CS 33

Multithreaded Programming V

Alternatives to Mutexes:
Atomic Instructions

- Read-modify-write performed atomically
- *Lock prefix* may be used with certain IA32 and x86-64 instructions to make this happen
  - lock incr x
  - lock add $2, x
- It's expensive
- It's not portable
  - no POSIX-threads way of doing it
  - Windows supports
    - » InterlockedIncrement
    - » InterlockedDecrement

Alternatives to Mutexes:
Spin Locks

- **Consider**

```
pthread_mutex_lock(&mutex);
new->next = list_ele->next;
list_ele->next = new;
pthread_mutex_unlock(&mutex);
```

- **A lot of overhead is required to put thread to sleep, then wake it up**
- **Rather than do that, repeatedly test mutex until it's unlocked, then lock it**
  - **makes sense only on multiprocessor system**

Compare and Exchange

`cmpxchg src_reg, dest`

- **compare contents of *%rax* with contents of *dest***
  - » **if equal, then *dest* = *src_reg* (and *ZF* = *1*)**
  - » **otherwise *%rax* = *dest* (and *ZF* = *0*)**

Spin Lock

- **the spin lock is pointed to by the first arg (*%rdi*)**
  - **locked is 1, unlocked is 0**

```
        .text
        .globl slock, sunlock
slock:
loop:
        movq $0, %rax
        movq $1, %r10
        lock cmpxchg %r10, 0(%rdi)
        jne loop
        ret
sunlock:
        movq $0, 0(%rdi)
        ret
```


Improved Spin Lock

```
        .text
        .globl slock, sunlock
slock:
loop:
        cmp $0, 0(%rdi)  # compare using normal instructions
        jne loop
        movq $0, %rax
        movq $1, %r10
        lock cmpxchg %r10, 0(%rdi) # verify w/ cmpxchg
        jne loop
        ret
sunlock:
        movq $0, 0(%rdi)
        ret
```

Yet More From POSIX …

```
int pthread_spin_init(pthread_spin_t *s,
      int pshared);
int pthread_spin_destroy(pthread_spin_t *s);
int pthread_spin_lock(pthread_spin_t *s);
int pthread_spin_trylock(pthread_spin_t *s);
int pthread_spin_unlock(pthread_spin_t *s);
```

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.

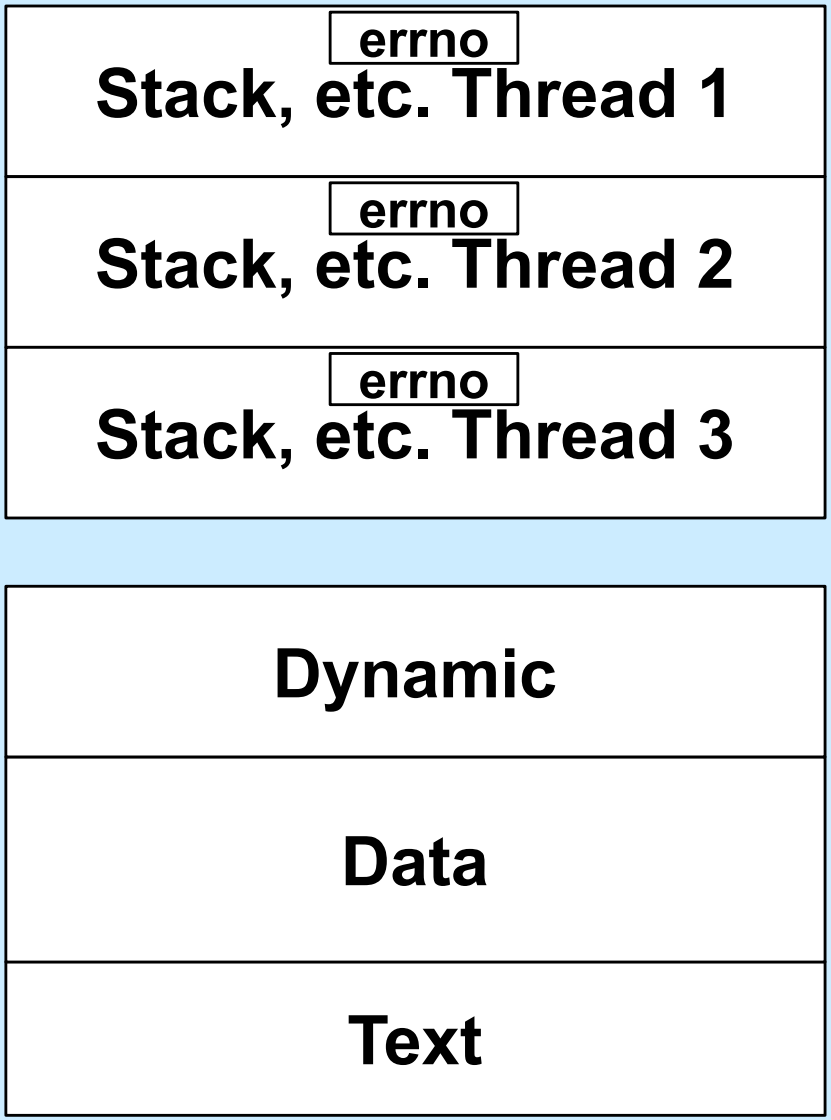
What's done???

