Threads Synchronization

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Mutex (1)

- **Mutex is an abbrev. for "mutual exclusion"**
  - Primary means of implementing thread synchronization.
    - Protects shared data when multiple writes occurs.
  - A mutex variable acts like a "lock" protecting access to a shared resource.
    - Only one thread can lock (or own) a mutex variable at any given time.
    - Even if several threads try to lock a mutex, only one thread will be successful. Other threads are blocked until the owner releases the lock.
  - Mutex is used to prevent "race" conditions.
    - race condition: anomalous behavior due to unexpected critical dependence on the relative timing of events.

Mutex (2)

```
int deposit(int amount)
{
  int balance;

  balance = get_balance();
  balance += amount;
  put_balance(balance);
  return balance;
}
```

```
int withdraw(int amount)
{
  int balance;

  balance = get_balance();
  balance -= amount;
  put_balance(balance);
  return balance;
}
```

T1 executes deposit(100)

T2 executes withdraw(300)

```
T1: balance = get_balance();
T1: balance += 100;
                              T2: balance = get_balance();
                              T2: balance -= 300;
                              T2: put_balance(balance);
T1: put_balance(balance);
```

Creating/Destroying Mutexes

- Static initialization
  - `pthread_mutex_t m = PTHREAD_MUTEX_INITIALIZER;`
- Dynamic initialization
  - ```
    pthread_mutex_t m;
    pthread_mutex_init (&m, (pthread_mutexattr_t *)NULL);
    ```
- Destroying a mutex
  - `pthread_mutex_destroy (&m);`
  - Destroys a mutex object, freeing the resources it might hold.
    ```

Using Mutexes (1)

- **`int pthread_mutex_lock (pthread_mutex_t *mutex)`**
  - Acquire a lock on the specified **`mutex`** variable.
  - If the **`mutex`** is already locked by another thread, block the calling thread until the **`mutex`** is unlocked.
- **`int pthread_mutex_unlock (pthread_mutex_t *mutex)`**
  - Unlock a **`mutex`** if called by the owning thread.
- **`int pthread_mutex_trylock (pthread_mutex_t *mutex)`**
  - Attempt to lock a **`mutex`**.
  - If the **`mutex`** is already locked, return immediately with a "busy" error code.

Using Mutexes (2)

```
pthread_mutex_t m =
     PTHREAD_MUTEX_INITIALIZER;

int deposit(int amount)
{
  int balance;

  pthread_mutex_lock(&m);

  balance = get_balance();
  balance += amount;
  put_balance(balance);

  pthread_mutex_unlock(&m);

  return balance;
}
```

```
int withdraw(int amount)
{
  int balance;

  pthread_mutex_lock(&m);

  balance = get_balance();
  balance -= amount;
  put_balance(balance);

  pthread_mutex_unlock(&m);

  return balance;
}
```

Condition Variables (1)

- **Another way for thread synchronization**
  - While mutexes implement synchronization by controlling thread access to data, condition variables allow threads to synchronize based upon the actual value of data.
  - Without condition variables, the programmer would need to have threads continually polling to check if the condition is met.
    - This can be very resource consuming since the thread would be continuously busy in this activity.
  - A condition variable is always used in conjunction with a mutex lock.

Condition Variables (2)

- **How condition variables work**
  - A thread locks a mutex associated with a condition variable.
  - The thread tests the condition to see if it can proceed.
  - If it can
    - Your thread does its work
    - Your thread unlocks the mutex
  - If it cannot
    - The thread sleeps. The mutex is automatically released.
    - Some other threads signals the condition variable.
    - Your thread wakes up from waiting with the mutex automatically locked, and it does its work.
    - Your thread releases the mutex when it's done.

Creating/Destroying CV

- **Static initialization**
  - `pthread_cond_t cond =`
    `PTHREAD_COND_INITIALIZER;`
- **Dynamic initialization**
  - `pthread_cond_t cond;`
    `pthread_cond_init (&cond, (pthread_condattr_t *)NULL);`
- **Destroying a condition variable**
  - `pthread_cond_destroy (&cond);`
  - Destroys a condition variable, freeing the resources it might hold.

Using Condition Variables

- `int pthread_cond_wait (pthread_cond_t *cond, pthread_mutex_t *mutex)`
  - Blocks the calling thread until the specified condition is signalled.
  - This should be called while mutex is locked, and it will automatically release the mutex while it waits.
- `int pthread_cond_signal (pthread_cond_t *cond)`
  - Signals another thread which is waiting on the condition variable.
  - Calling thread should have a lock.
- `int pthread_cond_broadcast(pthread_cond_t *cond)`
  - Used if more than one thread is in a blocking wait state.

Producer-Consumer (1)

