Project 2

Adding Preemption

Tom Magrino

Slide heritage: Previous TAs → Krzysztof Ostrowski → Robert Escriva

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Announcements

- Project 1 due Sunday at 11:59PM.
- Project 2 one week from Sunday at 11:59PM.
- Email `cs4410staff@systems.cs.cornell.edu` for help.

What are does adding preemption involve?

1. Make your code threadsafe.
2. Install the interrupt handler.
3. ???
4. Profit!*

*Profit will come in the form of grades

Deliverables

- Add preemption to your scheduler.
  - You will use clock interrupts for preemption.
  - All code you wrote before must be made (mini)thread-safe.
- Alarms; sleeping with a timeout.
- Multilevel feedback scheduling policy.
  - Assign priorities to threads.
  - Round-robin between threads of the same priority.
  - Scheduler will change thread priority based on feedback from thread behavior.

Implementation plan

1. Start receiving clock interrupts.
   - Register interrupt handler.
   - Start measuring time in ticks.
2. Add preemption.
   - Synchronize access to global structures.
     - Interrupts may come at any time.
     - Our synchronization method of choice: disabling interrupts. †
   - Switch threads in the interrupt handler.

† You only really need to disable interrupts in `minithread.c`

Implementation plan

3. Add alarms.
   - Create software structure(s) to track pending alarms.
   - Use the software clock to measure elapsed time.
   - Start firing alarms from the clock interrupt handler.
4. Add sleeping.

```
minithread_sleep_with_timeout(int delay);
```

   - Register alarms, block/unblock threads.

Implementation plan

5. Add multi-level feedback scheduling.
   - Implement multilevel feedback queues.
     - Use a regular queue as the underlying structure.
     - Add a cyclic search for dequeue.
   - Extend your scheduler to use the new policy.
     - Switch to the new data structure.
     - Cycle through all four levels (to avoid starvation).
     - Add feedback and move threads between levels.

Interacting with Interrupts

- Definitions:

```
typedef void (*interrupt_handler_t)
                     (void *);
void minithread_clock_init(
    interrupt_handler_t clock_handler);
```

- Sample clock handler:

```
void clock_handler(void* arg) {
    /* Handle timer interrupt here */
}
```

Writing an Interrupt Handler

- The interrupt handler is interruptible!
  You should disable interrupts (temporarily) while in the handler.
- Interrupt handlers *should* be fast:
  - System functions, `printf`, etc. are all too expensive.
  - You definitely
    CANNOT BLOCK!.

Enabling/Disabling Interrupts

- Definitions for changing interrupts:

```
typedef int interrupt_level_t;
#define ENABLED 1;
#define DISABLED 0;
interrupt_level_t set_interrupt_level(
    interrupt_level_t newlevel);
```

- **Strongly recommended** usage:

```
interrupt_level_t oldlevel =
    set_interrupt_level(DISABLED)
do_something();
set_interrupt_level(oldlevel);
```

Keeping Time

- Change the `PERIOD` in `interrupts.h`:

```
#define SECOND 1000000
#define MILLISECOND 1000
#define PERIOD (100*MILLISECOND)
```

- Measuring elapsed time
  - System functions are way too slow.
  - Software clock: just count interrupts.

```
extern long ticks;
```

How are interrupts processed?

- Always execute in the context of a thread...
  ... that happened to be running when the interrupt was triggered.
- The process of an interrupt:
  - Current state is saved on the stack of the running thread.
  - Handler is called.
  - After the handler completes, the saved state is restored.

Interrupts and System Calls

- Windows' system libraries are not (mini)thread-safe...
  ... so interrupts are disabled (underneath, not by you) while the process is inside system calls.
- What happens if e.g. a thread spends a lot of time printing to the screen?
  - Most interrupts are missed.
  - Scheduler cannot promptly switch between processes.
  - Software clock drifts; alarms don't fire on time.

Why the need to synchronize?

- Clock interrupts may arrive at any (unprotected) place in your code.
- Any thread may be preempted while reading/writing the scheduler's data-structures.
- Multiple threads could concurrently try accessing the same structures.
- The clock handler needs to access the same global structures (so that it may preempt threads).

Synchronization Strategies

- What not to use: spin locks
  - Cannot use with interrupts disabled.
    - Active waiting is time consuming.
    - If we're consuming processor time, who will unlock the lock?
- What to use: disabling interrupts
  - Works well on uniprocessors.
  - Critical sections must be short (interrupts should not be disabled for long).
  - Disabling interrupts unnecessarily will be penalized.
  - Follow the recommended pattern of usage.