A Solution ...

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

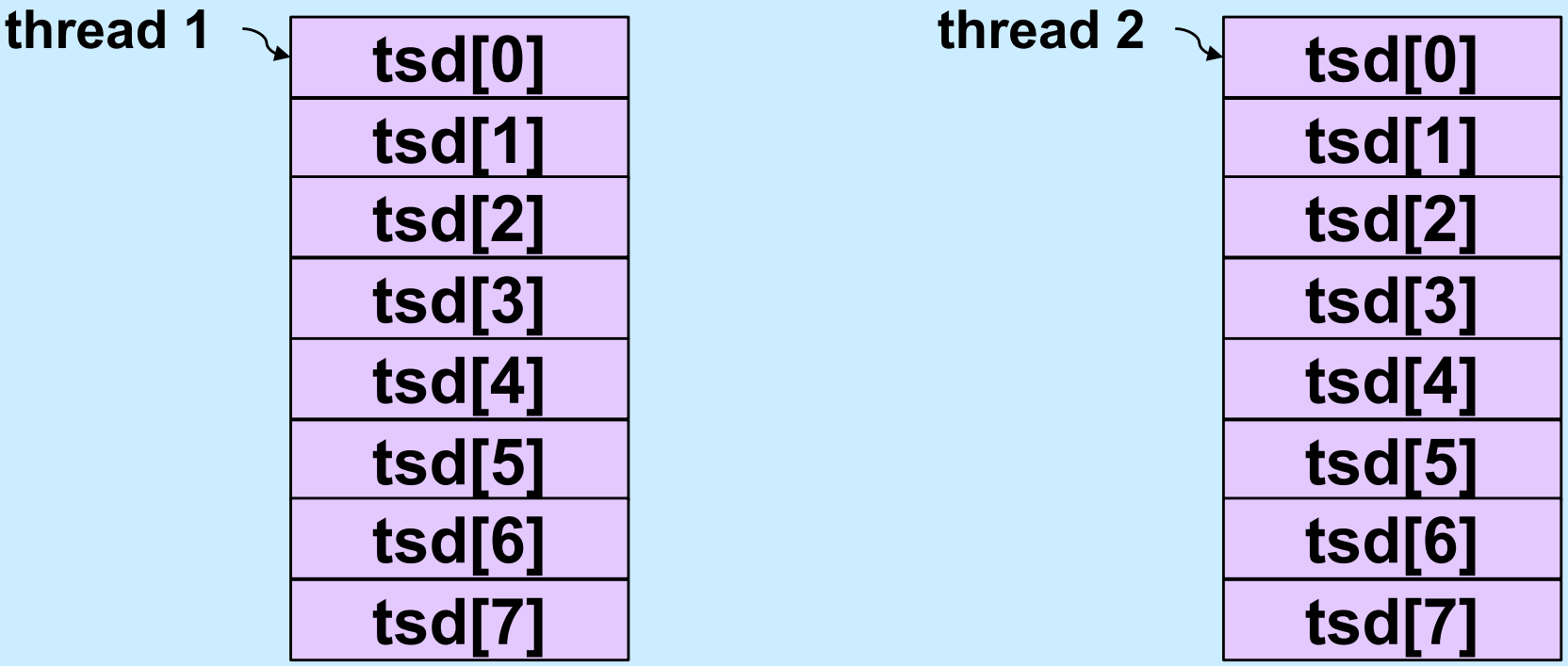
- **__errno_location returns an int * that's different for each thread**
  - **thus each thread has, effectively, its own copy of errno**

Process Address Space



Generalizing

- *Thread-specific data* (sometimes called *thread-local storage*)
  - data that's referred to by global variables, but each thread has its own private copy



