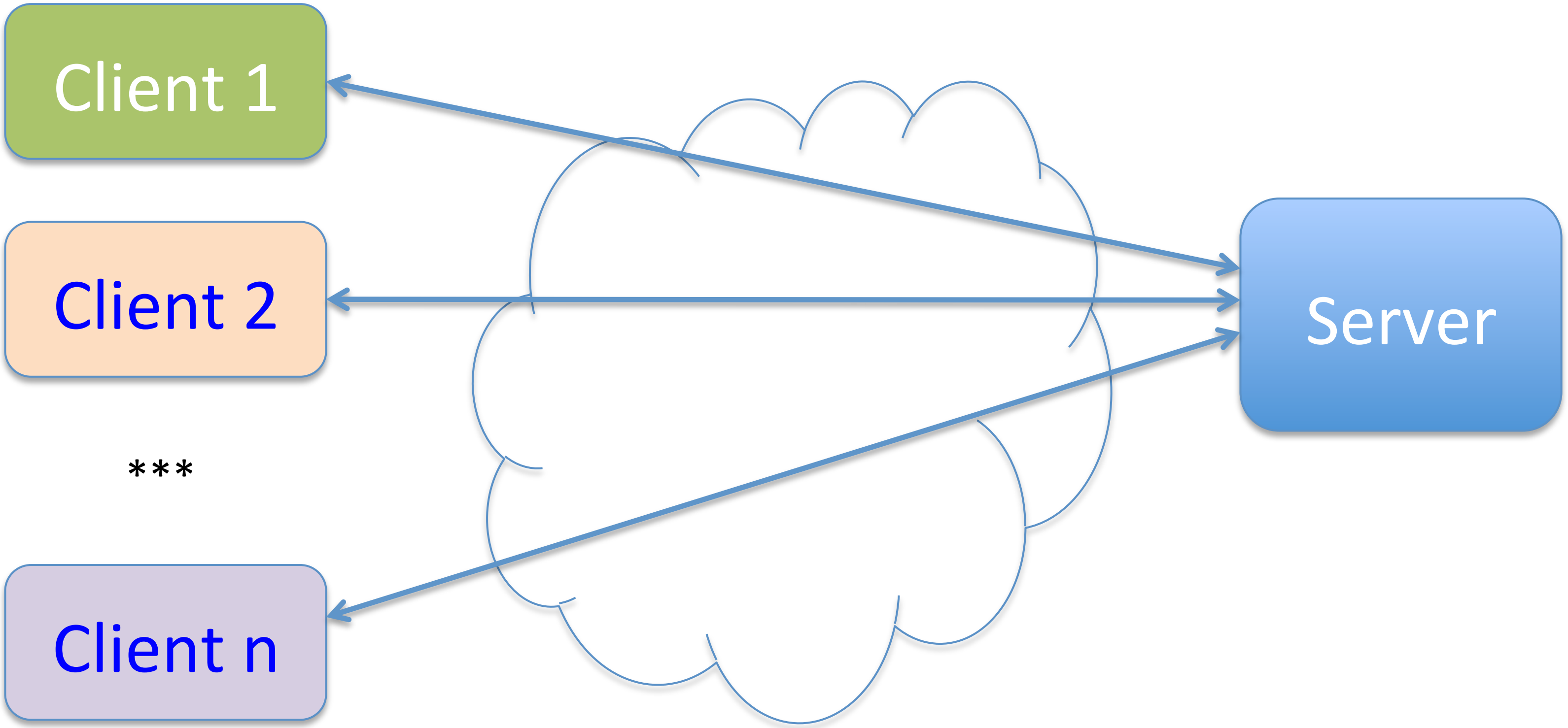


```
n = read(rfd,rbuf,rmax);
```

```
write(wfd, respbuf, len);
```

```
n = read(resfd,resbuf,resmax);
```

