# CONCURRENCY MODEL

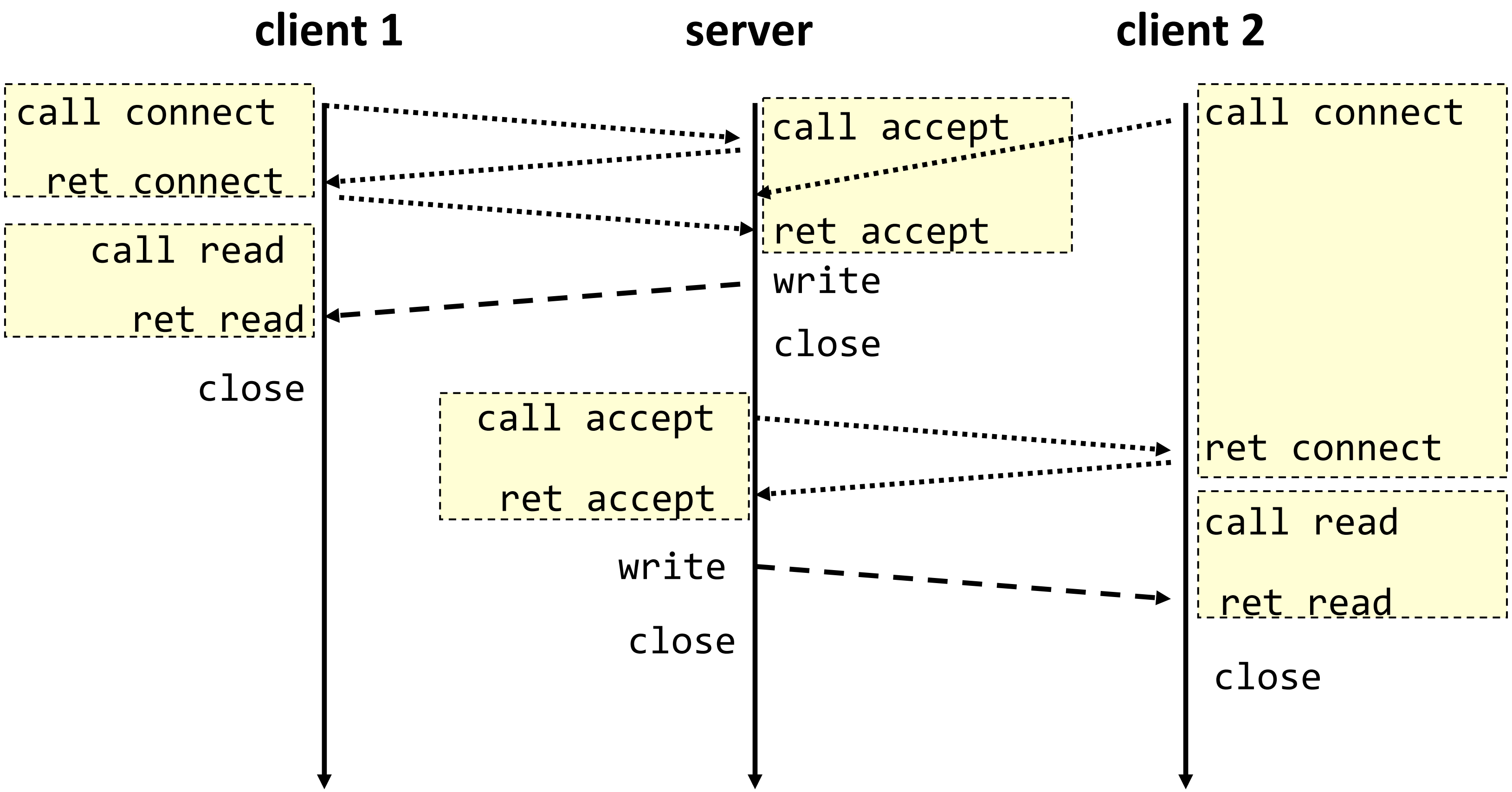
UNIX Programming 2014 Fall by Euiseong Seo

