PA6: Distributed Image Renderer

Jed Liu

Department of Computer Science
Cornell University

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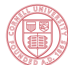

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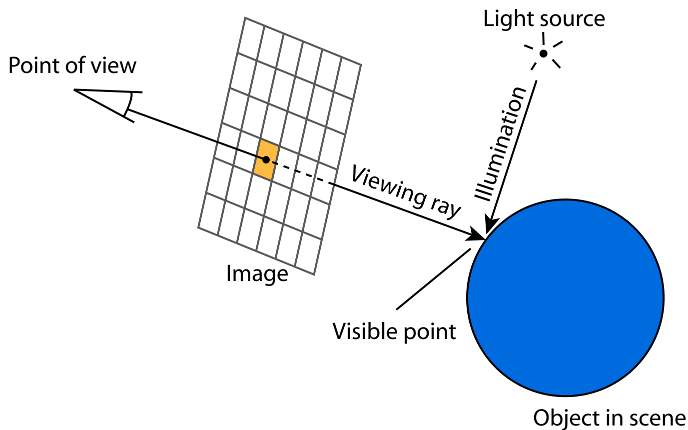
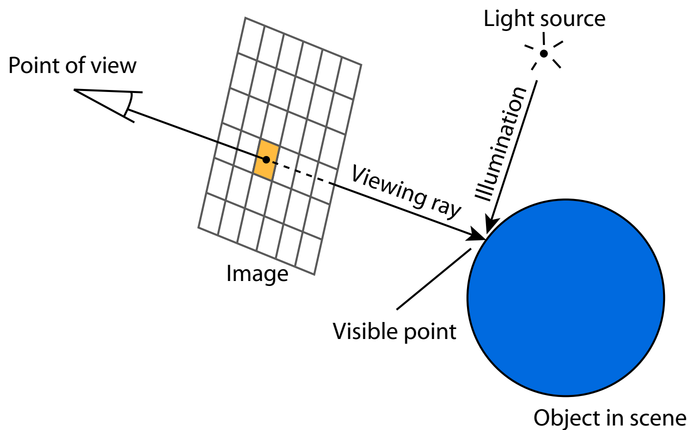
Ray Tracing 101



Ray Tracing 101

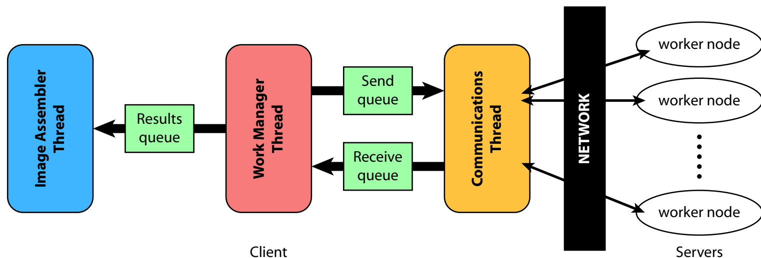


Embarrassingly parallel!

PA6 in a Nutshell

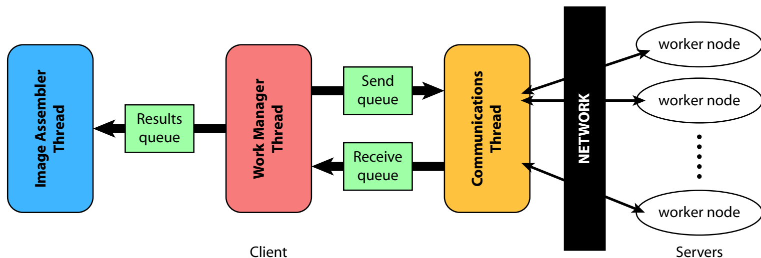
- We provide ray-tracing servers.
- You write a *multithreaded* client to use them to render an image.
- In the process, you will learn about:
  - Programming threads in Linux
  - Thread-safe data structures
  - Basic network programming
  - Basic task scheduling

System Architecture



- We give you the servers and image assembler.
- You implement everything else.

System Architecture



- We give you the servers and image assembler.
- You implement everything else.
- Don't panic. We also give you lots of help.

Outline

- Pthreads library
- Networking
  - Sockets API
  - Marshalling & unmarshalling
- Tools to make life easier
- Suggestions for getting started
- Resources

Caveat

- Many C functions will be covered
- Won't cover all aspects – just the important parts
  - All optional function parameters are glossed over
- Up to you to figure out error handling
  - Read man pages for this

POSIX Threads (aka Pthreads)

(POSIX: "Portable Operating System Interface")

Creating a thread

```
#include <pthread.h>
pthread_t thread_id;
void* f(void* args);
void* args = ...;
...
pthread_create(&thread_id, NULL, f, args);
```

- `pthread_exit()` – terminate current thread
- `pthread_join()` – wait until another thread terminates

An Example!

example0.c

Thread Synchronization: Mutexes

Creating mutexes

```
pthread_mutex_t mutex;
pthread_mutex_init(&mutex, NULL);
```

Using mutexes

```
pthread_mutex_lock(&mutex);
... // Critical section
pthread_mutex_unlock(&mutex);
```

Destroying mutexes

```
pthread_mutex_destroy(&mutex);
```

An Example!

example1.c

Synching Threads: Condition Variables

Creating condition variables

```
pthread_cond_t cond_var;
pthread_cond_init(&cond_var, NULL);
```

