CS 33

Multithreaded Programming II

Problem

```
   pthread_create(&thread, 0, start, 0);

   …


void *start(void *arg) {
   long BigArray[128*1024*1024];
   …
   return 0;
}
```

Thread Attributes

```
pthread_t thread;
pthread_attr_t thr_attr;

pthread_attr_init(&thr_attr);

...

/* establish some attributes */

...

pthread_create(&thread, &thr_attr, startroutine, arg);

...
```

Stack Size

```
pthread_t thread;
pthread_attr_t thr_attr;

pthread_attr_init(&thr_attr);
pthread_attr_setstacksize(&thr_attr, 130*1024*1024);

...

pthread_create(&thread, &thr_attr, startroutine, arg);

...
```

Execution Speed

```
// thread 1              // thread 2
lengthy_func();          x = 0;
x = 1;                   assert(x==0);
```

Mutual Exclusion

Threads and Mutual Exclusion

Thread 1:

```
x = x+1;
 /*
   movl x,%eax
   incr %eax
   movl %eax,x
 */
```

Thread 2:

```
x = x+1;
 /*
   movl x,%eax
   incr %eax
   movl %eax,x
 */
```

Quiz 1

Suppose gcc produces the following code. Will it still be the case that x’s value might not be incremented by 2?

a) yes
b) no

Thread 1:

```
x = x+1;
 /*
  incr x
 */
```

Thread 2:

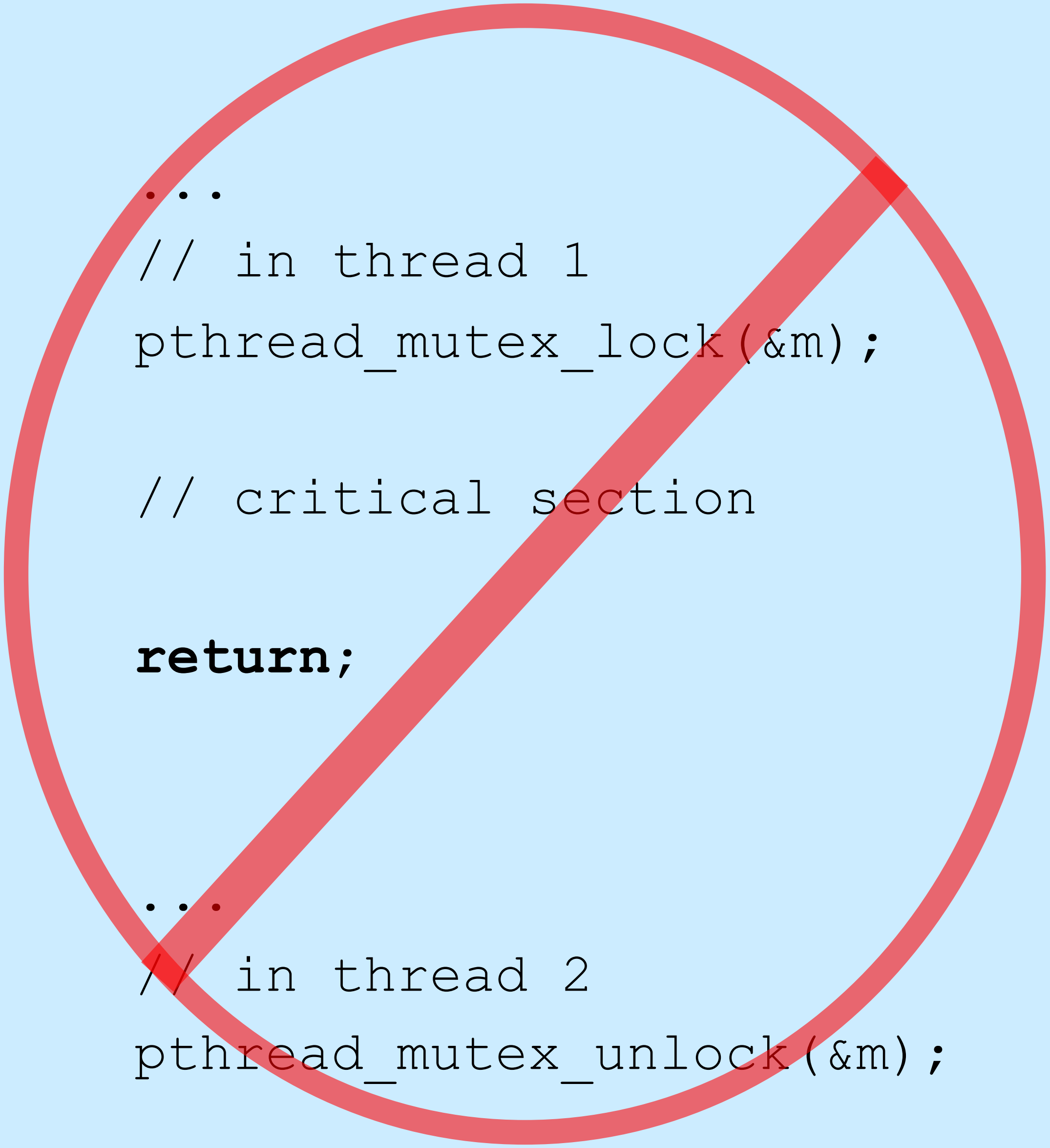
```
x = x+1;
 /*
  incr x
 */
```

POSIX Threads Mutual Exclusion

```
pthread_mutex_t m =
      PTHREAD_MUTEX_INITIALIZER;
      // shared by both threads
int x; // ditto

  pthread_mutex_lock(&m);

  x = x+1;

  pthread_mutex_unlock(&m);
```

Correct Usage

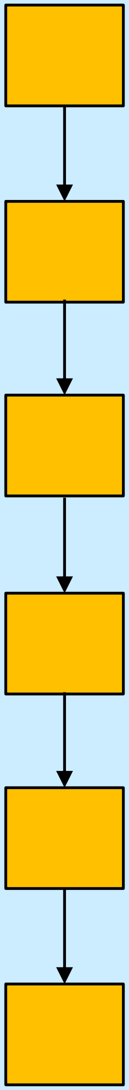
```
pthread_mutex_lock(&m);

// critical section

pthread_mutex_unlock(&m);
```



```
...
// in thread 1
pthread_mutex_lock(&m);

// critical section

return;


...
// in thread 2
pthread_mutex_unlock(&m);
```

A Queue

```
void enqueue(node_t *item) {
    pthread_mutex_lock(&mutex);
    item->next = NULL;
    if (tail == NULL) {
        head = item;
        tail = item;
    } else {
        tail->next = item;
    }
    pthread_mutex_unlock(&mutex);
}
```



```
node_t *dequeue() {
    node_t *ret;
    pthread_mutex_lock(&mutex);
    if (head == NULL) {
        ret = NULL;
    } else {
        ret = head;
        head = head->next;
        if (head == NULL)
            tail = NULL;
    }
    pthread_mutex_unlock(&mutex);
    return ret;
}
```

Removing a Freelist Block

```
void pull_from_freelist(fblock_t *fbp) {
    ...
    fbp->blink->flink = fbp->flink;
    fbp->flink->blink = fbp->blink;
    ...
}
```

Parallelizing It

- Coarse grained
  - one mutex for the heap
  - threads lock the mutex before doing any operation
  - unlock it afterwards
  - only one thread at a time

- Fine grained
  - one mutex for each block
  - threads lock mutexes of only the blocks they are using
  - multiple threads at a time

Removing a Freelist Block: Coarse Grained

```
void pull_from_freelist(fblock_t *fbp) {
    pthread_mutex_lock(&heap_mutex);
    ...
    fbp->blink->flink = fbp->flink;
    fbp->flink->blink = fbp->blink;
    ...
    pthread_mutex_unlock(&heap_mutex);
}
```