Client-Server Models

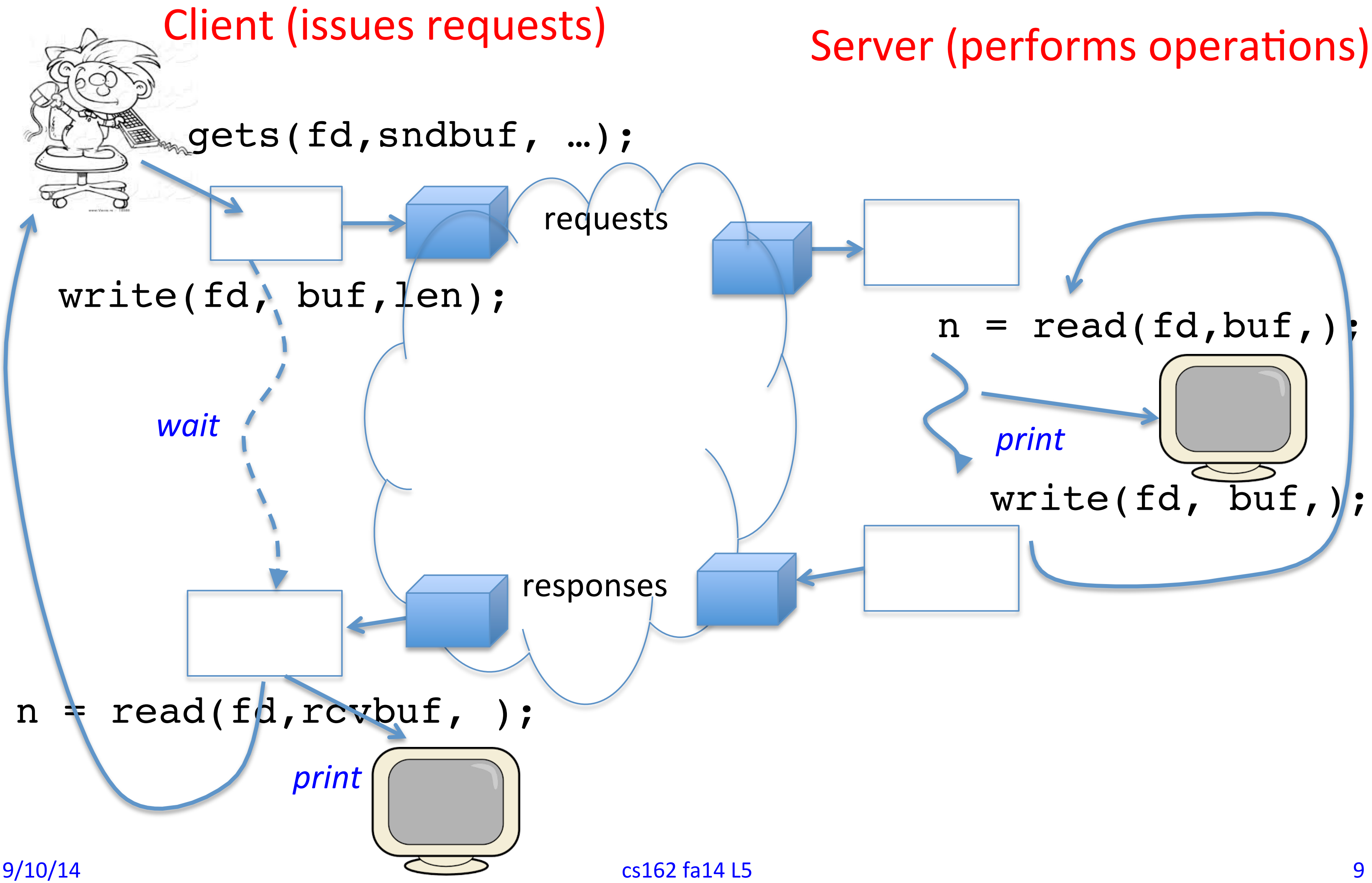


- File servers, web, FTP, Databases, …
- Many clients accessing a common server

Sockets

- Mechanism for inter-process communication
- Data transfer like files
  - Read / Write against a descriptor
- Over ANY kind of network
  - Local to a machine
  - Over the internet (TCP/IP, UDP/IP)
  - OSI, Appletalk, SNA, IPX, SIP, NS, …