Some Machinery

- `pthread_key_create(&key, cleanup_routine)`
  - **allocates a slot in the TSD arrays**
  - **provides a function to cleanup when threads terminate**
- `value = pthread_getspecific(key)`
  - **fetches from the calling thread's array**
- `pthread_setspecific(key, value)`
  - **stores into the calling thread's array**

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!
```

Static Local Storage

```
struct hostent *gethostbyname(const char *name) {
     static struct hostent hostent;

     ...  // lookup name; fill in hostent

     return(&hostent);
}
```


Coping

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

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**

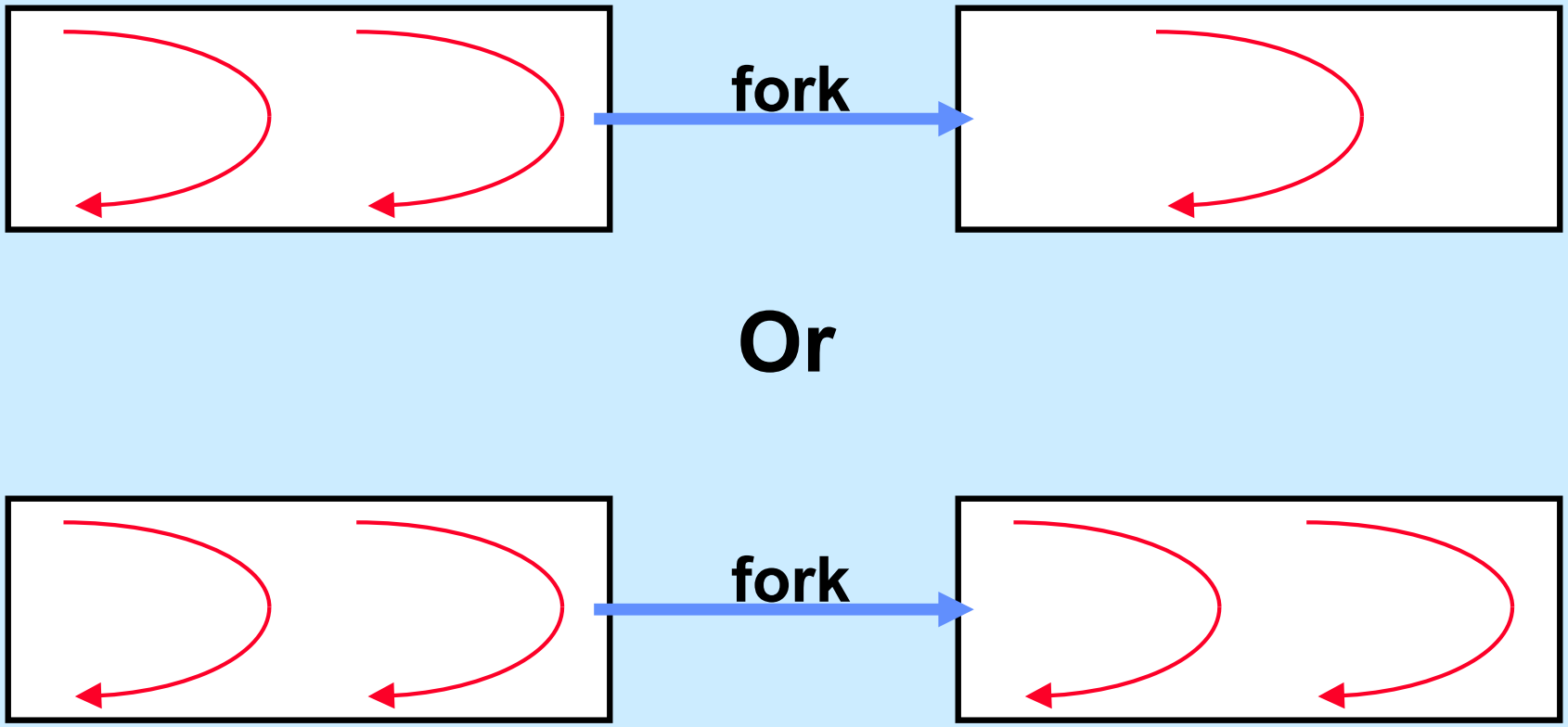
```
flockfile(stdout);
for(i=0; i<lim; i++)
  putc_unlocked(out[i]);
funlockfile(stdout);
```

What's Thread-Safe?

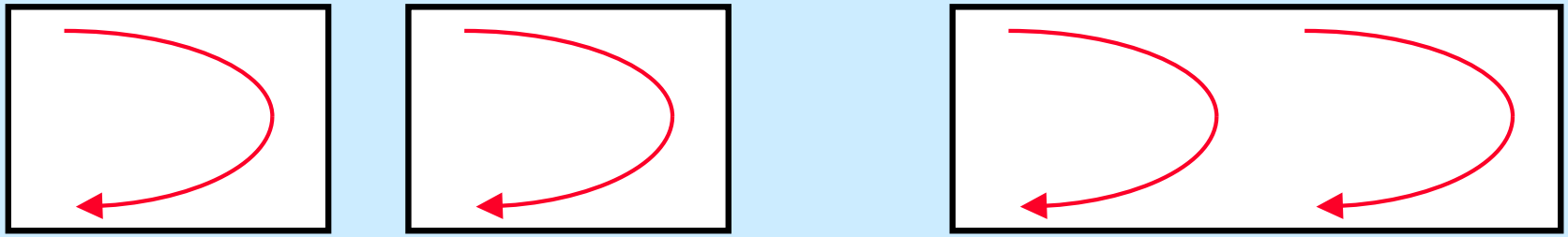
- **Everything except**

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()

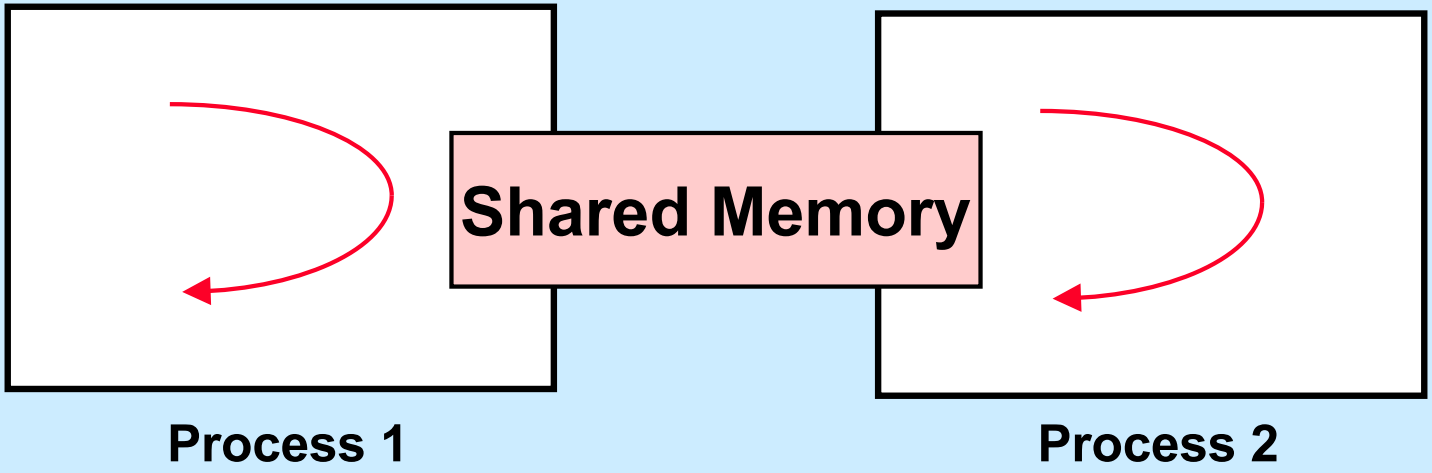
Fork and Threads



Processes vs. Threads



Communicating via Shared Memory



Cross-Process Synchronization

