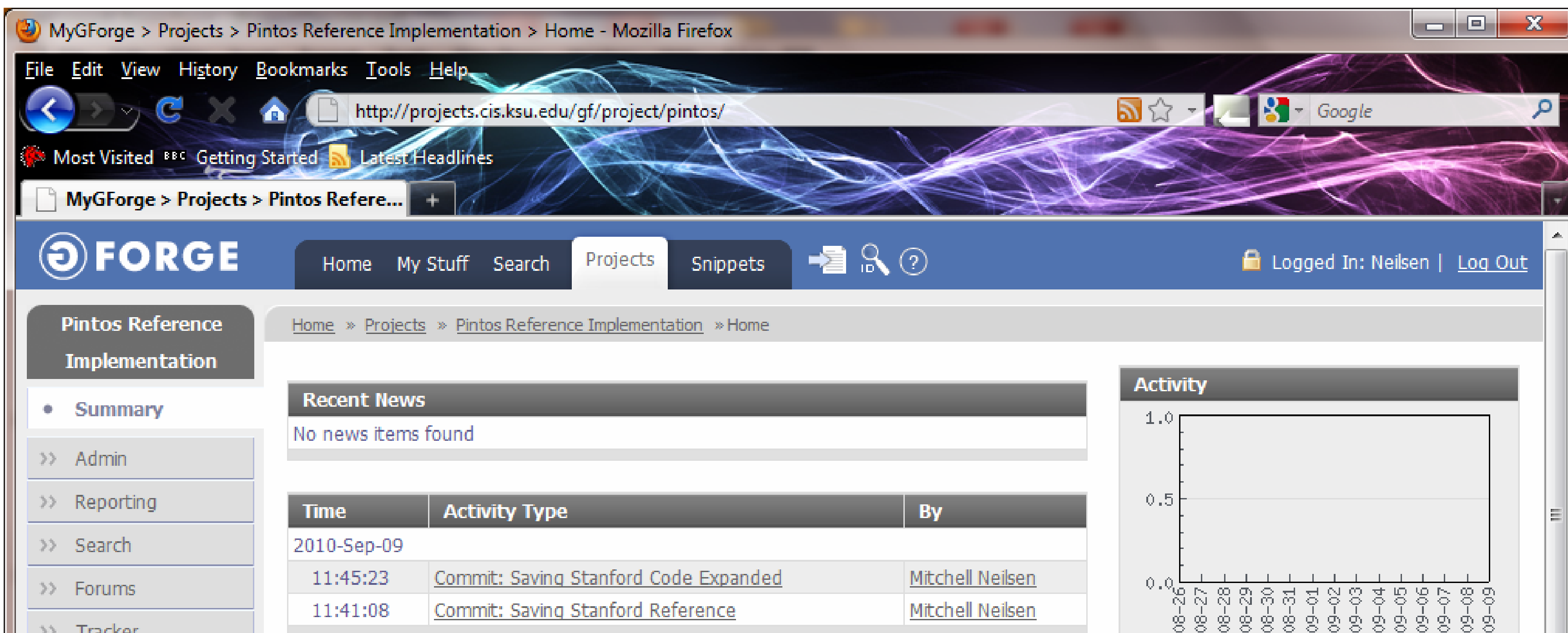
Project 1: Thread Scheduling

Introduction to Pintos

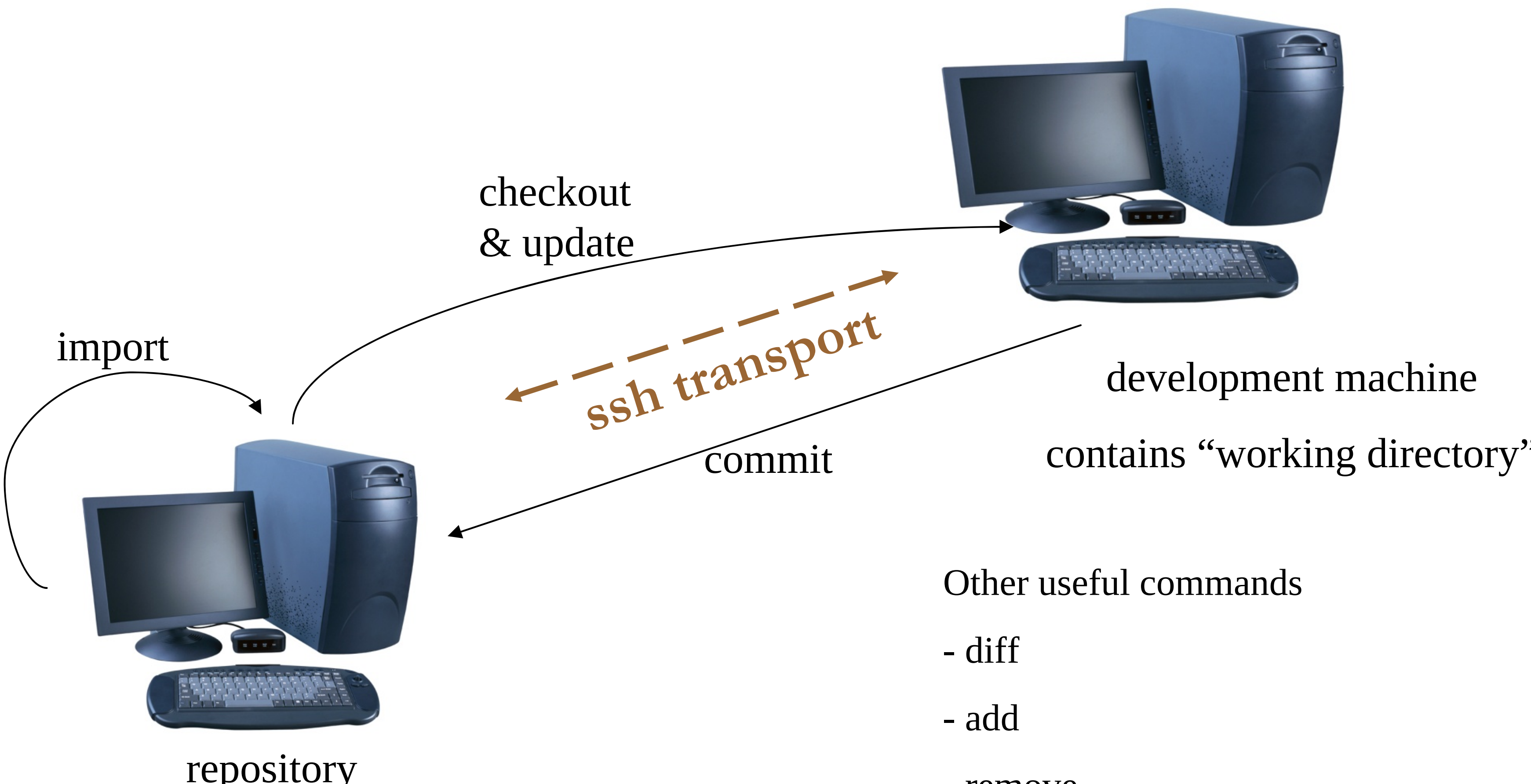
- Simple OS for the 80x86 architecture
- Capable of running on real hardware
- We use bochs and/or qemu to run Pintos
- Provided implementation supports kernel threads, user programs and file system
- In the projects, strengthen support for these and implement support for virtual memory

Version (Revision) Control System

- Start by choosing a code keeper for your group
- Keeper creates repository on CIS GForge, code.google.com, github.com, or sourceforge.net
- Base versions are checked out to create a working copy, and changes to working copy are commited using subversion, git, or some other version control system software.



Using Version Control System



Other useful commands

- diff
- add
- remove
- update

CVS Jargon

- “Do an update”
- “Pull the latest”
- “Commit your stuff”
- “Push your changes”
- “Diff against the HEAD”
- “Diff against BASE”
- “Outstanding diffs?”

Bring your working directory in sync with the CVS repository to pick up and integrate changes other team members may have made.

Upload your change to the CVS repository, allowing others to see them. May create a new revision if there were changes.