Silly Echo Server – running example



Client (issues requests)

```
gets(fd,sndbuf, …);
write(fd, buf,len);
```

wait

```
n = read(fd,rcvbuf, );
```

print

requests

responses

Server (performs operations)

```
n = read(fd,buf,);
```

print

```
write(fd, buf,);
```

Echo client-server example

```
void client(int sockfd) {
  int n;
  char sndbuf[MAXIN]; char rcvbuf[MAXOUT];
  getreq(sndbuf, MAXIN);        /* prompt */
  while (strlen(sndbuf) > 0) {
    write(sockfd, sndbuf, strlen(sndbuf)); /* send */
    memset(rcvbuf,0,MAXOUT);               /* clear */
    n=read(sockfd, rcvbuf, MAXOUT-1);      /* receive */
    write(STDOUT_FILENO, rcvbuf, n);        /* echo */
    getreq(sndbuf, MAXIN);                 /* prompt */
  }
}
```

```
void server(int consockfd) {
  char reqbuf[MAXREQ];
  int n;
  while (1) {
    memset(reqbuf,0, MAXREQ);
    n = read(consockfd,reqbuf,MAXREQ-1); /* Recv */
    if (n <= 0) return;
    n = write(STDOUT_FILENO, reqbuf, strlen(reqbuf));
    n = write(consockfd, reqbuf, strlen(reqbuf)); /* echo*/
  }
}
```

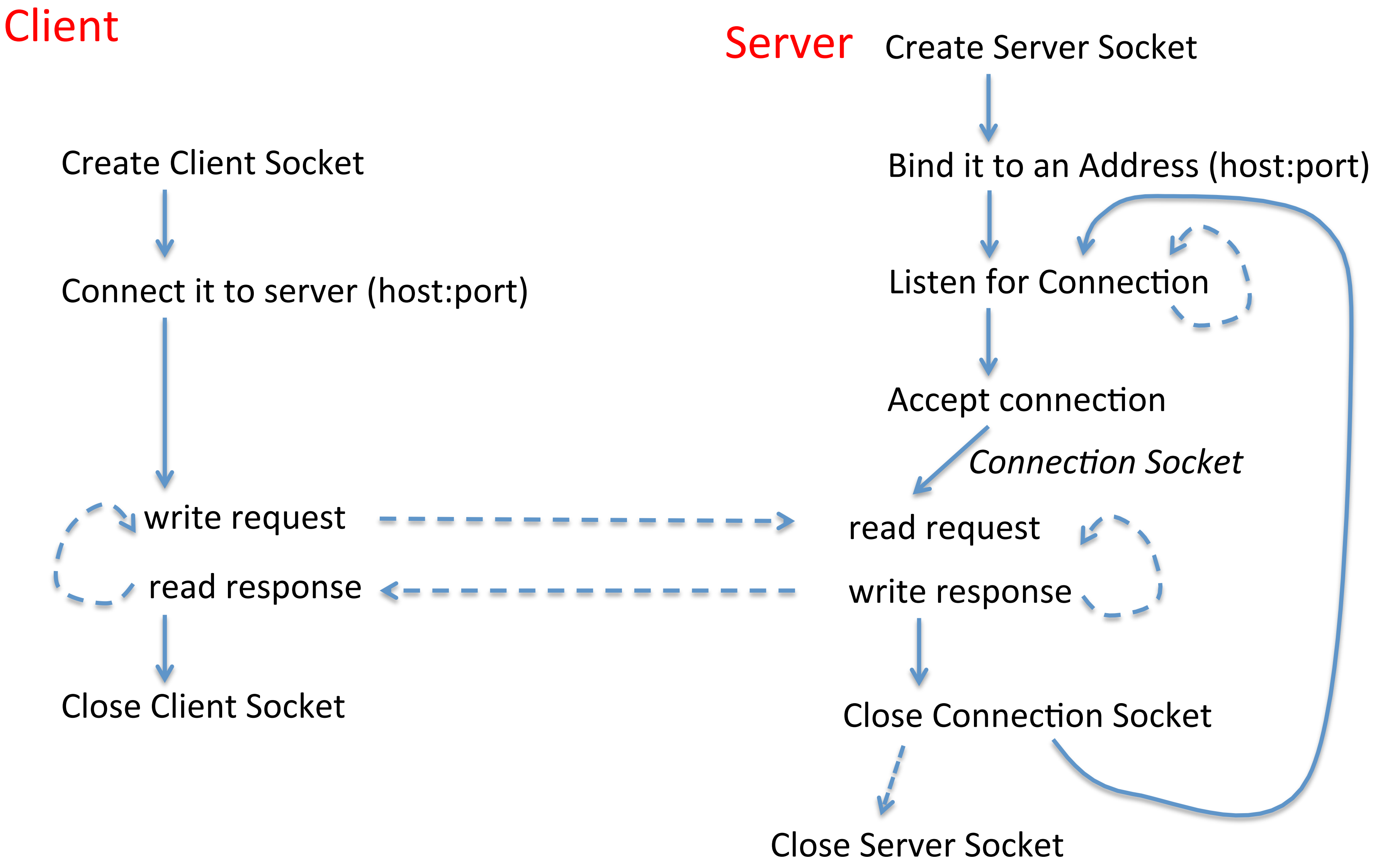
Prompt for input

```
char *getreq(char *inbuf, int len) {
  /* Get request char stream */
  printf("REQ: ");              /* prompt */
  memset(inbuf,0,len);          /* clear for good measure */
  return fgets(inbuf,len,stdin); /* read up to a EOL */
}
```