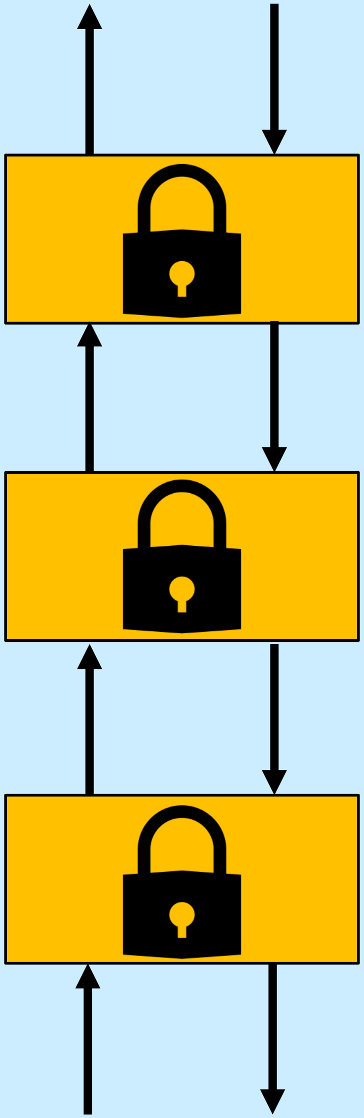
Removing a Freelist Block: Fine Grained (1)

```
void pull_from_freelist(fblock_t *fbp) {
    pthread_mutex_lock(&fpp->mutex);
    ...
    fbp->blink->flink = fbp->flink;
    fbp->flink->blink = fbp->blink;
    ...
    pthread_mutex_unlock(&fpp->mutex);
}
```

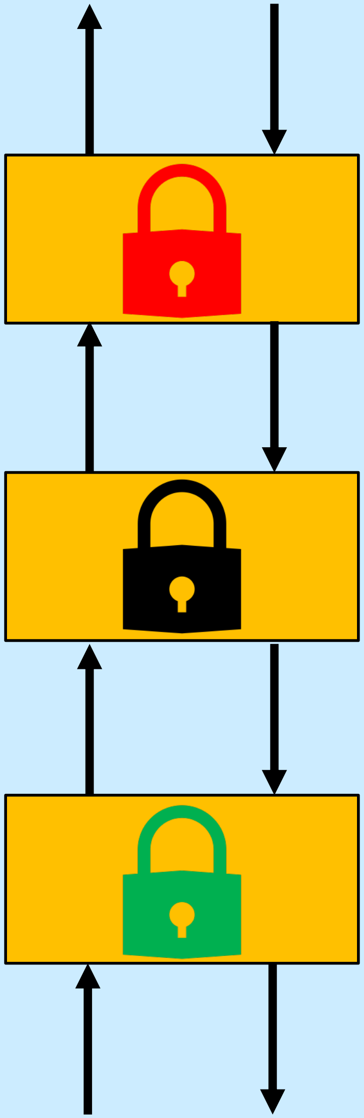
Removing a Freelist Block: Fine Grained (2)

```
void pull_from_freelist(fblock_t *fbp) {
    pthread_mutex_lock(&fpp->mutex);
    ...
    pthread_mutex_lock(&fpp->blink->mutex);
    fbp->blink->flink = fbp->flink;
    pthread_mutex_lock(&fpp->flink->mutex);
    fbp->flink->blink = fbp->blink;
    ...
    pthread_mutex_unlock(&fpp->blink->mutex);
    pthread_mutex_unlock(&fpp->flink->mutex);
    pthread_mutex_unlock(&fpp->mutex);
}
```

