CS4411 Project 2
Preemption, Alarms, etc

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All slides stolen.

What do you have to do?

- Required
  - Adding preemption to your scheduler
    - You will heavily rely on clock interrupts in this project
    - All your minithreads code must now be made thread-safe
  - Sleeping with timeout
  - Multilevel feedback scheduling policy
    - Strict priority scheduling between levels and round-robin within a level, quanta doubling at each level
    - Feedback used to move threads between the queues
- Optional
  - Unreliable datagrams

A more detailed plan (1)

- Start receiving clock interrupts
  - Register interrupt handler
  - Start measuring the elapsed time
- Add preemption
  - Synchronize access to global structures
    - Your „system” code may now be interrupted at any time
    - Our method of choice: disabling interrupts
  - Switch threads in the interrupt handler

A more detailed plan (2)

- Add alarms
  - Create a structure to manage info about alarms
  - Use your software clock to measure time
  - Start firing alarms in the clock interrupt handler
- Add sleeping

  `minithread_sleep_with_timeout()`

  - Register alarms, block and unblock threads

A more detailed plan (3)

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

The basics of interrupts (1)

- Installing the interrupt handler
  - Register it during initialization

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

void minithread_clock_init(
        interrupt_handler_t clock_handler);
```

  - How to declare it in your code

```
void clock_handler(void* arg)
{
    ...
}
```

The basics of interrupts (2)

- Remember that...
  - Initially interrupts are disabled, need to enable them
  - You can still receive interrupts while in the interrupt handler, so you should disable them temporarily
  - You must not spend much time inside the handler
    - Should not call system functions, print to screen etc. since they consume too much time
    - You definitely... **CANNOT BLOCK!**

The basics of interrupts (3)

- Disabling clock interrupts (what to call)

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

- A **strongly recommended** way to use the above

```
interrupt_level_t intlevel =
         set_interrupt_level(DISABLED);

(here comes your code)

set_interrupt_level(intlevel);
```

Interrupts and time

- Adjusting the frequency
  - Need to modify "**interrupts.h**"

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

granularity 1μs

- Measuring elapsed time
  - Don't use system functions (they are way too slow)
  - Software clock: just count the interrupts

