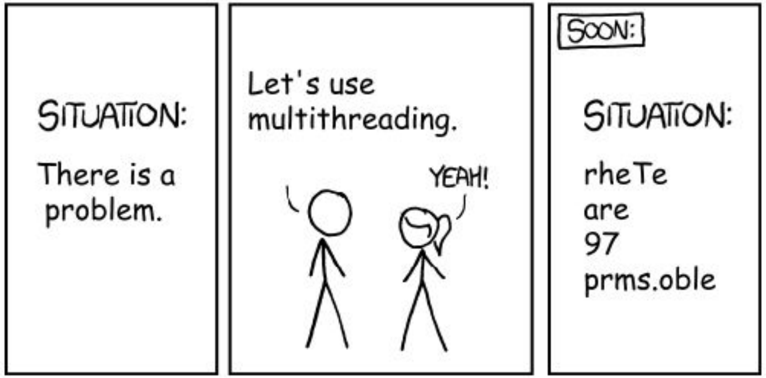
CSE 333
Section 9

Concurrency, pthreads



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Logistics

- Exercise 17
  - Out after sections
  - Due **Monday** (8/18) @ **10:00am**
- Homework 4
  - Due next **Wednesday** (8/20) @ **11:59pm**
- **Final Exam next Friday (8/22) @ 1:10-2:10pm**
  - Review next Thursday 8/21 during section!

HW4 and nc

Web Server

1. Establish client connections
   a. Server socket set up
      in hw4/ServerSocket.cc
2. Read client requests
   a. Parse HTTP requests
      in hw4/HttpConnection.cc
3. Respond to requests
   a. Write HTTP responses
      in hw4/HttpServer.cc
4. Fix security vulnerabilities
   a. Escape characters
      in hw4/Utils.cc

Okay to copy and modify lecture/exercise code for HW4, just make sure you know what's going on!

Steps 2, 3, and 4 involve a lot of string manipulation which can be tedious! There might be something to help with that ☺

Using nc with HW4

1. Launch the server

```
./http333d <port> ../projdocs/ unit_test_indices/*
```

2. Connect with nc

```
nc -C <HostName> <port>
```

3. Write an HTTP request and send it

(Note: nc -C is needed on attu/vm/CSE workstations to use \r\n for newlines when talking to web servers. The option might be different on other machines (e.g., macs used to need -c, but -C seems to work these days)

Writing an HTTP Request

- Example HTTP Request layout can be found in `HttpRequest.h`

- Example HW4 file request:
  - `GET /static/test_tree/books/artofwar.txt HTTP/1.1`

- Example HW4 query request:
  - `GET /query?terms=books+of+war HTTP/1.1`

- To send a request, hit [Enter] ***twice***
- Compare the output of `solution_binaries/http333d` to `./http333d`

Boost Library

Boost

Boost is a free C++ library that provides support for various tasks in C++

- **Note:** Boost does NOT follow the Google style guide!!!
- These will be helpful for you in hw4 to parse HTTP Requests!

Boost adds many string algorithms that you may have seen in Java

- Include with `#include <boost/algorithm/string.hpp>`
- Documentation: https://www.boost.org/doc/libs/1_60_0/doc/html/string_algo.html
- The worksheet contains some examples (googling helps as well)
- **DO NOT** use the regex library, the string library should be enough.
  - i.e., OK to use any boost libraries that do not require changing hw4 Makefile

Helpful Functions

```
void boost::trim(string& input);
```

- Removes all leading and trailing whitespace from the string
- `input` is an input *and* output parameter (non-const reference)

```
void boost::replace_all(string& input,
                        const string& search,
                        const string& format);
```

- Replaces all instances of `search` inside `input` with `format`

Or you can use ordinary string functions if you like

Helpful Functions

```
void boost::split(vector<string>& output,
                  const string& input,
                  boost::PredicateT match_on,
                  boost::token_compress_mode_type compress);
```

- Split the string by the characters in `match_on`

```
boost::PredicateT boost::is_any_of(const string& tokens);
```

- Returns predicate that matches on any of the characters in tokens

pthreads

What are pthreads?

- **P**OSIX **thread**s -- a library for using threads for concurrency `<pthread.h>`
- Threads are a lightweight form of concurrency
  - Almost like writing sequential code!
- There are newer, smarter thread libraries out there
  - But pthreads are *classic*
  - Great for learning the basics of concurrency
  - And, we’re probably stuck with them for the rest of time!
    - Yay legacy code!

