# 第12章 并发编程

## 并发编程 Concurrent Programming

100076202： 计算机系统导论

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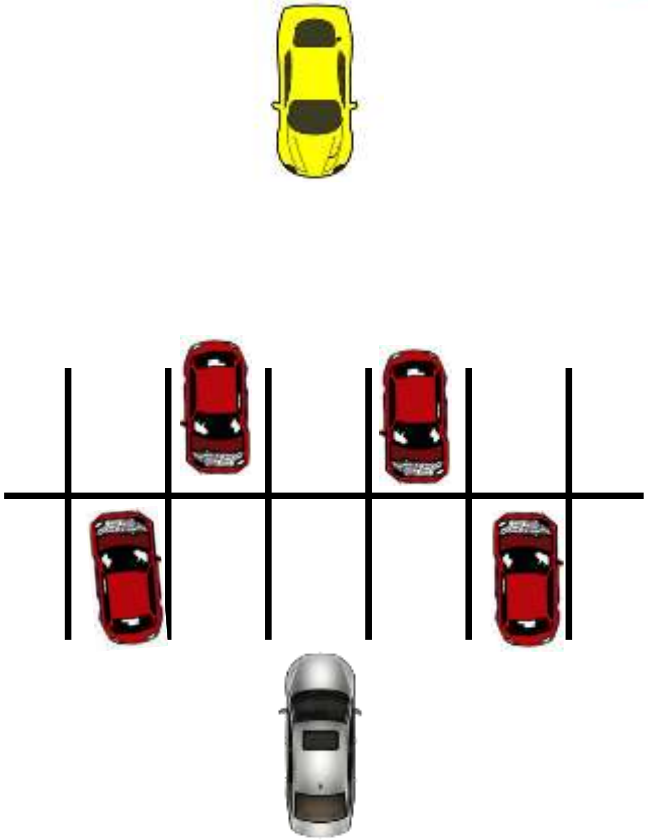
# 并发编程很难！
# Concurrent Programming is Hard!

- 人类的思维往往是顺序的 **The human mind tends to be sequential**

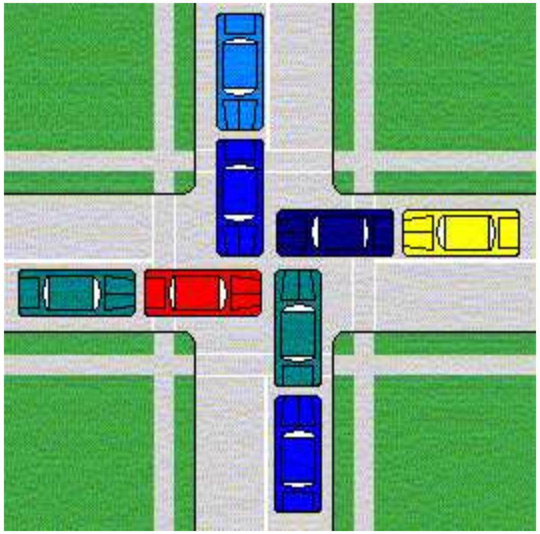
- 时间的概念常常误导人 **The notion of time is often misleading**

- 考虑计算机系统中所有可能的事件顺序非常容易出错，而且经常是不可能的 **Thinking about all possible sequences of events in a computer system is at least error prone and frequently impossible**

# 数据竞争 Data Race



# 死锁 Deadlock

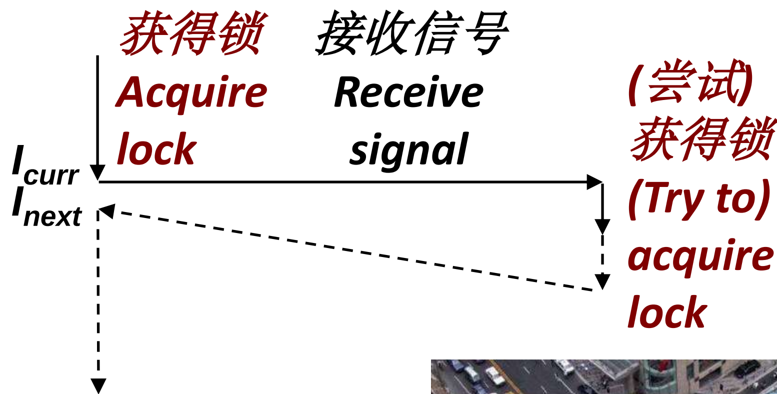


# 死锁 Deadlock

- 信号处理程序示例 **Example from signal handlers.**
- 为什么不在处理程序中使用printf？ **Why don’t we use printf in handlers?**

```
void catch_child(int signo) {
    printf("Child exited!\n"); // this call may reenter printf/puts! BAD! DEADLOCK!
    while (waitpid(-1, NULL, WNOHANG) > 0) continue; // reap all children
}
```

- **Printf代码： Printf code:**
  - 获得锁 Acquire lock
  - 做工作 Do something
  - 释放锁 Release lock

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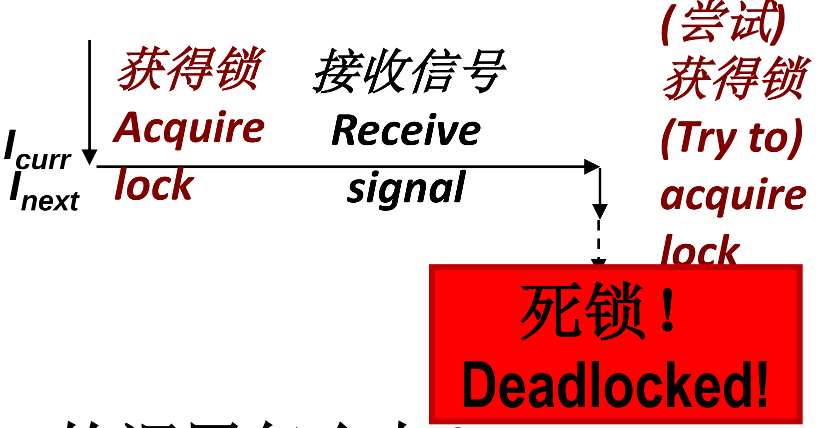



- 如果信号处理程序中断对printf的调用怎么办？ **What if signal handler interrupts call to printf?**

# 测试printf死锁 Testing Printf Deadlock

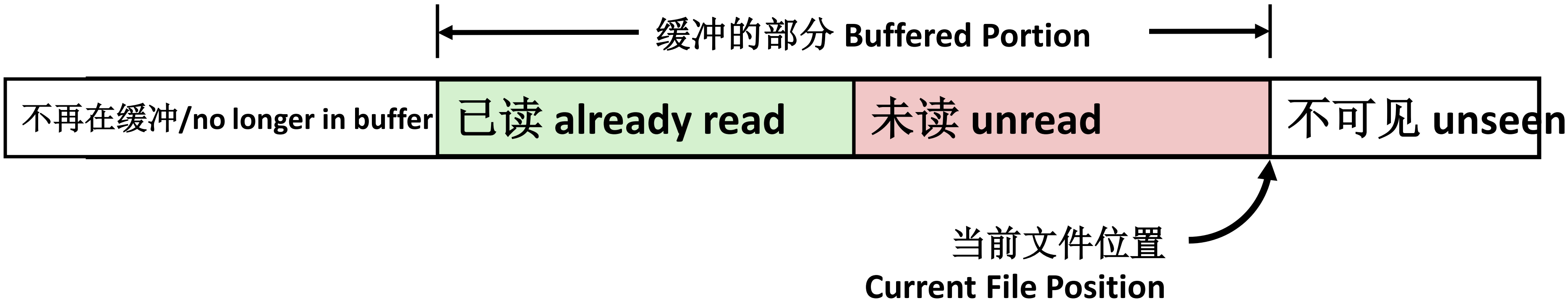
```
void catch_child(int signo) {
   printf("Child exited!\n"); // this call may reenter printf/puts! BAD!  DEADLOCK!
   while (waitpid(-1, NULL, WNOHANG) > 0) continue; // reap all children
}

int main(int argc, char** argv) {
  ...
  for (i = 0; i < 1000000; i++) {
    if (fork() == 0) {
      // in child, exit immediately
      exit(0);
    }
    // in parent
    sprintf(buf, "Child #%d started\n", i);
    printf("%s", buf);
  }
  return 0;
}
```

```
Child #0 started
Child #1 started
Child #2 started
Child #3 started
Child exited!
Child #4 started
Child exited!
Child #5 started
   .
   .
   .
Child #5888 started
Child #5889 started
```

# 为何printf需要锁？
# Why Does Printf require Locks?

- **Printf (和fprintf、sprintf)实现带缓冲的输入/输出 Printf (and fprintf, sprintf) implement *buffered* I/O**

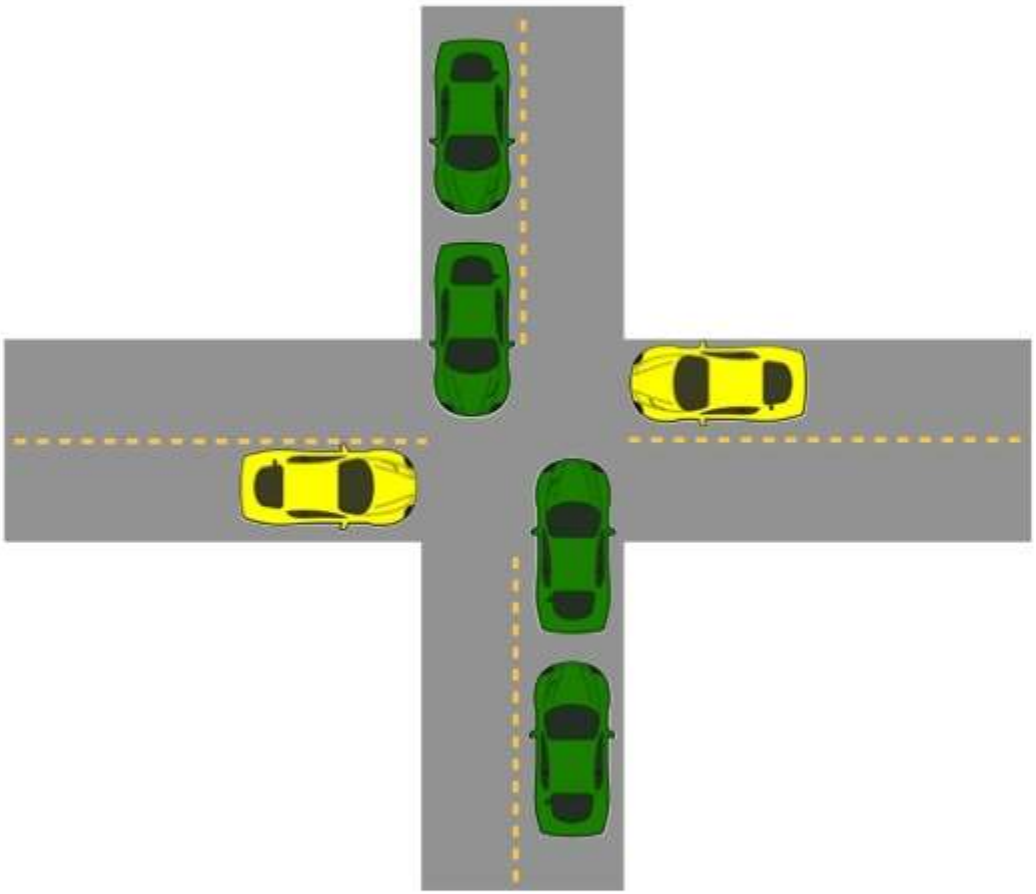



- **需要锁以访问该共享缓冲区 Require locks to access the shared buffers**

# 活锁 Livelock

# 活锁 Livelock

# 饿死 Starvation



- 黄色车必须让位给绿色车 **Yellow must yield to green**
- 源源不断的绿色汽车 **Continuous stream of green cars**
- 整个系统取得了进展，但有些个体无限期地等待 **Overall system makes progress, but some individuals wait indefinitely**

# 并发编程很难！
# Concurrent Programming is Hard!

- 并发程序的经典问题类： **Classical problem classes of concurrent programs:**
  - **竞争**：结果取决于系统其他地方的任意调度决策 ***Races:*** outcome depends on arbitrary scheduling decisions elsewhere in the system
    - 示例：谁坐飞机上的最后一个座位？ Example: who gets the last seat on the airplane?
  - **死锁**：资源分配不当阻碍前进 ***Deadlock:*** improper resource allocation prevents forward progress
    - 示例：交通堵塞 Example: traffic gridlock
  - 活锁/饥饿/公平：外部事件和/或系统调度决策可能会阻止子任务进度 ***Livelock / Starvation / Fairness***: external events and/or system scheduling decisions can prevent sub-task progress
    - 例如：有人总是跳到你前面排队 Example: people always jump in front of you in line

# 并发编程很难！
# Concurrent Programming is Hard!

- 并发编程的许多方面超出了我们课程的范围。。 **Many aspects of concurrent programming are beyond the scope of our course..**
  - 但并非所有 but, not all ☺
  - 我们将在接下来的几节课中讨论这些方面 We'll cover some of these aspects in the next few lectures.

