Pintos: Threads Project

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Introduction to Pintos

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

Development Environment

- Log on to the Linux cluster remotely using SSH

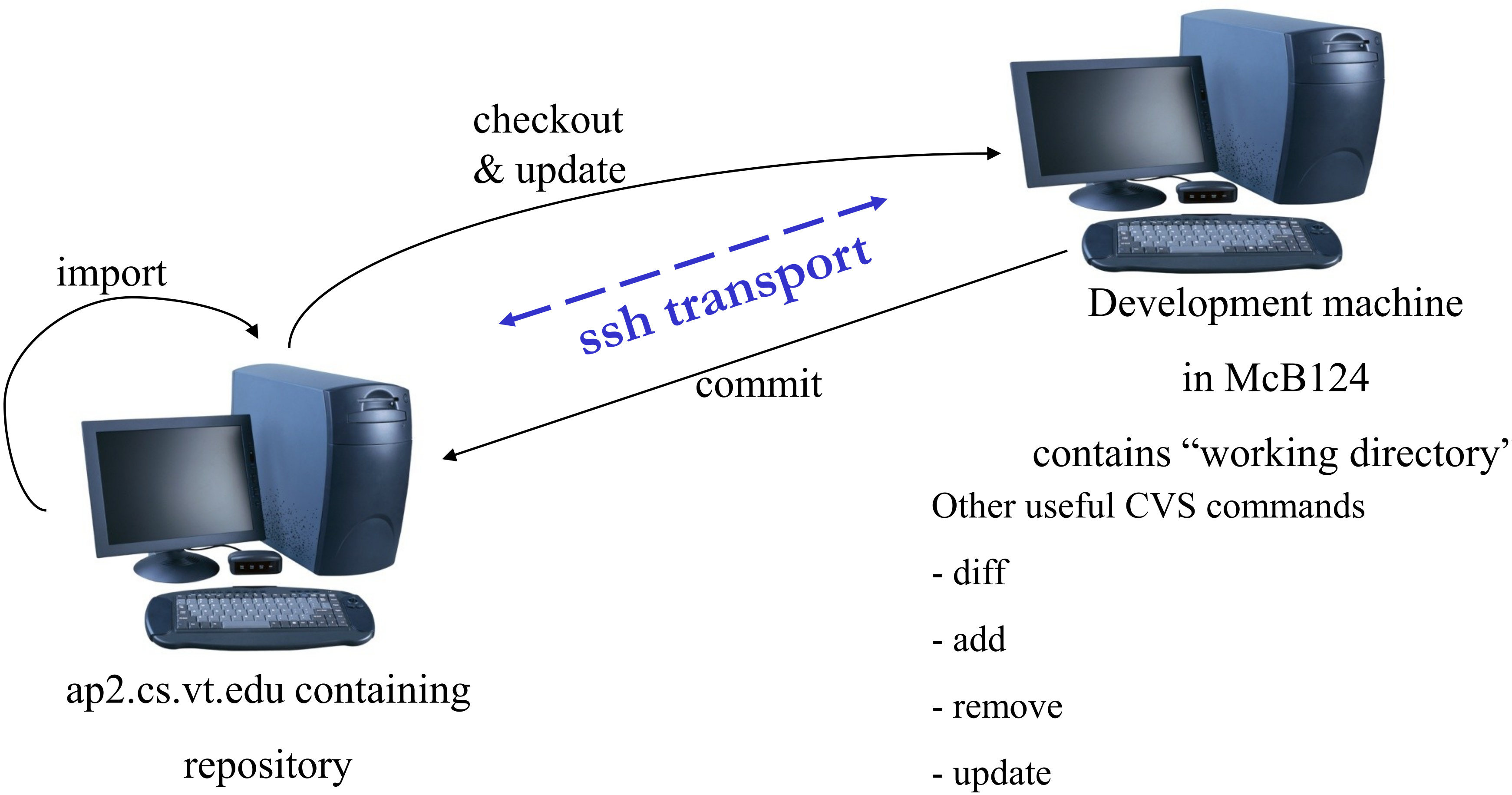
  ssh –Y yourlogin@rlogin.cs.vt.edu (for trusted X11 forwarding)
- Need ssh client
- X11 server preferable, but not absolutely needed
- Use CVS
  - for managing and merging code written by the team members
  - keeping track of multiple versions of files

