CS 33

Multithreaded Programming VI

Cancellation

Sample Code

```
void *thread_code(void *arg) {
  node_t *head = 0;
  while (1) {
    node_t *nodep;
    nodep = (node_t *)malloc(sizeof(node_t));
    if (read(0, &node->value,
        sizeof(node->value)) == 0) {
      free(nodep);
      break;
    }
    nodep->next = head;
    head = nodep;
  }
  return head;
}
```

```
pthread_cancel(thread);
```


Cancellation Concerns

- Getting cancelled at an inopportune moment
- Cleaning up

Cancellation State

- **Pending cancel**
  - `pthread_cancel(thread)`
- **Cancels enabled or disabled**
  - `int pthread_setcancelstate(`
    `{PTHREAD_CANCEL_DISABLE`
    `PTHREAD_CANCEL_ENABLE},`
    `&oldstate)`
- **Asynchronous vs. deferred cancels**
  - `int pthread_setcanceltype(`
    `{PTHREAD_CANCEL_ASYNCHRONOUS,`
    `PTHREAD_CANCEL_DEFERRED},`
    `&oldtype)`

Cancellation Points

- aio_suspend
- close
- creat
- fcntl (when F_SETLCKW is the command)
- fsync
- mq_receive
- mq_send
- msync
- nanosleep
- open
- pause
- pthread_cond_wait
- pthread_cond_timedwait
- pthread_join
- pthread_testcancel
- read
- sem_wait
- sigwait
- sigwaitinfo
- sigsuspend
- sigtimedwait
- sleep
- system
- tcdrain
- wait
- waitpid
- write

Cleaning Up

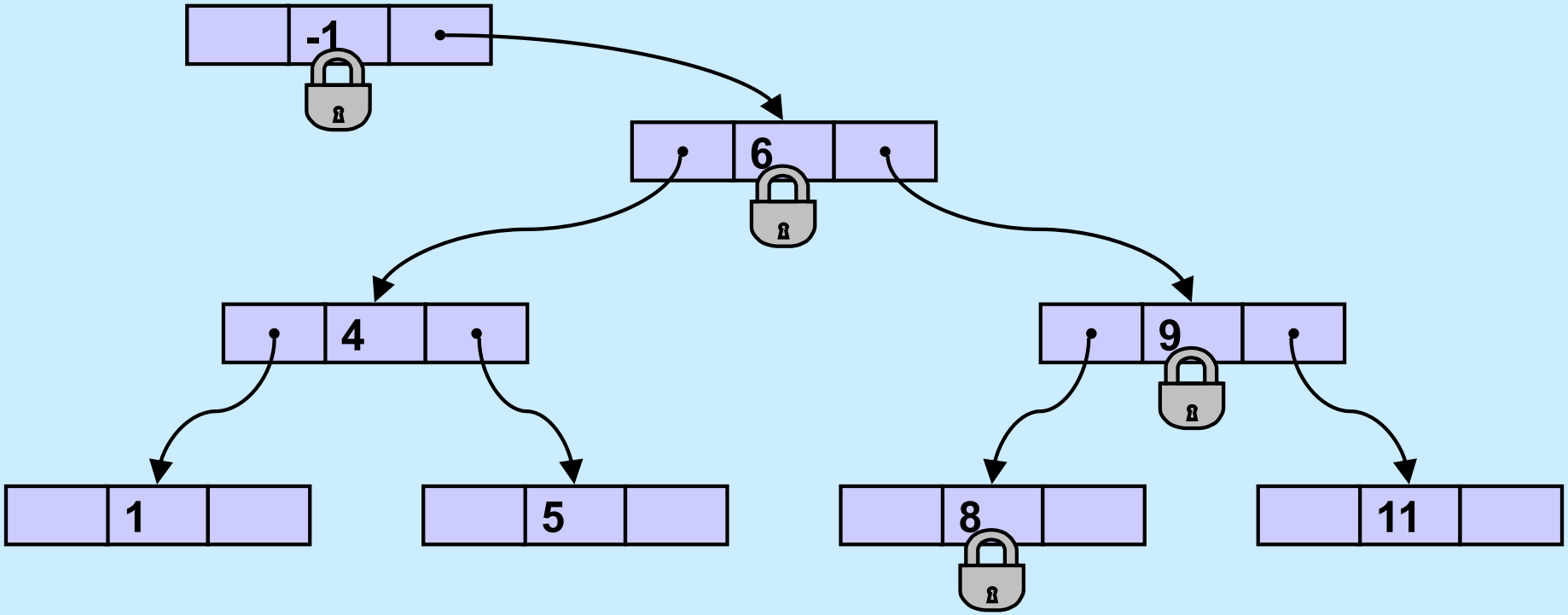
- `void pthread_cleanup_push((void)(*routine)(void *), void *arg)`
- `void pthread_cleanup_pop(int execute)`

