Project 1

Non-Preemptive Multitasking (with minithreads)

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Slide heritage: Previous TAs → Robert Escriva → Zhiyuan Teo

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Announcements

- Project 1 has been published, due September 21, 2012.
- Make sure you are added on CMS for CS 4411, and that you have been assigned a group partner.
- Students without partners who haven't contacted us will be purged from CMS soon (see course webpage for list).
- No formal lecture next week; instead an FAQ session with some tips.
- Email `cs4410staff@systems.cs.cornell.edu` for help.

Outline

Goals of this project

- Learn how threading and scheduling work.
- Learn simple synchronization primitives.
- Actually implement said processes.*

* "In theory, there is no difference between theory and practice. But, in practice, there is." Jan L. A. van de Snepscheut

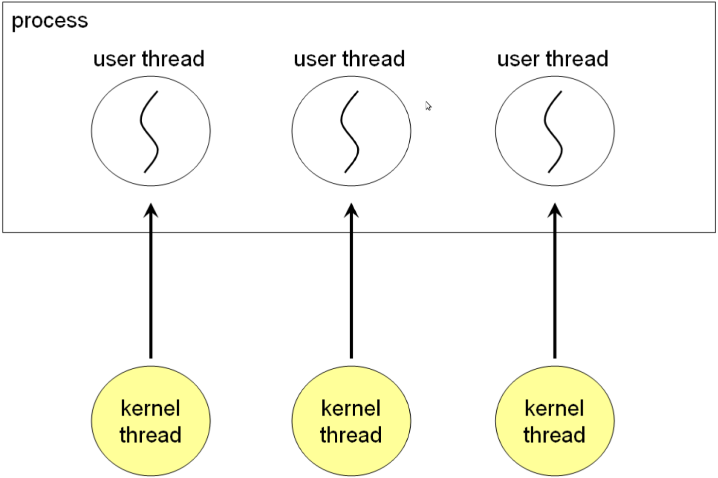
Deliverables

- A working implementation of minithreads.
- Required pieces (we recommend this order for implementation)
  - FIFO Queue with "$\mathcal{O}(1)$" append/prepend/dequeue.
  - Non-preemptive threads and FCFS scheduling.
  - Semaphore implementation.
  - A simple "retail shop" application.
- Optional (for those itching to start part II):
  - Add preemption.
  - Optional material is not graded (yet); focus on getting Part 1 right.

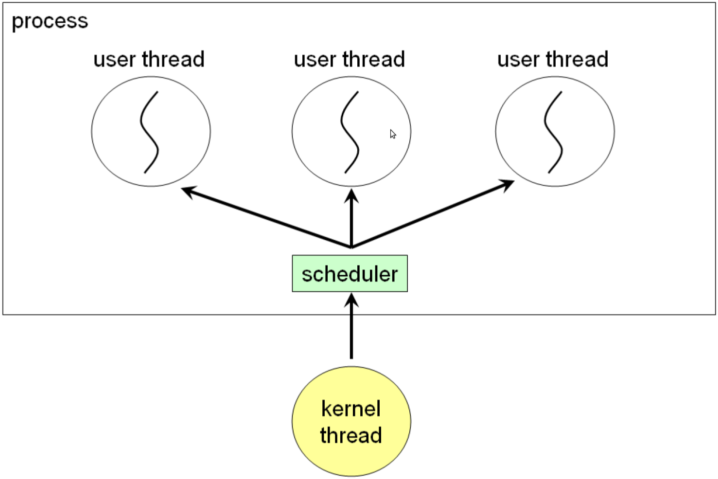
What are minithreads?

- User-level threads for Windows/OSX/Linux
  - User-level threads can perform better in some cases.
  - User-level threads can also be useful in OSes that do not provide kernel level threads.