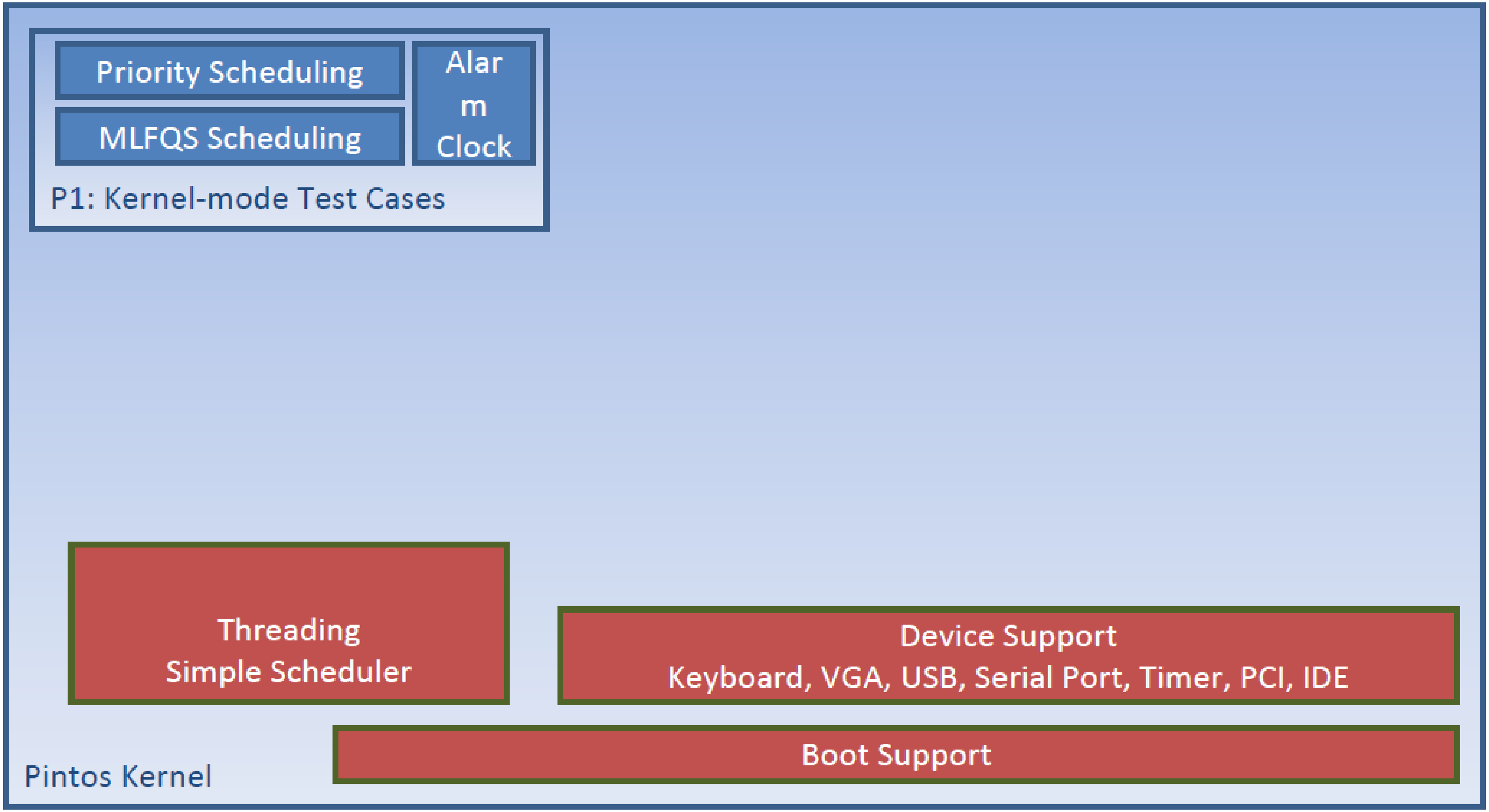
Compare your working version to the version last checked in by any team member.

Compare your working version to the version you last checked out. Any changes you’ve made are “outstanding” – group members can’t see them yet.