# Echo Server Revisited

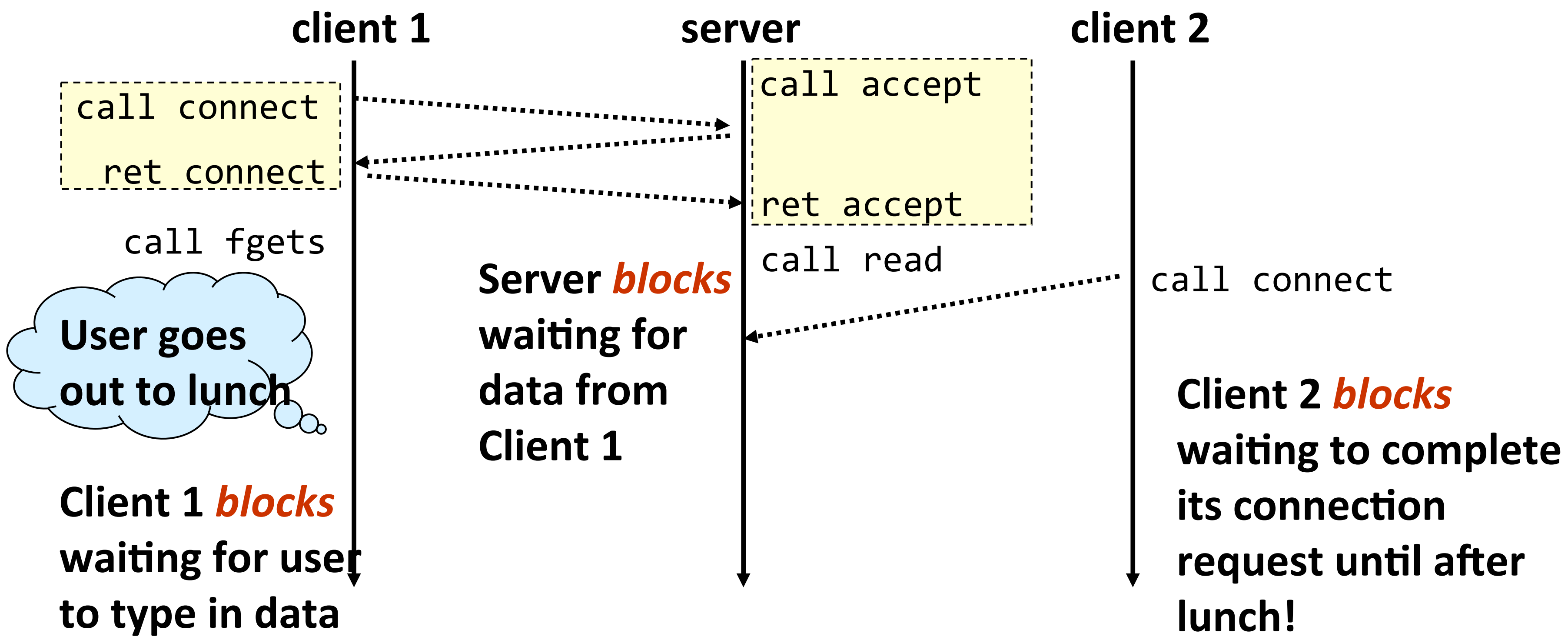
```
int main (int argc, char *argv[]) {
   ...
   listenfd = socket(AF_INET, SOCK_STREAM, 0);

   bzero((char *)&saddr, sizeof(saddr));
   saddr.sin_family = AF_INET;
   saddr.sin_addr.s_addr = htonl(INADDR_ANY);
   saddr.sin_port = htons(port);
   bind(listenfd, (struct sockaddr *)&saddr, sizeof(saddr));

   listen(listenfd, 5);
   while (1) {
      connfd = accept(listenfd, (struct sockaddr *)&caddr, &clen);
      while ((n = read(connfd, buf, MAXLINE)) > 0) {
         printf (“got %d bytes from client.\n”, n);
         write(connfd, buf, n);
      }
      close(connfd);
   }
}
```