Multiple Pulls



Multiple Pulls

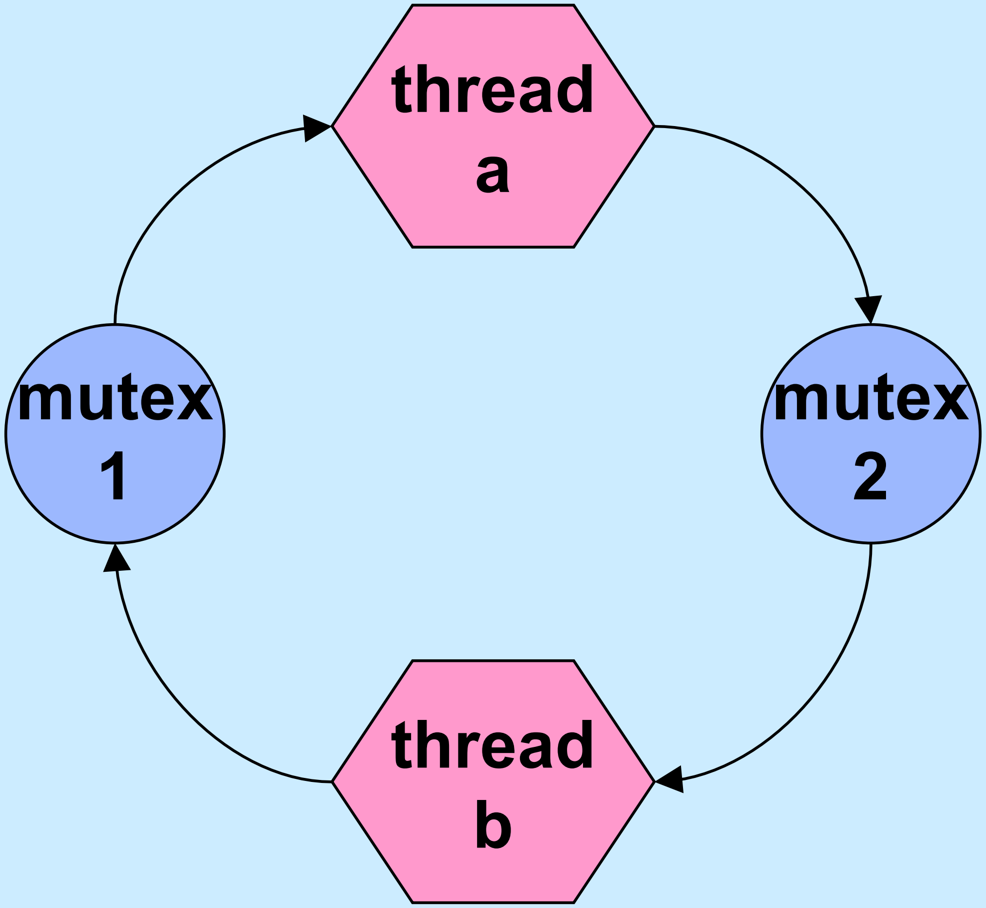


Taking Multiple Locks

```
func1( ) {
  pthread_mutex_lock(&m1);
  /* use object 1 */
  pthread_mutex_lock(&m2);
  /* use objects 1 and 2 */
  pthread_mutex_unlock(&m2);
  pthread_mutex_unlock(&m1);
}
```

```
func2( ) {
  pthread_mutex_lock(&m2);
  /* use object 2 */
  pthread_mutex_lock(&m1);
  /* use objects 1 and 2 */
  pthread_mutex_unlock(&m1);
  pthread_mutex_unlock(&m2);
}
```

Preventing Deadlock



Taking Multiple Locks, Safely

```
proc1( ) {
  pthread_mutex_lock(&m1);
  /* use object 1 */
  pthread_mutex_lock(&m2);
  /* use objects 1 and 2 */
  pthread_mutex_unlock(&m2);
  pthread_mutex_unlock(&m1);
}
```

```
proc2( ) {
  pthread_mutex_lock(&m1);
  /* use object 1 */
  pthread_mutex_lock(&m2);
  /* use objects 1 and 2 */
  pthread_mutex_unlock(&m2);
  pthread_mutex_unlock(&m1);
}
```

Dining Philosophers Problem

Practical Issues with Mutexes

- Used a lot in multithreaded programs
  - speed is really important
    - shouldn’t slow things down much in the success case
  - checking for errors slows things down (a lot)
    - thus errors aren’t checked by default

Set Up

```
int pthread_mutex_init(pthread_mutex_t *mutexp,
    pthread_mutexattr_t *attrp)

int pthread_mutex_destroy(pthread_mutex_t *mutexp)

int pthread_mutexattr_init(pthread_mutexattr_t *attrp)

int pthread_mutexattr_destroy(pthread_mutexattr_t *attrp)
```

Stupid (i.e., Common) Mistakes ...