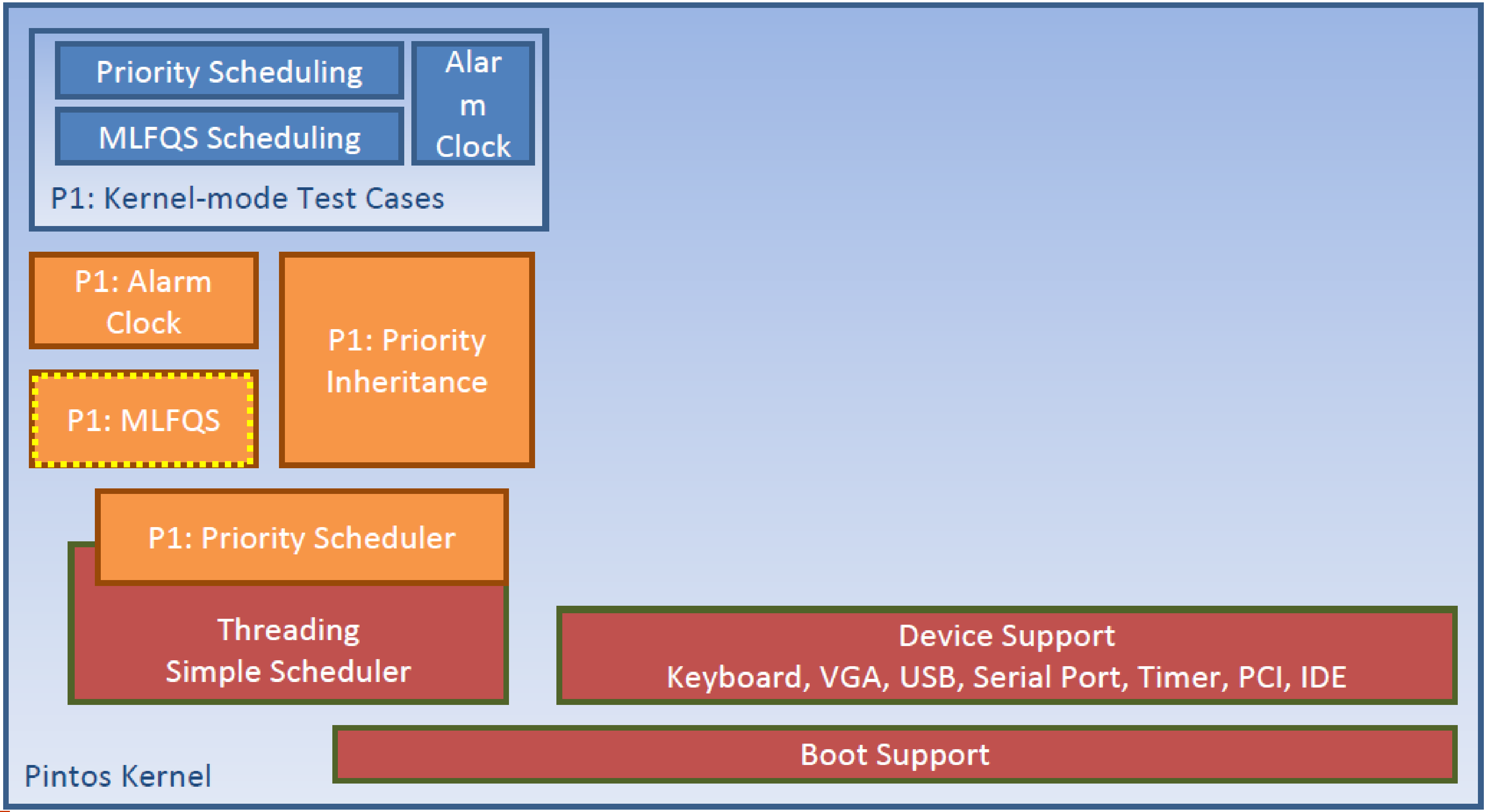
Project 1 Overview

- Extend the functionality of a minimally functional thread system
- Implement
  - Alarm Clock
  - Priority Scheduling
    - Including priority inheritance
  - Advanced MLFQ Scheduler [Extra Credit]

Project 1: Components



Project 1: Components

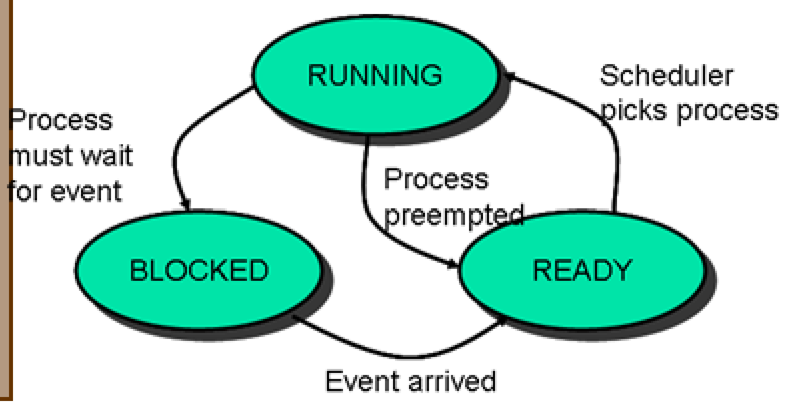


Pintos Thread System

src/threads/thread.h

```
struct thread
  {
    tid_t tid;                /* Thread identifier. */
    enum thread_status status;          /* Thread state. */
    char name[16];   /* Name (for debugging purposes). */
    uint8_t *stack;    /* Saved stack pointer. */
    int priority;         /* Priority. */
    struct list_elem allelem;  /* List element for all-threads list.*/
    /* Shared between thread.c and synch.c. */
    struct list_elem elem;              /* List element. */

You add more fields here as you need them.

#ifdef USERPROG
    /* Owned by userprog/process.c. */
    uint32_t *pagedir;                  /* Page directory. */
#endif
    /* Owned by thread.c. */
    unsigned magic;   /* Detects stack overflow. */
  };
```

```
4 kB +-----------------------------------+
     |          kernel stack             |
     |               |                   |
     |               |                   |
     |               V                   |
     |         grows downward            |
     |                                   |
     |                                   |
     |                                   |
     |                                   |
     |                                   |
     |                                   |
     |                                   |
     |                                   |
     +-----------------------------------+
     |              magic                |
     |                :                  |
     |                :                  |
     |               name                |
     |              status               |
0 kB +-----------------------------------+
```