```
pthread_mutexattr_t mattr;
pthread_condattr_t cattr;
pthread_mutex_t mut;
pthread_cond_t cond;

pthread_mutexattr_init(&mattr);
pthread_condattr_init(&cattr);

pthread_mutexattr_setpshared(&mattr,
      PTHREAD_PROCESS_SHARED);
pthread_condattr_setpshared(&cattr,
      PTHREAD_PROCESS_SHARED);

pthread_mutex_init(&mut, &mattr);
pthread_cond_init(&cond, &cattr);
```


Cross-Process Producer-Consumer (1)

```
typedef struct buffer {
  char buf[BSIZE];
  sem_t filled;
  sem_t empty;
  int nextin;
  int nextout;
} buffer_t;
```

Cross-Process Producer-Consumer (2)

```
int main() {
  buffer_t *buffer;

  if ((buffer = mmap(0, sizeof(buffer_t),
       PROT_READ|PROT_WRITE,
       MAP_SHARED|MAP_ANONYMOUS, -1, 0))
       == (void *)-1) {
    perror("mmap");
    exit(1);
  }
```


Cross-Process Producer-Consumer (3)

```
    buffer->nextin = buffer->nextout = 0;
    sem_init(&buffer->filled, 1, 0);
    sem_init(&buffer->empty, 1, BSIZE);

    if (fork() == 0)
      consumer_driver(buffer);
    else
      producer_driver(buffer);

    return 0;
}
```

Cross-Process Producer-Consumer (4)

```
void producer_driver(
    buffer_t *b) {
  int item;

  while (1) {
    item = getchar();
    if (item == EOF) {
      produce(b, '\0');
      break;
    } else {
      produce(b, (char)item);
    }
  }
}
```

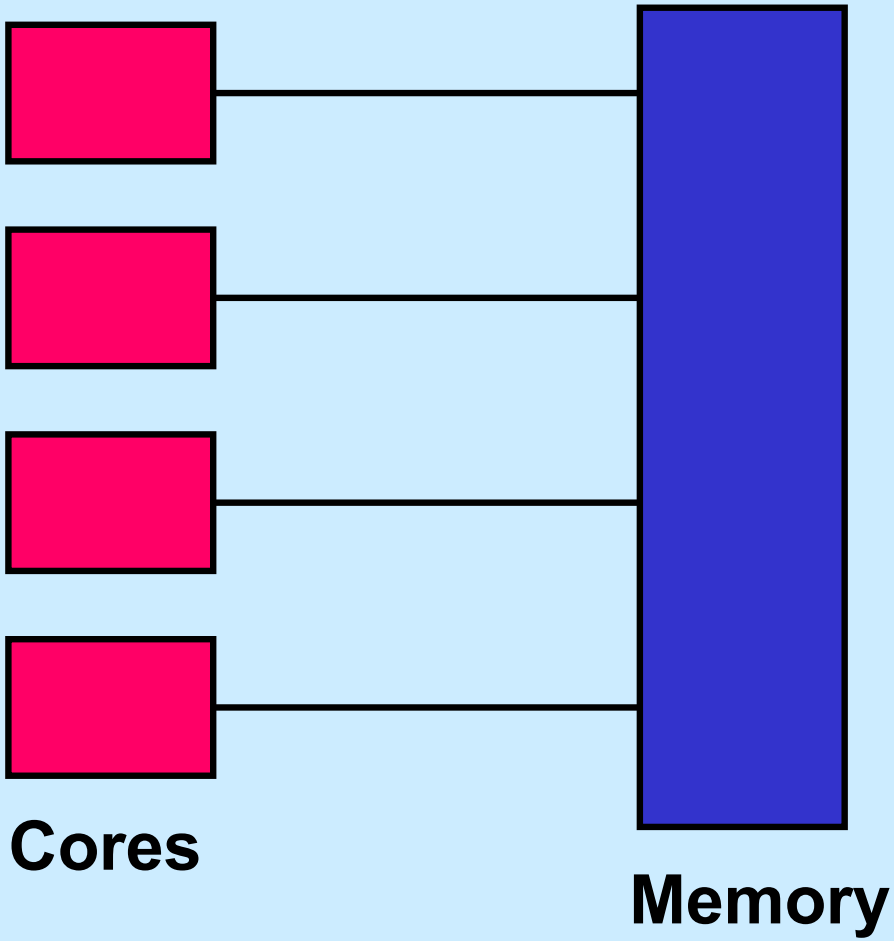
```
void consumer_driver(
    buffer_t *b) {
  char item;
  while (1) {
    if ((item = consume(b))
        == '\0')
      break;
    putchar(item);
  }
}
```

Cross-Process Producer-Consumer (5)

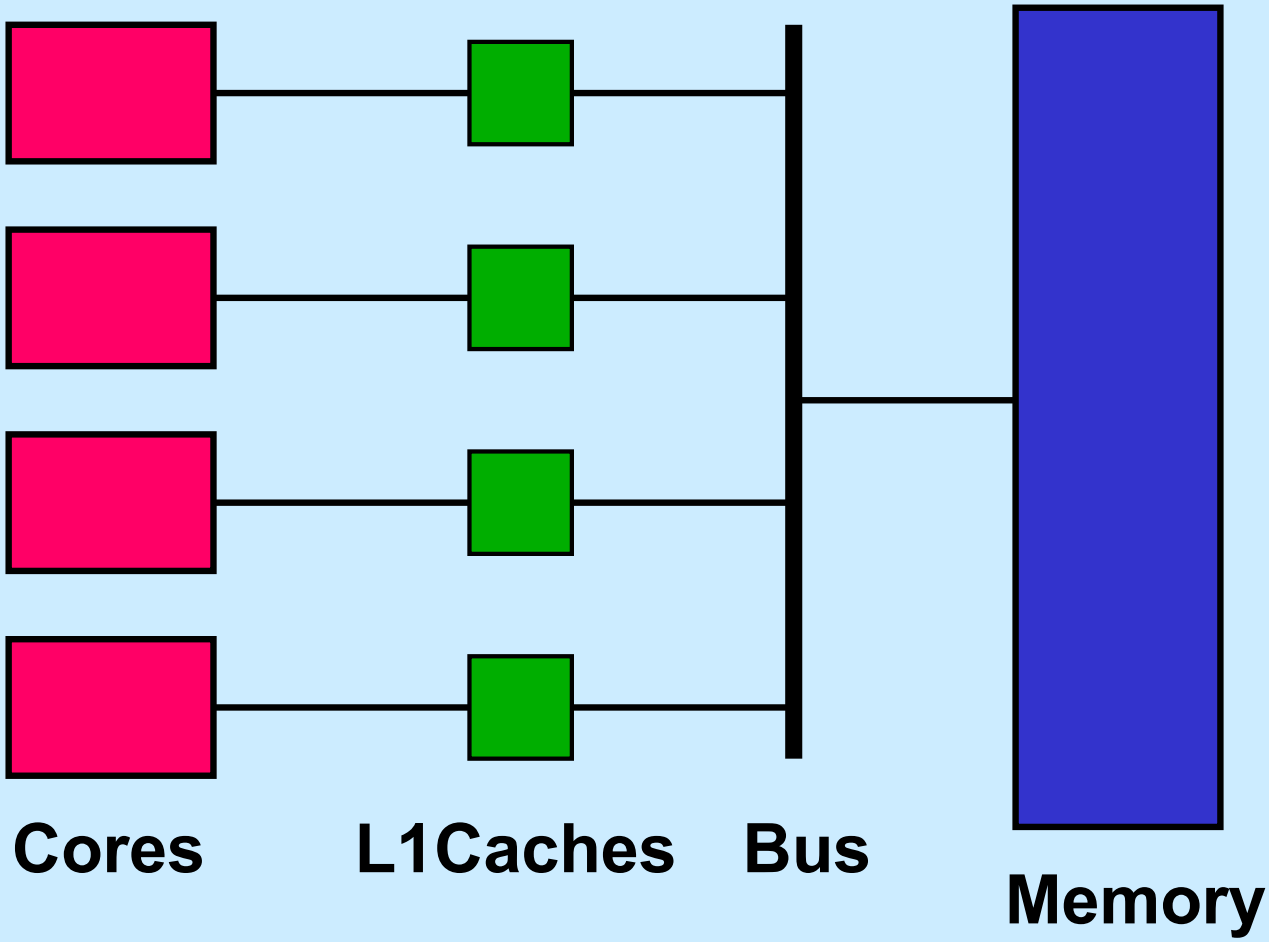
```
void produce(buffer_t *b,
     char item) {
   sem_wait(&b->empty);
   b->buf[b->nextin] = item;
   b->nextin++;
   b->nextin %= BSIZE;
   sem_post(&b->filled);
}
```