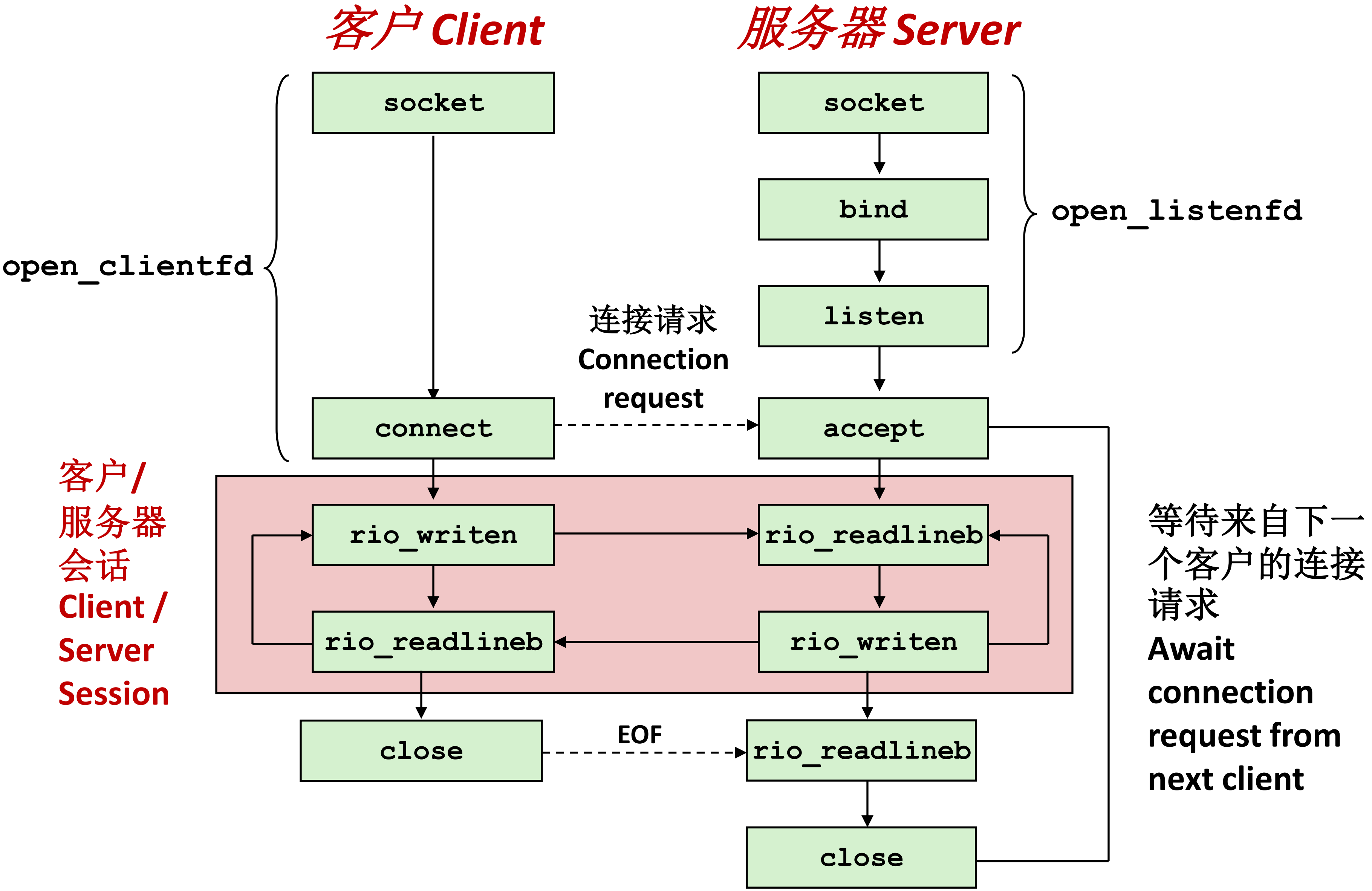
# 并发编程很难！
# Concurrent Programming is Hard!

它可能很难，但… **It may be hard, but …**

它可能是有用的，有时也是必要的！ **it can be useful and sometimes necessary!**

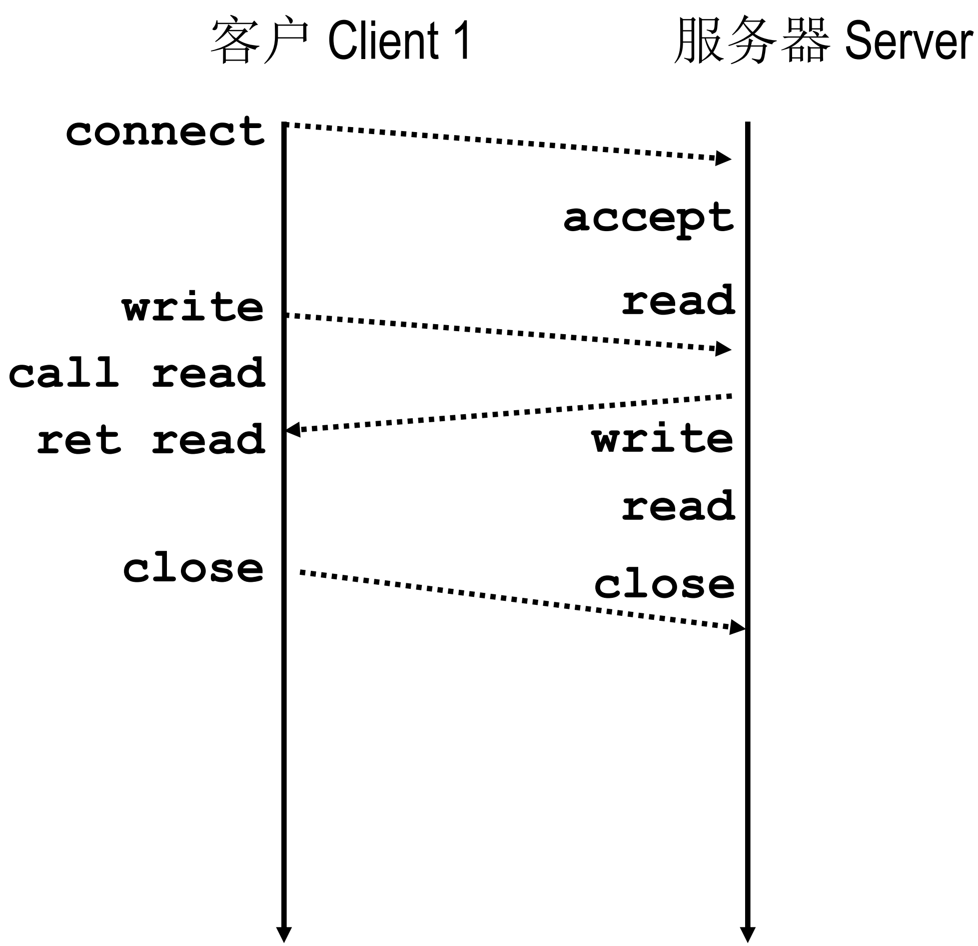
越来越有必要 **more and more necessary!**

# 提醒：迭代式回声服务器
# Reminder: Iterative Echo Server



# 迭代服务器 Iterative Servers

- 迭代服务器一次处理一个请求 Iterative servers process one request at a time



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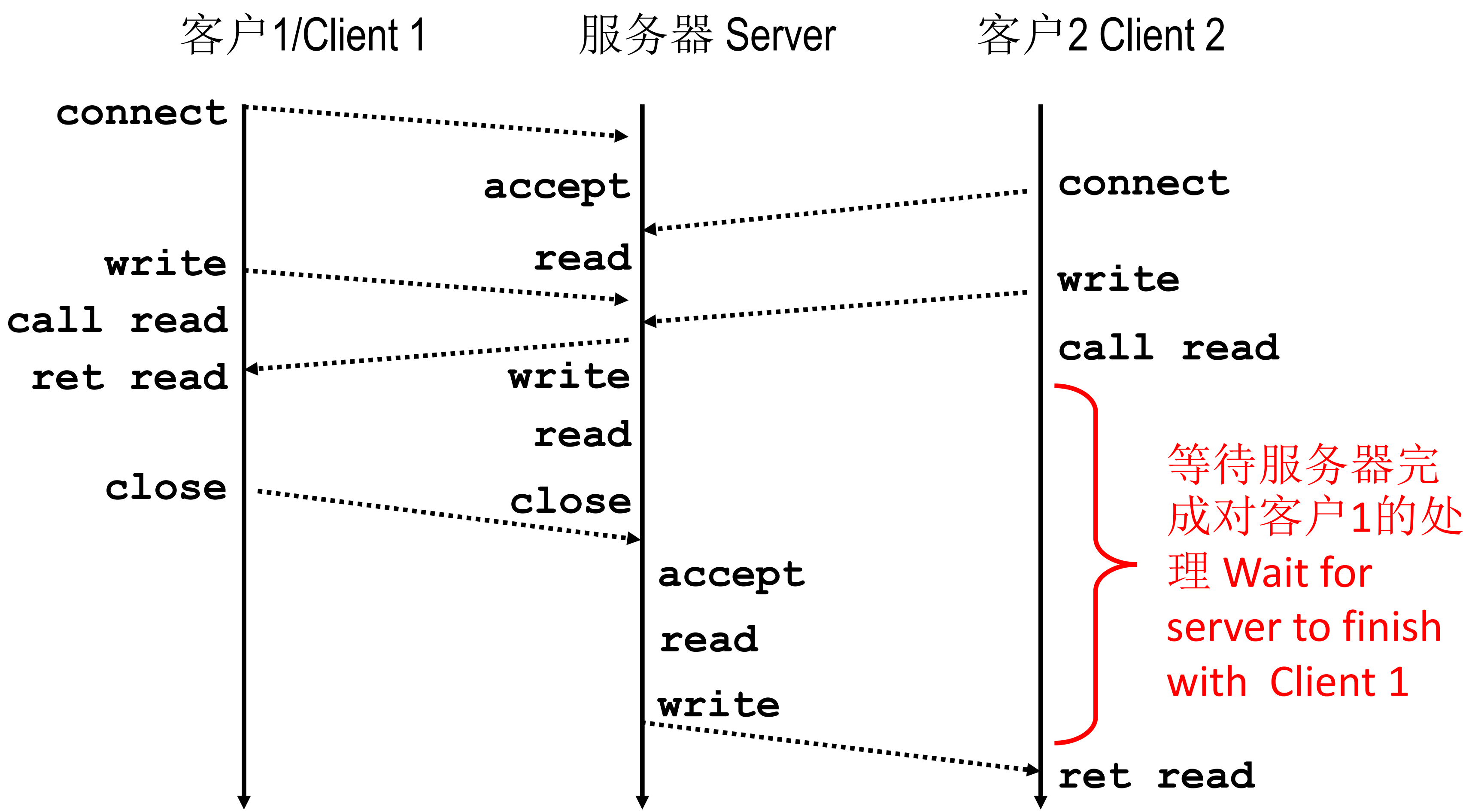
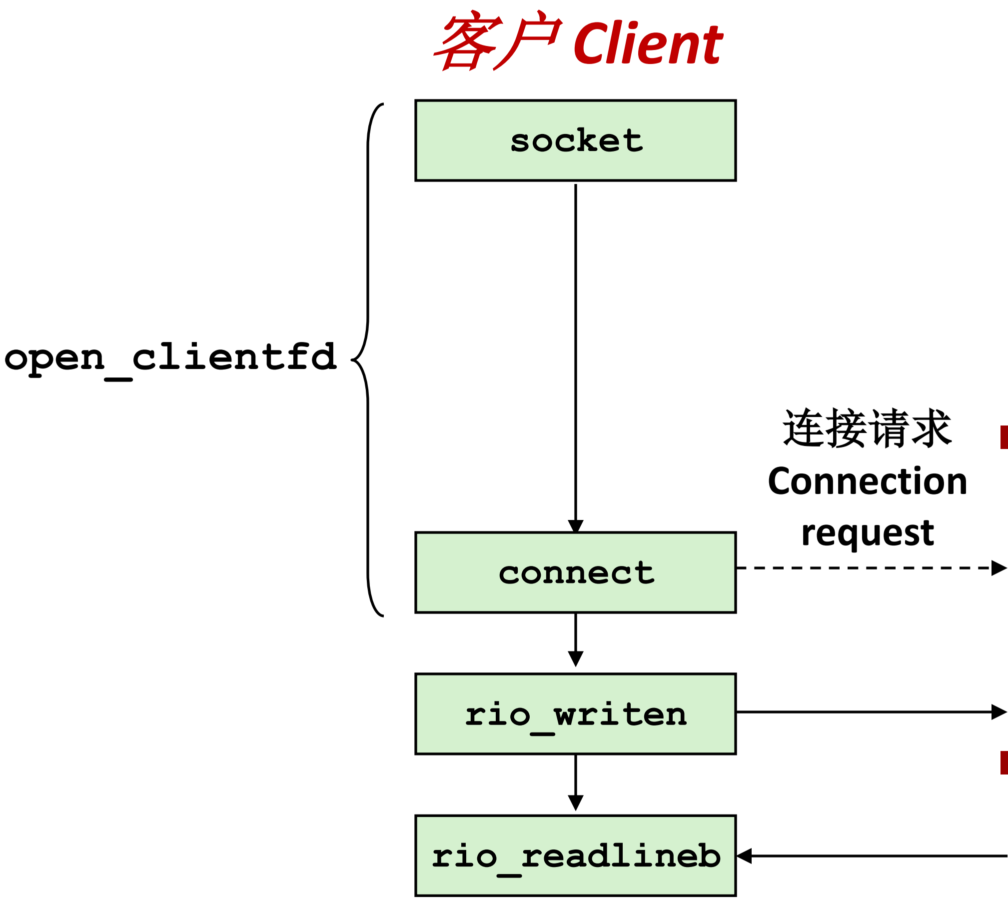


