

# CS 3502

## Operating Systems

### POSIX Threads(pthread) Programming

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<https://kevinsuo.github.io/>

# Outline

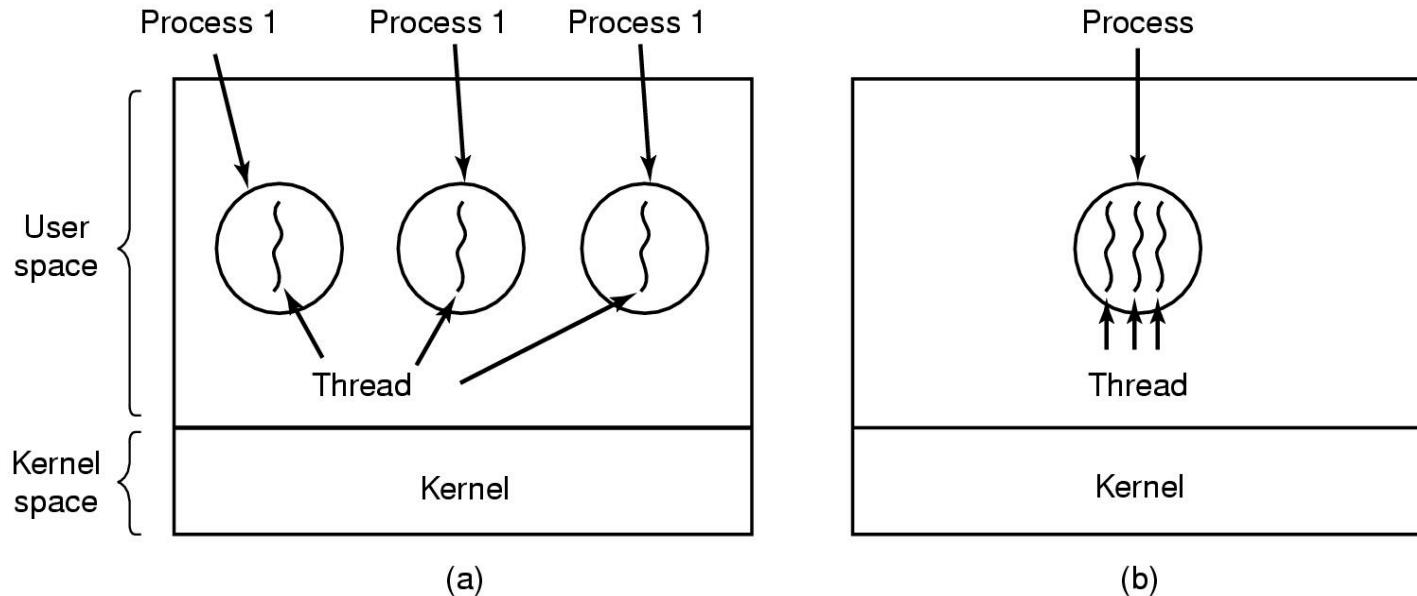
---

- What is pthread?
  - Thread model
  - Pthread overview
- Pthread management
  - Creation and termination
  - Identification
  - Join and detach
- Pthread data sharing
  - Mutex
  - Condition variable
  - Barrier
  - Semaphore