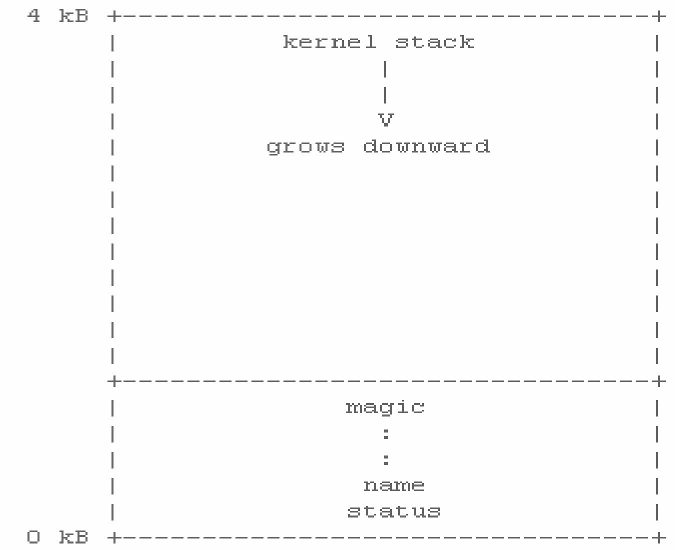


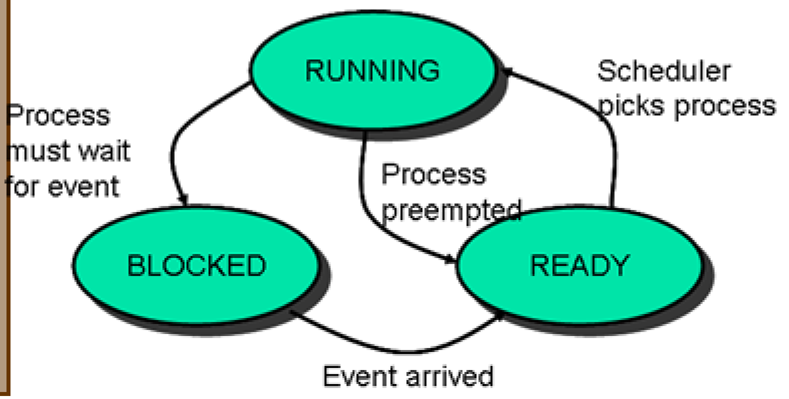
Pintos Thread System

src/threads/thread.c

```
..
  /* Random value for struct thread's `magic' member.
   Used to detect stack overflow.  See the big comment at the top
   of thread.h for details. */
#define THREAD_MAGIC 0xcd6abf4b

/* List of processes in THREAD_READY state, that is, processes
   that are ready to run but not actually running. */
static struct list ready_list;

/* List of all processes.  Processes are added to this list
   when they are first scheduled and removed when they exit. */
static struct list all_list;

/* Idle thread. */
static struct thread *idle_thread;
```

See src/lib/kernel/list.c for list handling functions





Pintos Thread System (contd…)

- Read threads/thread.c, threads/switch.S, and threads/synch.c to understand
  - How the switching between threads occur
  - How the provided scheduler works
  - How the various synchronizations primitives work

Alarm Clock

- Reimplement timer_sleep( ) in devices/timer.c without busy waiting

```
/* Suspends execution for approximately TICKS timer ticks. */
void timer_sleep (int64_t ticks){
  int64_t start = timer_ticks ();
  ASSERT (intr_get_level () == INTR_ON);
  while (timer_elapsed (start) < ticks)
    thread_yield ();
}
```

- Implementation details
  - Remove thread from ready list and put it back after sufficient ticks have elapsed
  - Use semaphore to block thread on semaphore associated with thread getting blocked; e.g., initialize semaphore with count?

