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Pthreads: condition variables, barriers, semaphores

CS450/CS550: Parallel Programming

Week 4

Condition variables

- Condition variables are **synchronization** primitives that enable threads to wait until a particular condition occurs
- Condition variables are user-mode objects that **cannot be shared across processes**
- Condition variables enable threads to atomically release a lock and enter the sleeping state
- Condition variables should be used as a place to wait and **be notified**
- They are **not the condition** itself and they are not events

Create and destroy conditions

- Create a condition variable:
  `int pthread_cond_init(pthread_cond_t *cond, const pthread_condattr_t *attr);`
- Destroy a condition variable:
  `int pthread_cond_destroy(pthread_cond_t *cond);`
  - returns 0 on success, an error code otherwise
  - `cond`: output parameter, condition
  - `attr`: input parameter, attributes (default is `NULL`)

Waiting and waking up for conditions

- Waiting on a condition:

```
int pthread_cond_wait(pthread_cond_t *cond,
pthread_mutex_t *mutex);
```

- Unblock at least one of the blocked threads:

```
int pthread_cond_signal(pthread_cond_t *cond);
```

- Unblock all threads currently blocked by the condition variable:

```
int pthread_cond_broadcast(pthread_cond_t *cond);
```

  - functions return 0 on success, an error code otherwise
  - `cond`: input parameter, condition
  - `mutex`: input parameter, an associated mutex

Usage pattern of condition variables

- The typical usage pattern of condition variables is following:

```
pthread_mutex_lock(&lock);
while (the_condition)
    pthread_cond_wait(&cond, &lock);
do_stuff();
pthread_mutex_unlock(&lock);
```

- A thread, signalling the condition variable, typically looks like:

```
pthread_mutex_lock(&lock);
if (alter_condition)
    pthread_cond_signal(&cond);
pthread_mutex_unlock (&lock)
```

Example 1: Condition variables

Barriers

- A barrier is a type of synchronization method
- A barrier for a group of threads or processes in the source code means any thread/process must stop at this point and cannot proceed until all other threads/processes reach it
- A barrier may be in a raised or lowered state
- A **latch** is a barrier that starts in the raised state and cannot be re-raised once it is in the lowered state
- A **count-down latch** is a latch that is automatically lowered once a pre-determined number of threads/processes have arrived

Initialize and destroy barriers

- Initialize the barrier `bar`:

```
int pthread_barrier_init(pthread_barrier_t
*restrict bar, const pthread_barrierattr_t
*restrict attr, unsigned count);
```

  - `attr`: the barrier object attributes (`NULL` for default values)
  - `count`: the number of threads that must wait before any of them successfully return from the call

- Destroy the barrier `bar`:

```
int pthread_barrier_destroy(pthread_barrier_t
*bar);
```

The use of barriers

- Synchronize participating threads at the barrier:
  `int pthread_barrier_wait(pthread_barrier_t *barrier);`
- The calling thread shall block until the required number of threads have called `pthread_barrier_wait` specifying the barrier
- If a signal is delivered to a thread blocked on a barrier, the thread shall resume waiting at the barrier if the barrier wait has not completed
- A thread that has blocked on a barrier shall not prevent any unblocked thread that is eligible to use the same processing resources from eventually making forward progress in its execution

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Example 2: Barriers

Semaphores

- A **semaphore** is a variable or abstract data type used to control access to a common resource by multiple threads and avoid critical section problems in a concurrent system
- Semaphores are a useful tool in the prevention of race conditions
- Semaphores which allow an arbitrary resource count are called **counting semaphores**
- Semaphores which are restricted to the values 0 and 1 are called **binary semaphores**
- The semaphore concept was invented by Edsger Dijkstra in 1962
- To use semaphores in C, the **semaphore.h** header should be included

Create and destroy semaphores

- Initialize a semaphore:
  `int sem_init(sem_t *sem, int pshared, unsigned int value);`
  - `sem`: a pointer to a semaphore object to initialize
  - `pshared`: a flag indicating whether or not the semaphore should be shared with forked processes
  - `value`: an initial value to set the semaphore to
- Destroy a semaphore:
  `int sem_destroy(sem_t *sem);`

Operations with semaphores

- Lock the semaphore `sem` only if it is currently not locked:
  ```
  int sem_trywait(sem_t *sem);
  ```
- Lock the semaphore `sem`:
  ```
  int sem_wait(sem_t *sem);
  ```
- Unlock the semaphore `sem`:
  ```
  int sem_post(sem_t *sem);
  ```

Example 3: Semaphores

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Getting semaphore values

- Get the value of a semaphore:
```
int sem_getvalue(sem_t *restrict sem,
 int *restrict sval);
```
- The `sem_getvalue` function updates the location referenced by the `sval` argument to have the value of the semaphore referenced by `sem` without affecting the state of the semaphore
- If `sem` is locked, then the object to which `sval` points shall either be set to zero or to a negative number whose absolute value represents the number of processes waiting for the semaphore at some unspecified time during the call

Binary semaphores

- Binary semaphores are synchronization mechanisms with integer values varying between 0 and 1
- Binary semaphores are used to implement locks
- Binary semaphores provide a single access unit to a critical section: only one entity can access the critical section at once

Example 4: Binary semaphores

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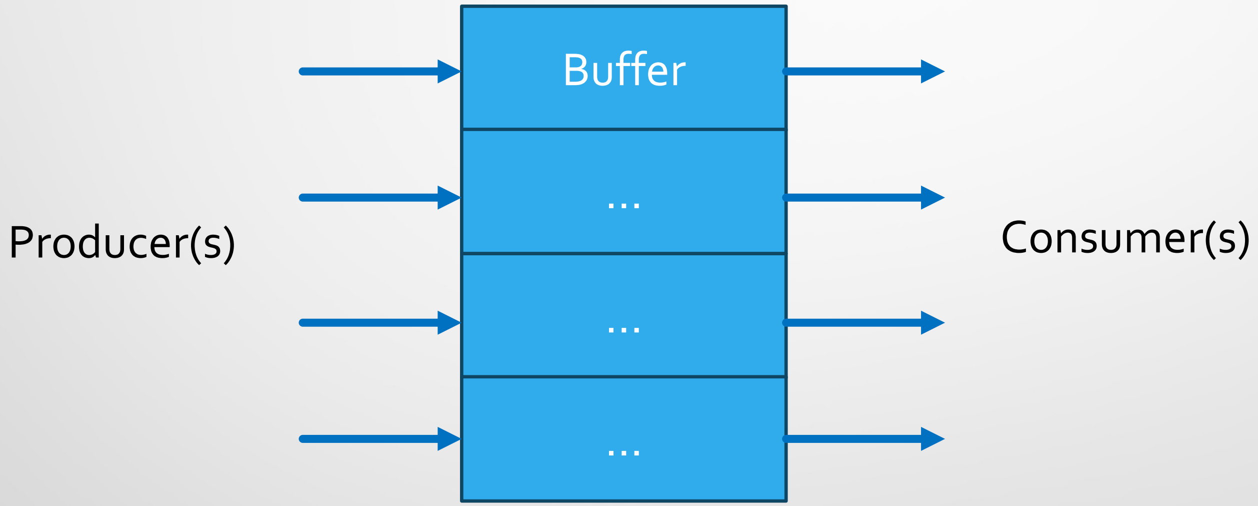
Producer-Consumer Problem

- The producer-consumer problem (bounded-buffer problem) is a family of synchronization problems described by Dijkstra since 1965



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Example 5: Producer-Consumer Problem