CVS Setup

- Start by choosing a code keeper for your group
- Keeper creates repository on ‘ap2’
- Summary of commands to setup CVS

```
ssh ap2
cd /shared/cs3204
mkdir Proj-keeper_pid
setfacl --set u::rwx,g::---,o::--- Proj-keeper_pid
# for all other group members do:
setfacl -m u:member-pid:rwx Proj-keeper_pid
setfacl -d --set u::rwx,g::---,o::--- Proj-keeper_pid
# for all group members, including the keeper, do:
setfacl -d -m u:member_pid:rwx Proj-keeper_pid
cvs -d /shared/cs3204/Proj-keeper_pid init
cd /home/courses/cs3204/pintos/pintos
cvs -d /shared/cs3204/Proj-keeper_pid import -m "Imported sources" pintos foobar start
```

Using CVS


checkout
& update
ssh transport
import
commit
Development machine
in McB124
contains “working directory”
ap2.cs.vt.edu containing
repository
Other useful CVS commands
- diff
- add
- remove
- update

CVS Jargon

- "Do an update"
- "Pull the latest"

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

- "Commit your stuff"
- "Push your changes"

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

- "Diff against the HEAD"

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

- "Diff against BASE"
- "outstanding diffs?"

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.

cvs –nq update -d

- cvs update – download latest changes from repository and merge into working copy
- ‘-n’ show me what’d do, don’t do it
- ‘-d’ pick up additional subdirectories (not done by default)

- Outputs:
- (nothing) – means you are up-to-date
- P or U – means there’s a newer version
- M – means you have outstanding diffs
- C – means there’s a newer version and you have outstanding diffs and they can’t be reconciled
- ? – this file is not part of the repository

Getting started with Pintos

- Set env variable CVS_RSH to /usr/bin/ssh

  export CVS_RSH=/usr/bin/ssh

  If you don't, it will assume "rsh" which is not a supported service. Connection failures or timeouts will result.

- Check out a copy of the repository to directory 'dir'

  ```
  cvs -d :ext:your_pid@ap2.cs.vt.edu:/shared/cs3204/Proj-keeper_pid checkout -d dir pintos
  ```

- Add ~cs3204/bin to path add to .bash_profile

  ```
  export PATH=~cs3204/bin:$PATH
  ```

- Build pintos

  ```
  cd dir/src/threads
  make
  cd build
  pintos run alarm-multiple
  ```

Project 1 Overview

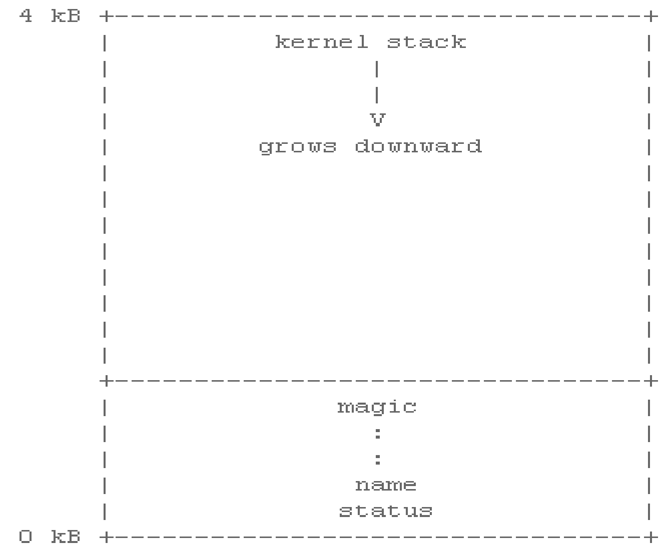
- Extend the functionality of a minimally functional thread system
- Implement
  - Alarm Clock
  - Priority Scheduling
    - Including priority inheritance
  - Advanced Scheduler