# The Thread Model

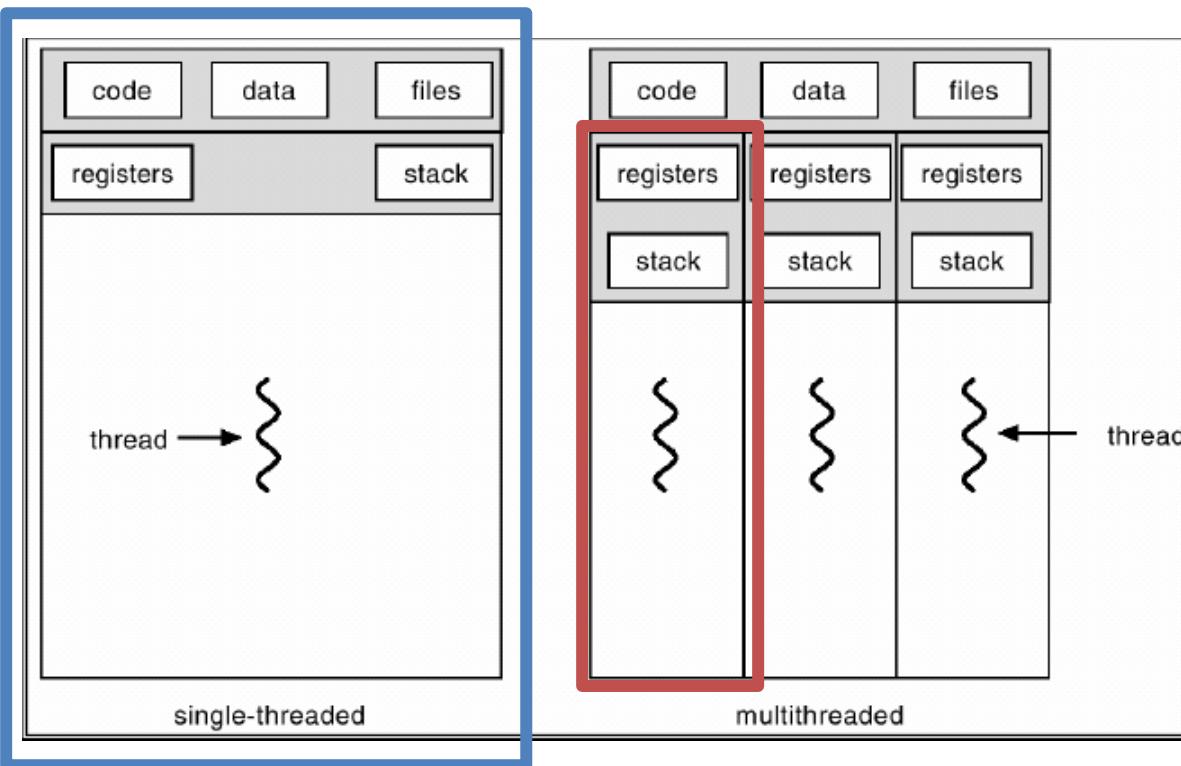
- Process: for resource grouping and execution
- Thread: a finer-granularity entity for execution and parallelism



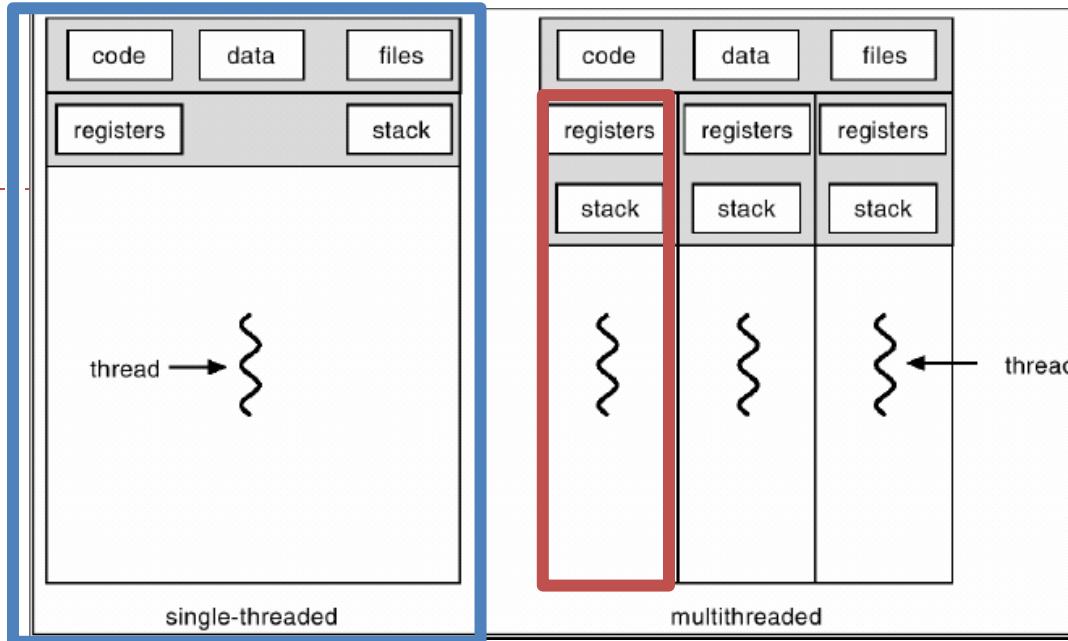
- (a) Three processes each with one thread, but **different address spaces**  
(b) One process with three threads, **sharing the address space**