```
#include <stdio.h>
#include <stdlib.h>
#include <pthread.h>

#define QSIZE            5
#define LOOP             30

typedef struct {
   int data[QSIZE];
   int index;
   int count;
   pthread_mutex_t lock;
   pthread_cond_t notfull;
   pthread_cond_t notempty;
} queue_t;

void *produce (void *args);
void *consume (void *args);
void put_data (queue_t *q, int d);
int  get_data (queue_t *q);
```

Producer-Consumer (2)

```
int main ()
{
   queue_t *q;
   pthread_t producer, consumer;

   q = qinit();

   pthread_create(&producer, NULL, produce, (void *)q);
   pthread_create(&consumer, NULL, consume, (void *)q);

   pthread_join (producer, NULL);
   pthread_join (consumer, NULL);

   qdelete();
}
```

Producer-Consumer (3)

```
queue_t *qinit()
{
   queue_t *q;

   q = (queue_t *) malloc(sizeof(queue_t));
   q->index = q->count = 0;
   pthread_mutex_init(&q->lock, NULL);
   pthread_cond_init(&q->notfull, NULL);
   pthread_cond_init(&q->notempty, NULL);

   return q;
}

void qdelete(queue_t *q)
{
   pthread_mutex_destroy(&q->lock);
   pthread_cond_destroy(&q->notfull);
   pthread_cond_destroy(&q->notempty);
   free(q);
}
```

Producer-Consumer (4)

```
void *produce(void *args)
{
   int i, d;
   queue_t *q = (queue_t *)args;
   for (i = 0; i < LOOP; i++) {
      d = random() % 10;
      put_data(q, d);
      printf("put data %d to queue\n", d);
   }
   pthread_exit(NULL);
}
void *consume(void *args)
{
   int i, d;
   queue_t *q = (queue_t *)args;
   for (i = 0; i < LOOP; i++) {
      d = get_data(q);
      printf("got data %d from queue\n", d);
   }
   pthread_exit(NULL);
}
```

Producer-Consumer (5)

```
void put_data(queue_t *q, int d)
{
    pthread_mutex_lock(&q->lock);
    while (q->count == QSIZE) pthread_cond_wait(&q->notfull, &q->lock);
    q->data[(q->index + q->count) % QSIZE] = d;
    q->count++;
    pthread_cond_signal(&q->notempty);
    pthread_mutex_unlock(&q->lock);
}
int get_data(queue_t *q)
{
    int d;
    pthread_mutex_lock(&q->lock);
    while (q->count == 0) pthread_cond_wait(&q->notempty, &q->lock);
    d = q->data[q->index];
    q->index = (q->index + 1) % QSIZE;
    q->count--;
    pthread_cond_signal(&q->notfull);
    pthread_mutex_unlock(&q->lock);
    return d;
}
```

Thread Safety (1)

- **Thread-safe**
  - Functions called from a thread must be thread-safe.
  - We identify four (non-disjoint) classes of thread-unsafe functions:
    - Class 1: Failing to protect shared variables
    - Class 2: Relying on persistent state across invocations
    - Class 3: Returning a pointer to a static variable
    - Class 4: Calling thread-unsafe functions

Thread Safety (2)

- **Class 1: Failing to protect shared variables.**
  - Fix: Use mutex operations.
  - Issue: Synchronization operations will slow down code.

```
pthread_mutex_t lock = PTHREAD_MUTEX_INITIALIZER;
int cnt = 0;

/* Thread routine */
void *count(void *arg) {
    int i;

    for (i=0; i<NITERS; i++) {
        pthread_mutex_lock (&lock);
        cnt++;
        pthread_mutex_unlock (&lock);
    }
    return NULL;
}
```

Thread Safety (3)

- **Class 2: Relying on persistent state across multiple function invocations.**
  - Random number generator relies on static state
  - Fix: Rewrite function so that caller passes in all necessary state.