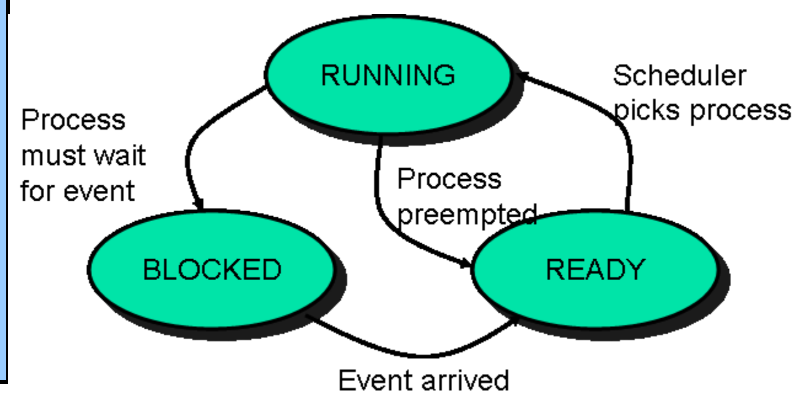
Pintos Thread System

```
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. */
  };
```





Pintos Thread System (contd…)

- Read threads/thread.c 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

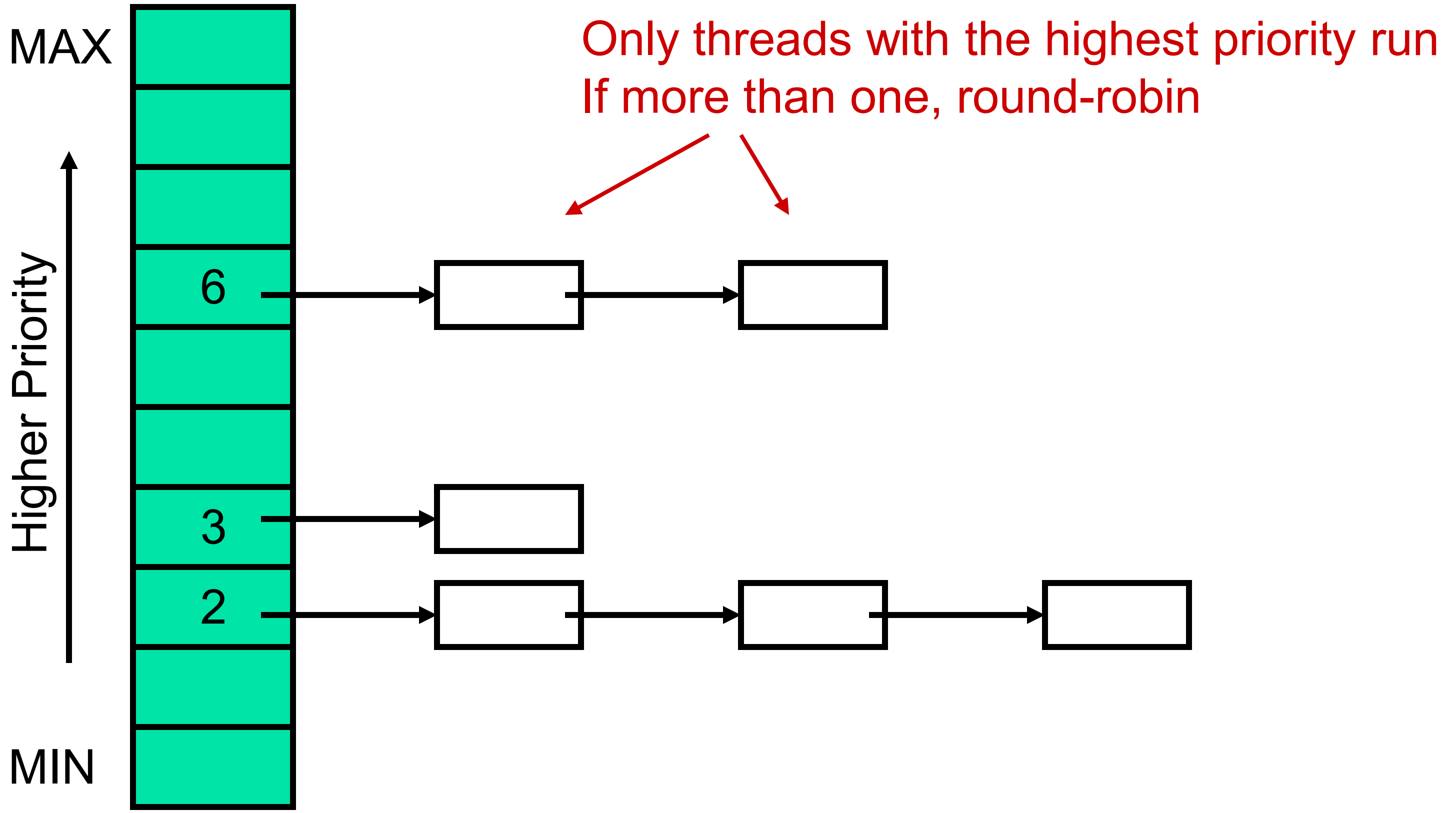
```
/* Suspends execution for approximately TICKS timer ticks. */
void timer_sleep (int64_t ticks){
  int64_t start = timer_ticks ();
  ASSERT (intr_get_level () == INTR_ON);
  while (timer_elapsed (start) < ticks)
    thread_yield ();
}
```

