Introduction to Computer Systems
15-213/18-243 Fall 2010
November 15th, 2010

Threading and Thread Safety

Overview

- **News**
- **Threading**
  - Basics
  - Thread Lifecycle
- **Thread Safety**
  - Race Conditions
  - Synchronization Techniques
- **Proxy Lab**

News

- **Proxy** due Tuesday Nov 23rd at 11:59pm

- **DBUG info session:** Saturday Nov 20th, 12-2PM in GHC 4401.

Threading

Multi-Threaded process

Thread 1

stack 1

Thread 1 context:
- Data registers
- Condition codes
- SP-1
- PC-1

Thread 2

stack 2

Thread 2 context:
- Data registers
- Condition codes
- SP-2
- PC-2

...

Thread N

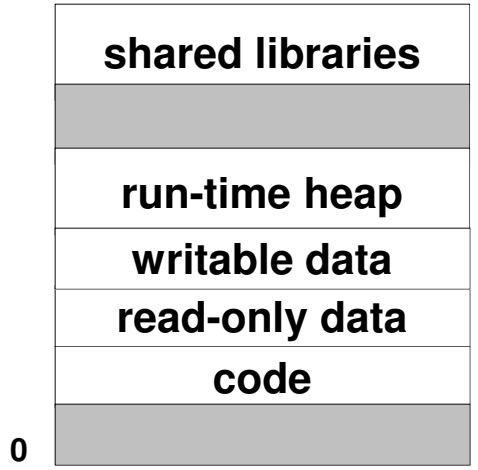
stack N

Thread N context:
- Data registers
- Condition codes
- SP-N
- PC-N

Shared resources:

Kernel context:
- VM structures
- Descriptor table

Private Address Space



Posix Threads (Pthreads) Interface

- **Standard interface for ~60 functions**
  - Creating and reaping threads.
    - pthread_create
    - pthread_join
  - Determining your thread ID
    - pthread_self
  - Terminating threads
    - pthread_cancel
    - pthread_exit
  - Synchronizing access to shared variables
    - pthread_mutex_init
    - pthread_mutex_[un]lock
    - pthread_rwlock_init
    - pthread_rwlock_[wr]rdlock

