Script generated by TTT

Title: Simon: Programmiersprachen (15.11.2013)

Date: Fri Nov 15 14:14:18 CET 2013

Duration: 90:34 min

Pages: 96

Marking Statements as Atomic

Rather than writing assembler: use made-up keyword `atomic`:

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Program 2
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atomic {
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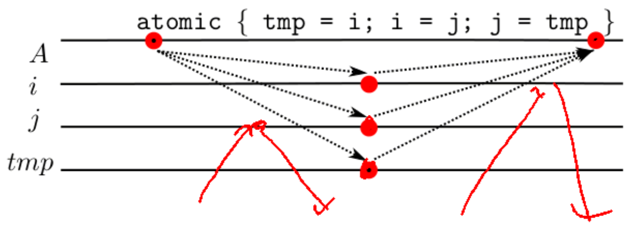

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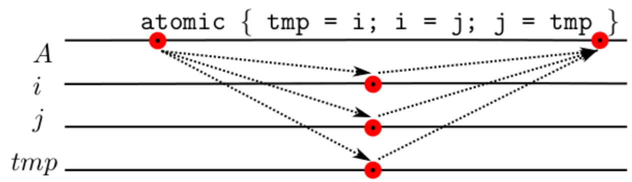

- `atomic` only translatable when a corresponding atomic CPU instruction exist
- the notion of requesting *atomic execution* is a general concept

Wait-Free Synchronization

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  b = 0;
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atomic {
  r = b;
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atomic {
  r = (k==i);
  if (r) i = j;
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Operations *update* a memory cell and *return* the previous value.

- the first two operations can be seen as setting a flag `b` to $v \in \{0, 1\}$ if `b` not already contains v
  - this operation is called *modify-and-test*
- the third case generalizes this to arbitrary values
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$\leadsto$ use as building blocks for algorithms that can *fail*

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Common usage pattern for *compare and swap*:

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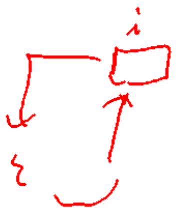

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⇝ calculating new value must be *repeatable*

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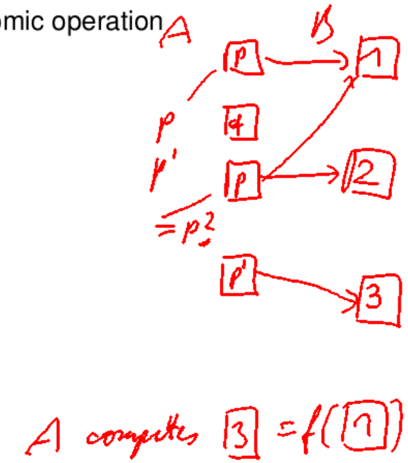

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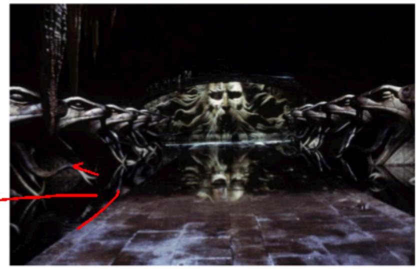
We will collectively refer to these data structures as *locks*.

Locks

 ⇒ 

A lock is a data structure that

- protects a *critical section*: a piece of code that may produce incorrect results when executed concurrently from several threads
- it ensures *mutual exclusion*: no two threads execute at once
- *block* other threads as soon as one thread executes the critical section
- can be *acquired* and *released*
- may *deadlock* the program