Kernel threads



User threads

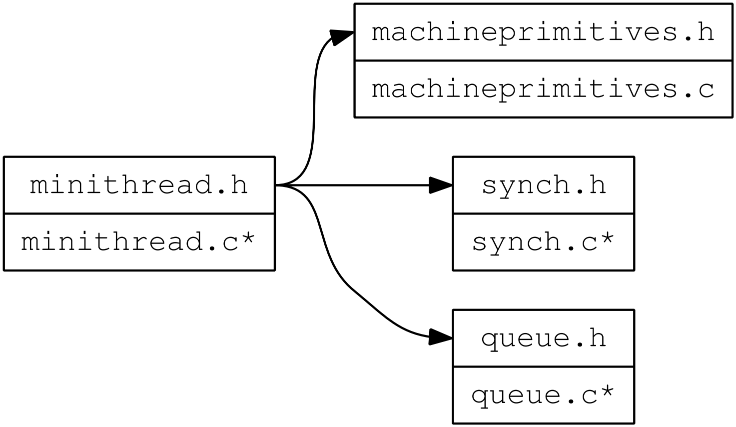


Starting point

- Interfaces for the queue (`queue.h`), minithreads (`minithread.h`), and semaphores (`synch.h`).
- Machine specific parts (`machineprimitives.h`).
  - Context switching, stack initialization, etc.
- Simple (non-exhaustive) test applications.
  - Statistically, there are a large number of untested potential bugs.
  - Write some tests of your own (be abusive to minithreads; it can take it).

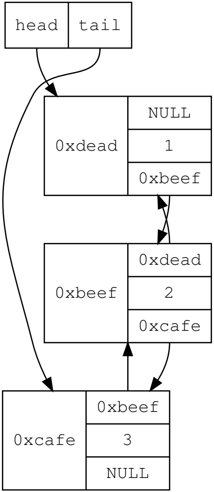
Outline

Minithreads structure



* files to finish implementing

Queues



- Singly- or doubly-linked lists can both satisfy $O(1)$.
- Data in queue is stored as `void *`
  - Allows the queue to hold arbitrary data (that is the size of a pointer).
- `queue_dequeue` takes `void **`.

Examples of `queue_dequeue`

Usage:

```
void *datum = NULL;
queue_dequeue(run_queue, &datum);
/* check return value */
```

Internals:

```
int queue_dequeue(queue_t queue,
                  void **item) {
    *item = queue->head->datum;
}
```

Minithread structure

- Need to create a Thread Control Block (TCB) for each thread.
- The TCB must have:
  - Stack top pointer (saved `esp`).
  - Stack base pointer (given to us by `minithread_allocate_stack`).
  - Thread identifier.
  - Anything else you find useful.

Operations to implement (`minithread.c`)

`minithread_t minithread_fork(proc, arg);`
Create a thread and make it runnable.

`minithread_t minithread_create(proc, arg);`
Create a thread and but don’t make it runnable.

`void minithread_yield();` Voluntarily give up CPU; let another thread in the run queue run.

Operations to implement (`minithread.c`)

`void minithread_start(minithread_t t);`
Makes a thread runnable by putting it onto the ready queue. Useful in semaphore operations, or to start a thread after it has been created through `minithread_create()`.

`void minithread_stop();` Stops running a thread immediately (ie blocks the thread); the next scheduled thread on the ready queue should run. Also useful in semaphore operations.

Creating minithreads

- Two methods
  - `minithread_t minithread_create(proc, arg);`
  - `minithread_t minithread_fork(proc, arg);`
- `proc` is a `proc_t` (a function pointer)

```
/* the definition of arg_t */
typedef int* arg_t;
/* the definition of proc_t */
typedef int (*proc_t) (arg_t);
/* how you declare a proc_t */
int run_this_proc (arg_t arg);
```

Create/fork internals

We give you functions to allocate and initialize the stack. Here's how they are defined:

```
void minithread_allocate_stack
     (stack_pointer_t *stackbase,
      stack_pointer_t *stacktop);
extern void minithread_initialize_stack
     (stack_pointer_t *stacktop,
      proc_t body_proc,
      arg_t body_arg,
      proc_t final_proc,
      arg_t final_arg);
```

minithread_initialize_stack

Sets up your stack to look as though a context switch occurred.