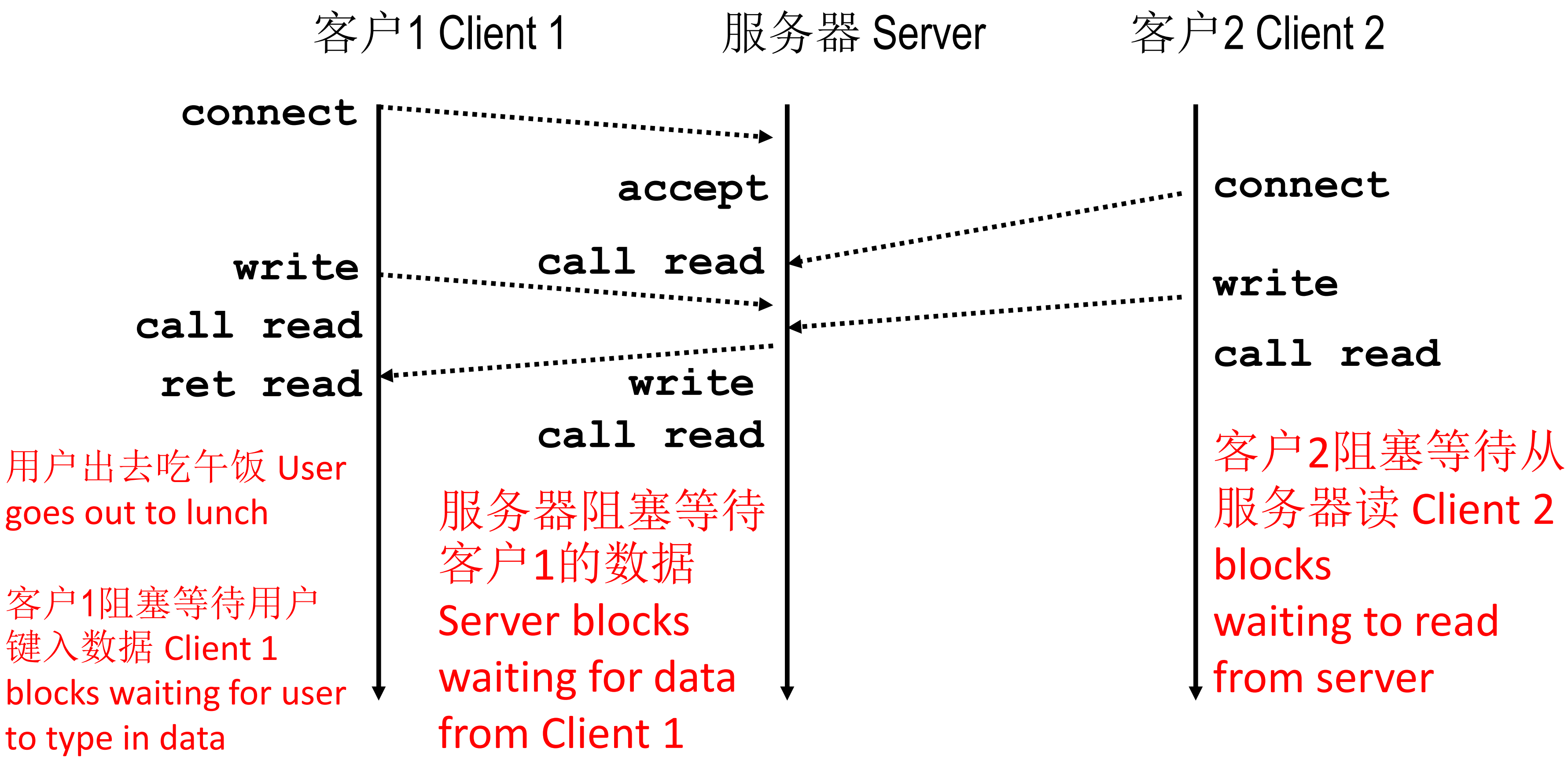
# 第二个客户阻塞在哪里？
# Where Does Second Client Block?

- 第二个客户尝试连接到迭代服务器 **Second client attempts to connect to iterative server**




- **connect调用返回 Call to connect returns**
  - 尽管连接还没有被接受 Even though connection not yet accepted
  - 服务器端TCP管理器对请求进行排队 Server side TCP manager queues request
  - 该功能称为“TCP侦听backlog” Feature known as “TCP listen backlog”
- **rio_writen调用返回 Call to rio_writen returns**
  - 服务器端TCP管理器缓冲输入数据 Server side TCP manager buffers input data
- **rio_readlineb调用阻塞 Call to rio_readlineb blocks**
  - 服务器没有写数据 Server hasn’t written anything for it to read yet.

# 迭代服务器的基本缺陷
# Fundamental Flaw of Iterative Servers




- 解决方案：使用并发服务器 **Solution: use *concurrent servers* instead**
  - 并发服务器使用多个并发流同时为多个客户端提供服务 Concurrent servers use multiple concurrent flows to serve multiple clients at the same time

# 编写并发服务器的方法 Approaches for Writing Concurrent Servers

允许服务器并发处理多个客户 Allow server to handle multiple clients concurrently

## 1. 基于进程 Process-based

- 内核自动交错多个逻辑流 Kernel automatically interleaves multiple logical flows
- 每个流都有自己的私有地址空间 Each flow has its own private address space

## 2. 基于事件 Event-based

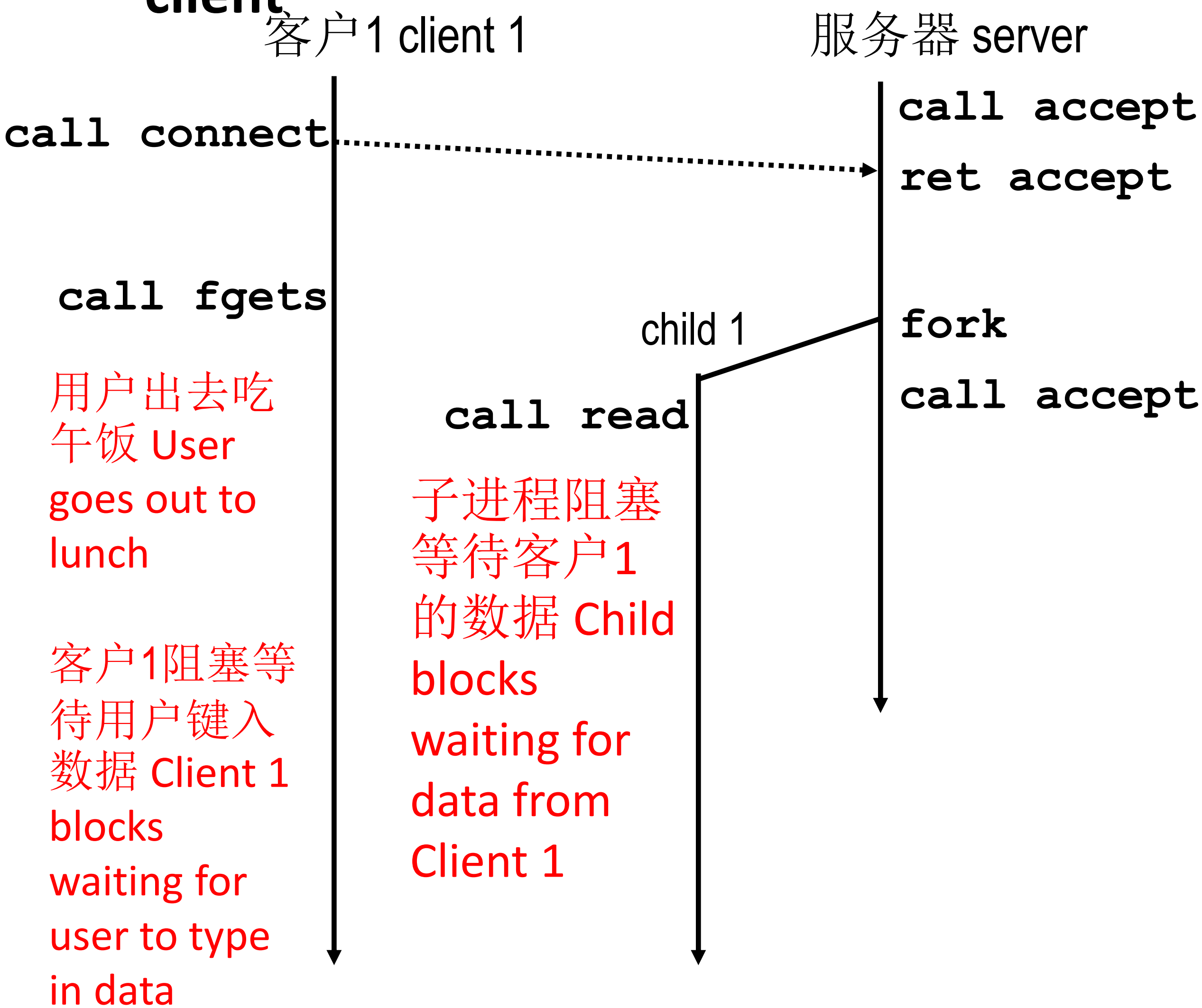
- 程序员人工交错多个逻辑流 Programmer manually interleaves multiple logical flows
- 所有流共享相同的地址空间 All flows share the same address space
- 使用称为*I/O多路复用*的技术 Uses technique called *I/O multiplexing*

## 3. 基于线程 Thread-based

- 内核自动交错多个逻辑流 Kernel automatically interleaves multiple logical flows
- 每个流共享相同的地址空间 Each flow shares the same address space
- 基于进程和基于事件两种方法的混合 Hybrid of of process-based and event-based

# 方法#1：基于进程的服务器
# Approach #1: Process-based Servers

- 为每个客户生成单独的进程 **Spawn separate process for each client**



# 方法#1：基于进程的服务器
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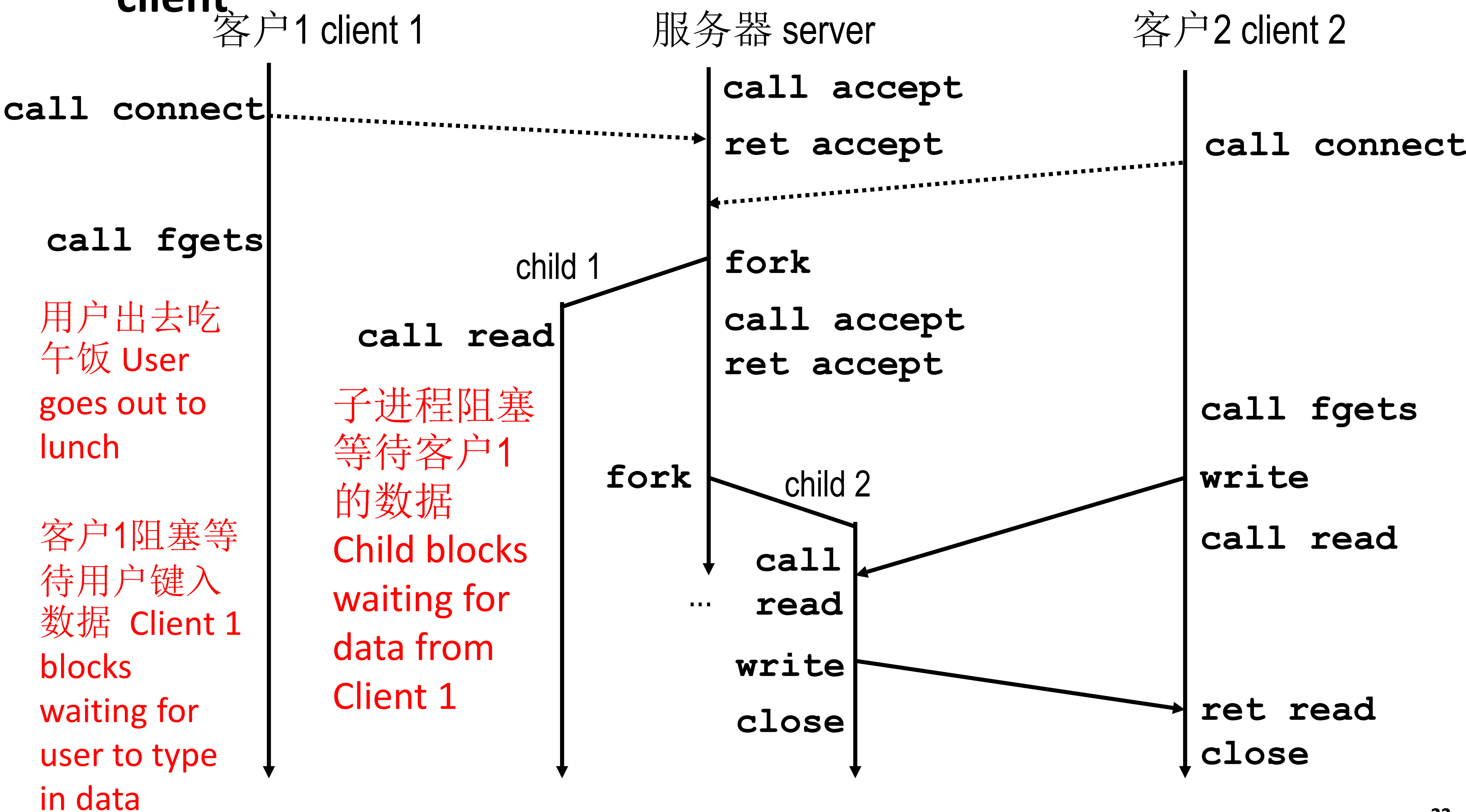

# 迭代式回声服务器 Iterative Echo Server

```
int main(int argc, char **argv)
{
    int listenfd, connfd;
    socklen_t clientlen;
    struct sockaddr_storage clientaddr;


    listenfd = Open_listenfd(argv[1]);
    while (1) {
        clientlen = sizeof(struct sockaddr_storage);
        connfd = Accept(listenfd, (SA *) &clientaddr, &clientlen);
        echo(connfd);
        Close(connfd);
     }
     exit(0);
}
```

- 接受一个连接请求 Accept a connection request
- 处理回声请求直到客户终止 Handle echo requests until client terminates

echoserverp.c

# 制作并发回声服务器
# Making a Concurrent Echo Server

```
int main(int argc, char **argv)
{
    int listenfd, connfd;
    socklen_t clientlen;
    struct sockaddr_storage clientaddr;


    listenfd = Open_listenfd(argv[1]);
    while (1) {
        clientlen = sizeof(struct sockaddr_storage);
        connfd = Accept(listenfd, (SA *) &clientaddr, &clientlen);


            echo(connfd);    /* Child services client */
            Close(connfd);  /* child closes connection with client */
            exit(0);



    }
}
```

echoserverp.c

# 制作并发回声服务器
# Making a Concurrent Echo Server

```
int main(int argc, char **argv)
{
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    listenfd = Open_listenfd(argv[1]);
    while (1) {
        clientlen = sizeof(struct sockaddr_storage);
        connfd = Accept(listenfd, (SA *) &clientaddr, &clientlen);
        if (Fork() == 0) {

            echo(connfd);     /* Child services client */
            Close(connfd);    /* Child closes connection with client */
            exit(0);          /* Child exits */
        }

    }
}
```

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            echo(connfd);     /* Child services client */
            Close(connfd);    /* Child closes connection with client */
            exit(0);          /* Child exits */
        }
        Close(connfd); /* Parent closes connected socket (important!) */
    }
}
```

echoserverp.c

为何？ Why?

# 制作并发回声服务器
# Making a Concurrent Echo Server