# Iterative Model

- One request at a time



# Only One Client at a Time

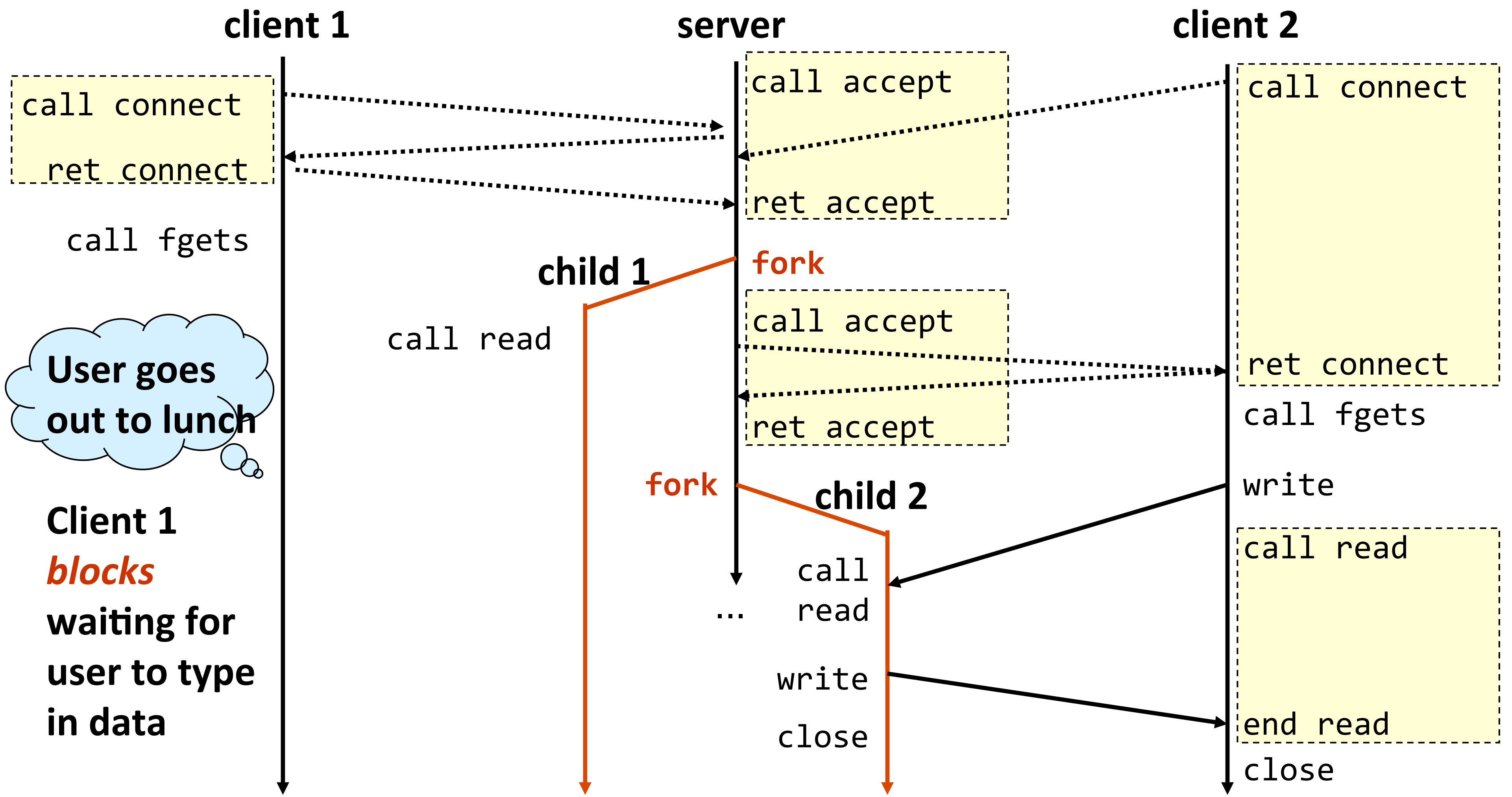



- Solution: use concurrent servers instead
  - Use multiple concurrent flows to serve multiple clients at the same time.

# Creating Concurrent Flows

- Processes
  - Kernel automatically interleaves multiple logical flows
  - Each flow has its own private address space
- I/O multiplexing with `select()`
  - User manually interleaves multiple logical flows
  - Each flow shares the same address space
  - Popular for high-performance server designs
- Threads
  - Kernel automatically interleaves multiple logical flows
  - Each flow shares the same address space
  - Hybrid of processes and I/O multiplexing

# Process-based Servers



# Echo Server

- Iterative version

```
int main (int argc, char *argv[])
{
   . . .

   while (1) {
      connfd = accept (listenfd, (struct sockaddr *)&caddr,
                       &caddrlen));

      while ((n = read(connfd, buf, MAXLINE)) > 0) {
         printf (“got %d bytes from client.\n”, n);
         write(connfd, buf, n);
      }

      close(connfd);
   }
}
```

# Echo Server: Process-based

```
int main (int argc, char *argv[])
{
   . . .
   signal (SIGCHLD, handler);

   while (1) {
      connfd = accept (listenfd, (struct sockaddr *)&caddr,
                                 &caddrlen));
      if (fork() == 0) {
         close(listenfd);
         while ((n = read(connfd, buf, MAXLINE)) > 0) {
            printf ("got %d bytes from client.\n", n);
            write(connfd, buf, n);
         }
         close(connfd);
         exit(0);
      }
      close(connfd);
   }
}
```

```
void handler(int sig) {
   pid_t pid;
   int stat;
   while ((pid = waitpid(-1, &stat,
                         WNOHANG)) > 0);
   return;
}
```