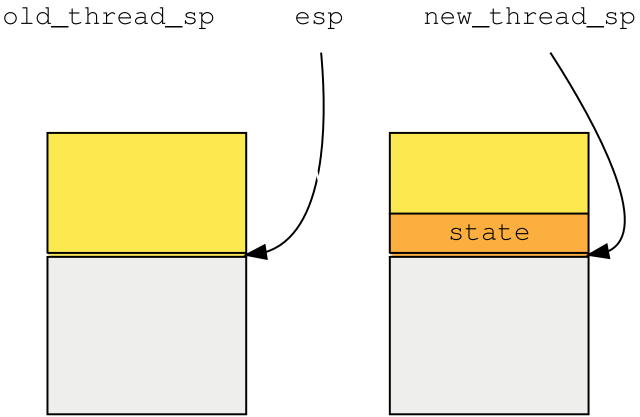
stack_base →	0xff0	final_proc addr
	0xfec	final_arg
	0xfe8	body_proc addr
	0xfe4	body_arg
stack_top →	0xfe0	root_proc addr

Context switching

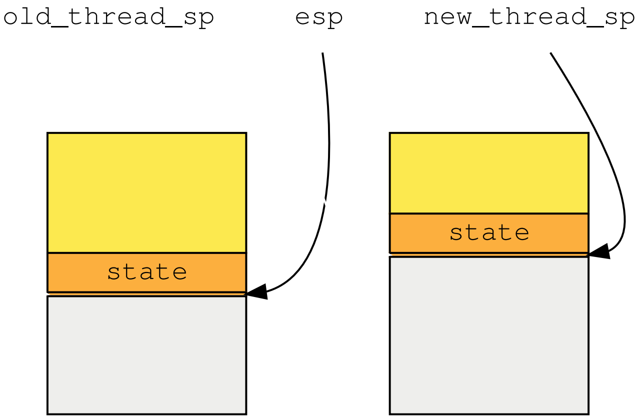
- Swap the currently executing thread with one from the run queue.
- State to save:
  - Registers
  - Program counter
  - Stack pointer
- We give you a function for this:

```
void minithread_switch
     (stack_pointer_t *old_thread_sp,
      stack_pointer_t *new_thread_sp);
```

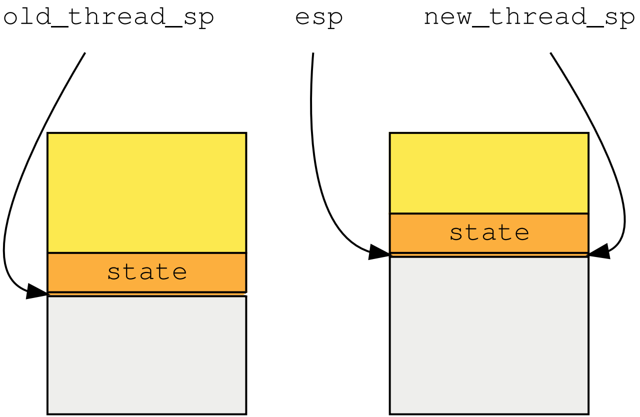
Before starting a context switch



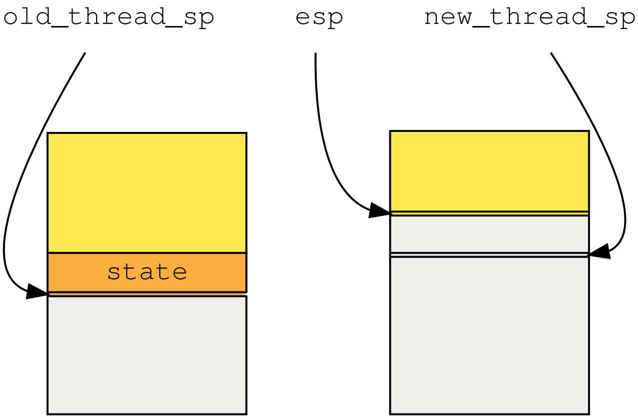
Push old context



Change stack pointers



Pop off new context



Yielding a thread

- We haven't specified any preemption. We need a way to voluntarily switch between threads.