```
int main(int argc, char **argv)
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    listenfd = Open_listenfd(argv[1]);
    while (1) {
        clientlen = sizeof(struct sockaddr_storage);
        connfd = Accept(listenfd, (SA *) &clientaddr, &clientlen);
        if (Fork() == 0) {
            Close(listenfd); /* Child closes its listening socket */
            echo(connfd);    /* Child services client */
            Close(connfd);   /* Child closes connection with client */
            exit(0);         /* Child exits */
        }
        Close(connfd); /* Parent closes connected socket (important!) */
    }
}
```

echoserverp.c

# 基于进程的并发回声服务器
# Process-Based Concurrent Echo Server

```
int main(int argc, char **argv)
{
    int listenfd, connfd;
    socklen_t clientlen;
    struct sockaddr_storage clientaddr;

    Signal(SIGCHLD, sigchld_handler);
    listenfd = Open_listenfd(argv[1]);
    while (1) {
        clientlen = sizeof(struct sockaddr_storage);
        connfd = Accept(listenfd, (SA *) &clientaddr, &clientlen);
        if (Fork() == 0) {
            Close(listenfd); /* Child closes its listening socket */
            echo(connfd);    /* Child services client */
            Close(connfd);   /* Child closes connection with client */
            exit(0);         /* Child exits */
        }
        Close(connfd); /* Parent closes connected socket (important!) */
    }
}
```

echoserverp.c

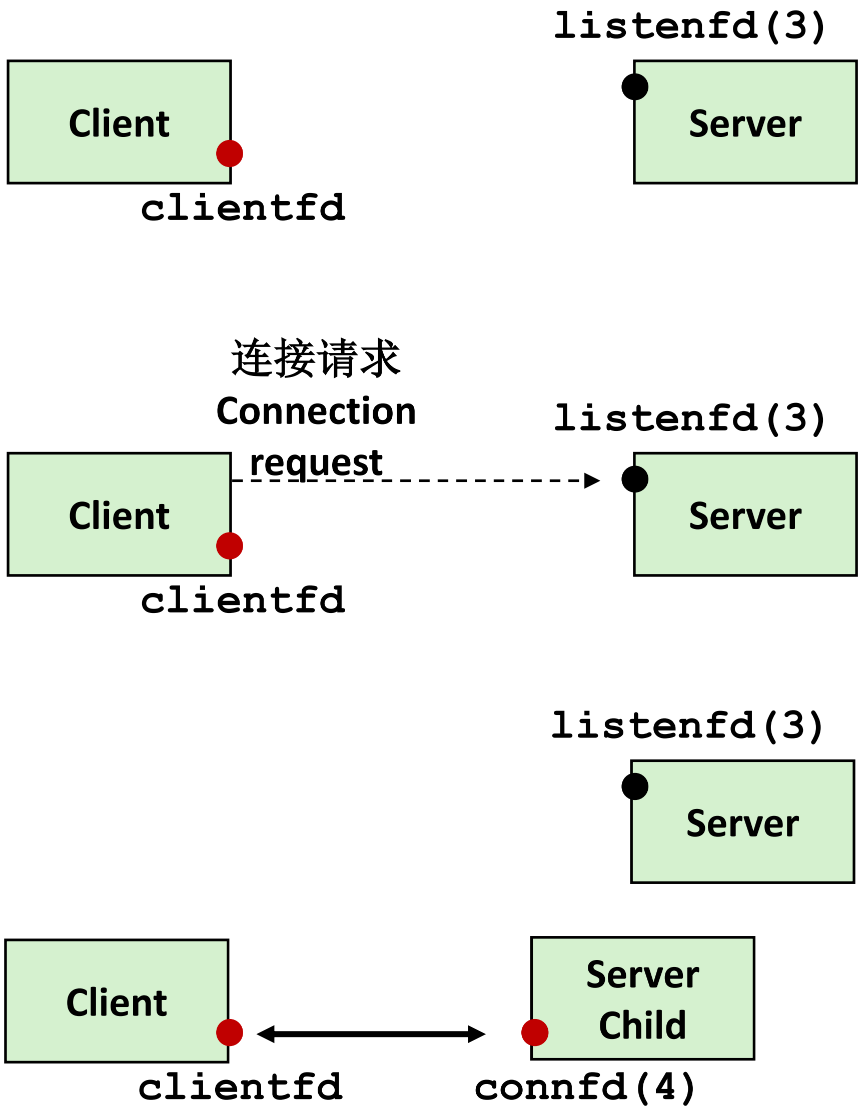
# 基于进程的并发回声服务器（续） Process-Based Concurrent Echo Server (cont)

```
void sigchld_handler(int sig)
{
    while (waitpid(-1, 0, WNOHANG) > 0)
        ;
    return;
}
```

echoserverp.c

- 回收所有的僵尸子进程 Reap all zombie children

# 并发服务器：accept揭秘
# Concurrent Server: `accept` Illustrated




*1.服务器阻塞在accept，等待侦听描述符listenfd上的连接请求*

***1. Server blocks in `accept`, waiting for connection request on listening descriptor `listenfd`***

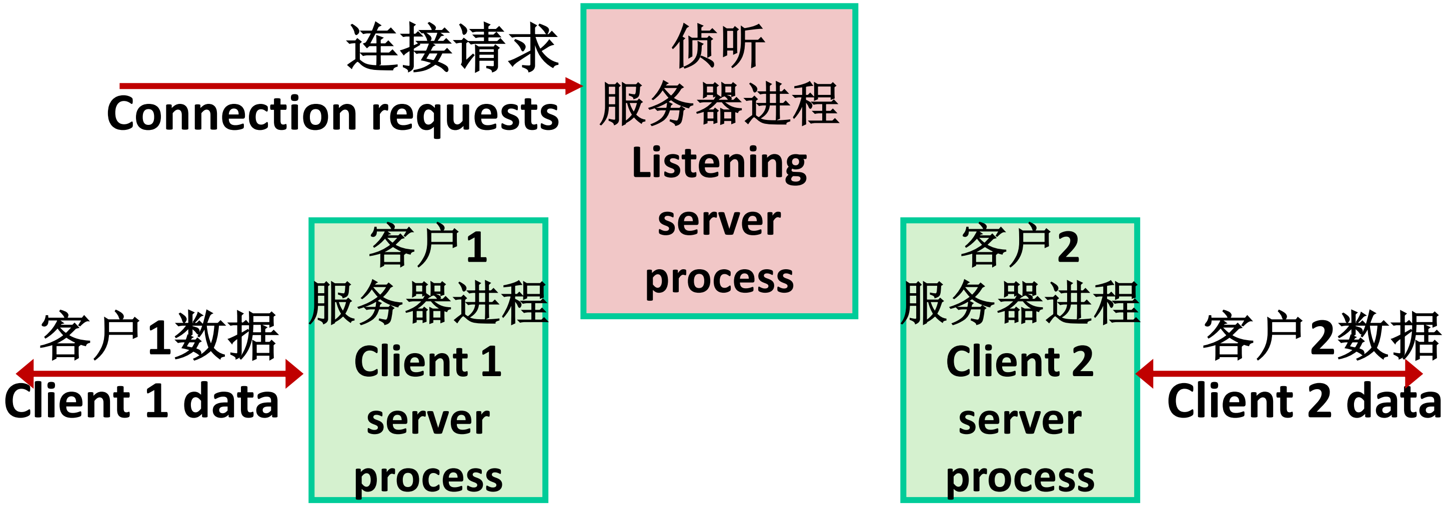
*2.客户端通过调用connect发出连接请求*

***2. Client makes connection request by calling `connect`***

*3.服务器从accept返回connfd。创建子进程以处理客户端。现在已在clientfd和connfd之间建立连接*

***3. Server returns `connfd` from `accept`. Forks child to handle client. Connection is now established between `clientfd` and `connfd`***

# 基于进程的服务器执行模型 Process-based Server Execution Model




- 每个客户端由独立的子进程处理 Each client handled by independent child process
- 它们之间没有共享状态 No shared state between them
- 父子进程都有listenfd和connfd的副本 Both parent & child have copies of listenfd and connfd
  - 父进程必须关闭connfd Parent must close `connfd`
  - 子进程应关闭listenfd Child should close `listenfd`

# 基于进程的服务器的问题
# Issues with Process-based Servers

- 侦听服务器进程必须回收僵尸子进程 **Listening server process must reap zombie children**
  - 以避免致命的内存泄漏 to avoid fatal memory leak

```
int main(int argc, char **argv)
{
    int listenfd, connfd;
    socklen_t clientlen;
    struct sockaddr_stor[illegible]entadd[illegible]

    listenfd = Open_lis[illegible]d([illegible]1]);
    while (1) {
        clientlen = siz[illegible]struc[illegible]ad[illegible]orage);
        connfd = Accept[illegible]tenfd, [illegible]ientaddr, &clientlen);
        if (Fork() == 0)[illegible]
            echo(connfd); [illegible]Chi[illegible]ces client */
            Close(connfd); [illegible]oses connection with clien
            exit(0);         /[illegible] exits */
        }
```

# 基于进程的服务器的问题
# Issues with Process-based Servers

- 父进程必须关闭其connfd副本 **Parent process must `close` its copy of `connfd`**
  - 内核保持每个套接字/打开文件的引用计数 Kernel keeps reference count for each socket/open file
  - 创建进程后，connfd引用计数为2 After fork, **`refcnt(connfd)=2`**
  - 在connfd引用计数为0之前，连接不会关闭 Connection will not be closed until **`refcnt(connfd) = 0`**

```
int main(int argc, char **argv)
{
    int listenfd, connfd;
    socklen_t clientlen;
    struct sockaddr_stor        entadd