# The Thread Model



Process	Thread
Have data/code/heap	Share code, data, heap
Include at least one thread	Multiple can coexist in a process
Have own address space, isolated from other processes	Only have own stack and registers



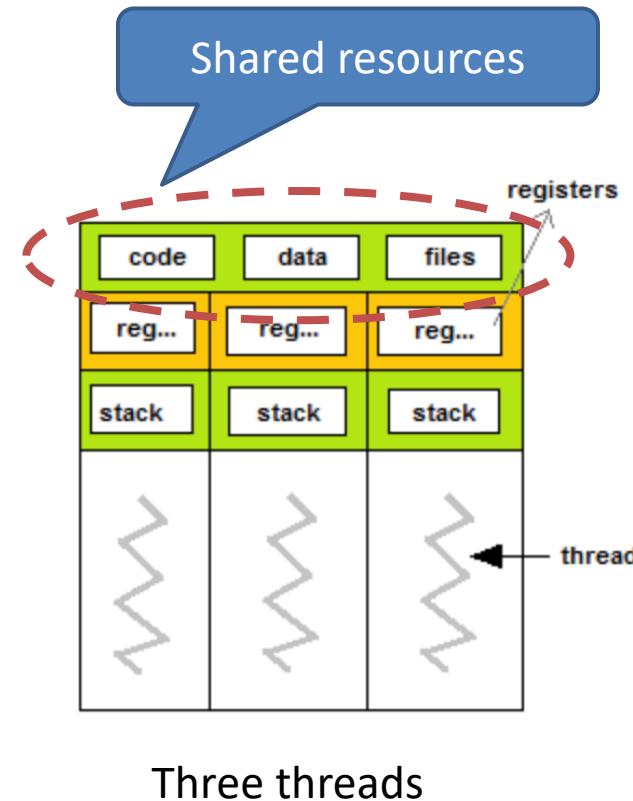
Per process items	Per thread items
Address space Global variables Open files Child processes Pending alarms Signals and signal handlers Accounting information	Program counter Registers Stack State

Items shared by all threads in a process

Items private to each thread

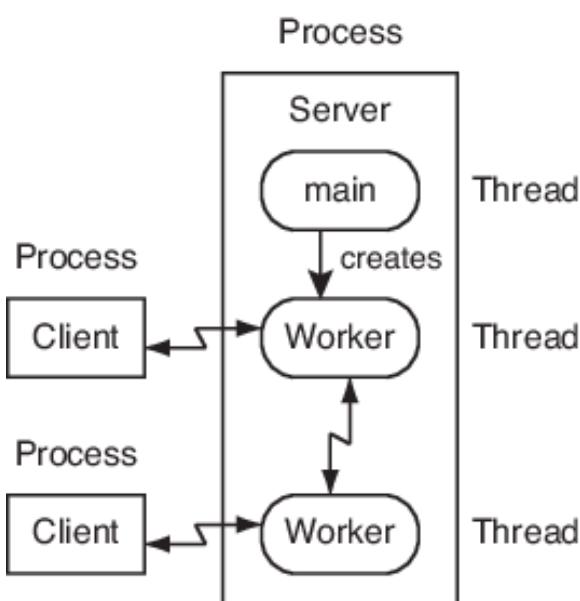
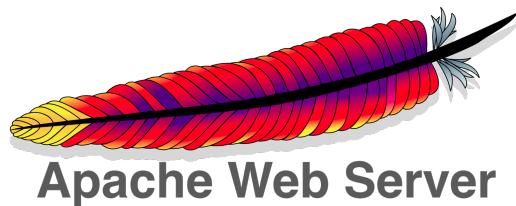