Sample Code, Revisited

```
void *thread_code(void *arg) {
  node_t *head = 0;
  pthread_cleanup_push(
      cleanup, &head);
    while (1) {
      node_t *nodep;
      nodep = (node_t *)
      malloc(sizeof(node_t));
      if (read(0, &node->value,
          sizeof(node->value)) == 0) {
        free(nodep);
        break;
      }
      nodep->next = head;
      head = nodep;
    }
  pthread_cleanup_pop(0);
  return head;
}
```

```
void cleanup(void *arg) {
  node_t **headp = arg;
  while(*headp) {
    node_t *nodep = head->next;
    free(*headp);
    *headp = nodep;
  }
}
```

A More Complicated Situation …



Start/Stop

- **Start/Stop interface**

```
void wait_for_start(state_t *s){
  pthread_mutex_lock(&s->mutex);
  while(s->state == stopped)
    pthread_cond_wait(&s->queue, &s->mutex);
  pthread_mutex_unlock(&s->mutex);
}
void start(state_t *s) {
  pthread_mutex_lock(&s->mutex);
  s->state = started;
  pthread_cond_broadcast(&s->queue);
  pthread_mutex_unlock(&s->mutex);
}
```


Start/Stop

- **Start/Stop interface**

```
void wait_for_start(state_t *s){
  pthread_mutex_lock(&s->mutex);
  while(s->state == stopped)
    pthread_cond_wait(&s->queue,
      &s->mutex);
  pthread_mutex_unlock(&s->mutex);
}
void start(state_t *s) {
  pthread_mutex_lock(&s->mutex);
  s->state = started;
  pthread_cond_broadcast(&s->queue);
  pthread_mutex_unlock(&s->mutex);
}
```

Quiz 3

You're in charge of designing POSIX threads. Should *pthread_cond_wait* be a cancellation point?

a) no
b) yes; cancelled threads must acquire the mutex before invoking cleanup handler
c) yes; but they don't acquire mutex

Start/Stop

- **Start/Stop interface**

```
void wait_for_start(state_t *s){
  pthread_mutex_lock(&s->mutex);
  pthread_cleanup_push(
    pthread_mutex_unlock, &s);
  while(s->state == stopped)
    pthread_cond_wait(&s->queue, &s->mutex);
  pthread_cleanup_pop(1);
}
void start(state_t *s) {
  pthread_mutex_lock(&s->mutex);
  s->state = started;
  pthread_cond_broadcast(&s->queue);
  pthread_mutex_unlock(&s->mutex);
}
```


Cancellation and Conditions

```
pthread_mutex_lock(&m);
pthread_cleanup_push(pthread_mutex_unlock, &m);
while(should_wait)
  pthread_cond_wait(&cv, &m);

// … (code perhaps containing other cancellation points)

pthread_cleanup_pop(1);
```

A Problem ...

- **In thread 1:**

```
if ((ret = open(path,
     O_RDWR) == -1) {
   if (errno == EINTR) {
      ...
   }
   ...
}
```

- **In thread 2:**

```
if ((ret = socket(AF_INET,
     SOCK_STREAM, 0)) {
   if (errno == ENOMEM) {
      ...
   }
   ...
}
```

There's only one errno!

However, somehow it works.