Basic idea: Parent thread with child threads

- Parent thread: the “main” thread
    - Manages children
    - Spawns off child threads
    - Should set up children for success
        - e.g., by creating shared resources
    - May wait around for children to terminate, or just let them be free!
        - “Helicopter parent vs. hands-off parenting”
- Child thread
    - Does their own work (chores?)
    - Should play nice with their sibling threads
        - Hogging resources is not nice :(

Concurrency with **pthreads**

- EX17 and HW4 both use pthreads to create thread concurrency

Creation	pthread_**create**	**Parent: “Go do this {function}”**
Termination	pthread_**exit** OR start_routine returns	**Child: “I’m done with my task!”**
	pthread_**cancel**	**Parent: “I changed my mind, you can stop now”**
Resource Clean-up	pthread_**join**	**Parent: “I’ll wait for you to finish and report back your result”** (resource persists until joined)
	pthread_**detach**	**Parent: “You’re free now, go forth and prosper”** (automatically cleans up on termination)

pthread_create

```
#include <pthread.h>
int pthread_create( pthread_t *thread,
           const pthread_attr_t *attr,
           void *(*start_routine) (void *),
           void *arg);
```

- pthread_create creates a new thread into *thread, with attributes *attr (NULL means default attributes -- we will use null!)
- Returns 0 on success and an error number on error (can check against error constants)
- The new thread runs start_routine(arg)
- Compile and link with -pthread.

Other Ways Threads Terminate

- Let the thread function exit by itself; work is done
- Thread calls `pthread_exit` (thread terminates its own execution)
- Main thread calls `pthread_cancel` to close a child thread.
- The process exits from `main` or calls `exit`

pthread_exit

```
void pthread_exit(void *retval);
```

- Equivalent of `exit(retval);` for a thread instead of a process
  - This means it is called in the thread function (child thread)
  - Will only terminate the thread instead of the entire process (other threads will still run)
- The thread will automatically exit once it returns from `start_routine()`
  - `retval` is an output parameter to indicate success or failure (usually pass the address of a global variable to view).

Synchronizing Threads – Called by Parent Thread

```
void pthread_join(pthread_t thread, void **retval);
```

- Waits for the thread specified by thread to terminate
- The thread equivalent of `waitpid()`
- The exit status of the terminated thread is placed in `**retval`

```
int pthread_detach(pthread_t thread);
```

- Mark thread specified by thread as detached – it will clean up its resources as soon as it terminates

Exercise 1

Exercise 1

```
int g = 0;
void *worker(void *ignore) {
  for (int k = 1; k <= 3; k++) {
    g = g + k;
  }
  printf("g = %d\n", g);
  return NULL;
}

int main() {
  pthread_t t1, t2;
  int ignore;
  ignore = pthread_create(&t1, NULL, &worker, NULL);
  ignore = pthread_create(&t2, NULL, &worker, NULL);
  pthread_join(t1, NULL);
  pthread_join(t2, NULL);
  return EXIT_SUCCESS;
}
```

What are the possible outputs of this program?

What is the range of values that g can have at the end of the program?

Exercise 1

```c
int g = 0;
void *worker(void *ignore) {
  for (int k = 1; k <= 3; k++) {
    g = g + k;
  }
  printf("g = %d\n", g);
  return NULL;
}

int main() {
  pthread_t t1, t2;
  int ignore;
  ignore = pthread_create(&t1, NULL, &worker, NULL);
  ignore = pthread_create(&t2, NULL, &worker, NULL);
  pthread_join(t1, NULL);
  pthread_join(t2, NULL);
  return EXIT_SUCCESS;
}
```

What are the possible outputs of this program?

Lots of possible answers, here are four:

```
g = 6   |  g = 12  |  g = 7  |  g = 6
g = 12  |  g = 12  |  g = 9  |  g = 11
```

Exercise 1

```
int g = 0;
void *worker(void *ignore) {
  for (int k = 1; k <= 3; k++) {
    g = g + k;
  }
  printf("g = %d\n", g);
  return NULL;
}

int main() {
  pthread_t t1, t2;
  int ignore;
  ignore = pthread_create(&t1, NULL, &worker, NULL);
  ignore = pthread_create(&t2, NULL, &worker, NULL);
  pthread_join(t1, NULL);
  pthread_join(t2, NULL);
  return EXIT_SUCCESS;
}
```

What is the range of values that g can have at the end of the program?