Socket creation and connection

- File systems provide a collection of permanent objects in structured name space
  - Processes open, read/write/close them
  - Files exist independent of the processes
- Sockets provide a means for processes to communicate (transfer data) to other processes.
- Creation and connection is more complex
- Form 2-way pipes between processes
  - Possibly worlds away

Sockets in concept



Client

Create Client Socket

Connect it to server (host:port)

write request

read response

Close Client Socket

Server

Create Server Socket

Bind it to an Address (host:port)

Listen for Connection

Accept connection

Connection Socket

read request

write response

Close Connection Socket

Close Server Socket

Client Protocol

```
char *hostname;
int sockfd, portno;
struct sockaddr_in serv_addr;
struct hostent *server;

server = buildServerAddr(&serv_addr, hostname, portno);

/* Create a TCP socket */
sockfd = socket(AF_INET, SOCK_STREAM, 0)

/* Connect to server on port */
connect(sockfd, (struct sockaddr *) &serv_addr, sizeof(serv_addr)
printf("Connected to %s:%d\n",server->h_name, portno);

/* Carry out Client-Server protocol */
client(sockfd);

/* Clean up on termination */
close(sockfd);
```

Server Protocol (v1)

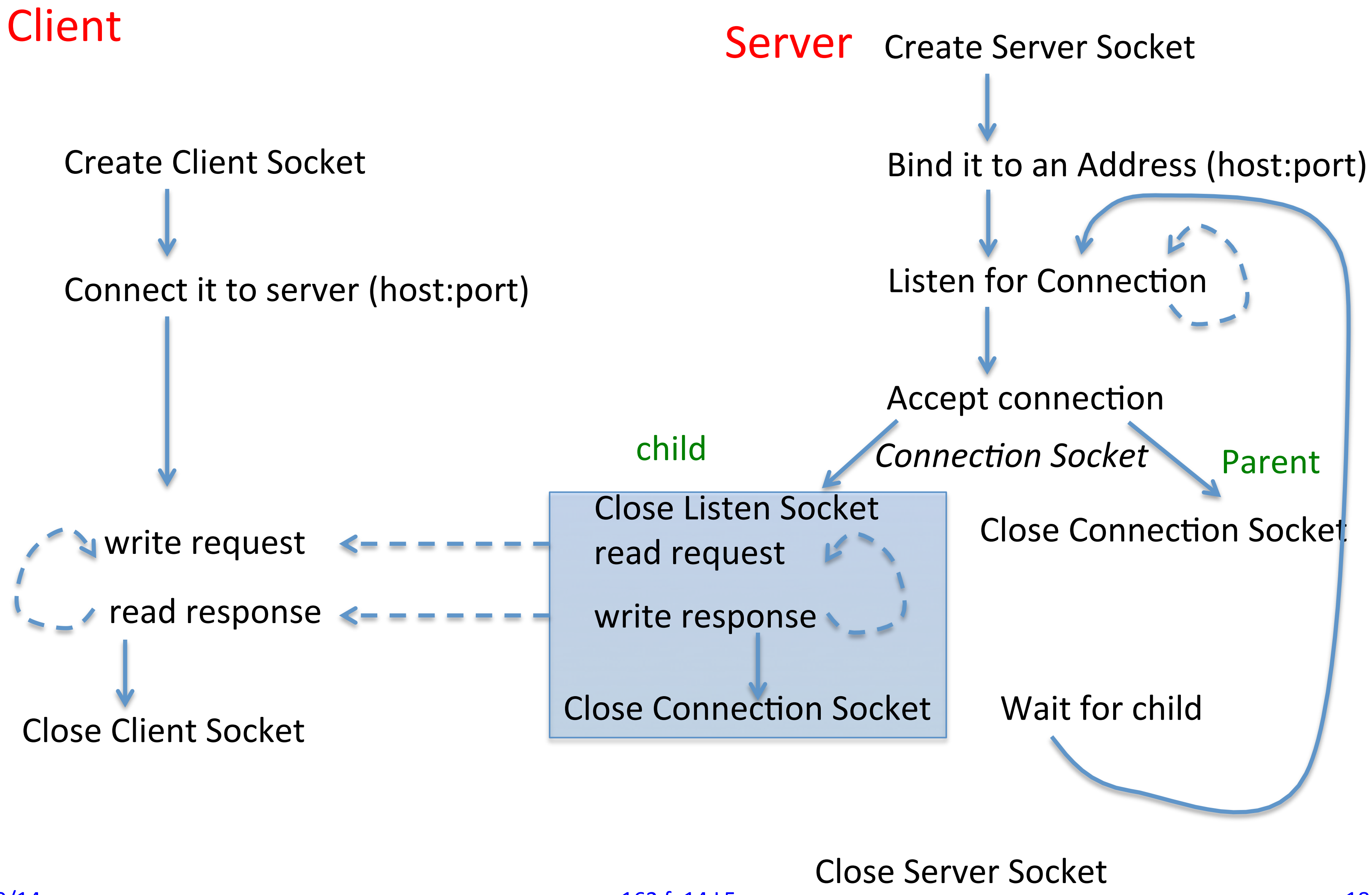
```
/* Create Socket to receive requests*/
lstnsockfd = socket(AF_INET, SOCK_STREAM, 0);

/* Bind socket to port */
bind(lstnsockfd, (struct sockaddr *)&serv_addr,sizeof(serv_addr));
while (1) {
/* Listen for incoming connections */
   listen(lstnsockfd, MAXQUEUE);

/* Accept incoming connection, obtaining a new socket for it */
   consockfd = accept(lstnsockfd, (struct sockaddr *) &cli_addr,
                      &clilen);

   server(consockfd);

   close(consockfd);
  }
close(lstnsockfd);
```

Administrative break

How does the server protect itself?

- Isolate the handling of each connection
- By forking it off as another process

Sockets in concept



Client

Create Client Socket

Connect it to server (host:port)

write request

read response

Close Client Socket

Server

Create Server Socket

Bind it to an Address (host:port)