- Implementation details
  - Remove thread from ready list and put it back after sufficient ticks have elapsed

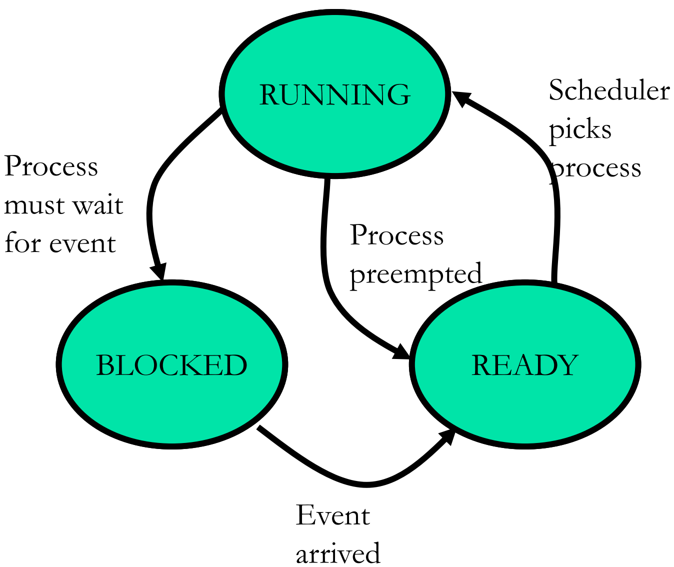
Priority Scheduler

- 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? [comp.risks]
- 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

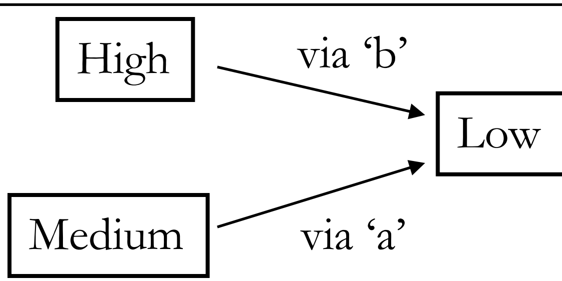
Multiple Priority Donations: Example

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

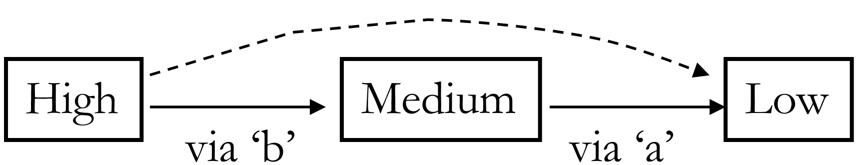
```
static void m_thread_func (void *locks_)
{
  struct locks *locks = locks_;
  lock_acquire (locks->b);
  lock_acquire (locks->a);

  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

- 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 & Deadline

- Tests – 50%
  - All group members get the same grade
- Design – 50%
  - data structures, algorithms, synchronization, rationale and coding standards
  - Each group member will submit those individually: you can discuss them in the group, and ask each other questions – but must create write-up individually. Instructions will be posted on the website.
- Due Feb 23, 2009 by 11:59pm

Good Luck!