# The Thread Model

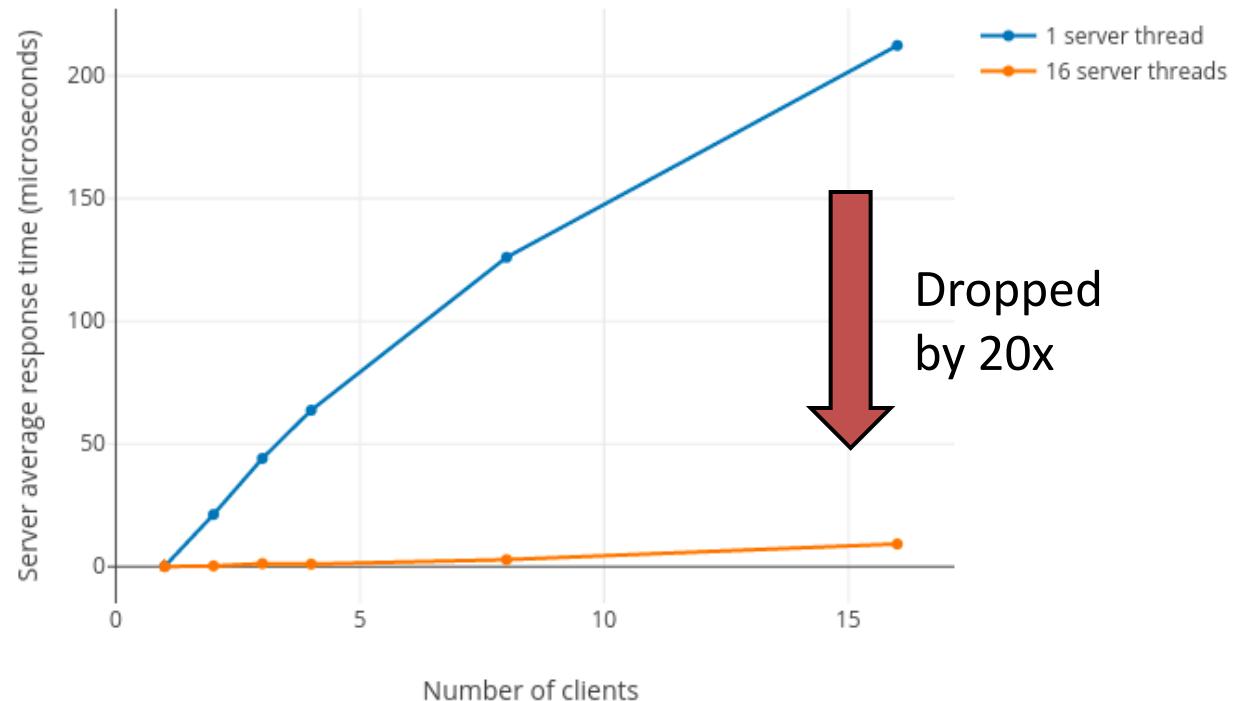


- Because threads within the same process share resources
  - Changes made by one thread to **shared system resources** (closing a file) will be seen by all other threads
  - Two pointers having the same value point to the **same data**
  - Reading and writing to the **same memory location** is possible, and therefore requires explicit synchronization by the programmer!

# Multi-threads for application performance



Multi-threaded performance vs. single-threaded (test1)

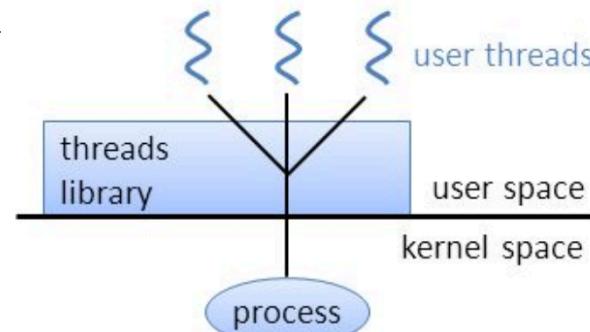


# Threading Models

- N:1 (User-level threading)