`g = [4 - 12]`

Assembly Instructions

Instructions for `g = g + k`:

```
mov     0x2ebf(%rip),%edx
mov     -0x4(%rbp),%eax
add     %edx,%eax
mov     %eax,0x2eb4(%rip)
```

← Loads global `g` into local register

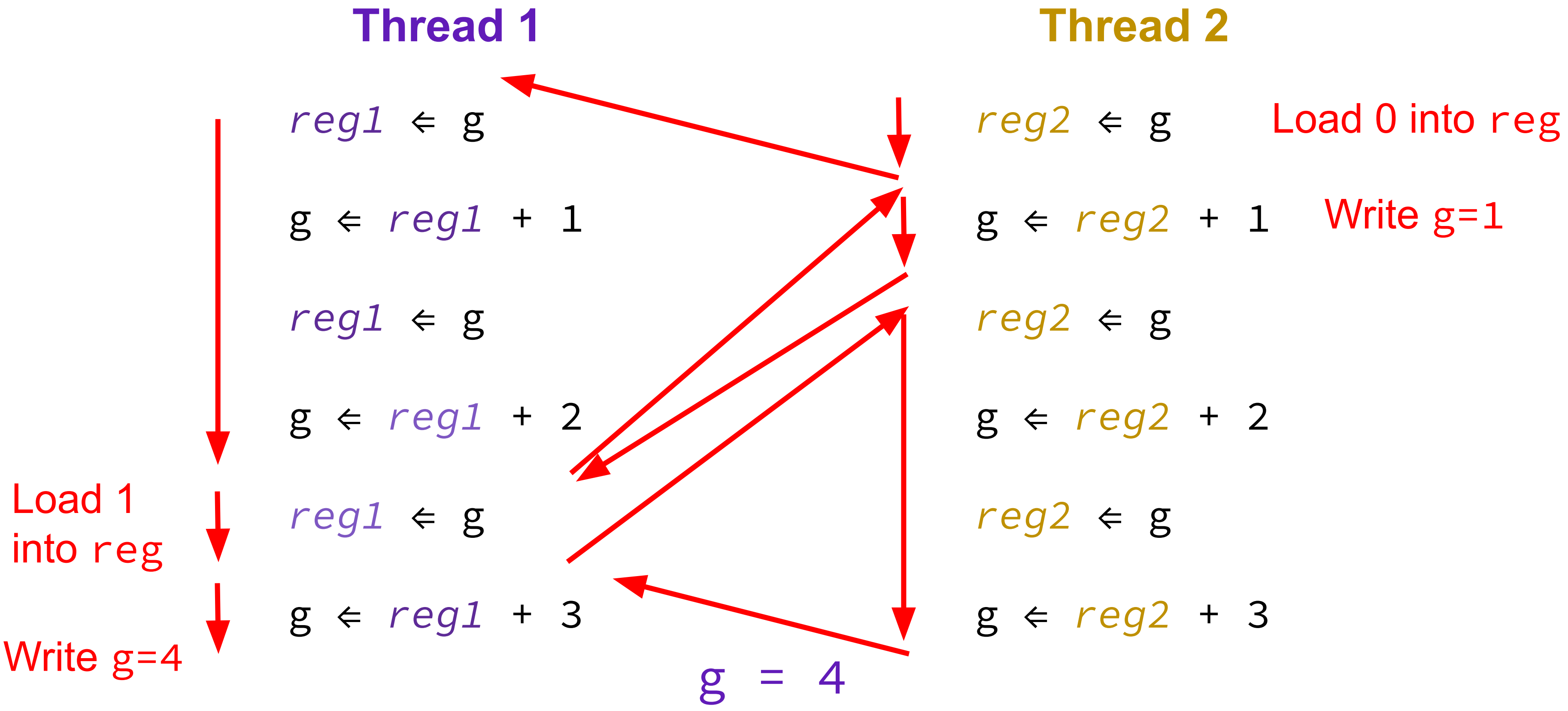
← Loads `k` into `%eax` register

← Adds copy of g in %edx to `%eax` register

← Stores addition result back into global `g`

The "trick" is that because threads execute concurrently, the processor might be switched to a different thread after executing any instruction. When this sequence of code is executed, it could be interrupted between any two instructions by another thread that reads or writes global variable g.