Multi-threaded Hello World

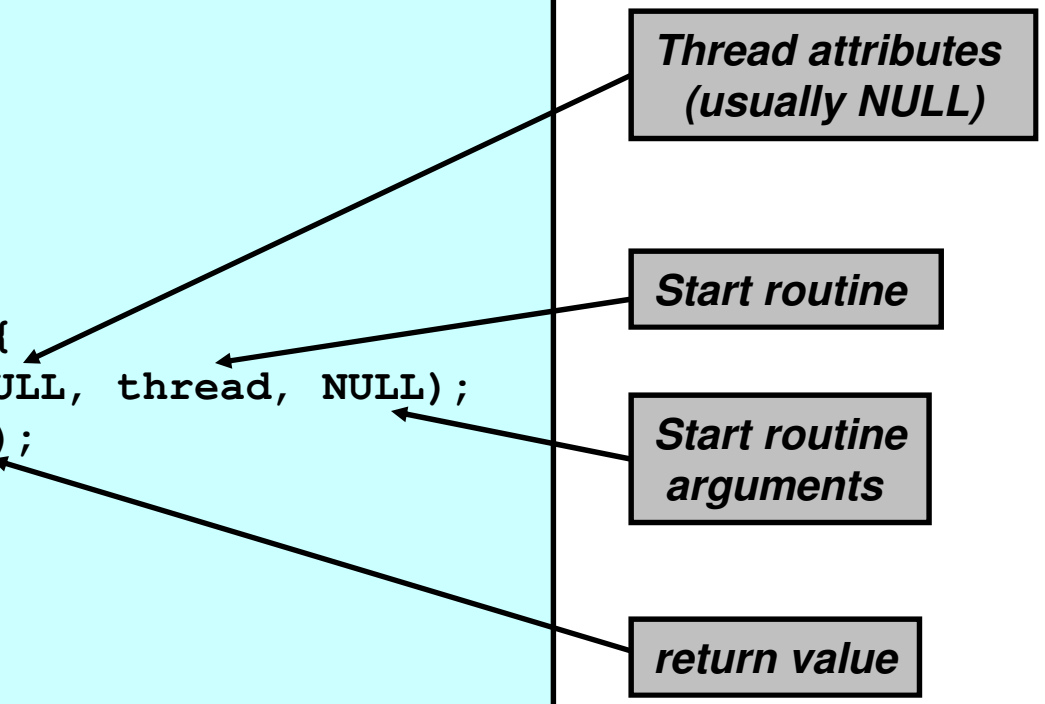
```
/* hello.c - Pthreads "hello, world" program */

#include "csapp.h"

void *thread(void *vargp);

int main() {
  pthread_t tid;
  int i;
  for(i = 0; i < 42; ++i) {
    pthread_create(&tid, NULL, thread, NULL);
    pthread_join(tid, NULL);
  }
  exit(0);
}

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



Exiting a process and thread

- pthread_exit() only terminates the current thread, NOT the process

- exit() terminates ALL the threads in the process, i.e., the process itself

Joinable & Detached Threads

- **Joinable thread can be reaped and killed by other threads**
  - must be reaped (with pthread_join) to free memory resources.
- **Detached thread cannot be reaped or killed by other threads**
  - resources are automatically reaped on termination.
- **Default state is joinable**
  - use pthread_detach(pthread_self()) to make detached.

Thread Safety

Race condition

- **A race occurs when the correctness of a program depends on one thread reaching point x in its control flow before another thread reaches point y.**
  - Access to shared variables and data structures
  - Threads dependent on a condition

- **Use synchronization to avoid race conditions**

- **Ways to do synchronization**
  - Semaphores
  - Mutex
  - Read-write locks

Synchronization

- **Semaphore**
  - Restricts the number of threads that can access a shared resource
- **Mutex**
  - Special case of semaphore that restricts access to one thread
- **Read-write locks**
  - Multiple readers allowed
  - Single writer allowed
  - No readers allowed when writer is present

Semaphore

- **Classic solution: Dijkstra's P and V operations on semaphores.**

- **Semaphore: non-negative integer synchronization variable.**
  - P(s): [while (s == 0) wait(); s--;]
  - V(s): [s++;]
  - OS guarantees that operations between brackets [ ] are executed indivisibly.
  - Only one P or V operation at a time can modify s.
  - Semaphore invariant: (s >= 0)
  - Initialize s to the number of simultaneous threads allowed

Posix synchronization functions

- **Semaphores**
  - sem_init
  - sem_wait
  - sem_post

- **Read-write locks**
  - pthread_rwlock_init
  - pthread_rwlock_rdlock
  - Pthread_rwlock_wrlock

NETWORKING REVIEW

Connection Establishment Functions

- **Server Sockets**
  - socket(…)
  - bind(…)
  - listen(…)
  - accept(…)
  - close(…)
- **Client Sockets**
  - socket(…)
  - connect(…)
  - close(…)

socket(domain, type, protocol)

int sock_fd= socket(PF_INET, SOCK_STREAM, IPPROTO_TCP);

- **domain –Protocol Family to use**
  - PF_INET is the IPv4 family of protocols
- **type –Type of protocol to use**
  - SOCK_STREAM suggests a steady data stream with guaranteed in-order delivery
- **protocol –Specific protocol to use**
  - IPPROTO_TCP suggests to use TCP (stream-based socket protocol)

bind(sock_fd, my_addr, addrlen)

```
structsockaddr_insockaddr;
memset(&sockaddr, 0, sizeof(sockaddr);
sockaddr.sin_family= AF_INET;
sockaddr.sin_addr.s_addr= INADDR_ANY;
sockaddr.sin_port= htons(listenPort)
err = bind(sock_fd, (structsockaddr*) sockaddr, sizeof(sockaddr));
```

- sock_fd–file descriptor of socket
- my_addr–address to which to bind
- addrlen–size (in bytes) of address struct

listen(sock_fd, backlog)

err = listen(sock_fd, MAX_WAITING_CONNECTIONS);

- **sock_fd–socket on which to listen**
- **backlog –Maximum size of list of waiting connections**

accept(sock_fd, addr, addrlen)

```
structsockaddr_inclient_addr;
socklen_tmy_addr_len= sizeof(client_addr);
client_fd= accept(listener_fd, &client_addr, &my_addr_len);
```

- **sock_fd–listening socket from which to accept connection**
- **addr–pointer to sockaddrstructto hold client address**
- **addrlen–pointer to length of addrthat is overwritten with actual length of connection**

connect(sock_fd, addr, addrlen)