```
char consume(buffer_t *b) {
   char item;
   sem_wait(&b->filled);
   item =
        b->buf[b->nextout];
   b->nextout++;
   b->nextout %= BSIZE;
   sem_post(&b->empty);
   return item;
}
```

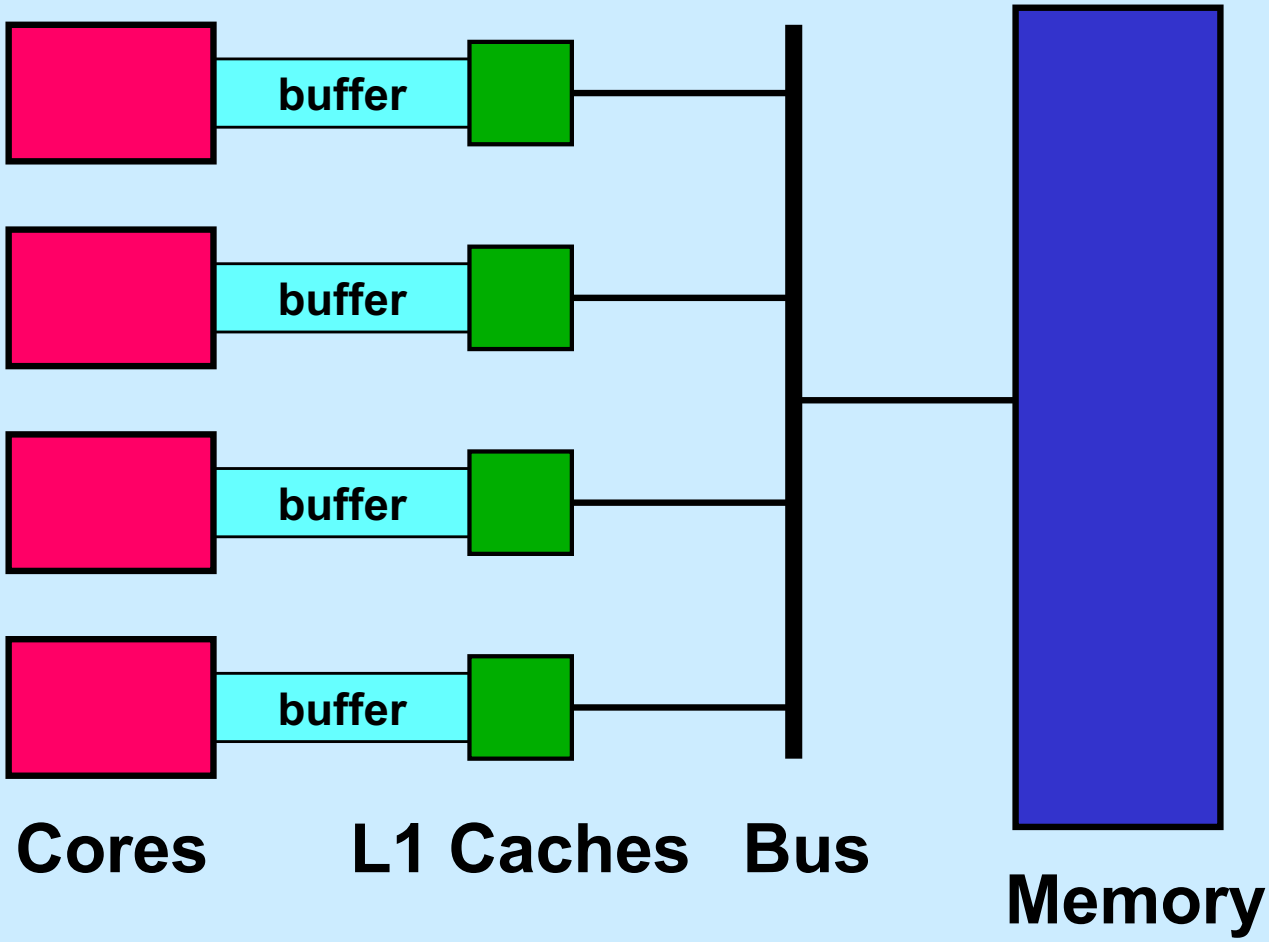
Multi-Core Processor: Simple View



Multi-Core Processor: More Realistic View



Multi-Core Processor: Even More Realistic



Concurrent Reading and Writing

Thread 1:

```
i = shared_counter;
```

Thread 2:

```
shared_counter++;
```


Mutual Exclusion w/o Mutexes

```
void peterson(long me) {
  static long loser;                  // shared
  static long active[2] = {0, 0};     // shared
  long other = 1 - me;                // private
  active[me] = 1;
  loser = me;
  while (loser == me && active[other])
    ;
  // critical section
  active[me] = 0;
}
```


Quiz 1

```
void peterson(long me) {
  static long loser;                  // shared
  static long active[2] = {0, 0};     // shared
  long other = 1 - me;                // private
  active[me] = 1;
  loser = me;
  while (loser == me && active[other])
    ;
  // critical section
  active[me] = 0;
}
```

This works on sunlab machines.

a) true

b) false

Busy-Waiting Producer/Consumer

```
void producer(char item) {

  while(in - out == BSIZE)
    ;

  buf[in%BSIZE] = item;

  in++;
}
```

```
char consumer( ) {
  char item;
  while(in - out == 0)
    ;

  item = buf[out%BSIZE];

  out++;

  return(item);
}
```

Quiz 2

```
void producer(char item) {

  while(in - out == BSIZE)
    ;

  buf[in%BSIZE] = item;

  in++;
}
```

```
char consumer( ) {
  char item;
  while(in - out == 0)
    ;

  item = buf[out%BSIZE];

  out++;