- GNU Portable Threads

<https://www.gnu.org/software/pth/>

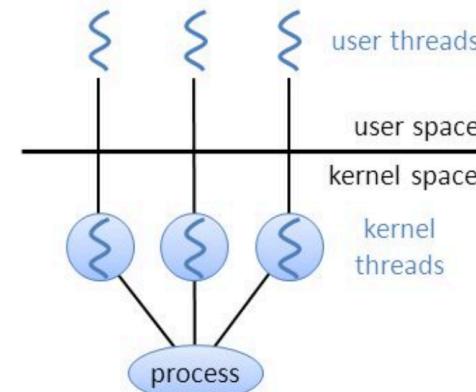


- 1:1 (Kernel-level threading)

- Native POSIX Thread Library (Pthread)

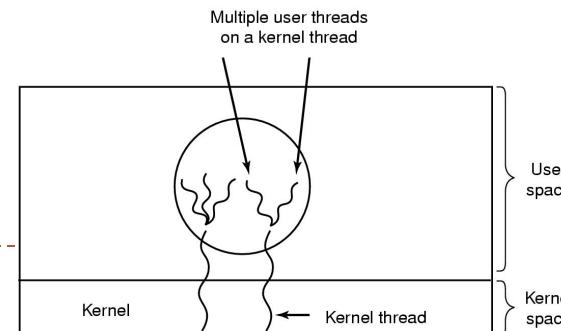
[https://en.wikipedia.org/wiki/Native\\_POSIX\\_Thread\\_Library](https://en.wikipedia.org/wiki/Native_POSIX_Thread_Library)

Linux/MacOS/Windows



- M:N (Hybrid threading)

- Solaris <https://www.oracle.com/solaris/solaris11/>



# Pthreads Overview

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- What are Pthreads?
  - An IEEE standardized thread programming interface (IEEE POSIX 1003.1c)
  - <http://www.open-std.org/jtc1/sc22/WG15/>
  - POSIX (Portable Operating System Interface) threads

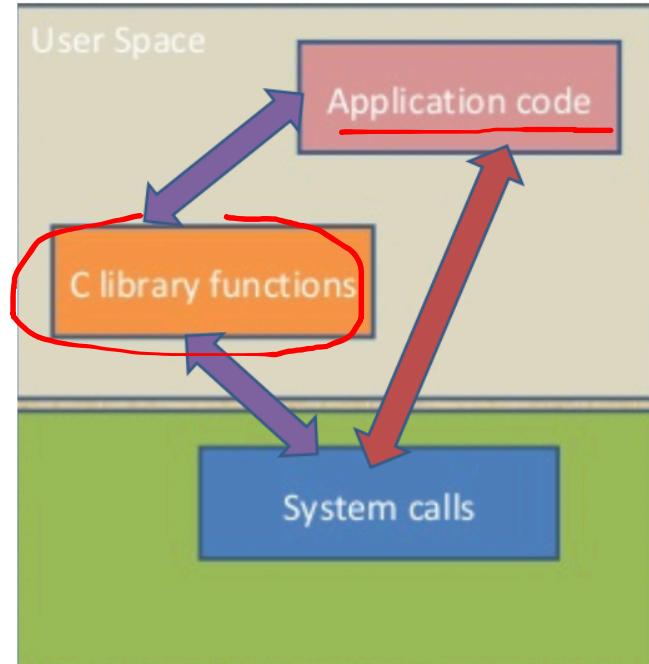


# Pthreads Overview

- What are Pthreads?
  - Defined as a set of C language programming types and procedure calls, implemented with a pthread.h header/include file and a thread library

Pthread\_create()  
in the user space

Clone()  
in the kernel



# Why Pthreads ?

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- Performance!
  - Lightweight
  - Communication
  - Fine granularity of concurrency
  - Easy to use
  - ...