```
structsockaddr_inremote_addr;
/* initialize remote_addr*/
err = connect(listener_fd, &remote_addr, sizeof(remote_addr));
```

- **sock_fd–socket to connect to**
- **addr–pointer to sockaddrstructthat holds remote address**
- **addrlen–length of addrthat is overwritten with actual length of connection**

Socket Communication Functions

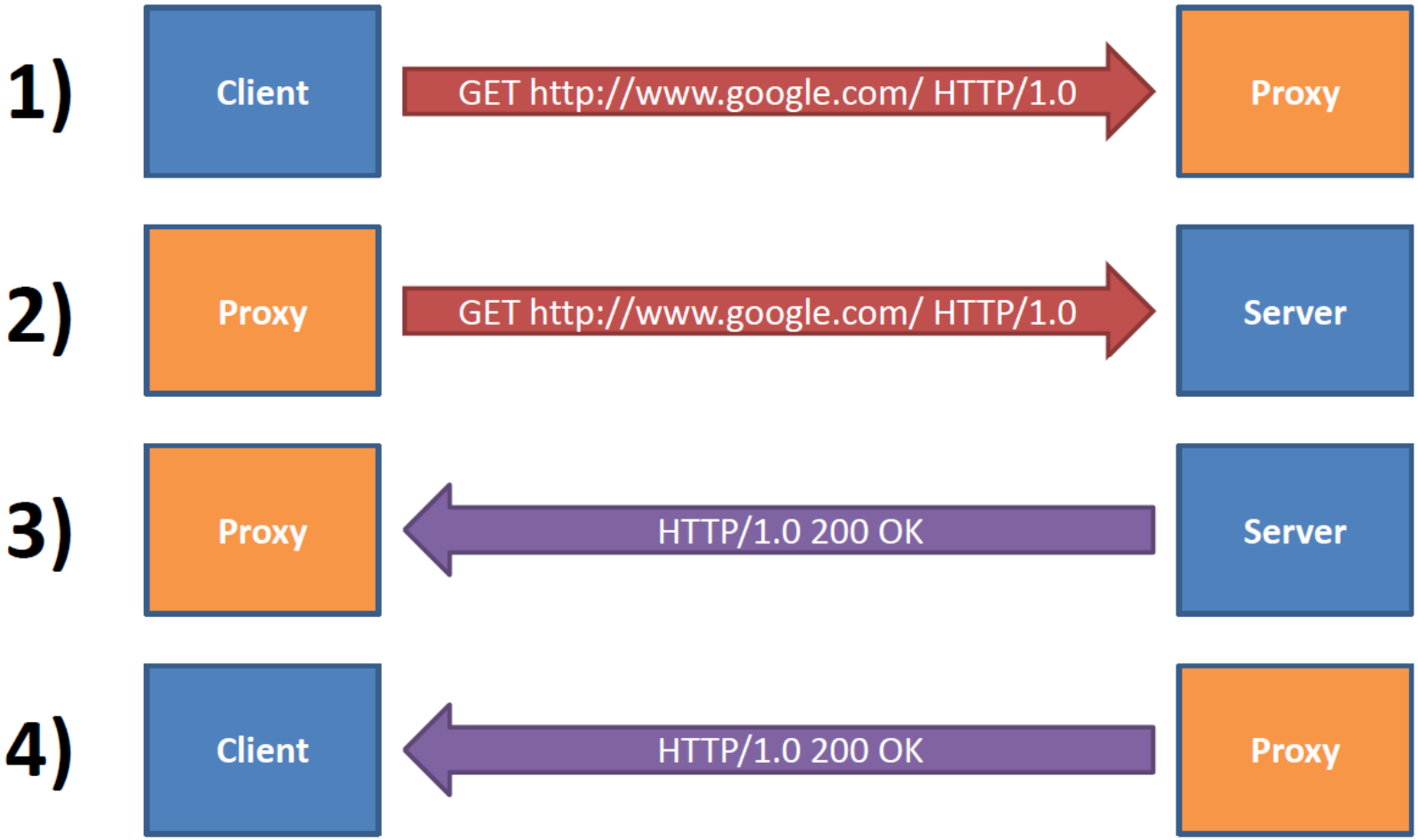
- send(sock_fd, buf, buf_len, flags)
- recv(sock_fd, buf, max_len, flags)

- Like read and write, but takes flags. Check man page to use flags.

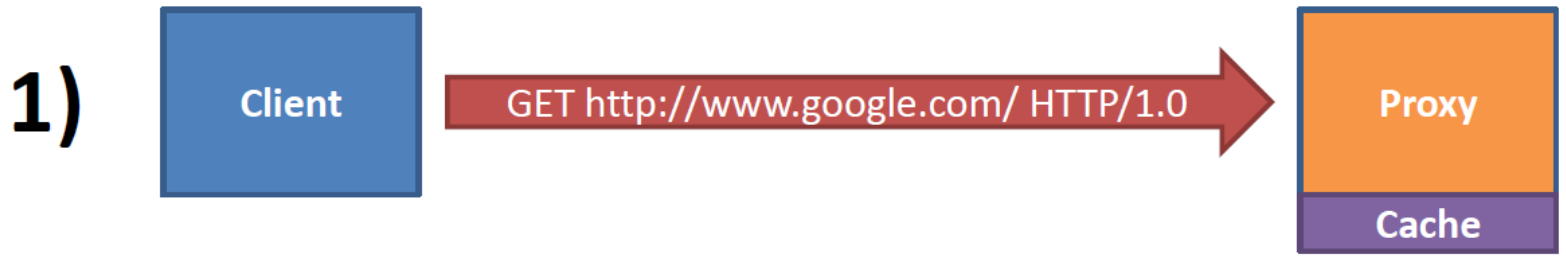
Proxy Lab

- **Graceful error handling**
  - Proxy should not exit once it has finished initialization
- **Document design decisions**
- **Code organization**
  - Break proxy into multiple functions
- **Complete lab in three stages**
  - Basic sequential proxy
  - Handling concurrent requests
  - Caching
- **Understand what is robust about the rio package**
  - Behavior of network sockets
- **You may use select, but it will be a lot more work than threads.**

What is a proxy?



What is a Caching Proxy



The Proxy has already serviced a request for http://www.google.com/ and has stored the result.

The Proxy simply responds with the stored result for http://www.google.com/. The Client is unaware that it has not communicated with the google.com server directly.

Important Notes on ProxyLab

RIO Package

- Provided for you in csapp.c
- The rio package has a very strict method for dealing with error. Should your proxy use the same method?
- Remember you are submitting your files in a compressed folder and therefore edits in your copy of csapp.c/csapp.h should be submitted as well.

Gethostbyname

This is the wrapper in csapp.c. What could go wrong?