Semaphores and Mutexes

A (counting) *semaphore* is an integer s with the following operations:

```
void signal() {                 void wait() {
  atomic { s = s + 1; }           bool avail;
}                                 do {
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                                      avail = s>0;
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                                  } while (!avail);
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```

free/release

acquire

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- can be used to block and unblock a thread

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- the operating system lets t return from its call to `de_schedule()`

Practical Implementation of Semaphores

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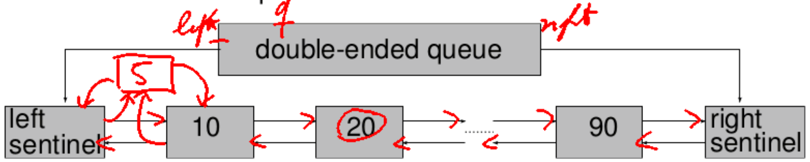
- `wait()` may busy wait for a few iterations
  - saves de-scheduling if the lock is released frequently
  - better throughput for semaphores that are held for a short time
- `signal()` might have to inform the OS that `s` has been written

⇝ using a semaphore with a single thread reduces to `if (s) s--; s++;`

- using semaphores in sequential code has no or little penalty
- program with concurrency in mind?

Making a Queue Thread-Safe

Consider a double ended queue:



double-ended queue: adding an element

```
void PushLeft(DQueue* q, int val) {
  QNode *qn = malloc(sizeof(QNode));
  qn->val = val;
  // prepend node qn
  QNode* leftSentinel = q->left;
  QNode* oldLeftNode = leftSentinel->right;
  qn->left = leftSentinel;
  qn->right = oldLeftNode;
  leftSentinel->right = qn;
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- add a lock to the double-ended queue data structure

Implementing the Removal

By using the same lock `q->s`, we can write a thread-safe `PopRight`:

double-ended queue: removal

```
int PopRight(DQueue* q) {
  QNode* oldRightNode;
  QNode* leftSentinel = q->left;
  QNode* rightSentinel = q->right;
  wait(q->s); // wait to enter the critical section
  oldRightNode = rightSentinel->left;
  if (oldRightNode==leftSentinel) { signal(q->s); return -1; }
  QNode* newRightNode = oldRightNode->left;
  newRightNode->right = rightSentinel;
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- error case complicates code ⇝ semaphores are easy to get wrong
- abstract common concept: take lock on entry, release on exit

Monitors: An Automatic, Re-entrant Mutex

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2. if that lock is already taken, proceed if it is taken by the current thread

⇝ need a way to release the lock after the return of the last recursive call

Implementation of a Basic Monitor

A monitor contains a mutex `s` and the thread currently occupying it:

```
typedef struct monitor mon_t;
struct monitor { int tid; int count; };
void monitor_init(mon_t* m) { memset(m, 0, sizeof(mon_t)); }
```

Define `monitor_enter` and `monitor_leave`:

- ensure mutual exclusion of accesses to `mon_t`
- track how many times we called a monitored procedure recursively

```
void monitor_enter(mon_t *m) {
  bool mine = false;
  while (!mine) {
    atomic {
      mine = thread_id()==m->tid;
      if (mine) m->count++; else
        if (m->tid==0) {
          mine = true; m->count=1;
          m->tid = thread_id();
        }
    };
    if (!mine) de_schedule(&m->tid);}
}
```

```
void monitor_leave(mon_t *m) {
  atomic {
    m->count--;
    if (m->count==0) {
      // wake up threads
      m->tid=0;
    }
  }
}
```

Rewriting the Queue using Monitors

Instead of the mutex, we can now use monitors to protect the queue:

double-ended queue: monitor version

```
void PushLeft(DQueue* q, int val) {
  monitor_enter(q->m);
  ...
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void ForAll(DQueue* q, void* data, void (*callback)(void*,int)){
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Recursive calls possible:

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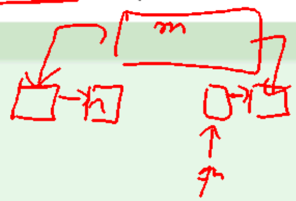

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Recursive calls possible:

- the function passed to `ForAll` can invoke `PushLeft`
- example: `ForAll(q,q,&PushLeft)` duplicates entries
- using monitor instead of mutex ensures that recursive call does not block

Condition Variables

✓ Monitors simplify the construction of thread-safe resources.