    listenfd = Open_lis      d(      1]);
    while (1) {
        clientlen = siz    struc      ade     orage);
        connfd = Accept    tenfd,      ientaddr, &clientlen);
        if (Fork() == 0)
            echo(connfd);         Chi      ces client */
            Close(connfd);              oses connection with clien
            exit(0);              /     exits */
        }
```

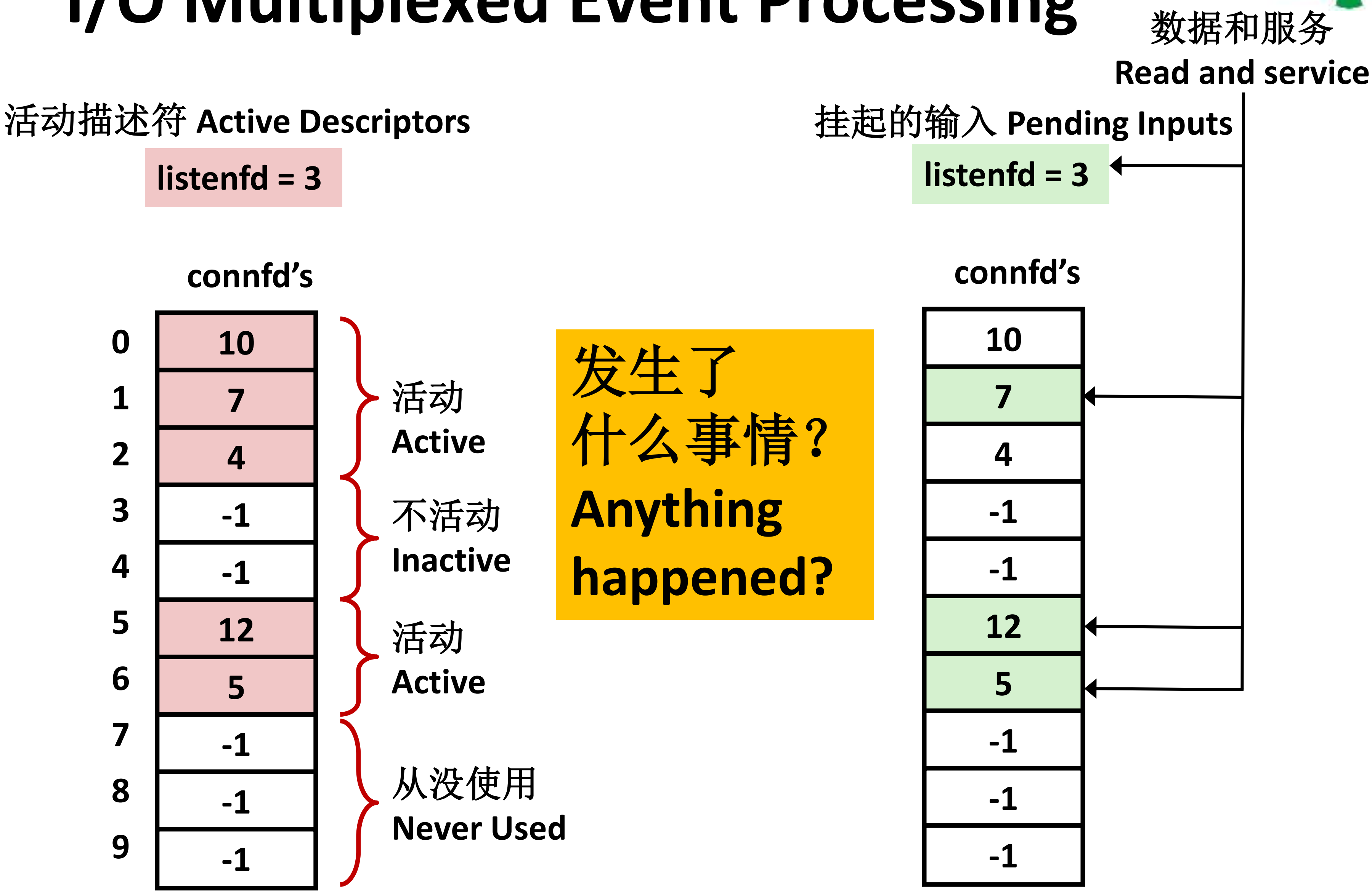
# 基于进程的服务器优点和缺点
# Pros and Cons of Process-based Servers

- + 并发处理多个连接 **Handle multiple connections concurrently**
- + 清晰的共享模型 **Clean sharing model**
  - 描述符（否）descriptors (no)
  - 文件表（是）file tables (yes)
  - 全局变量（否）global variables (no)
- + 简单直接 **Simple and straightforward**
- – 额外的进程控制开销 **Additional overhead for process control**
- – 进程之间共享数据并不简单 **Nontrivial to share data between processes**
  - (前面举的例子太过简单并不能说明问题 This example too simple to demonstrate)

# 方法#2：基于事件的服务器
# Approach #2: Event-based Servers

- 服务器维护活动连接集合 **Server maintains set of active connections**
  - connfd数组 Array of connfd's
- 重复： **Repeat:**
  - 确定哪些描述符（connfd或listenfd）具有挂起的输入 Determine which descriptors (`connfd`'s or `listenfd`) have pending inputs
    - 例如：使用**select**函数 e.g., using `select` function
    - 挂起输入的到达是一个事件 arrival of pending input is an *event*
  - 如果listenfd有输入，则**接受**连接 If listenfd has input, then `accept` connection
    - 并将新的connfd添加到数组 and add new connfd to array
  - 使用挂起的输入服务所有连接 Service all connfd's with pending inputs
- 详细信息参见教材中基于选择的服务器 **Details for select-based server in book**

# I/O多路复用事件处理
# I/O Multiplexed Event Processing



# 基于事件的服务器优点和缺点
# Pros and Cons of Event-based Servers

- **+ 一个逻辑控制流和地址空间 One logical control flow and address space.**
- **+ 可以用调试器进行单步跟踪 Can single-step with a debugger.**
- **+ 没有进程或线程控制开销 No process or thread control overhead.**
  - 成为高性能Web服务器和搜索引擎的设计选择，例如Node.js、nginx、Tornado Design of choice for high-performance Web servers and search engines. e.g., Node.js, nginx, Tornado

- **– 比基于进程或线程的设计代码要明显复杂很多 Significantly more complex to code than process- or thread-based designs.**
- **– 很难提供细粒度的并发 Hard to provide fine-grained concurrency**
  - 例如如何处理部分HTTP请求首部 E.g., how to deal with partial HTTP request headers
- **– 不能利用多核的优势 Cannot take advantage of multi-core**
  - 单一的控制线程 Single thread of control

# 方法#3：基于线程的服务器 Approach #3: Thread-based Servers

- 与方法#1（基于进程）非常相似 **Very similar to approach #1 (process-based)**
  - …但是使用线程代替进程 …but using threads instead of processes

# 传统进程视图 Traditional View of a Process

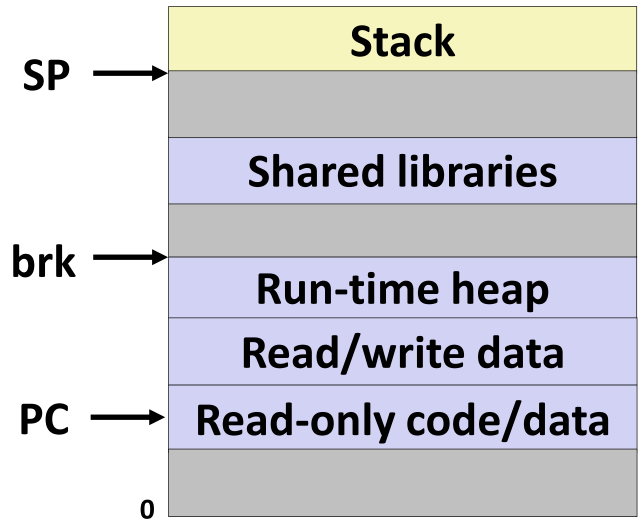
- 进程=进程上下文+代码、数据和栈 Process = process context + code, data, and stack

进程上下文
Process context

**Program context:**
- Data registers
- Condition codes
- Stack pointer (SP)
- Program counter (PC)

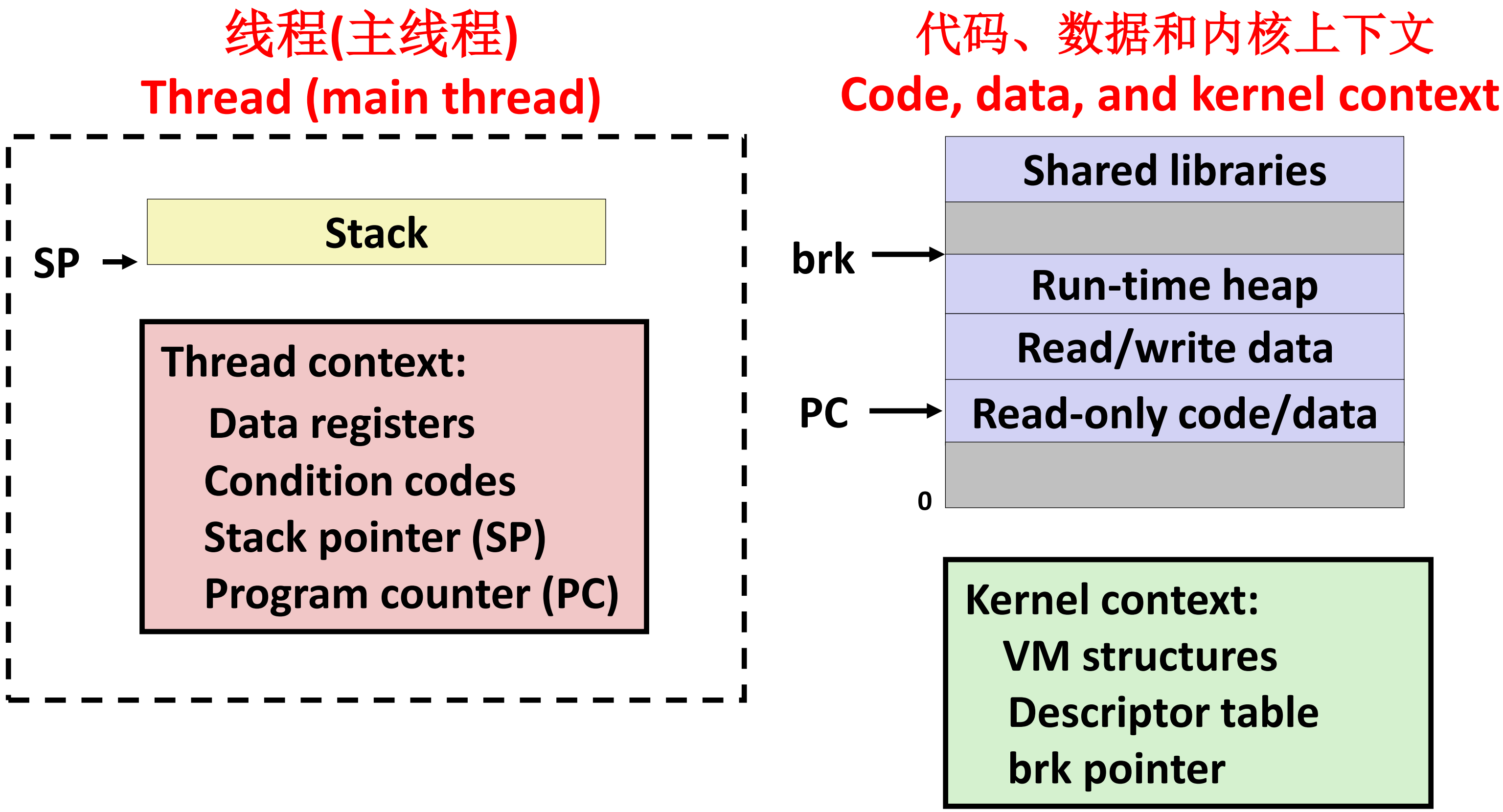
**Kernel context:**
- VM structures
- Descriptor table
- brk pointer

代码、数据和栈 Code, data, and stack



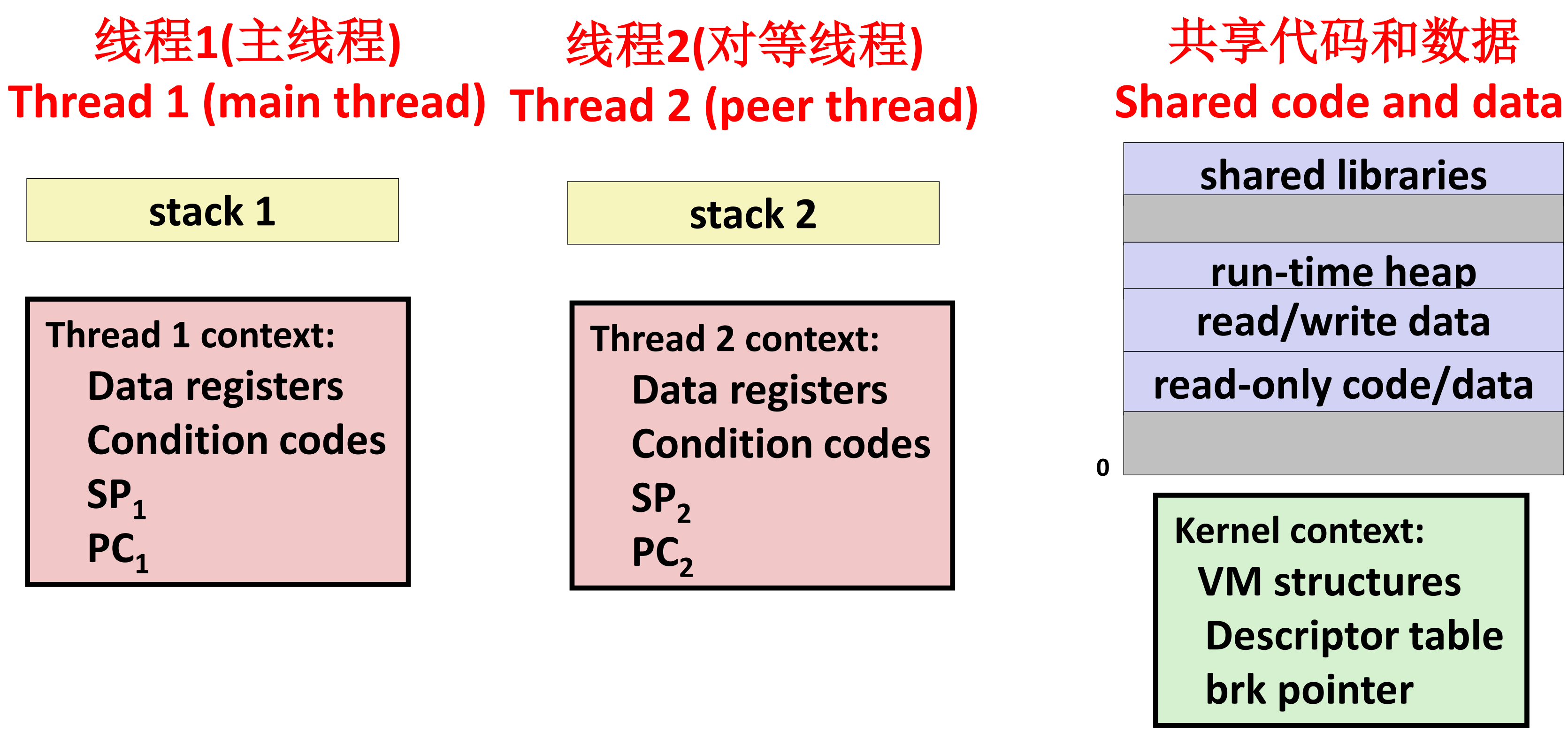
# 另一种进程视图 Alternate View of a Process

- 进程=线程+代码、数据和内核上下文 Process = thread + code, data, and kernel context



# 一个进程有多个线程-多线程进程
# A Process With Multiple Threads

- 多个线程可以与一个进程关联 **Multiple threads can be associated with a process**
  - 每个线程都有自己的逻辑控制流 Each thread has its own logical control flow
  - 每个线程共享相同的代码、数据和内核上下文 Each thread shares the same code, data, and kernel context
  - 每个线程都有自己的局部变量栈 Each thread has its own stack for local variables
    - 但不受其他线程的保护 but not protected from other threads
  - 每个线程都有自己的线程id（TID） Each thread has its own thread id (TID)

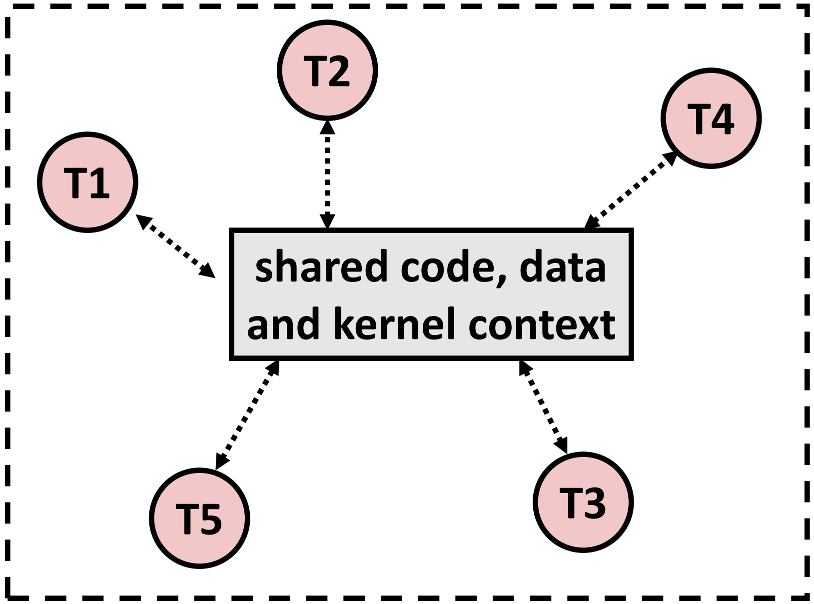


# 线程的逻辑视图 Logical View of Threads

- **与进程关联的线程形成对等线程池 Threads associated with process form a pool of peers**
  - 与进程形成层次树不同 Unlike processes which form a tree hierarchy

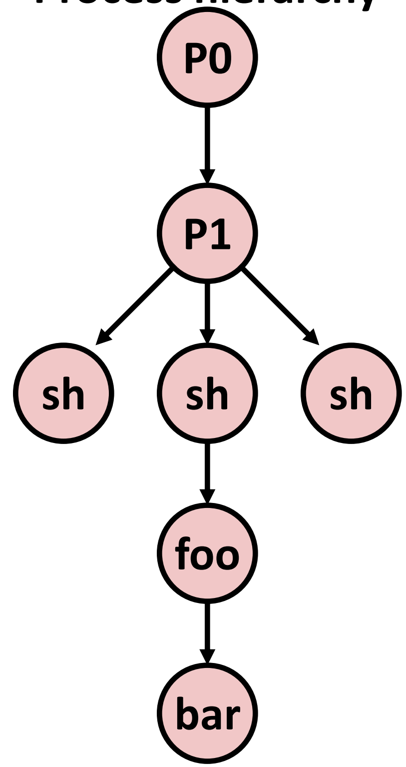
与进程foo关联的线程

**Threads associated with process foo**




进程层次结构

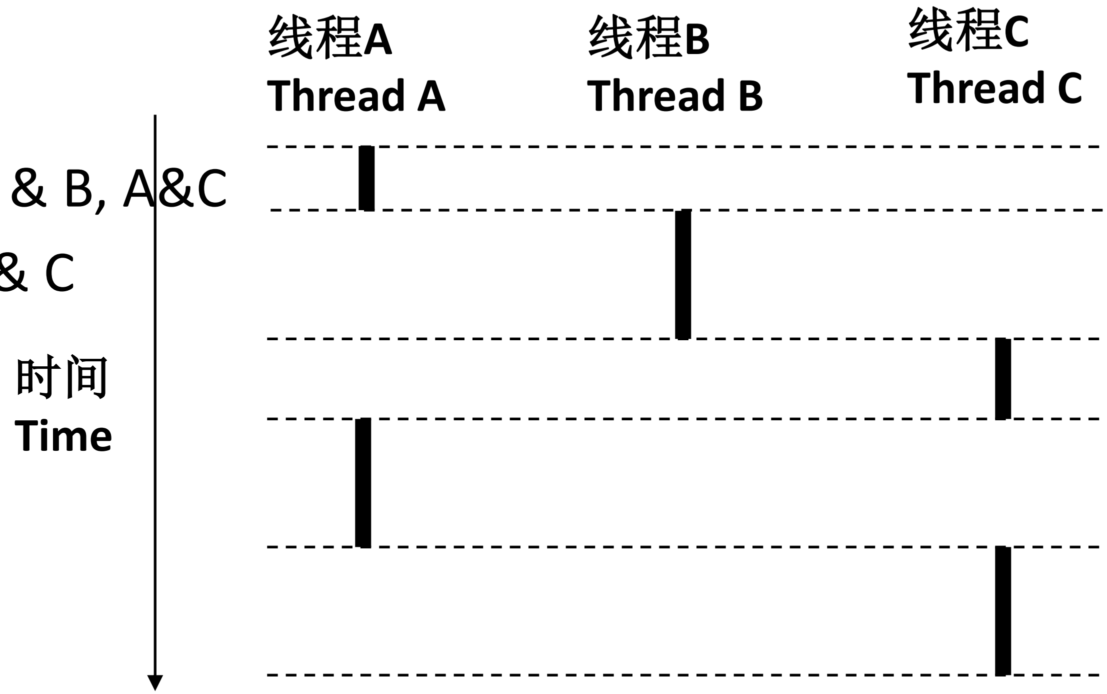
**Process hierarchy**



# 并发线程 Concurrent Threads

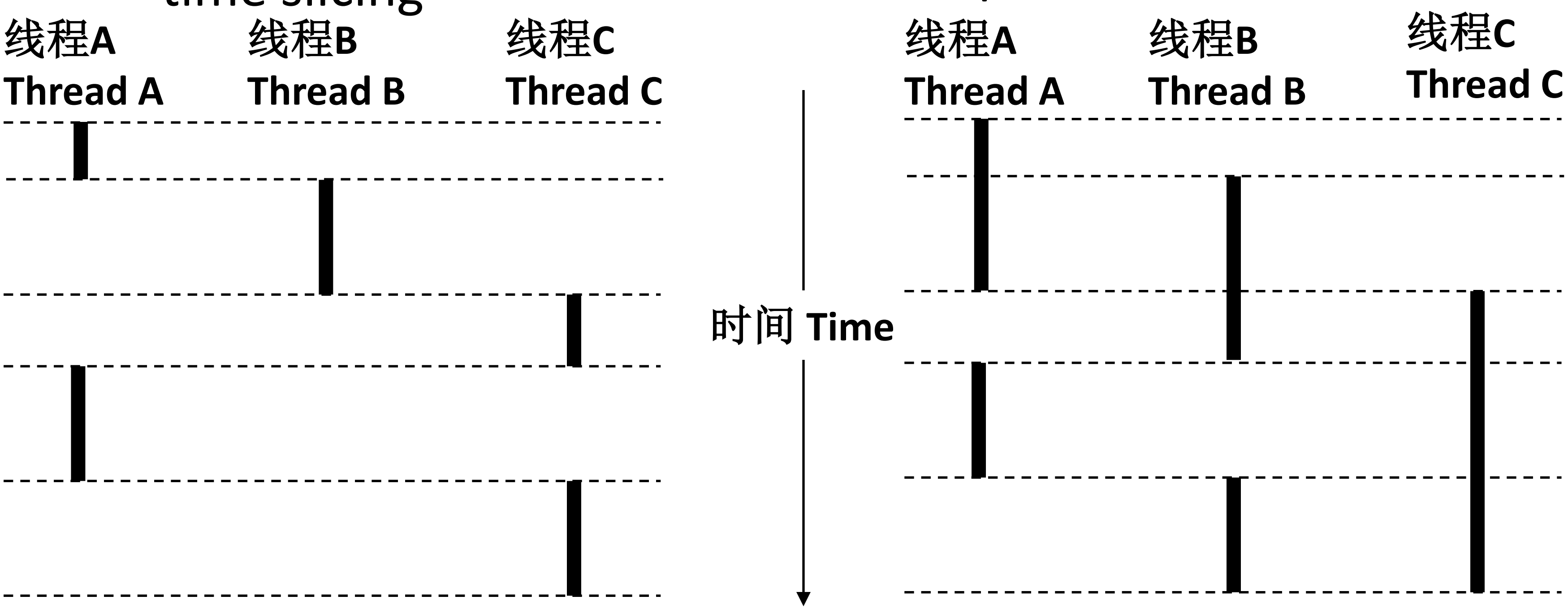
- 两个线程是并发的，如果它们的流程在时间上重叠 **Two threads are *concurrent* if their flows overlap in time**
- 否则，它们是顺序的 **Otherwise, they are sequential**

- 示例： **Examples:**
  - 并发 Concurrent: A & B, A&C
  - 顺序 Sequential: B & C



# 并发线程执行 Concurrent Thread Execution

- **单核处理器 Single Core Processor**
  - 通过分时模拟并行 Simulate parallelism by time slicing
- **多核处理器 Multi-Core Processor**
  - 可以实现真正并行 Can have true parallelism




**2个核心上运行3个线程**
**Run 3 threads on 2 cores**

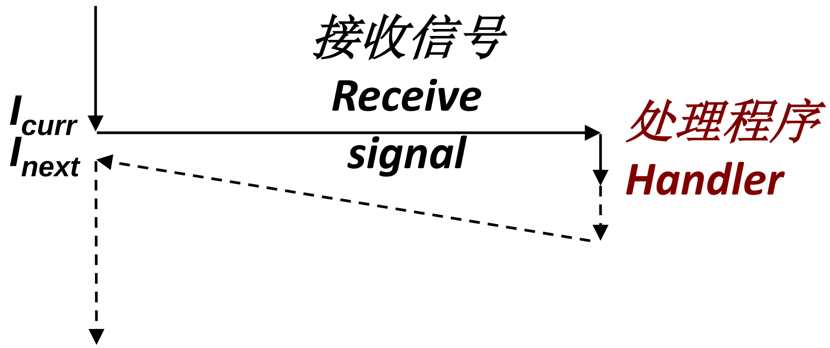
# 线程对比进程 Threads vs. Processes

- 线程和进程如何相似 **How threads and processes are similar**
  - 每个都有自己的逻辑控制流 Each has its own logical control flow
  - 每个都可以与其他并发运行（可能在不同的核心上）Each can run concurrently with others (possibly on different cores)
  - 每个都要进行上下文切换 Each is context switched

# 线程对比进程 Threads vs. Processes

- **线程和进程的区别 How threads and processes are different**
  - 线程共享所有代码和数据（局部栈除外） Threads share all code and data (except local stacks)
    - 进程（通常）不会 Processes (typically) do not
  - 线程的开销略低于进程 Threads are somewhat less expensive than processes
    - 进程控制（创建和回收）的开销是线程控制的两倍 Process control (creating and reaping) twice as expensive as thread control
    - Linux上的数字： Linux numbers:
      - 约2万个时钟周期来创建和回收进程 ~20K cycles to create and reap a process
      - 约1万个时钟周期（或更少）来创建和回收线程 ~10K cycles (or less) to create and reap a thread

# 线程对信号 Threads vs. Signals




- 信号处理程序与普通程序共享状态 **Signal handler shares state with regular program**
  - 包括栈 Including stack
- 信号处理程序中断正常程序的执行 **Signal handler interrupts normal program execution**
  - 不预期的过程调用 Unexpected procedure call
  - 返回到正常执行流 Returns to regular execution stream
  - *不是*一个对等体 *Not* a peer
- 有限的同步形式 **Limited forms of synchronization**
  - 主程序可以阻塞/解阻塞信号 Main program can block / unblock signals
  - 主程序可以暂停信号 Main program can pause for signal

# Posix线程（Pthread）接口
# Posix Threads (Pthreads) Interface

- ***Pthreads*：标准接口，包含约60个函数，可以从C语言程序操作线程 *Pthreads:* Standard interface for ~60 functions that manipulate threads from C programs**
  - 创建和回收线程 Creating and reaping threads
    - `pthread_create()`
    - `pthread_join()`
  - 确定线程ID Determining your thread ID
    - `pthread_self()`
  - 终止线程 Terminating threads
    - `pthread_cancel()`
    - `pthread_exit()`
    - `exit()` [终止所有线程 terminates all threads]
    - `return` [终止当前线程 terminates current thread]
  - 对共享变量的访问进行同步 Synchronizing access to shared variables
    - `pthread_mutex_init`
    - `pthread_mutex_[un]lock`

# Pthread的“hello, world”程序
# The Pthreads "hello, world" Program