```
extern long ticks;
```

More about interrupts (1)

- How are interrupts processed?
  - Always executed in the context of some thread...
    ...whichever happens to be currently running.
  - What happens after the interrupt:
    - Current state is saved on the stack of the running thread
    - Handler is called
    - After the handler completes, the saved state is restored

More about interrupts (2)

- Interrupts and system calls
  - System libraries are not 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 is drifting, alarms don’t fire on time

Adding synchronization (1)

- Why the need to synchronize
  - Clock interrupts could arrive at any time
  - Any thread might be preempted while reading or updating the structures of the scheduler itself...
  - ...so this way multiple threads could be updating the same structures at the same time!
  - Clock handler itself needs to access the same global structures (to make scheduling decisions)

Adding synchronization (2)

- What not to use: spin locks
  - Cannot use it in the interrupt handler
    - Any kind of active waiting would be too time consuming
    - And anyway... who's going to enable the lock if it's locked?
- What to use: disabling interrupts
  - A good, efficient method on uniprocessors
  - Critical section must be short!
  - Disabling interrupts unnecessarily will be penalized
  - Follow the recommended pattern of usage

Interrupts: Beware...

- Beware of the following...
  - Unmatched enabling / disabling
    - You could be called with interrupts disabled (enabling them will compromise system safety)
    - You should never let the application code run with interrupts disabled
  - Disabling interrupts unnecessarily
    - You should not disable them outside *minithreads*
  - Disabling interrupts for too long

Alarms: Implementing

- What you need to implement:

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

- What you need underneath...
  - Some structure to keep information about alarms
  - Code in interrupt handler that fires alarms
    - Use the global variable ticks that you're updating on every interrupt to calculate the elapsed time

Alarms: Using

- Issues with using alarms
  - Alarms are fired in the interrupt handler, therefore...
    - Interrupts are disabled at that time
    - You cannot spend much time in your callback
    - You cannot block
    - Alarm handler is called in the context of the **currently executing thread**...

      ...which most of the time will be **different from the thread that registered the alarm**.

Sleeping with timeout (1)

- What you need to implement:

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

- Semantics:
  - Block the caller (and relinquish the CPU)
    - So you don't put him back on the ready queue
  - Wake up after the timeout expires
    - Make it runnable (put back on the ready queue), but not necessarily the current thread.

Sleeping with timeout (2)

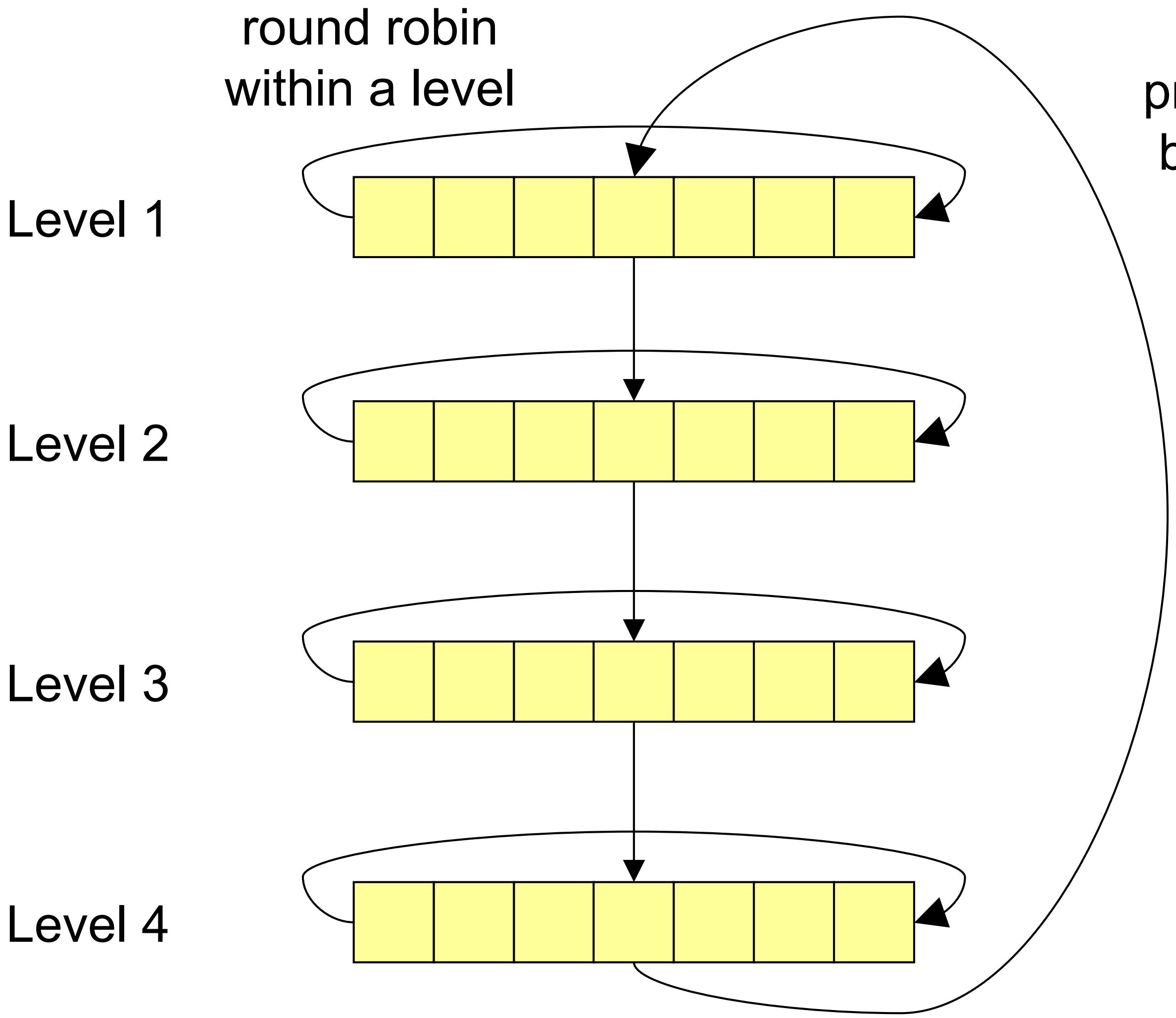
- How to implement
  - You should use the alarm functions
  - You should use the semahores rather than explicit `minithread_start` and `minithread_stop`
    - Yields a cleaner, more modular structure
  - Avoid race conditions
    - Should register alarm / start waiting atomically

Multilevel queues

- What to implement:

```
typedef void* 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);
```

A new scheduling policy



priority scheduling between levels...

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

Changing scheduling policy (1)

- Choosing threads for execution
  - We cycle through all four levels (moving starting point for dequeue)
  - After a given number of quanta, move to next level
  - Spend 80 / 40 / 24 / 16 quanta in levels 0 to 3, respectively
  - While at a given level, look for threads to schedule starting from a corresponding queue (keep looking in the following levels if empty)
  - Skip to next level if a queue is empty
  - While queue nonempty, keep scheduling threads from this queue in a round-robin fashion
  - Asign 1 / 2 / 4 / 8 quanta at a time at levels 0 to 3, correspondingly

Changing scheduling policy (2)

- Adding priorities to threads
  - We deed to extend the TCB to keep those
  - Use a thread’s priority when enqueueing it
  - Priority determines the queue...
    - ...and the queue determines time slice and the frequency with which a thread will be scheduled
  - Initially all threads get the highest priority
  - As time goes, thread priorities decrease
    - We switch to a lower priority when a thread is blocking, yielding or has outrun its time slice

Changing scheduling policy (3)

- Adding aging
  - Need to lower the thread’s priority (in TCB)
  - Do it when when changing the active thread
    - Keep the current priority as it is
      - When a thread is blocking (stop and semahores)
      - When a thread is yielding
    - Lower priority (if not the lowest)
      - When a thread has outrun its quanta
  - Priorities are never raised
    - Could you think of any other reasonable policies?

Grading

- Correctness
  - Beware of race conditions: synchronization!
  - Correct enabling and disabling of interrupts, follow our pattern
  - Cleaning threads and structures, avoiding memory leaks
- Efficiency
  - Disabling interrupts: only for a short time and only when it is indeed necessary
  - Processing in the interrupt handler should be fast!
  - Idle thread should not take up non-idle time
  - Consider using semaphores if necessary rather than polling
- Elegance
  - Your code should have a modular structure