Listen for Connection

Accept connection

Connection Socket

child

Close Listen Socket

read request

write response

Close Connection Socket

Parent

Close Connection Socket

Wait for child

Close Server Socket

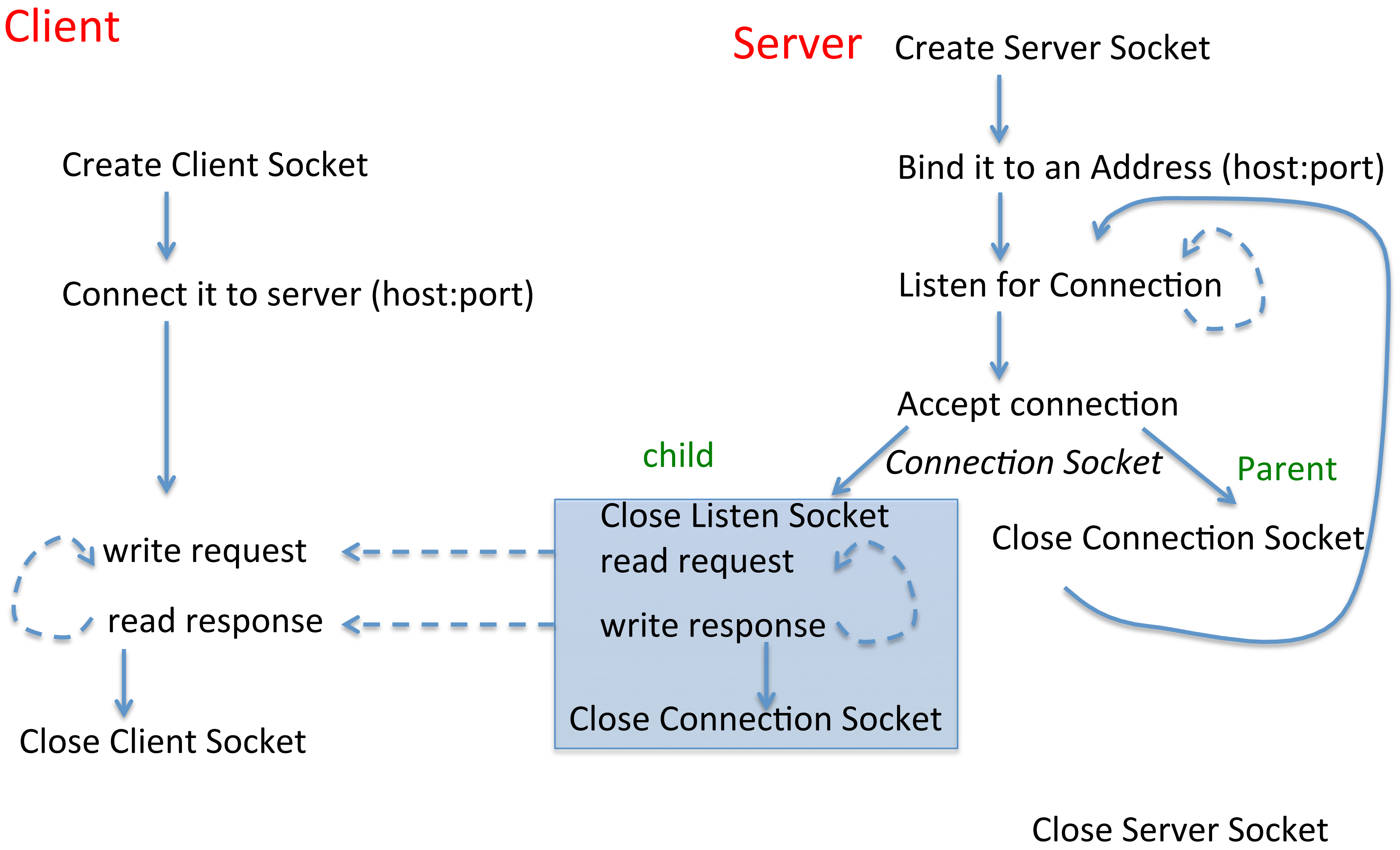
Server Protocol (v2)

```
while (1) {
    listen(lstnsockfd, MAXQUEUE);
    consockfd = accept(lstnsockfd, (struct sockaddr *) &cli_addr,
                         &clilen);
    cpid = fork();              /* new process for connection */
    if (cpid > 0) {             /* parent process */
      close(consockfd);
      tcpid = wait(&cstatus);
    } else if (cpid == 0) {      /* child process */
      close(lstnsockfd);        /* let go of listen socket */

      server(consockfd);

      close(consockfd);
      exit(EXIT_SUCCESS);         /* exit child normally */
    }
  }
close(lstnsockfd);
```