# Implementation Issues

- Servers should restart accept() if it is interrupted by a transfer of control to SIGCHLD handler
  - Not necessary for systems with POSIX signal handling
  - Required for portability on some older Unix systems
- Server must reap zombie children
  - to avoid fatal memory leak
- Server must close its copy of connfd
  - Kernel keeps reference for each socket
  - After fork(), ref. count of connfd becomes 2
  - Connection will not be closed until ref. count becomes 0

# Process-based Designs

- Pros
  - Handles multiple connections concurrently
  - Easy to implement and clear to understand sharing model
  - Simple and straightforward
- Cons
  - Additional overhead for process control
    - Process creation and termination
    - Process switching
  - Nontrivial to share data between processes
    - Requires IPC (Inter-Process Communication) mechanisms
      - FIFO, shared memory and semaphores

# I/O Multiplexing

- Event-based concurrent servers
  - Maintain a pool of connected descriptors
  - Repeat followings forever
    - Use select() system call to block until
      - (a) New connection request arrives on the listening descriptor
      - (b) New data arrives on an existing connected descriptor
    - If (a), add new connection to connection descriptor pool
    - If (b), read any available data from connection
      - Close connection on EOF and remove it from pool.
  - I/O multiplexing provides more control with less overhead

# Select on Sockets

- Prototype

```
#include <sys/select.h>
int select(int nfds, fd_set *readfds, fd_set *writefds,
           fd_set *exceptfds, struct timeval *timeout);
```

- select() returns number of FDs contained in the three returned descriptor sets
- select() blocks for timeout waiting for a file descriptor to become ready
- FDs in readfds will be tested whether they have something to read
- FDs in writefds will be tested whether they are available for writing

# Select on Sockets

- FDs in `exceptfds` will be watched for exceptions
- Three given FD sets will be changed accordingly
  - Only FDs in ready will be included in the result sets

# Macros for FD Sets

- Macros for manipulating set descriptors
  - void FD_ZERO (fd_set *fdset)
    - Turn off all bits in fdset
  - void FD_SET (int fd, fd_set *fdset)
    - Turn on bit fd in fdset
  - void FD_CLR (int fd, fd_set *fdset)
    - Turn off bit fd in fdset
  - int FD_ISSET (int fd, fd_set *fdset)
    - Is bit fd in fdset turned on?

# Echo Server: Event-based (1)

```
typedef struct {
   int   maxfd;          // largest descriptor in read_set
   int   nready;         // number of ready desc. from select
   fd_set read_set;      // set of all active descriptors
   fd_set ready_set;     // subset of desc. ready for reading
} pool;

int main (int argc, char *argv[])
{
   int listenfd, connfd, val;
   pool p;

   ...
   listenfd = ...                   // socket(), bind(), listen()

   // initialize pool
   p.maxfd = listenfd;
   FD_ZERO(&p.read_set);
   FD_SET(listenfd, &p.read_set);
```

# Echo Server: Event-based (2)

```
   while (1) {
      p.ready_set = p.read_set;
      p.nready = select(p.maxfd+1, &p.ready_set, NULL, NULL, NULL);

      if (FD_ISSET(listenfd, &p.ready_set)) {
         connfd = accept (listenfd, (struct sockaddr *)&caddr,
                          &caddrlen));
         FD_SET(connfd, &p.read_set);
         if (connfd > p.maxfd) p.maxfd = connfd;
         p.nready--;

      }
      check_clients (listenfd, &p);
   }

}
```

# Echo Server: Event-based (3)

```
void check_clients (int listenfd, pool *p) {
   int s, n;
   char buf[MAXLINE];
   for (s = 0; s < p->maxfd+1 && p->nready > 0; s++) {
      if (s == listenfd) continue;
      if (FD_ISSET(s, &p->read_set) && FD_ISSET(s, &p->ready_set)) {
         p->nready--;
         if ((n = read(s, buf, MAXLINE)) > 0)
            write(s, buf, n);
         if (n == 0) {                 // EOF
            close(s);
            FD_CLR(s, &p->read_set);
            if (s == p->maxfd) {
               p->maxfd--;
               while (!FD_ISSET(p->maxfd, &p->read_set)) p->maxfd--;
            }
         }
      }
   }
}
```

# Event-based Designs

- Pros
  - One logical control flow
  - Can single-step with a debugger
  - No process or thread control overhead
    - Design of choice for high-performance Web servers and search engines
- Cons
  - Significantly more complex to code than process- or thread-based designs
  - Can be vulnerable to Denial-of-Service attack