```c
/*
 * hello.c - Pthreads "hello, world" program
 */
#include "csapp.h"
void *thread(void *vargp);

int main(int argc, char** argv)
{
    pthread_t tid;
    Pthread_create(&tid, NULL, thread, NULL);
    Pthread_join(tid, NULL);
    return 0;
}
```

hello.c

*线程ID Thread ID*

*线程属性 Thread attributes (通常为空 usually NULL)*

*线程例程 Thread routine*

*线程参数 Thread argu (void *p)*

*返回值 Return value (void **p)*

```c
void *thread(void *vargp) /* thread routine */
{
    printf("Hello, world!\n");
    return NULL;
}
```

hello.c

# 线程化的“hello, world”执行
# Execution of Threaded “hello, world”

主线程 Main thread

调用 call `Pthread_create()`

`Pthread_create()` returns 返回

对等线程 Peer thread

调用 call `Pthread_join()`

`printf()`

`return NULL;`

主线程等待对等线程终止

Main thread waits for peer thread to terminate

对等线程终止

Peer thread terminates

`Pthread_join()` returns 返回

`exit()`

终止主线程和任何对等线程

Terminates main thread and any peer threads

# 或者… Or, …

主线程 Main thread

调用 call `Pthread_create()`

`Pthread_create()` returns 返回

对等线程 Peer thread

`printf()`

`return NULL;`

**对等线程终止 Peer thread terminates**

调用 call `Pthread_join()`

**主线程不需等待对等线程终止 Main thread doesn't need to wait for peer thread to terminate**

`Pthread_join()` returns 返回

`exit()`

**终止主线程和任何对等线程 Terminates main thread and any peer threads**

**而且非常多种可能的代码执行方式 And many many more possible ways for this code to execute.**

# 基于线程的并发回声服务器
# Thread-Based Concurrent Echo Server

```
int main(int argc, char **argv)
{
    int listenfd, *connfdp;
    socklen_t clientlen;
    struct sockaddr_storage clientaddr;
    pthread_t tid;

    listenfd = Open_listenfd(argv[1]);
    while (1) {
        clientlen=sizeof(struct sockaddr_storage);
        connfdp = Malloc(sizeof(int));
        *connfdp = Accept(listenfd, (SA *) &clientaddr, &clientlen);
        Pthread_create(&tid, NULL, thread, connfdp);
    }
    return 0;                                    echoservert.c
}
```

- 为每个客户生成新线程 Spawn new thread for each client
- 把连接文件描述符的拷贝传递给新线程 Pass it copy of connection file descriptor
- 注意使用Malloc()！ [但是没有释放Free()] Note use of **Malloc()**! [but not **Free()**]

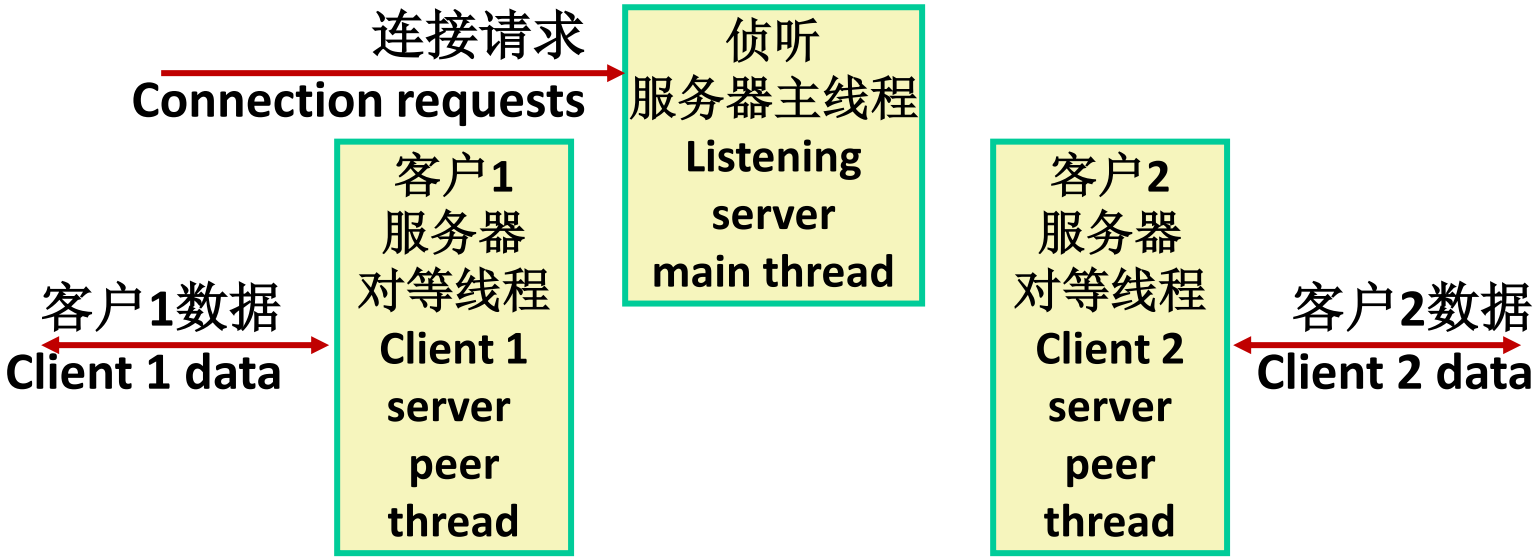
# 基于线程的并发服务器（续）
# Thread-Based Concurrent Server (cont)