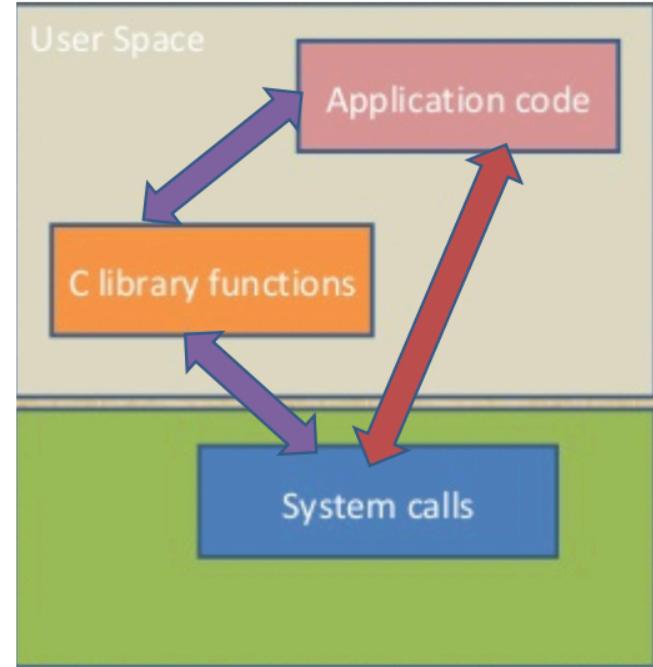


# Why Pthreads ?

Time in second with running 50000  
fork() or Pthread\_create()  
10~50 times faster

Pthread\_create()  
in the user space

Clone()  
in the kernel



Platform	fork()			pthread_create()		
	real	user	sys	real	user	sys
IBM 1.9 GHz POWER5 p5-575	50.66	3.32	42.75	1.13	0.54	0.75
INTEL 2.4 GHz Xeon	23.81	3.12	8.97	1.70	0.53	0.30
INTEL 1.4 GHz Itanium 2	23.61	0.12	3.42	2.10	0.04	0.01



# Outline

---

- What is pthread?
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  - Semaphore



# Hello World!

---

<https://github.com/kevinsuo/CS3502/blob/master/hello-pthread.c>

```
#include <stdio.h>

int main(void) {
    printf("hello, world\n");

    return 0;
}
```



# helloworld-pthread.c

```
#include <pthread.h>
#include <stdio.h>
#include <stdlib.h>
#define NUM_THREADS 5
```

```
void *PrintHello(void *threadid)
{
    long tid;
    tid = (long)threadid;
    printf("Hello World! It's me, thread #%ld!\n", tid);
    pthread_exit(NULL);
}
```

```
int main(int argc, char *argv[])
{
    pthread_t threads[NUM_THREADS];
    int rc;
    long t;
    for(t=0;t<NUM_THREADS;t++){
        printf("In main: creating thread %ld\n", t);
        rc = pthread_create(&threads[t], NULL, PrintHello, (void *)t);
        if (rc){
            printf("ERROR; return code from pthread_create() is %d\n", rc);
            exit(-1);
        }
    }
    pthread_exit(NULL);
```

Header file

What the thread will do?

Create new threads

Pthread exit

# The Pthreads API

- The API is defined in the ANSI/IEEE POSIX 1003.1 – 1995
  - Naming conventions: all identifiers in the library begins with `pthread_`
  - Three major classes of subroutines
    - ▶ Thread management, mutexes, condition variables

Routine Prefix	Functional Group
<code>pthread_</code>	Threads themselves and miscellaneous subroutines
<code>pthread_attr_</code>	Thread attributes objects
<code>pthread_mutex_</code>	Mutexes
<code>pthread_mutexattr_</code>	Mutex attributes objects.
<code>pthread_cond_</code>	Condition variables
<code>pthread_condattr_</code>	Condition attributes objects
<code>pthread_key_</code>	Thread-specific data keys