  return(item);
}
```

This works on sunlab machines.

a) **true**
b) **false**

Coping

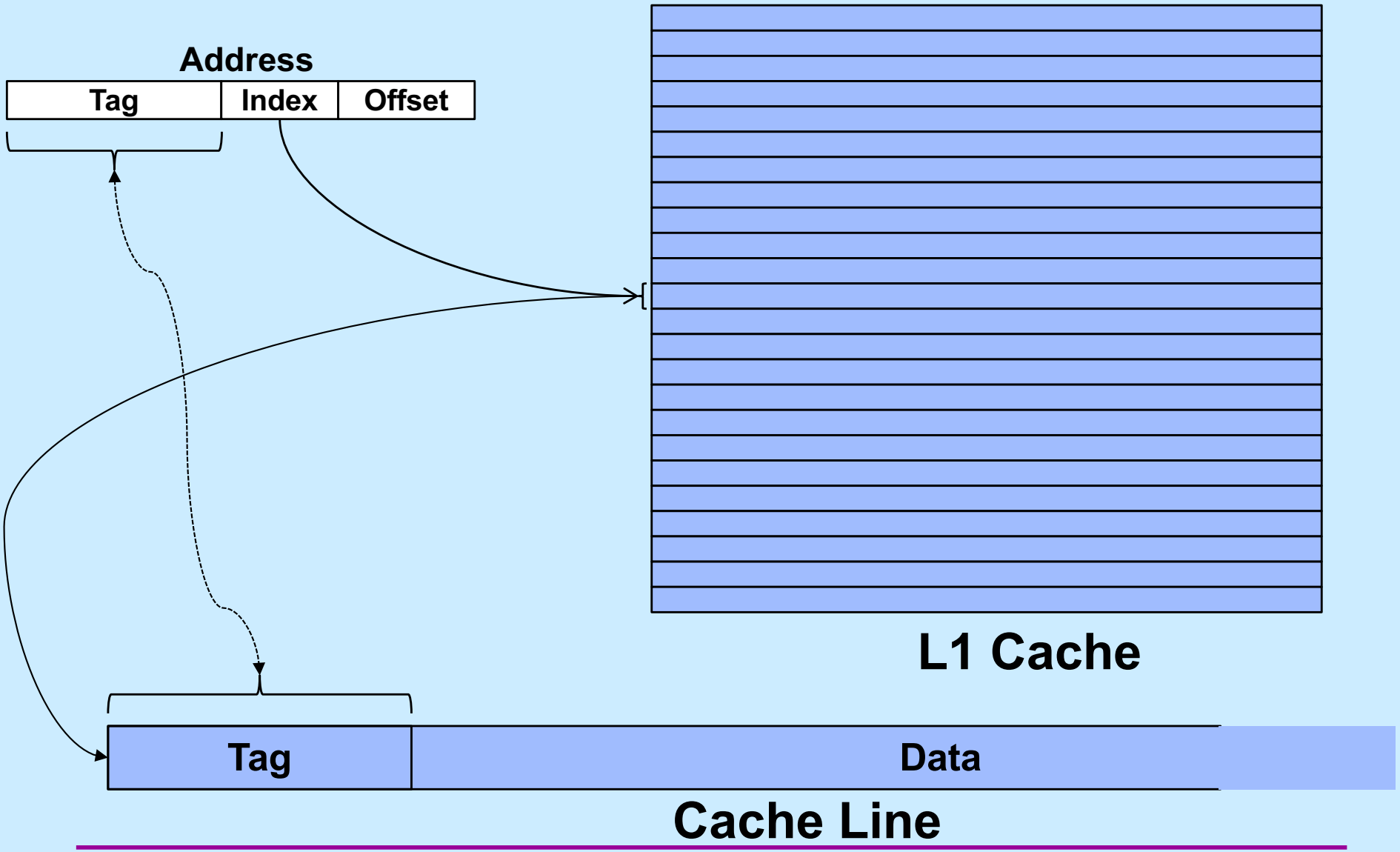
- Don’t rely on shared memory for synchronization
- Use the synchronization primitives

Which Runs Faster?

```
volatile int a, b;

void *thread1(void *arg) {
  int i;
  for (i=0; i<reps; i++) {
    a = 1;
  }
}

void *thread2(void *arg) {
  int i;
  for (i=0; i<reps; i++) {
    b = 1;
  }
}
```

```
volatile int a,
  padding[128], b;

void *thread1(void *arg) {
  int i;
  for (i=0; i<reps; i++) {
    a = 1;
  }
}

void *thread2(void *arg) {
  int i;
  for (i=0; i<reps; i++) {
    b = 1;
  }
}
```

Cache Lines



False Sharing