Semaphores [Dijkstra]

- **A *Semaphore* is initialized with an integer** *N*
- **Provides two functions:**
  - sem_wait (S) (originally called *P*, called ***sema_down*** in Pintos)
  - sem_signal (S) (originally called *V* , called ***sema_up*** in Pintos)
- **Guarantees** sem_wait **will return only** *N* **more times than** sem_signal **called**
  - Example: If *N* == 1, then semaphore is a mutex with sem_wait as lock and sem_signal as unlock
- **Semaphores allow elegant solutions to some problems**

Semaphore

A semaphore is a structure consisting of 2 parts:

```
struct semaphore {
    int count;   // number of resources available
    queue Q;   // queue of process/thread ids of blocked
}
```

Shorthand notation:

semaphore S = 1 → S.count = 1, S.Q = { }

Operations on Semaphores

There are two basic semaphore operations:

sem_wait(S):

if (S.count > 0) then S.count = S.count -1;

else block calling process in S.Q;

sem_signal(S):

if (S.Q is non-empty) then wakeup a process in S.Q;

else S.count = S.count + 1;

Semaphore Example: Mutual Exclusion

```
Semaphore S = 1;

Thread A:                                   Thread B:
 sem_wait(S);                                sem_wait(S);
    (do work in critical section CS);           (do work in CS);
 sem_signal(S);                              sem_signal(S);
```

Semaphore Example: Order Execution

Semaphore S = 0;

Thread A → Thread B:

Thread A:
 (do work);
 sem_signal(S);

Thread B:

sem_wait(S);
(do work);

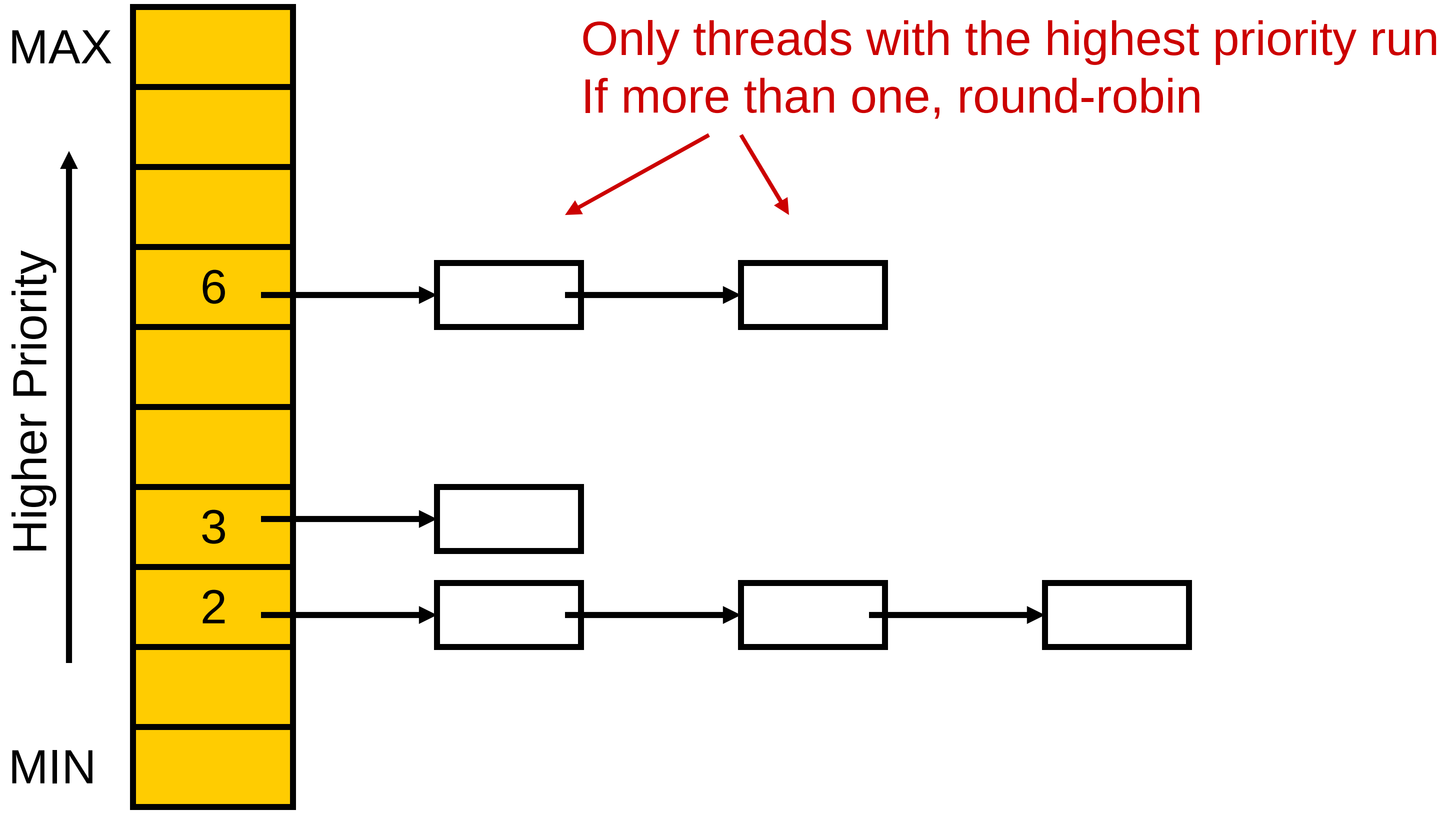
Pintos Semaphores

- struct semaphore s;
- sema_init(&s, 1);
- sema_down(&s);
- sema_up(&s);