Still: Efficiency problem when using resource to synchronize:

- if a thread t waits for a data structure to be filled:
  - t will call e.g. `PopRight` and obtain `-1`
  - t then has to call again, until an element is available
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```
struct monitor { int tid; int count; int cond; };
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Define these two functions:

1. `wait` for the condition to become true
   - called while being *inside* the monitor
   - temporarily *releases* the monitor and blocks
   - when *signalled*, re-acquires the monitor and returns
2. `signal` waiting threads that they may be able to proceed
   - one/all waiting threads that called *wait* will be woken up, two possibilities:

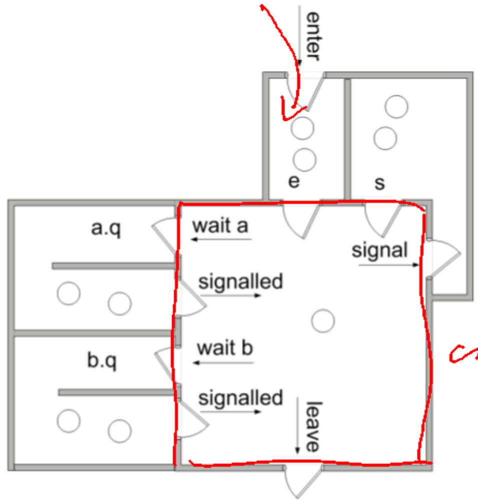
     signal-and-urgent-wait : the *signalling* thread suspends and continues once the *signalled* thread has released the monitor

     signal-and-continue the *signalling* thread continues, any *signalled* thread enters when the monitor becomes available

Signal-And-Urgent-Wait Semantics

Requires one queues for each condition c and a suspended queue s:

- a thread who tries to enter a monitor is added to queue e if the monitor is occupied



source: http://en.wikipedia.org/wiki/Monitor_(synchronization)

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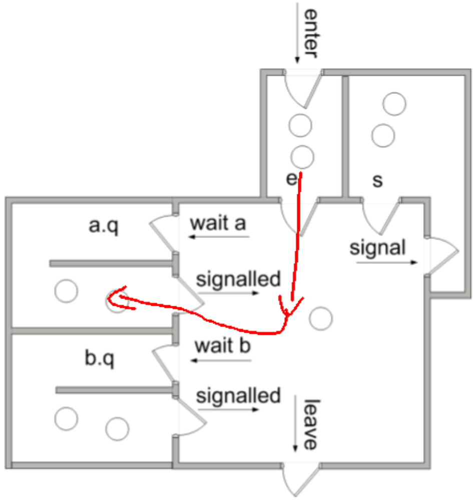

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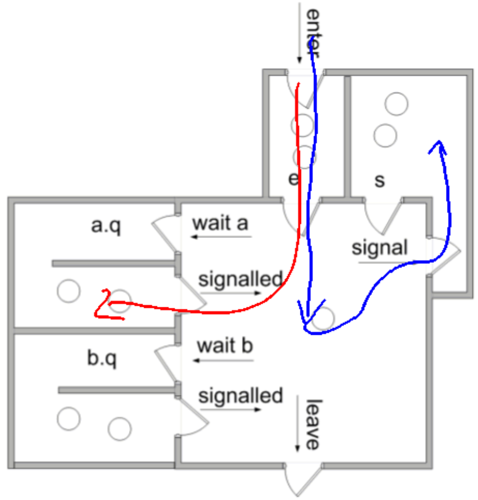

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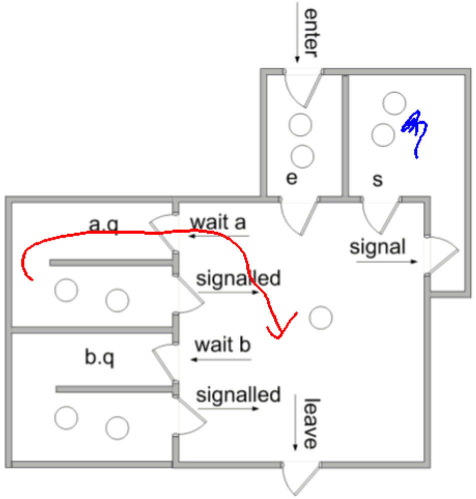