Waiting for a condition

```
pthread_cond_wait(&cond_var, &mutex);
```

Signalling a condition

```
// Unblocks single thread.
pthread_cond_signal(&cond_var);
// Unblocks multiple threads.
pthread_cond_broadcast(&cond_var);
```

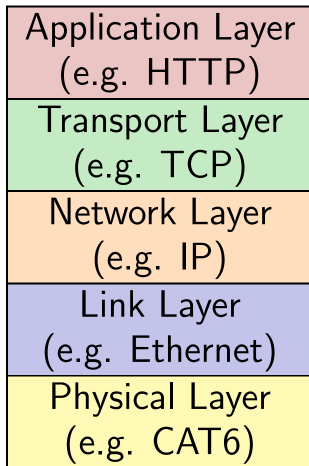
Destroying condition variables

```
pthread_cond_destroy(&cond_var);
```

An Example!

example2.c

Networking 101: Protocol Stack



Networking 101

What happens in your browser when you go to `http://cuinfo.cornell.edu/`?

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What happens in your browser when you go to `http://cuinfo.cornell.edu/`?

1. Use DNS to resolve `cuinfo.cornell.edu` to 132.236.218.15
2. Establish TCP connection to 132.236.218.15 on port 80
3. Use HTTP protocol to fetch web page and related files

- Demo

Networking in PA6

- We will establish for you TCP connections to given `hostname:port` combinations.
- Your clients should implement a protocol that the server understands.
  - Will be specified in the write-up.
- Network programming in C done using **sockets API**
  - For TCP, exposes a stream interface

Sockets API

Socket I/O

```
int sock = ...;
char* buf = ...;
int amt_to_read = ...;
int amt_to_write = ...;

// Reading
int amt_read =
  read(sock, buf, amt_to_read);

// Writing
int amt_written =
  write(sock, buf, amt_to_write);
```

Handling Simultaneous Connections

- Problem: if nothing to be read, `read()` blocks until remote end sends more data
- Usually okay if just have a single connection. What about multiple connections?
  - Could be blocked reading from A when there is data ready to be processed from B.

Handling Simultaneous Connections

- Problem: if nothing to be read, `read()` blocks until remote end sends more data
- Usually okay if just have a single connection. What about multiple connections?
  - Could be blocked reading from A when there is data ready to be processed from B.
- `select()`: Wait until data available from at least one out of a set of sockets

Using pselect() (I)

```
int* socks_to_watch = ...;
int num_socks = ...;
int i, num_ready;

int nfds = 0;
fd_set fds;
FD_ZERO(&fds);  // Initialize fds
for (i = 0; i < num_socks; i++) {
  int sock = socks_to_watch[i];
  FD_SET(sock, &fds);  // Add socket to set
  if (sock >= nfds) nfds = sock + 1;
}

num_ready =
  pselect(nfds, &fds, NULL, NULL, NULL, NULL);
```

Using pselect() (II)

```
num_ready =
   pselect(nfds, &fds, NULL, NULL, NULL, NULL);

if (num_ready > 0) {
  // There is data to be read.
  for (i = 0; i < num_socks; i++) {
    int sock = socks_to_watch[i];
    if ( FD_ISSET(sock, &fds)) {
      // Data available from sock
    }
  }
}
```

Signals

- Now have single thread multiplexing reads across several sockets.
- But what about writes?
  - Need to unblock `pselect()` when there's data available to be sent
- Use signals to interrupt `pselect()`
  - Need to mask signals until `pselect()` called.
  - Doing this right can be complicated.
  - We set things up for you; up to you to handle `pselect()`'s `EINTR` error condition correctly.

Marshalling & Unmarshalling

- Network data format doesn't always match data layout in memory
  - e.g. `struct { char a; int b; }`
  - Endianness may not match
- Need to convert between memory & network representation
  - Marshalling: memory $\longrightarrow$ network
  - Unmarshalling: network $\longrightarrow$ memory

`hton` & `ntoh`

- Always need to perform endianness conversion in program
- TCP/IP standardizes on big endian
- How to write portable code?
  - Use `htonl()` and `ntohl()` to convert ints
  - Also have `htons()` and `ntohs()` for shorts
  - Write code once, works everywhere

Tools to Make Life Easier: netcat

- Dumps network data to screen
- Can act as server or client
- Also has tunnelling mode
  - Sits between server & client
- Installed as `nc` on CSUG machines
  - Type "`nc -h`" for help on using it

Tools to Make Life Easier: valgrind

- Analyzes memory usage
- Detects buffer overflows, memory leaks, double-frees, segfaults

Suggestions for Getting Started

- Start early!
- Tackle threading before networking
  - Implement thread-safe queues first
- Talk to netcat before talking to the servers
  - Make sure you're sending well-formed messages before trying to read responses
- Start early!
- Leave work manager for last
  - Should be easy after everything else is working
  - In meantime, have manager send out single request to each server
- Start early and **ask us if you get stuck**

Resources

- `man` pages
  - `man 2 <syscall-function>`
  - `man 3 <library-function>`
  - `man 3p <posix-library-function>`
- Wikipedia has articles on many C functions, often with example code
- Googling for C function names often turns up informative pages with example code
- Office hours, `cs316-l@cs.cornell.edu`