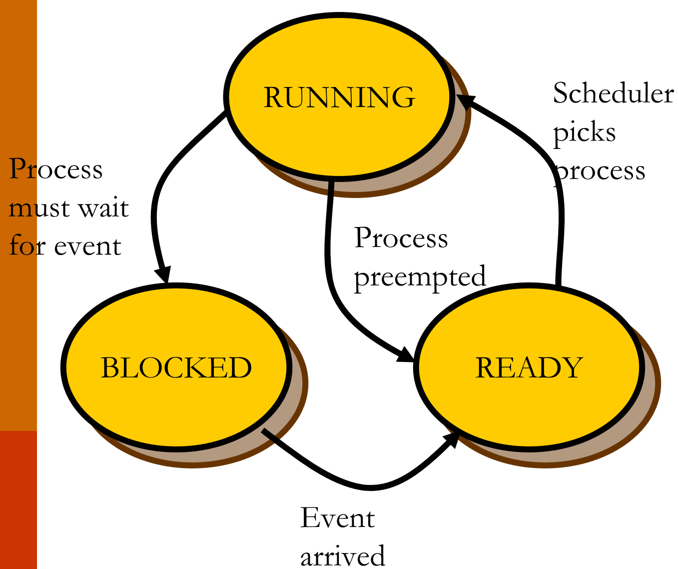
Priority Scheduler

- Ready thread with highest priority gets the processor
- When a thread is added to the ready list that has a higher priority than the currently running thread, immediately yield the processor to the new thread
- When threads are waiting for a lock, semaphore or a condition variable, the highest priority waiting thread should be woken up first
- Implementation details
  - compare priority of the thread being added to the ready list with that of the running thread
  - select next thread to run based on priorities
  - compare priorities of waiting threads when releasing locks, semaphores, condition variables

Priority Based Scheduling



Using thread_yield() to implement preemption



- Current thread ("RUNNING") is moved to READY state, added to READY list.
- Then scheduler is invoked. Picks a new READY thread from READY list.
- Case a): there's only 1 READY thread. Thread is rescheduled right away
- Case b): there are other READY thread(s)
  - b.1) another thread has higher priority – it is scheduled
  - b.2) another thread has same priority – it is scheduled provided the previously running thread was inserted in tail of ready list.
- "thread_yield()" is a call you can use whenever you identify a need to preempt current thread.
- Exception: inside an interrupt handler, use "intr_yield_on_return()" instead

Priority Inversion

- Strict priority scheduling can lead to a phenomenon called "priority inversion"
- Supplemental reading:
  - What really happened on the Mars Pathfinder?
- Consider the following example where prio(H) > prio(M) > prio(L)
  - H needs a lock currently held by L, so H blocks
  - M that was already on the ready list gets the processor before L
  - H indirectly waits for M
  - (on Path Finder, a watchdog timer noticed that H failed to run for some time, and continuously reset the system)

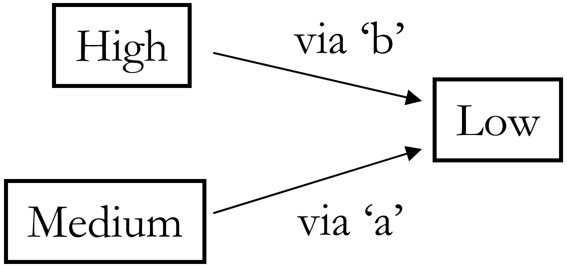
Priority Donation

- When a high priority thread H waits on a lock held by a lower priority thread L, donate H's priority to L and recall the donation once L releases the lock
- Implement priority donation for locks
- Handle the cases of multiple donations and nested donations

Multiple Priority Donations: Example

Low Priority thread

```
lock_acquire (&a);
lock_acquire (&b);

thread_create ("a", PRI_DEFAULT + 1, a_thread_func, &a);
msg ("Main thread should have priority %d.  Actual priority: %d.", PRI_DEFAULT + 1, thread_get_priority ());

thread_create ("b", PRI_DEFAULT + 2, b_thread_func, &b);
msg ("Main thread should have priority %d.  Actual priority: %d.", PRI_DEFAULT + 2, thread_get_priority ());
```