```
/* Thread routine */
void *thread(void *vargp)
{
    int connfd = *((int *)vargp);
    Pthread_detach(pthread_self());
    Free(vargp);
    echo(connfd);
    Close(connfd);
    return NULL;
}
```

echoservert.c

- 运行线程在“分离的”模式 Run thread in “detached” mode.
  - 与其它线程独立运行 Runs independently of other threads
  - 当终止时自动回收（由内核） Reaped automatically (by kernel) when it terminates
- 释放分配给保存connfd的存储空间 Free storage allocated to hold **connfd**
- 关闭connfd（重要！） Close **connfd** (important!)

# 基于线程的服务器执行模式
# Thread-based Server Execution Model




- 每个客户由单个对等线程处理 Each client handled by individual peer thread
- 线程共享除TID之外的所有进程状态 Threads share all process state except TID
- 每个线程都有一个单独的局部变量栈 Each thread has a separate stack for local variables

# 基于线程的服务器的问题
# Issues With Thread-Based Servers

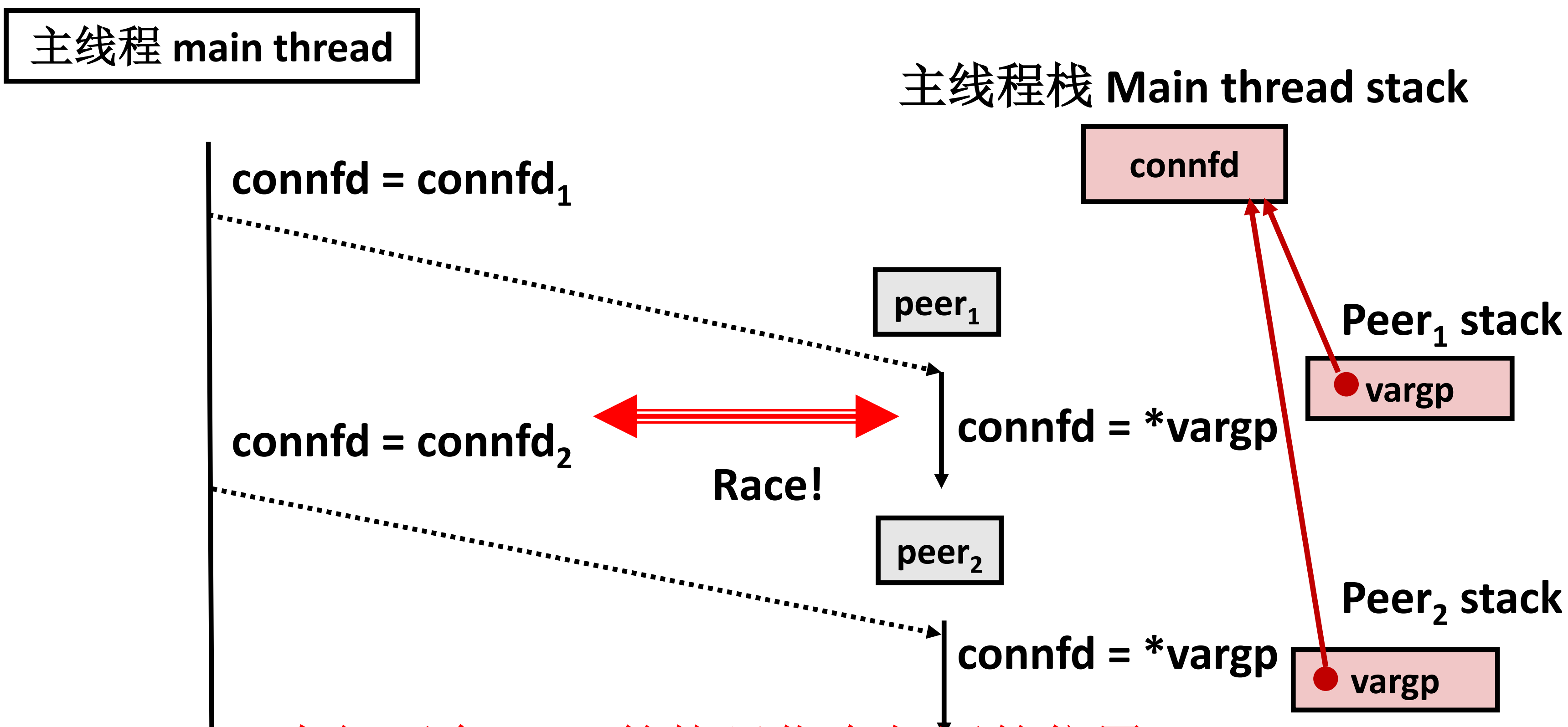
- **必须运行“分离”以避免内存泄漏 Must run “detached” to avoid memory leak**
  - 在任何时间点，线程都是*可结合的或分离的* At any point in time, a thread is either *joinable* or *detached*
  - *可结合的*线程可以被其他线程回收和杀死 *Joinable* thread can be reaped and killed by other threads
    - 必须回收（使用pthread_join）以释放内存资源 must be reaped (with `pthread_join`) to free memory resources
  - *分离的*线程不能被其他线程回收或杀死 *Detached* thread cannot be reaped or killed by other threads
    - 终止时自动回收资源 resources are automatically reaped on termination
  - 默认状态为可结合的 Default state is joinable
    - 使用pthread_detach(pthread_self())进行分离 use `pthread_detach(pthread_self())` to make detached

# 基于线程的服务器的问题
# Issues With Thread-Based Servers

- 必须小心避免意外共享 **Must be careful to avoid unintended sharing**
  - 例如，将指针传递到主线程的栈 For example, passing pointer to main thread's stack
    - `Pthread_create(&tid, NULL, thread, (void *)&connfd);`
- 线程调用的所有函数都必须是*线程安全的* **All functions called by a thread must be *thread-safe***
  - （下次课）/ (next lecture)

# 意外共享的潜在形式
# Potential Form of Unintended Sharing

```
while (1) {
    int connfd = Accept(listenfd, (SA *) &clientaddr, &clientlen);
    Pthread_create(&tid, NULL, thread, &connfd);
}
```




*为何两个vargp的拷贝指向相同的位置？*

*Why would both copies of vargp point to same location?*

# 一个进程有多个线程
# A Process With Multiple Threads

- 多个线程可以与一个进程关联 **Multiple threads can be associated with a process**
  - 每个线程都有自己的逻辑控制流 Each thread has its own logical control flow
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    - 但不受其他线程的保护 but not protected from other threads
  - 每个线程都有自己的线程id（TID） Each thread has its own thread id (TID)

**线程1（主线程）**
**Thread 1 (main thread)**

**stack 1**

**Thread 1 context:**
**Data registers**
**Condition codes**
**$SP_1$**
**$PC_1$**

**线程2（对等线程）**
**Thread 2 (peer thread)**

**stack 2**

**Thread 2 context:**
**Data registers**
**Condition codes**
**$SP_2$**
**$PC_2$**

**共享代码和数据**
**Shared code and data**

**shared libraries**

**run-time heap**
**read/write data**
**read-only code/data**

**0**

**Kernel context:**
**VM structures**
**Descriptor table**
**brk pointer**

# 但是所有的内存都是共享的
# But ALL memory is shared

**Thread 1 context:**
- Data registers
- Condition codes
- $SP_1$
- $PC_1$

**Thread 2 context:**
- Data registers
- Condition codes
- $SP_2$
- $PC_2$

**线程1(主线程)**
**Thread 1 (main thread)**

stack 1

**线程2(对等线程)**
**Thread 2 (peer thread)**

stack 2

| |
|---|
| shared libraries |
| |
| run-time heap |
| read/write data |
| read-only code/data |
| |

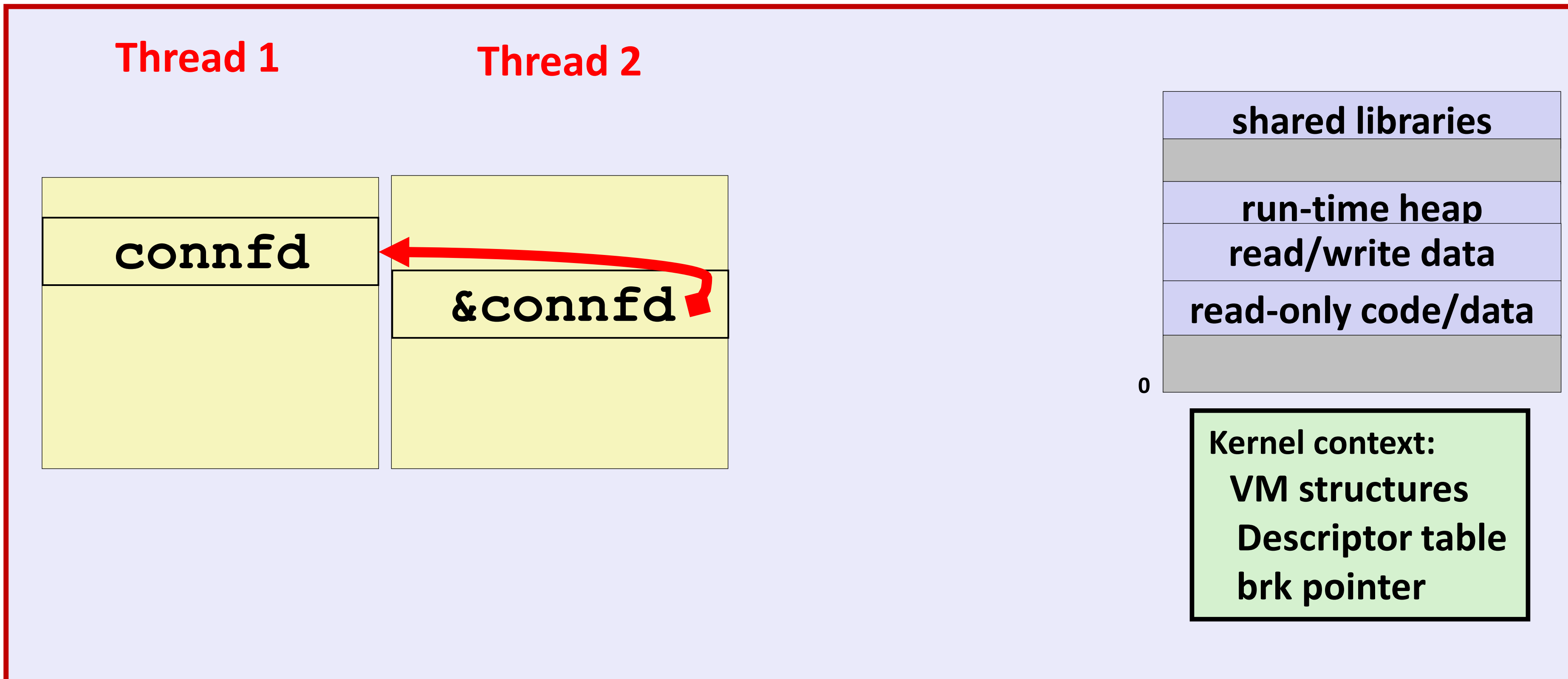
0

**Kernel context:**
- VM structures
- Descriptor table
- brk pointer