Information so important that it has its own section

- Unmatched enabling/disabling.
  - Your function could be called with interrupts disabled (enabling them would compromise your system's safety).
  - Application code should *never* run with interrupts disabled.
- Disabling interrupts unnecessarily.
  - You should use better synchronization methods outside `minithreads.c`
- Disabling interrupts for too long.

Implementing Alarms

- What you need to implement:

```
int register_alarm(
    int delay,
    void (*func)(void *),
    void* arg);
void deregister_alarm(int alarmid);
```

- What you need behind the scenes:
  - Some structure to keep information about registered alarms.‡
  - Code in the interrupt handler to fire alarms.
    - Use `ticks` to calculate elapsed time.

‡We do **not** recommend using queues from project 1.

Using Alarms

- Alarms are fired in the interrupt handler.
  - Interrupts are disabled in the interrupt handler.
  - You cannot spend much time in your callback.
  - You cannot block.

  - Alarm handler is called in the context of the **currently executing thread**...

    ... which is likely to be **different from the thread that registered the alarm**.

Implementing thread sleeping

- What you need to implement:

```
void minithread_sleep_with_timeout(
    int delay);
```

- Expected behavior:
  - Block the caller (and relinquish the CPU).
    The caller should not be on the ready queue.
  - Wake up the thread after the timeout expires.
    Make the thread runnable (on the ready queue); a context switch is unnecessary.

Behind the scenes

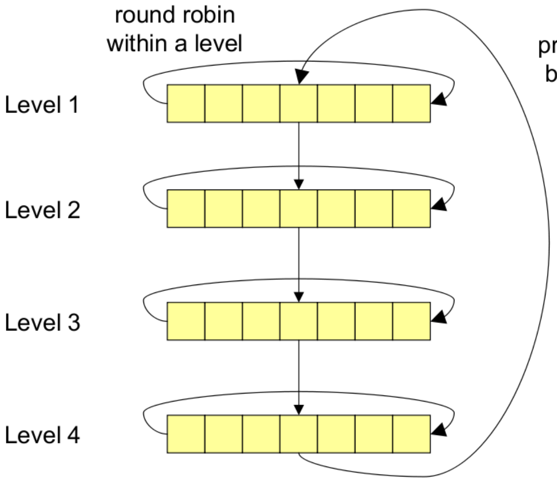
- You should use the alarm functions.
- You should use semaphores instead of `minithread_start()` and `minithread_stop()`
  - This is more-modular structure.
- Avoid race conditions[§]:
  - Side effects of this function should be atomic.

[§] It's good practice to spot the race condition

Multilevel Queue Prototypes

```
typedef struct multilevel_queue*
    multilevel_queue_t;
multilevel_queue_t multilevel_queue_new(
    int number_of_levels);
int multilevel_queue_enqueue(
    multilevel_queue_t queue,
    int level, any_t item);
int multilevel_queue_dequeue(
    multilevel_queue_t queue,
    int level, any_t *item);
int multilevel_queue_free(
    multilevel_queue_t queue);
```

MLQ Structure



priority scheduling between levels...

...but we're not always starting at the highest level (no starvation)

Scheduling Policy

- Cycle through all four levels (moving the starting point for a dequeue).
- After a given number of quanta, move to the next level.
- Spend 80 / 40 / 24 / 16 quanta in levels 0 to 3, respectively.
- Assign 1 / 2 / 4 / 8 quanta at a time to levels 0 to 3, respectively.
- If there are no threads to schedule for a level, look in the following levels.
- Schedule in round-robin fashion within a level.

Thread Priorities

- Extend the TCB to keep a thread's priority.
- A thread's priority determines which queue (0-3) a thread goes into.
  - A thread's queue determines the size/frequency of a thread's allocated run time.
- A thread starts at the highest priority.
- Priorities decrease over time.
  - A thread receives lower priority when it outruns its quanta.

Changing priorities

- Change the thread's priority (in the TCB).
- Re-evaluate priority on context switch.
  - Leave the priority unchanged
    - When a thread is blocking (stop/semaphores).
    - When a thread is yielding.
  - Lower the priority (until it hits bottom)
    - When a thread is preempted.
- Priorities are never raised.
- Any other reasonable policies?

Grading

- Correctness
  - Avoid race conditions.
  - Use interrupts correctly.
  - Do not leak memory.
- Efficiency
  - Interrupts should be disabled for short periods of time.
  - Don't disable interrupts unnecessarily.
  - Interrupt handler processing should be fast.
  - Schedule the idle thread only when there is nothing more to schedule.
  - Use semaphores where possible.
- Elegance
  - Your code should be modular and easy to understand.

Advice

- Start early.
- Work incrementally.
- Test thoroughly.