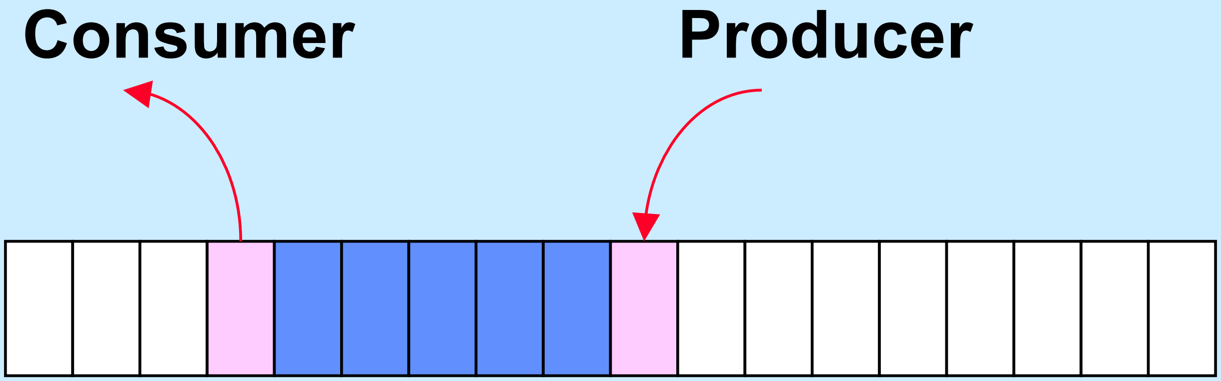
```
pthread_mutex_lock(&m1);
pthread_mutex_lock(&m1);
  // really meant to lock m2 ...
```

```
pthread_mutex_lock(&m1);
  ...
pthread_mutex_unlock(&m2);
  // really meant to unlock m1 ...
```

Runtime Error Checking

```
pthread_mutexattr_t err_chk_attr;
pthread_mutexattr_init(&err_chk_attr);
pthread_mutexattr_settype(&err_chk_attr,
      PTHREAD_MUTEX_ERRORCHECK);

pthread_mutex_t mut1;
pthread_mutex_init(&mut1, &err_chk_attr);

pthread_mutex_lock(&mut1);

if (pthread_mutex_lock(&mut1) == EDEADLK)
  fprintf(stderr, "error caught at runtime\n");

if (pthread_mutex_unlock(&mut2) == EPERM)
  fprintf(stderr, "another error: you didn’t lock it!\n");
```

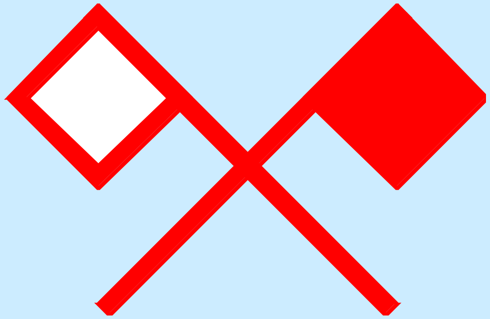
Producer-Consumer Problem



Guarded Commands

```
when (guard) [
  /*
     once the guard is true, execute this
     code atomically
    */

  ...

]
```

Semaphores



- **P(S) operation:**

```
when (S > 0) [
   S = S - 1;
]
```

- **V(S) operation:**

```
[S = S + 1;]
```

Quiz 2

```
semaphore S = 1;
int count = 0;

void func( ) {
   P(S);
   count++;
   ...
   count--;
   V(S);
}
```

The function func is called concurrently by n threads. What's the maximum value that count will take on?

a) 1
b) 2
c) n
d) indeterminate

- **P(S) operation:**

```
      when (S > 0) [
        S = S - 1;
      ]
```

- **V(S) operation:**

```
      [S = S + 1;]
```

Producer/Consumer with Semaphores

```
Semaphore empty = BSIZE;
Semaphore occupied = 0;
int nextin = 0;
int nextout = 0;
```

```
void Produce(char item) {
  P(empty);
  buf[nextin] = item;
  if (++nextin >= BSIZE)
    nextin = 0;
  V(occupied);
}
```

```
char Consume( ) {
  char item;
  P(occupied);
  item = buf[nextout];
  if (++nextout >= BSIZE)
    nextout = 0;
  V(empty);
  return item;
}
```

POSIX Semaphores

```
#include <semaphore.h>

int sem_init(sem_t *semaphore, int pshared, int init);
int sem_destroy(sem_t *semaphore);
int sem_wait(sem_t *semaphore);
    /* P operation */
int sem_trywait(sem_t *semaphore);
    /* conditional P operation */
int sem_post(sem_t *semaphore);
    /* V operation */
```