```
/* $begin gethostbyname */
struct hostent *Gethostbyname(const char *name) {
        struct hostent *p;
        if ((p = gethostbyname(name)) == NULL)
        dns_error("Gethostbyname error");     return p;
}
 /* $end gethostbyname */
```

Thread-Unsafe Functions (cont)

- Returning a ptr to a `static` variable
- Fixes:
  - 1. Rewrite code so caller passes pointer to `struct`
    - Issue: Requires changes in caller and callee
  - 2. *Lock-and-copy*
    - Issue: Requires only simple changes in caller (and none in callee)
    - However, caller must free memory

```
struct hostent
*gethostbyname(char name)
{
  static struct hostent h;
  <contact DNS and fill in h>
  return &h;
}
```

```
hostp = Malloc(...));
gethostbyname_r(name, hostp);
```

```
struct hostent
*gethostbyname_ts(char *name)
{
  struct hostent *q = Malloc(...);
  struct hostent *p;
  P(&mutex); /* lock */
  p = gethostbyname(name);
  *q = *p;   /* copy */
  V(&mutex);
  return q;
}
```

Alternative (Better) Solution

- As you know from writing malloc, many things happen behind the scenes when malloc/free are called. This includes overhead of both time and space.
- What might be a better solution?

Alternative (Better) Solution

- As you know from writing malloc, many things happen behind the scenes when malloc/free are called. This includes overhead of both time and space.
- What might be a better solution?
- Declare a variable on the stack and pass in a pointer to that variable.
- Why is this still ok?
- Why is it better?

On Testing Your Caching Proxy…

- DBUG
- Set up your browser.

Questions?