Concurrent Server

- Listen will queue requests
- Buffering present elsewhere
- But server waits for each connection to terminate before initiating the next

Sockets in concept



Client

Create Client Socket

Connect it to server (host:port)

write request

read response

Close Client Socket

Server

Create Server Socket

Bind it to an Address (host:port)

Listen for Connection

Accept connection

Connection Socket

child

Close Listen Socket

read request

write response

Close Connection Socket

Parent

Close Connection Socket

Close Server Socket

Server Protocol (v3)

```
while (1) {
    listen(lstnsockfd, MAXQUEUE);
    consockfd = accept(lstnsockfd, (struct sockaddr *) &cli_addr,
                         &clilen);
    cpid = fork();              /* new process for connection */
    if (cpid > 0) {             /* parent process */
      close(consockfd);
      //tcpid = wait(&cstatus);
    } else if (cpid == 0) {      /* child process */
      close(lstnsockfd);        /* let go of listen socket */

      server(consockfd);

      close(consockfd);
      exit(EXIT_SUCCESS);         /* exit child normally */
    }
  }
close(lstnsockfd);
```

Server Address - itself

```
memset((char *) &serv_addr,0, sizeof(serv_addr));
serv_addr.sin_family      = AF_INET;
serv_addr.sin_addr.s_addr = INADDR_ANY;
serv_addr.sin_port        = htons(portno);
```

- Simple form
- Internet Protocol
- accepting any connections on the specified port
- In “network byte ordering”

Client: getting the server address

```
struct hostent *buildServerAddr(struct sockaddr_in *serv_addr,
                                char *hostname, int portno) {
  struct hostent *server;
  /* Get host entry associated with a hostname or IP address */
  server = gethostbyname(hostname);
  if (server == NULL) {
    fprintf(stderr,"ERROR, no such host\n");
    exit(1);
  }

  /* Construct an address for remote server */
  memset((char *) serv_addr, 0, sizeof(struct sockaddr_in));
  serv_addr->sin_family = AF_INET;
  bcopy((char *)server->h_addr,
        (char *)&(serv_addr->sin_addr.s_addr), server->h_length);
  serv_addr->sin_port = htons(portno);

return server;
}
```

Namespaces for communication

- Hostname
  - www.eecs.berkeley.edu
- IP address
  - 128.32.244.172 (ipv6?)
- Port Number
  - 0-1023 are "well known" or "system" ports
    - Superuser privileges to bind to one
  - 1024 – 49151 are "registered" ports (registry)
    - Assigned by IANA for specific services
  - 49152–65535 ($2^{15}+2^{14}$ to $2^{16}–1$) are "dynamic" or "private"
    - Automatically allocated as "ephemeral Ports"

Recall: UNIX Process Management

- UNIX fork – system call to create a copy of the current process, and start it running
  - No arguments!
- UNIX exec – system call to *change the program* being run by the current process
- UNIX wait – system call to wait for a process to finish
- UNIX signal – system call to send a notification to another process

Signals – infloop.c

```
#include <stdlib.h>
#include <stdio.h>
#include <sys/types.h>

#include <unistd.h>
#include <signal.h>

void signal_callback_handler(int signum)
{
  printf("Caught signal %d - phew!\n",signum);
  exit(1);
}

int main() {
  signal(SIGINT, signal_callback_handler);

  while (1) {}
}
```

Got top?