```c
while (1) {
    int connfd = Accept(listenfd, (SA *) &clientaddr, &clientlen);
    Pthread_create(&tid, NULL, thread, &connfd);
}
```

Thread 1 context:
- Data registers
- Condition codes
- $SP_1$
- $PC_1$

Thread 2 context:
- Data registers
- Condition codes
- $SP_2$
- $PC_2$

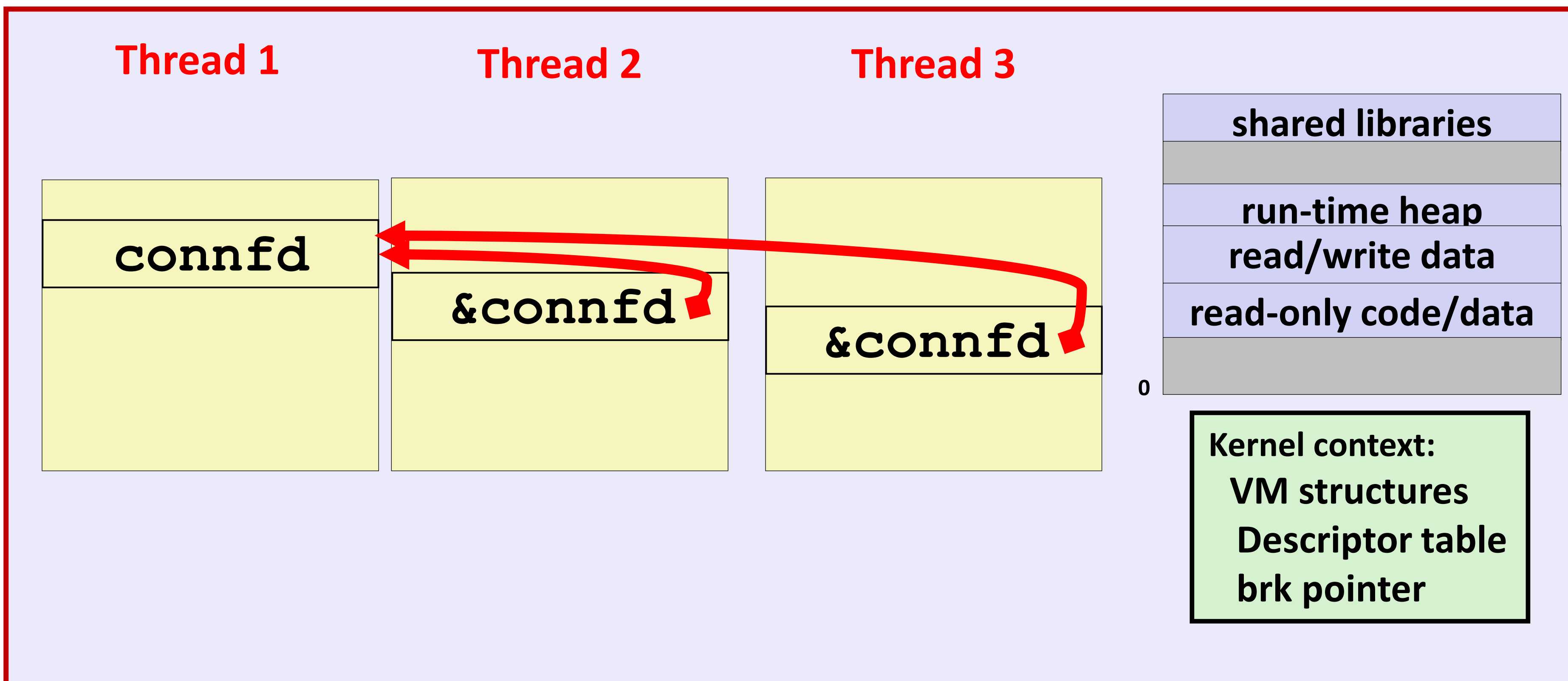


```
while (1) {
    int connfd = Accept(listenfd, (SA *) &clientaddr, &clientlen);
    Pthread_create(&tid, NULL, thread, &connfd);
}
```

**Thread 1 context:**
- Data registers
- Condition codes
- $SP_1$
- $PC_1$

**Thread 2 context:**
- Data registers
- Condition codes
- $SP_2$
- $PC_2$

**Thread 3 context:**
- Data registers
- Condition codes
- $SP_2$
- $PC_2$

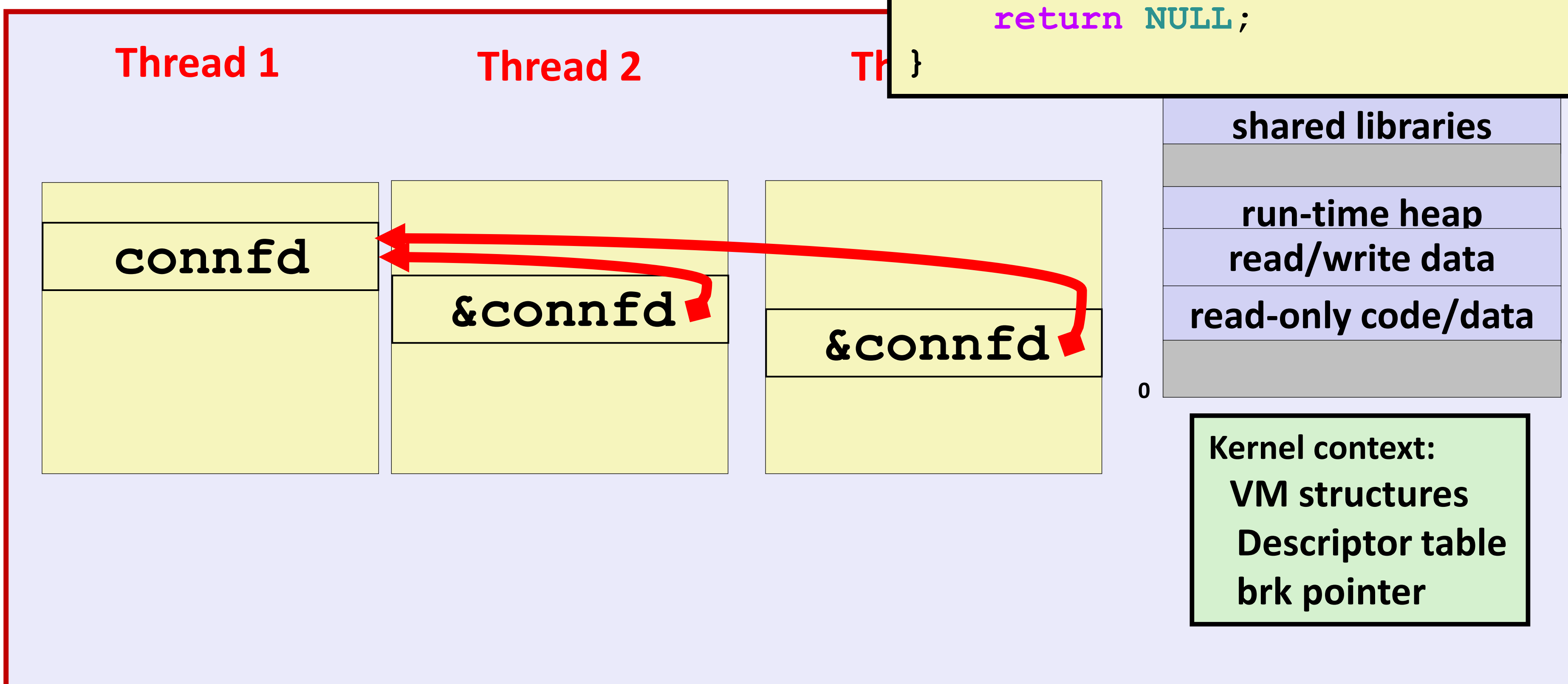


Thread 1 context:
- Data registers
- Condition codes
- $SP_1$
- $PC_1$

Thread 2 context:
- Data registers
- Condition codes
- $SP_2$
- $PC_2$

Thread
- Data
- Con
- $SP_2$
- $PC_2$

```
/* Thread routine */
void *thread(void *vargp)
{
    int connfd = *((int *)vargp)
    Pthread_detach(pthread_self(
    Free(vargp);
    echo(connfd);
    Close(connfd);
    return NULL;
}
```



# 这样会发生竞争吗？
# Could this race occur?

主线程 **Main**

```
int i;
for (i = 0; i < 100; i++) {
   Pthread_create(&tid, NULL,
                  thread, &i);
}
```

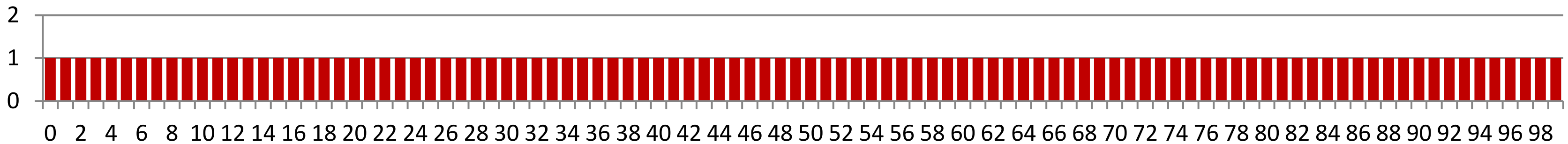
对等线程 **Thread**

```
void *thread(void *vargp)
{
   int i = *((int *)vargp);
   Pthread_detach(pthread_self());
   save_value(i);
   return NULL;
}
```

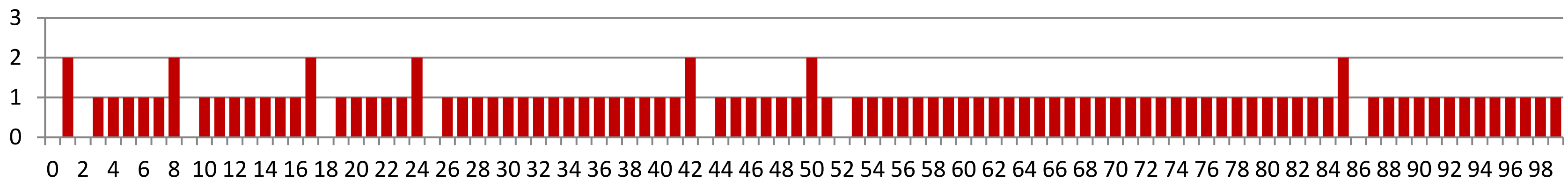
- 竞争测试 **Race Test**
  - 如果不存在竞争，那么每个线程得到不同的i值 If no race, then each thread would get different value of **`i`**
  - 保存值的集合将由每个0到99的拷贝组成 Set of saved values would consist of one copy each of 0 through 99

# 实验结果 Experimental Results

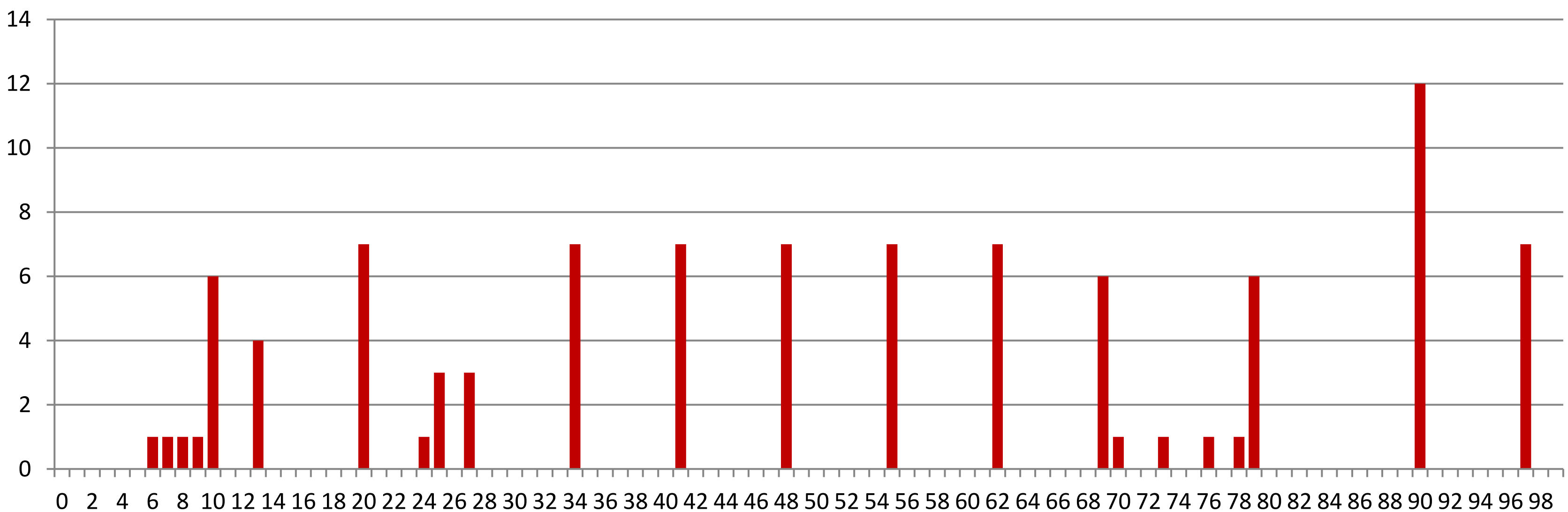
## 没有竞争 No Race




## 单核笔记本 Single core laptop




## 多核服务器 Multicore server




- **竞争真的会发生！ The race can really happen!**

# 正确传递线程参数
# Correct passing of thread arguments

```
/* Main routine */
        int *connfdp;
        connfdp = Malloc(sizeof(int));
        *connfdp = Accept( . . . );
        Pthread_create(&tid, NULL, thread, connfdp);
```

```
/* Thread routine */
void *thread(void *vargp)
{
    int connfd = *((int *)vargp);
        . . .
    Free(vargp);
        . . .
    return NULL;
}
```

- 生产者-消费者模型 Producer-Consumer Model
  - 在main函数分配空间 Allocate in main
  - 在线程例程中释放 Free in thread routine

# 基于线程的设计优点和缺点
# Pros and Cons of Thread-Based Designs

- **+ 易于在线程之间共享数据结构 Easy to share data structures between threads**
  - 例如日志信息、文件缓存 e.g., logging information, file cache
- **+ 线程比进程更有效率 Threads are more efficient than processes**

# 基于线程的设计优点和缺点
# Pros and Cons of Thread-Based Designs

- – 无意中的共享可能会导致细微且难以再现的错误！**Unintentional sharing can introduce subtle and hard-to-reproduce errors!**
  - 轻松共享数据是线程的最大优势和最大弱点 The ease with which data can be shared is both the greatest strength and the greatest weakness of threads
  - 很难知道哪些数据是共享的，哪些是私有的 Hard to know which data shared & which private
  - 难以靠测试检测 Hard to detect by testing
    - 竞争结果不佳的概率很低 Probability of bad race outcome very low
    - 但非零！ But nonzero!
  - 未来课次讲授 Future lectures

# 小结：并发的方法
# Summary: Approaches to Concurrency

- 基于进程 **Process-based**
  - 难以共享资源：易于避免意外共享 Hard to share resources: Easy to avoid unintended sharing
  - 添加/删除客户的开销高 High overhead in adding/removing clients
- 基于事件 **Event-based**
  - 乏味和低级 Tedious and low level
  - 对调度的全面控制 Total control over scheduling
  - 非常低的开销 Very low overhead
  - 无法创建细粒度的并发级别 Cannot create as fine grained a level of concurrency
  - 不能使用多核 Does not make use of multi-core
- 基于线程 **Thread-based**
  - 易于共享资源：可能太容易了 Easy to share resources: Perhaps too easy
  - 中等开销 Medium overhead
  - 对调度策略没有太多控制 Not much control over scheduling policies
  - 难以调试 Difficult to debug
    - 事件顺序不可重复 Event orderings not repeatable