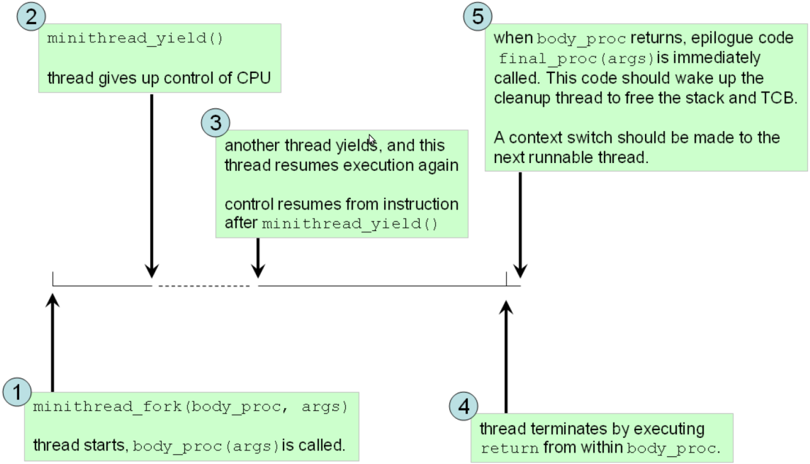
```
void minithread_yield();
```

- Use `minithread_switch` to implement `minithread_yield`
- What happens to the yielding thread?

final_proc

- final_proc is responsible for cleaning up the TCB, and stack after your thread terminates.
- It's not safe for a thread to free its own stack or TCB.
- Solution: Dedicated cleanup thread.
  - It should **wait** for threads to be ready for cleanup; otherwise it should be blocked.

Summary of minithread lifecycle



Initializing minithreads

```
void minithread_system_initialize
     (proc_t mainproc,
      arg_t mainarg);
```

- Starts up the system, and initializes global datastructures.
- Creates a thread to run `mainproc(mainarg)`
- This should be where all queues, global semaphores, etc. are initialized.

What about our Windows thread?

- We have a kernel thread used to call `minithread_system_initialize`. What should I do with it?
  - Re-use this thread as one of your behind-the-scenes threads.
  - Be careful not to cleanup or exit this thread.
- The program should never really exit, so it is a good idea to use the Windows thread (which never should be terminated) as the idle thread.

How to reuse the original stack for the idle thread

- Create a TCB for the idle thread in `minithread_system_initialize`.
- In the TCB, set `stacktop` and `stackbase` to `NULL`.
  - Don't need `stacktop` because the stack is already initialized.
  - Don't need `stackbase` because the stack will never be freed.
- What code should the idle thread execute?

A quick primer on concurrency

- Race condition: result of computation depends on the relative running speed of threads.
  - Multiple concurrent threads reading from/writing to the same memory location.
  - E.g. two threads manipulating a linked list.
- Atomic operation: either the operation goes to completion, or fails altogether.

Solution: synchronization

- We want critical section of code to run without other threads interfering.

```
queue process_queue;
lock process_queue_lock;
void manipulate_queue {
      lock_acquire (process_queue_lock);
      /* critical section begins */
            queue_dequeue (process_queue);
            queue_append (minithread_self);
      /* critical section ends */
      lock_release (process_queue_lock);
}
```

- Beware: deadlock and starvation!

Semaphores

- A synchronization primitive used to limit the number of threads accessing a shared resource.
- You decide how many threads can concurrently hold the semaphore when initializing it.
- Semaphore value is manipulated atomically:
  - `semaphore_P`: decrements the value by 1, if value was ≤ 0 blocks the thread (wait)
  - `semaphore_V`: increments the value by 1, if value was < 0 then unblocks one waiting thread (signal)
- Special case: binary semaphore is a lock.

Semaphore operations

`semaphore_t semaphore_create();` Create a semaphore (and allocate its resources).

`void semaphore_destroy(semaphore_t);` Destroy a semaphore (and `free` its resources).

`void semaphore_initialize(semaphore_t, int);` Set the initial value of a semaphore (how many `semaphore_P` functions may be called without blocking).

`void semaphore_P(semaphore_t);` Decrements a semaphore; (block if *value* ≤ 0 before decrementing).

`void semaphore_V(semaphore_t);` Increments a semaphore, unblocking a thread that is blocked on it.

Outline

Submitting your work

- Include a `README` file with your names and net IDs.
- Write SHORT notes about anything you think we should know (e.g. broken code).
- This `README` should be nearly empty as all of your code should work and be well-tested.

Concluding Advice

- Manage your memory and pointer, for they are the key to bug-free code.
- Write clean and understandable code.
  - Variables should have proper names (e.g. `stack_pointer` not `lol`)
  - Provide meaningful comments (but do not comment in excess).
  - Make your intentions clear. Do not make us make assumptions about what you wrote. This is a simple project, and we should be able to understand what you are doing with minimal effort.
- Do not terminate when program threads are done.
  - Idle threads never terminate.
  - Good luck!

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