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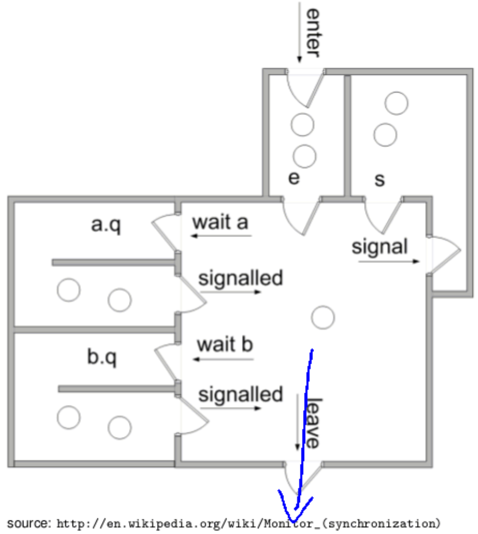

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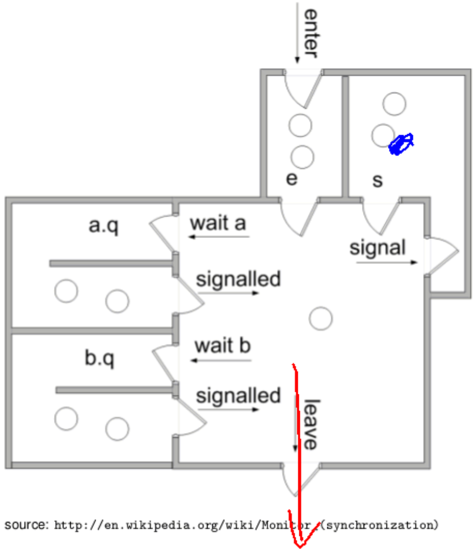

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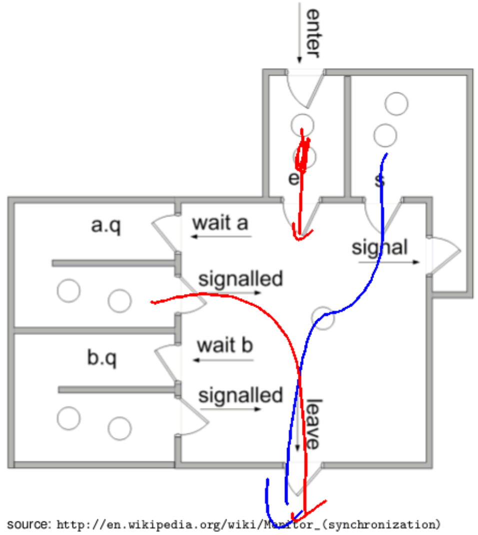

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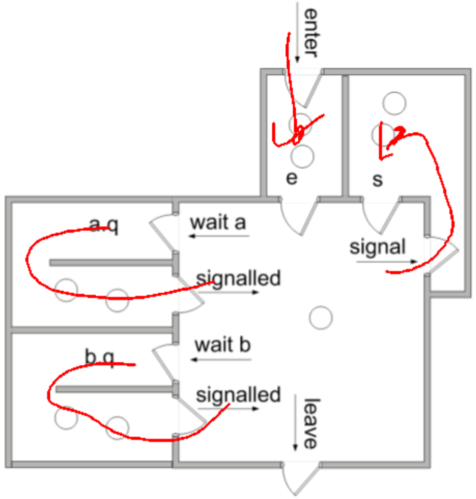

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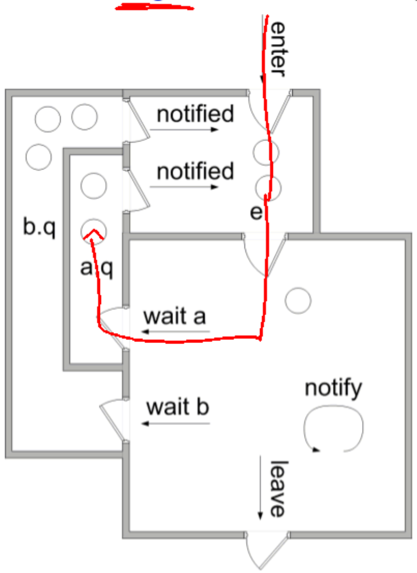
$\leadsto$ queue s has priority over e

Signal-And-Continue Semantics

Here, the `signal` function is usually called `notify`.