Medium Priority thread

```
static void a_thread_func (void *lock_)
{
  struct lock *lock = lock_;
  lock_acquire (lock);
  msg ("Thread a acquired lock a.");
  lock_release (lock);
  msg ("Thread a finished.");
}
```

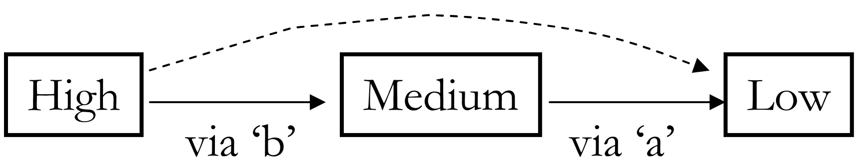
High Priority thread

```
static void b_thread_func (void *lock_)
{
  struct lock *lock = lock_;
  lock_acquire (lock);
  msg ("Thread b acquired lock b.");
  lock_release (lock);
  msg ("Thread b finished.");
}
```

Nested Priority Donations: Example

Low Priority thread

```
lock_acquire (&a);
locks.a = &a;
locks.b = &b;

thread_create ("medium", PRI_DEFAULT + 1, m_thread_func, &locks);
msg ("Low thread should have priority %d.  Actual priority: %d.",
PRI_DEFAULT + 1, thread_get_priority ());

thread_create ("high", PRI_DEFAULT + 2, h_thread_func, &b);
msg ("Low thread should have priority %d.  Actual priority: %d.",
PRI_DEFAULT + 2, thread_get_priority ());
```



Medium Priority thread

```
static void m_thread_func (void *locks_)
{
  struct locks *locks = locks_;
  lock_acquire (locks->b);
  lock_acquire (locks->a);

  msg ("Medium thread should have priority %d.
  Actual priority: %d.", PRI_DEFAULT + 2,
          thread_get_priority ());
...}
```

High Priority thread

```
static void h_thread_func (void *lock_)
{
  struct lock *lock = lock_;

  lock_acquire (lock);
 ...}
```

Advanced Scheduler [Extra Credit]

- Implement Multi Level Feedback Queue Scheduler
- Priority donation not needed in the advanced scheduler – two implementations are not required to coexist
  - Only one is active at a time
- Advanced Scheduler must be chosen only if '–mlfqs' kernel option is specified
- Read section on 4.4 BSD Scheduler in the Pintos manual for detailed information
- Some of the parameters are real numbers and calculations involving them have to be simulated using integers.
  - Write a fixed-point layer (header file)

Typesafe Fixed-Point Layer

```
typedef struct
  {
    double  re;
    double  im;
  } complex_t;

static inline complex_t
complex_add(complex_t x, complex_t y)
{
  return (complex_t){ x.re + y.re, x.im + y.im };
}

static inline double
complex_real(complex_t x)
{
  return x.re;
}
```

```
static inline double
complex_imaginary(complex_t x)
{
  return x.im;
}

static inline double
complex_abs(complex_t x)
{
  return sqrt(x.re * x.re + x.im * x.im);
}
```

Suggested Order

- Alarm Clock
  - easier to implement compared to the other parts
  - other parts not dependent on this
- Priority Scheduler
  - needed for implementing Priority Donation and Advanced Scheduler
- Priority Donation | Advanced Scheduler
  - these two parts are independent of each other
  - can be implemented in any order but only after Priority Scheduler is ready

Debugging your code

- printf, ASSERT, backtraces, gdb
- Running pintos under gdb
  - Invoke pintos with the gdb option

    pintos --gdb -- run testname
  - On another terminal invoke gdb

    pintos-gdb kernel.o
  - Issue the command

    debugpintos
  - All the usual gdb commands can be used: step, next, print, continue, break, clear etc
  - Use the pintos debugging macros described in manual

Tips

- Read the relevant parts of the Pintos manual
- Read the comments in the source files to understand what a function does and what its prerequisites are
- Be careful with synchronization primitives
  - disable interrupts only when absolutely needed
  - use locks, semaphores and condition variables instead
- Beware of the consequences of the changes you introduce
  - might affect the code that gets executed before the boot time messages are displayed, causing the system to reboot or not boot at all

Tips (contd…)

- Include ASSERTs to make sure that your code works the way you want it to
- Integrate your team's code often to avoid surprises
- Use gdb to debug
- Make changes to the test files, if needed
- Test using qemu simulator and the –j option with bochs (introduces variability whereas default options run in reproducibility mode)

Grading

- Tests – 50%
  - All group members get the same grade
- Design – 50%
  - Data structures, algorithms, synchronization, rationale and coding standards
  - Each team member should understand all data structures, algorithms, and rationale for implementation

Good Luck!