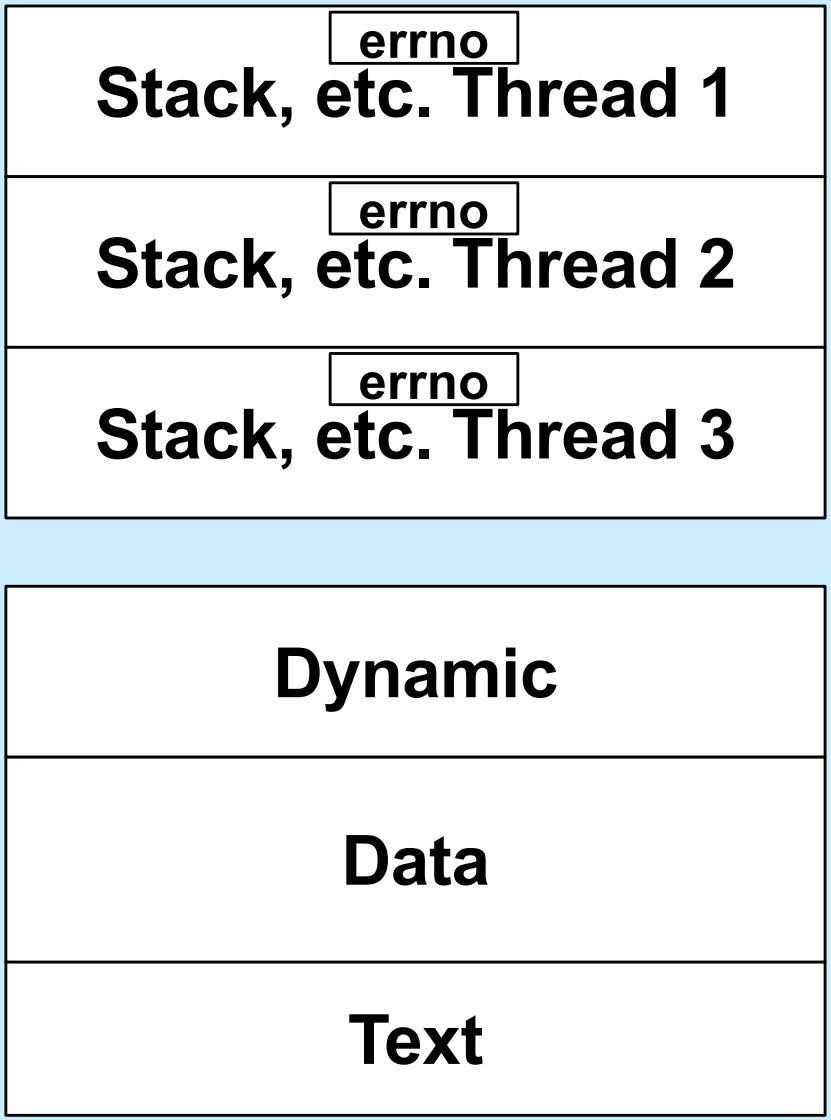
What's done???

A Solution ...

```
#define errno (*__errno_location())
```

- **__errno_location returns an int * that's different for each thread**
  - **thus each thread has, effectively, its own copy of errno**

Process Address Space



Beyond POSIX
TLS Extensions for ELF and gcc

- **Thread Local Storage (TLS)**

```
__thread int x=6;
  // Each thread has its own copy of x,
  // each initialized to 6.
  // Linker and compiler do the setup.
  // May be combined with static or extern.
  // Doesn't make sense for local variables!
```

Example: Per-Thread Windows

```
typedef struct {
  wcontext_t win_context;
  int file_descriptor;
} win_t;
__thread static win_t my_win;

void getWindow() {
  my_win.win_context = … ;
  my_win.file_decriptor = … ;
}

int threadWrite(char *buf) {
  int status = write_to_window(
       &my_win, buf);

  return(status);
}
```

```
void *tfunc(void * arg) {
  getWindow();

  threadWrite("started");
  …

  func2(…);
}

void func2(…) {

  threadWrite(
       "important msg");
  …
}
```