```
/* rand - return pseudo-random integer on 0..32767 */
int rand(void) {
    static unsigned int next = 1;
    next = next*1103515245 + 12345;
    return (unsigned int)(next/65536) % 32768;
}
/* srand - set seed for rand() */
void srand(unsigned int seed) {
    next = seed;
}
```

Thread Safety (4)

- **Class 3: Returning a ptr to a static variable.**
- **Fixes:**
  1. Rewrite code so caller passes pointer to **`struct`**.
     - Issue: Requires changes in caller and callee.
  2. *Lock-and-copy*
     - Issue: Requires only simple changes in caller (and none in callee)
       - » However, caller must free memory.

```
struct hostent
*gethostbyname(char *name){
  static struct hostent h;
  <contact DNS and fill in h>
  return &h;
}
```

```
hostp = malloc(...));
gethostbyname_r(name, hostp);
```

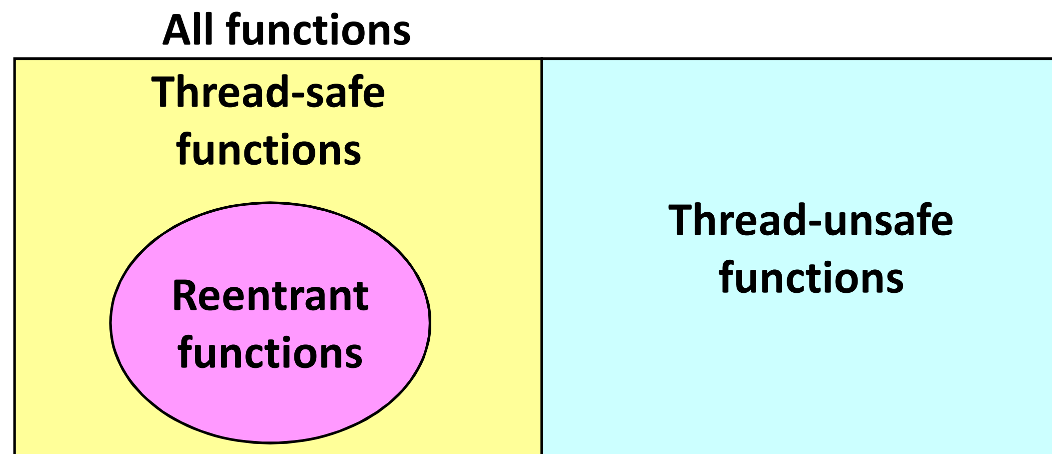
```
struct hostent
*gethostbyname_ts(char *name)
{
  struct hostent *unshared
                         = malloc(...);
  pthread_mutex_lock(&lock); /* lock */
  shared = gethostbyname(name);
  *unshared = *shared;   /* copy */
  pthread_mutex_unlock(&lock);
  return q;
}
```

Thread Safety (5)

- **Class 4: Calling thread-unsafe functions.**
  - Calling one thread-unsafe function makes an entire function thread-unsafe.
  - Fix: Modify the function so it calls only thread-safe functions

Reentrant Functions

- **A function is *reentrant* iff it accesses NO shared variables when called from multiple threads.**
  - Reentrant functions are a proper subset of the set of thread-safe functions.



    – NOTE: The fixes to Class 2 and 3 thread-unsafe functions require modifying the function to make it reentrant.

Thread-Safe Library

- **All functions in the Standard C Library (at the back of your K&R text) are thread-safe.**
  - Examples: `malloc, free, printf, scanf`
- **Most Unix system calls are thread-safe, with a few exceptions:**

Thread-unsafe function	Class	Reentrant version
asctime	3	asctime_r
ctime	3	ctime_r
gethostbyaddr	3	gethostbyaddr_r
gethostbyname	3	gethostbyname_r
inet_ntoa	3	(none)
localtime	3	localtime_r
rand	2	rand_r

Exercise

- **Make echo server**
  - Support multithread
  - Maintains
    - Clients connected
    - Bytes echoed