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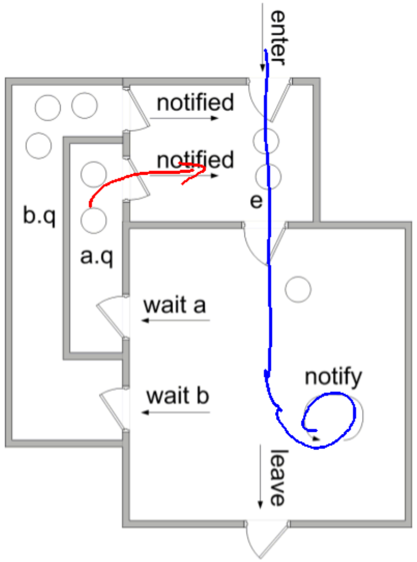

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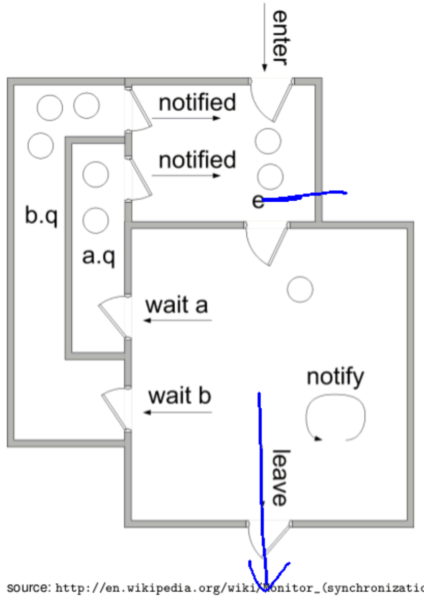

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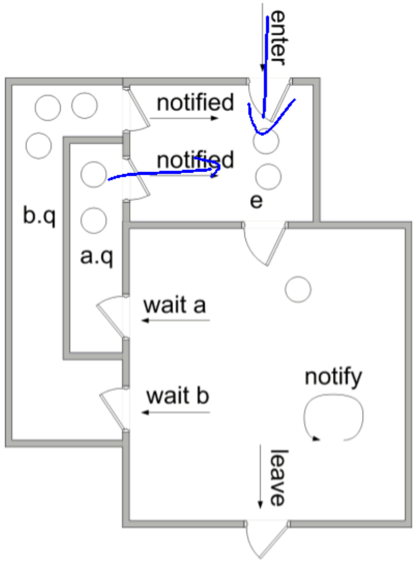

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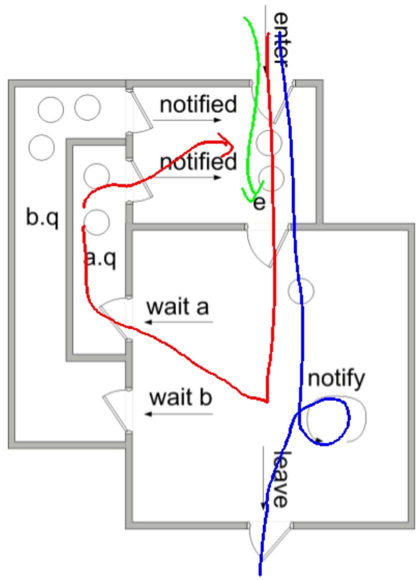

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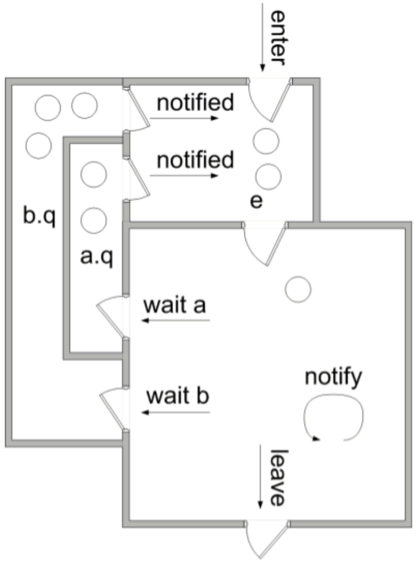