Thread Safety

- **Making the world safe for threads**

Static Local Storage

```
char *strtok(char *str, const char *delim) {
     static char *saveptr;

     ...  // find next token starting at either
      ... // str or saveptr
      ... // update saveptr

     return(&token);
}
```


Coping

- Use thread local storage
- Allocate storage internally; caller frees it
- Redesign the interface

Thread-Safe Version

```
char *strtok_r(char *str, const char *delim,
               char **saveptr) {

    ...  // find next token starting at either
     ... // str or *saveptr
     ... // update *saveptr

    return(&token);
}
```

Shared Data

- **Thread 1:**

```
printf("goto statement reached");
```

- **Thread 2:**

```
printf("Hello World\n");
```

- **Printed on display:**

```
go to Hell
```


Coping

- **Wrap library calls with synchronization constructs**
- **Fix the libraries**

Efficiency

- **Standard I/O example**
  - `getc()` **and** `putc()`
    - » **expensive and thread-safe?**
    - » **cheap and not thread-safe?**
  - **– two versions**
    - » `getc()` **and** `putc()`
      - **expensive and thread-safe**
    - » `getc_unlocked()` **and** `putc_unlocked()`
      - **cheap and not thread-safe**
      - **made thread-safe with** `flockfile()` **and** `funlockfile()`

Efficiency

- **Naive**

```
for(i=0; i<lim; i++)
  putc(out[i]);
```

- **Efficient**

```
flockfile(stdout);
for(i=0; i<lim; i++)
  putc_unlocked(out[i]);
funlockfile(stdout);
```

What's Thread-Safe?

- **Everything except**

asctime()
basename()
catgets()
crypt()
ctime()
dbm_clearerr()
dbm_close()
dbm_delete()
dbm_error()
dbm_fetch()
dbm_firstkey()
dbm_nextkey()
dbm_open()
dbm_store()
dirname()
dlerror()
drand48()
ecvt()
encrypt()
endgrent()
endpwent()
endutxent()
fcvt()
ftw()
gcvt()
getc_unlocked()
getchar_unlocked()
getdate()
getenv()
getgrent()
getgrgid()
getgrnam()
gethostbyaddr()
gethostbyname()
gethostent()
getlogin()
getnetbyaddr()
getnetbyname()
getnetent()
getopt()
getprotobyname()
getprotobynumber()
getprotoent()
getpwent()
getpwnam()
getpwuid()
getservbyname()
getservbyport()
getservent()
getutxent()
getutxid()
getutxline()
gmtime()
hcreate()
hdestroy()
hsearch()
inet_ntoa()
l64a()
lgamma()
lgammaf()
lgammal()
localeconv()
localtime()
lrand48()
mrand48()
nftw()
nl_langinfo()
ptsname()
putc_unlocked()
putchar_unlocked()
putenv()
pututxline()
rand()
readdir()
setenv()
setgrent()
setkey()
setpwent()
setutxent()
strerror()
strtok()
ttyname()
unsetenv()
wcstombs()
wctomb()

You'll Soon Finish CS 33 …

- You might
  - celebrate

  - take another systems course
    - » 32
    - » 138
    - » 166
    - » 167
    - » 168

  - become a 33 TA

Systems Courses Next Semester

- CS 32 (Intro to Software Engineering)
  - you've mastered low-level systems programming
  - now do things at a higher level
  - learn software-engineering techniques using Java, XML, etc.
- CS 138 (Distributed Systems)
  - you now know how things work on one computer
  - what if you've got lots of computers?
  - some may have crashed, others may have been taken over by your worst (and smartest) enemy
- CS 166 (Computer Systems Security)
  - liked buffer?
  - you'll really like 166
- CS 167/169/267 (Operating Systems)
  - still mystified about what the OS does?
  - write your own!

Systems Courses Next Semester

- CS 168 (Computer Networks)
  - intrigued by the little bit of networking we covered?
  - understand how it works and implement protocols yourself!

The End

Well, not quite …

Database is due on 12/17

Happy Coding and Happy Holidays!