Getting 4 from Exercise 1



Thread 1

```
reg1 ⇐ g
g ⇐ reg1 + 1
reg1 ⇐ g
g ⇐ reg1 + 2
reg1 ⇐ g
g ⇐ reg1 + 3
```

Thread 2

```
reg2 ⇐ g
g ⇐ reg2 + 1
reg2 ⇐ g
g ⇐ reg2 + 2
reg2 ⇐ g
g ⇐ reg2 + 3
```

Load 0 into `reg`

Write `g=1`

Load 1 into `reg`

Write `g=4`

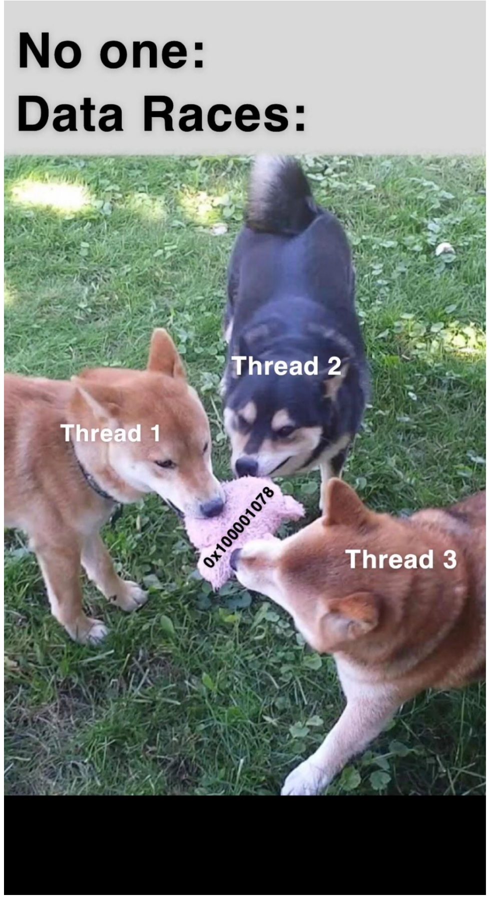
`g = 4`

Synchronization

Synchronization

- Remember, threads share an address space and system resources
- This makes it easy to communicate, but how do you avoid a total free-for-all?

- Protect your critical sections with locks!
  - Make sure nothing gets lost!
  - We'll be using `pthread_mutex`



Locking with `mutex`

```
int pthread_mutex_init(pthread_mutex_t *mutex,
              const pthread_mutexattr_t *attr);
```

- Initializes the mutex lock pointed to by `mutex` with lock attributes specified by `attr`.
- `attr` can be `NULL`.

```
int pthread_mutex_destroy(pthread_mutex_t *mutex);
```

- Destroys the lock
- Cleans up resource

Locking with `mutex`

```
int pthread_mutex_lock(pthread_mutex_t *mutex);
```

- Grabs the lock
- If resource is locked, function will be blocked until resource is unlocked

```
int pthread_mutex_unlock(pthread_mutex_t *mutex);
```

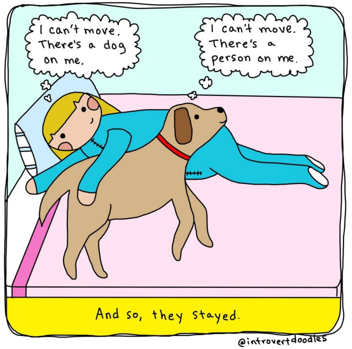
- Releases the lock

Problems with Synchronization

- Sharing Resources
  - Must be allocated / deallocated **exactly once**
  - Don’t use deallocated resources from other threads

Problems with Synchronization

- Sharing Resources
  - Must be allocated / deallocated **exactly once**
  - Don’t use deallocated resources from other threads
- Locking is hard!
  - Too much, and performance is **worse than sequential**
  - Too little, and threads clash - **often unexpected results (unwanted interleaving)**
  - Not careful, and **deadlock** freezes your program forever


I can't move. There's a dog on me.
I can't move. There's a person on me.
And so, they stayed.
@introvertdoodles