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- need additional queue s if waiting threads should have priority

source: http://en.wikipedia.org/wiki/Monitor_(synchronization)

Implementing Condition Variables

We implement the simpler *signal-and-continue* semantics:

- a *notified* thread is simply woken up and competes for the monitor

```
void cond_wait(mon_t *m) {
  assert(m->tid==thread_id());
  int old_count = m->count;
  m->tid = 0;
  de_schedule(&m->cond);
  bool next_to_enter;
  do {
    atomic {
      next_to_enter = m->tid==0;
      if (next_to_enter) {
        m->tid = thread_id();
        m->count = old_count;
      }
    }
    if (!next_to_enter) de_schedule(&m->tid);
  } while (!next_to_enter);
}
```

```
void cond_notify(mon_t *m) {
  // wake up other threads
  m->cond = 1;
}
```

A Note on Notify

With *signal-and-continue* semantics, two notify functions exist:

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What about the priority of notified threads?

- a notified thread is likely to block immediately on `&m->tid`
- ⇝ notified threads compete for the monitor with other threads
- if OS implements FIFO order: notified threads will run *after* threads that tried to enter since `wait` was called
- giving priority to waiting threads requires better interface to OS

Implementing `PopRight` with Monitors

We use the monitor `q->m` and the condition variable `q->c`. `PopRight`:

double-ended queue: removal

```
int PopRight(DQueue* q, int val) {
  QNode* oldRightNode;
  monitor_enter(q->m); // wait to enter the critical section
L: QNode* rightSentinel = q->right;
  oldRightNode = rightSentinel->left;
  if (oldRightNode==leftSentinel) { cond_wait(q->c); goto L; }
  QNode* newRightNode = oldRightNode->left;
  newRightNode->right = rightSentinel;
  rightSentingel->left = newRightNode;
  monitor_leave(q->m); // signal that we're done
  int val = oldRightNode->val;
  free(oldRightNode);
  return val;
}
```

- if the queue is empty, wait on `q->c`
- use a loop, in case the thread is woken up spuriously

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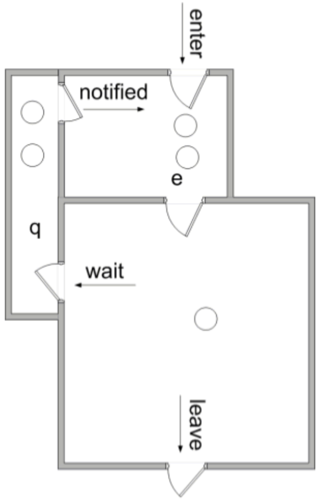
- create condition variable for each set of threads with the same p
  - notify variable if the predicate may have changed
- or, simpler: notify all threads each time any predicate changes

Monitors with a Single Condition Variable

Monitors with a single condition variable are built into *Java* and *C#*:



source: http://en.wikipedia.org/wiki/Monitor_(synchronization)

```
class C {
  public synchronized void f() {
    // body of f
  }}
```

is equivalent to

```
class C {
  public void f() {
    monitor_enter();
    // body of f
    monitor_leave();
  }}
```

with `Object` containing:

```
  private int mon_var;
  private int mon_count;
  private int cond_var;
  protected void monitor_enter();
  protected void monitor_leave();
```

Deadlocks with Monitors

Definition (Deadlock)

A deadlock is a situation in which two processes are waiting for the respective other to finish, and thus neither ever does.

(The definition generalizes to a set of actions with a cyclic dependency.)

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  public Foo other = null;
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    ... if (*) other.bar(); ...
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and two instances:

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a.other = b; b.other = a;
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Sequence leading to a deadlock:

- threads A and B execute `a.bar()` and `b.bar()`
- `a.bar()` acquires the monitor of `a`
- `b.bar()` acquires the monitor of `b`
- A happens to execute `other.bar()`
- A blocks on the monitor of b
- B happens to execute `other.bar()`
- $\leadsto$ both *block* indefinitely