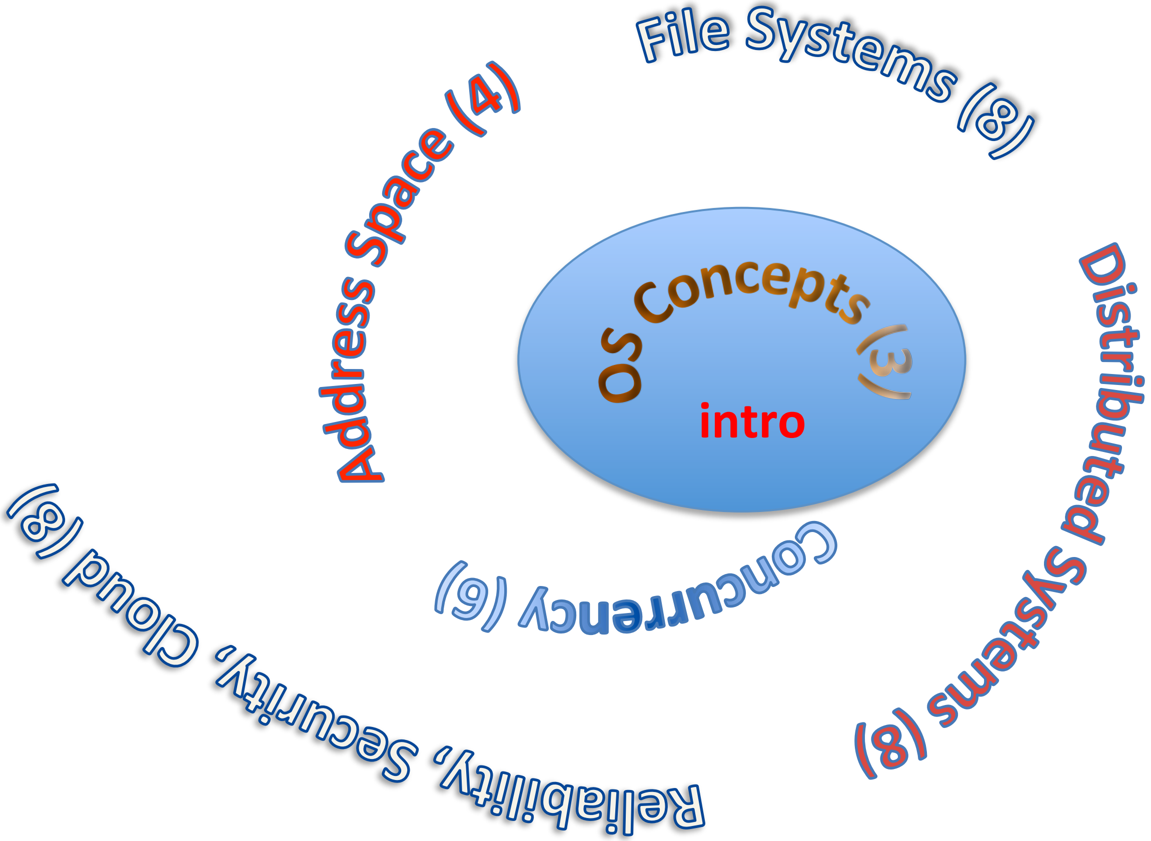
Process races: fork.c

```
if (cpid > 0) {
   mypid = getpid();
   printf("[%d] parent of [%d]\n", mypid, cpid);
   for (i=0; i<100; i++) {
     printf("[%d] parent: %d\n", mypid, i);
     //      sleep(1);
   }
 }  else if (cpid == 0) {
   mypid = getpid();
   printf("[%d] child\n", mypid);
   for (i=0; i>-100; i--) {
     printf("[%d] child: %d\n", mypid, i);
     //      sleep(1);
   }
 }
```

BIG OS Concepts so far

- Processes
- Address Space
- Protection
- Dual Mode
- Interrupt handlers (including syscall and trap)
- File System
  - Integrates processes, users, cwd, protection
- Key Layers: OS Lib, Syscall, Subsystem, Driver
  - User handler on OS descriptors
- Process control
  - fork, wait, signal --- exec
- Communication through sockets
- Client-Server Protocol

Course Structure: Spiral



OS Concepts (3)

intro

Concurrency (6)

Address Space (4)

File Systems (8)

Distributed Systems (8)

Reliability, Security, Cloud (8)