Exercise 2

Exercise 2

It’s pay day! A CSE333 student wrote this program to pay all CSE TAs, answer the questions on the next slide (or on the worksheet) about this program.

```
// Assume all necessary libraries
and header files are included
const int NUM_TAS = 10;

static int bank_accounts[NUM_TAS];
static pthread_mutex_t sum_lock;

void *thread_main(void *arg) {
  int *TA_index =
     static_cast<int *>(arg);

  pthread_mutex_lock(&sum_lock);
  bank_accounts[*TA_index] += 1000;
  pthread_mutex_unlock(&sum_lock);

  delete TA_index;
  return nullptr;
}
```

```
int main(int argc, char **argv) {
  pthread_t thds[NUM_TAS];
  pthread_mutex_init(&sum_lock, nullptr);

  for (int i = 0; i < NUM_TAS; i++) {
    int *num = new int(i);
    if (pthread_create(&thds[i], nullptr, &thread_main, num)!= 0){
      /*report error*/
    }
  }


  for (int i = 0; i < NUM_TAS; i++) {
    cout << bank_accounts[i] << endl;

  }

  pthread_mutex_destroy(&sum_lock);
  return 0;
}
```

Exercise 2

a. Does the program increase the TAs’ bank accounts correctly? Why or why not?

b. Could we implement this program using processes instead of threads? Why would or why wouldn’t we want to do this?

c. Assume that all the problems, if any, are now fixed. The student discovers that the program they wrote is kinda slow even though its a multithreaded program. Why might it be the case? And how would you fix that?

Exercise 2

a) Does the program increase the TAs' bank accounts correctly? Why or why not?

No, it's not correct. It requires main to call `pthread_join` to wait for each thread to finish before exiting the main program.

`pthread_exit()` will let a child thread finish leave to its parent, but it needs to be used in conjunction with `pthread_join` in order to check the results of the child thread.

Exercise 2

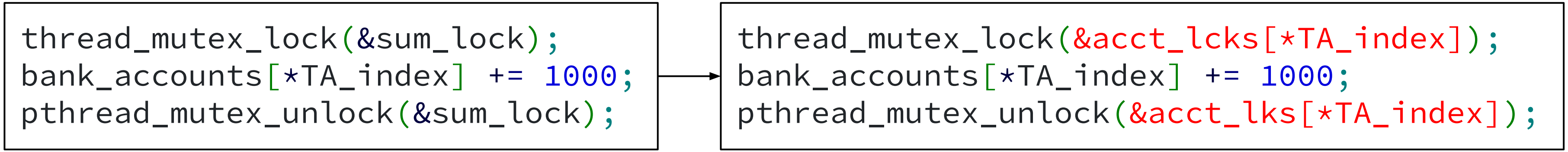
b) Could we implement this program using processes instead of threads? Why would or why wouldn’t we want to do this?

We could, but doing so would require some way for the processes to communicate with each other so that the data structure can be “shared” (remember that inter-process communication can be difficult and time consuming).

It is much easier to just use threads since each thread could directly access the data structure.

Exercise 2

c) Assume that all the problems, if any, are now fixed. The student discovers that the program they wrote is kinda slow even though its a multithreaded program. Why might it be the case? And how would you fix that?



```
thread_mutex_lock(&sum_lock);
bank_accounts[*TA_index] += 1000;
pthread_mutex_unlock(&sum_lock);
```

```
thread_mutex_lock(&acct_lcks[*TA_index]);
bank_accounts[*TA_index] += 1000;
pthread_mutex_unlock(&acct_lks[*TA_index]);
```

Only one thread can increase the value of one account at a time and there is no difference from incrementing each account sequentially because we only have a single lock on this line for every single thread to share.

To fix this, we can have one lock per account so that multiple threads can increment the account at the same time. (An alternative solution is to just not use locks as well since the threads made will not conflict with each other, but we should aim for safe options for the bank accounts)

Bonus!

ExtractRequestLine (Boost)

Write a function called ExtractRequestLine that takes in a well-formatted HTTP request as a string and returns a map with the keys as method, uri, version and the values from the corresponding request.

Example Input:

```
“GET /index.html HTTP/1\r\nHost: www.mywebsite.com\r\nConnection:
keep-alive\r\nUpgrade-Insecure-Requests: 1\r\n\r\n”
```

Map Returned:

```
{
   “method”  : “GET”
   “uri”     : “/index.html”
   “version” : “HTTP/1.1”
}
```

ExtractRequestLine (Boost)

```
map<string,string> ExtractRequestLine(const string& request) {
  vector<string> lines;
  boost::split(lines, request, boost::is_any_of("\r\n"),
               boost::token_compress_on);
  vector<string> components;
  string firstLine = lines[0];
  boost::split(components, firstLine, boost::is_any_of(" "),
               boost::token_compress_on);
  map<string, string> res;
  res["method"] = components[0];
  res["uri"] = components[1];
  res["version"] = components[2];
  return res;
}
```