Producer-Consumer with POSIX Semaphores

```
sem_init(&empty, 0, BSIZE);
sem_init(&occupied, 0, 0);
int nextin = 0;
int nextout = 0;
```

```
void produce(char item) {

  sem_wait(&empty);
  buf[nextin] = item;
  if (++nextin >= BSIZE)
   nextin = 0;
  sem_post(&occupied);
}
```

```
char consume( ) {
  char item;
  sem_wait(&occupied);
  item = buf[nextout];
  if (++nextout >= BSIZE)
   nextout = 0;
  sem_post(&empty);
  return item;
}
```

Quiz 3

Does the POSIX version of the producer-consumer solution work with multiple producers and consumers?

a) Yes

b) No, but it can be made to work by using mutexes to make sure that only one thread is executing the producer code at a time and only one thread is executing the consumer code at a time

c) It can’t easily be made to work

Start/Stop

- **Start/Stop interface**

```
void wait_for_start(state_t *s);



void start(state_t *s);



void stop(state_t *s);
```

Start/Stop

- **Start/Stop interface**

```
void wait_for_start(state_t *s){
  if (s->state == stopped)
    sleep();
}
void start(state_t *s) {
  state = started;
  wakeup_all();
}
void stop(state_t *s) {
  state = stopped;
}
```

Start/Stop

- **Start/Stop interface**

```
void wait_for_start(state_t *s){
  pthread_mutex_lock(&s->mutex);
  if (s->state == stopped) {
    pthread_mutex_unlock(&s->mutex);
    sleep();
  else pthread_mutex_unlock(&s->mutex);
}
void start(state_t *s) {
  pthread_mutex_lock(&s->mutex);
  state = started;
  wakeup_all();
  pthread_mutex_unlock(&s->mutex);
}
```

Start/Stop

- **Start/Stop interface**

```
void wait_for_start(state_t *s){
  pthread_mutex_lock(&s->mutex);
  if (s->state == stopped) {
    sleep();
  pthread_mutex_unlock(&s->mutex);
}
void start(state_t *s) {
  pthread_mutex_lock(&s->mutex);
  state = started;
  wakeup_all();
  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);
}
```

Condition Variables

```
when (guard) [
  statement 1;
  …
  statement n;
]
```

```
pthread_mutex_lock(&mutex);
while(!guard)
  pthread_cond_wait(
     &cond_var, &mutex);
statement 1;
…
statement n;
pthread_mutex_unlock(&mutex);
```

```
// code modifying the guard:
…
```

```
pthread_mutex_lock(&mutex);
// code modifying the guard:
…
pthread_cond_broadcast(
    &cond_var);
pthread_mutex_unlock(&mutex);
```

Set Up

```
int pthread_cond_init(pthread_cond_t *cvp,
    pthread_condattr_t *attrp)

int pthread_cond_destroy(pthread_cond_t *cvp)

int pthread_condattr_init(pthread_condattr_t *attrp)

int pthread_condattr_destroy(pthread_condattr_t *attrp)
```

PC with Condition Variables (1)

```
typedef struct buffer {
  pthread_mutex_t m;
  pthread_cond_t  more_space;
  pthread_cond_t  more_items;
  int             next_in;
  int             next_out;
  int             empty;
  char            buf[BSIZE];
} buffer_t;
```

PC with Condition Variables (2)

```
void produce(buffer_t *b,
    char item) {

  pthread_mutex_lock(&b->m);
  while (!(b->empty > 0))
   pthread_cond_wait(
       &b->more_space, &b->m);
  b->buf[b->nextin] = item;
  if (++(b->nextin) == BSIZE)
    b->nextin = 0;
  b->empty--;
  pthread_cond_signal(
     &b->more_items);
  pthread_mutex_unlock(&b->m);
}
```

```
char consume(buffer_t *b) {
  char item;
  pthread_mutex_lock(&b->m);
  while (!(b->empty < BSIZE))
   pthread_cond_wait(
       &b->more_items, &b->m);
  item = b->buf[b->nextout];
  if (++(b->nextout) == BSIZE)
    b->nextout = 0;
  b->empty++;
  pthread_cond_signal(
     &b->more_space);
  pthread_mutex_unlock(&b->m);
  return item;
}
```