# Compile

<https://github.com/kevinsuo/CS3502/blob/master/hello-pthread.c>

*Compile command*

```
gcc hello-pthread.c -o hello-pthread.o -pthread
```

*source file*

*With pthread  
library*

*create this executable file name  
(as opposed to default a.out)*

# Execution

<https://github.com/kevinsuo/CS3502/blob/master/hello-pthread.c>

./hello-pthread.o

*Run the output file*

```
ksuo@LinuxKernel2 ~> gcc hello-pthread.c -o hello-pthread.o -pthread  
ksuo@LinuxKernel2 ~> ./hello-pthread.o  
In main: creating thread 0  
In main: creating thread 1  
In main: creating thread 2  
In main: creating thread 3  
Hello World! It's me, thread #0!  
In main: creating thread 4  
Hello World! It's me, thread #1!  
Hello World! It's me, thread #2!  
Hello World! It's me, thread #3!  
Hello World! It's me, thread #4!
```



```

#include <pthread.h>
#include <stdio.h>
#include <stdlib.h>
#define NUM_THREADS      5

void *PrintHello(void *threadid)
{
    long tid;
    tid = (long)threadid;
    printf("Hello World! It's me, thread #%ld!\n", tid);
    pthread_exit(NULL);
}

int main(int argc, char *argv[])
{
    pthread_t threads[NUM_THREADS];
    int rc;
    long t;
    for(t=0;t<NUM_THREADS;t++){
        printf("In main: creating thread %d\n", t);
        rc = pthread_create(&threads[t], NULL, PrintHello, (void *)t);
        if (rc){
            printf("ERROR; return code from pthread_create() is %d\n", rc);
            exit(-1);
        }
    }
    pthread_exit(NULL);
}

```

# Example

<https://github.com/kevinsuo/CS3502/blob/master/hello-pthread.c>

```

ksuo@LinuxKernel2 ~> gcc hello-pthread.c -o hello-pthread.o -pthread
ksuo@LinuxKernel2 ~> ./hello-pthread.o
In main: creating thread 0
In main: creating thread 1
In main: creating thread 2
In main: creating thread 3
Hello World! It's me, thread #0!
In main: creating thread 4
Hello World! It's me, thread #1!
Hello World! It's me, thread #2!
Hello World! It's me, thread #3!
Hello World! It's me, thread #4!

```



# 1, Creation & Termination

pthread\_create (thread, attr, thread\_function, arg)

- 1<sup>st</sup> parameter: pthread in the array
- 3<sup>rd</sup> parameter: the function for the thread to run
- 4<sup>th</sup> parameter: arg is passed by reference as a pointer cast of type void

Initially, your main() program comprises a single, default thread.

e.g.,

```
pthread_t threads[NUM_THREADS];
int t;
for(t=0;t<NUM_THREADS;t++){
    rc = pthread_create(&threads[t], NULL, thread_function, (void *)t);
}
```

# 1, Creation example

[https://github.com/kevinsuo/CS3502/blob/master/pthread\\_create\\_example.c](https://github.com/kevinsuo/CS3502/blob/master/pthread_create_example.c)

```
#include <pthread.h>
#include <stdio.h>
#include <stdlib.h>
#define NUM_THREADS      5

void *doSomeThing(void *threadid)
{
    long tid = (long)threadid;
    printf("I am thread #%ld!\n", tid);
    pthread_exit(NULL);
}

int main(int argc, char *argv[])
{
    pthread_t threads[NUM_THREADS];
    int t;
    for(t=0;t<NUM_THREADS;t++){
        pthread_create(&threads[t], NULL, doSomeThing, (void *)t);
    }
    pthread_exit(NULL);
}
```

# 1, Creation example

---

```
$ gcc pthread_create_example.c -o create_example.o -pthread
```

```
ksuo@LinuxKernel2 ~> ./create-example.o
I am thread #0!
I am thread #1!
I am thread #3!
I am thread #2!
I am thread #4!
```

NUM\_THREADS=5

```
ksuo@LinuxKernel2 ~> ./create-example.o
I am thread #0!
I am thread #1!
I am thread #3!
I am thread #2!
I am thread #4!
I am thread #5!
I am thread #8!
I am thread #6!
I am thread #7!
I am thread #9!
```

NUM\_THREADS=10

---

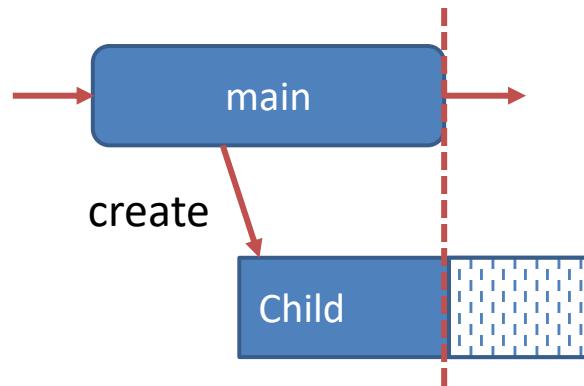


# 1, Creation & Termination

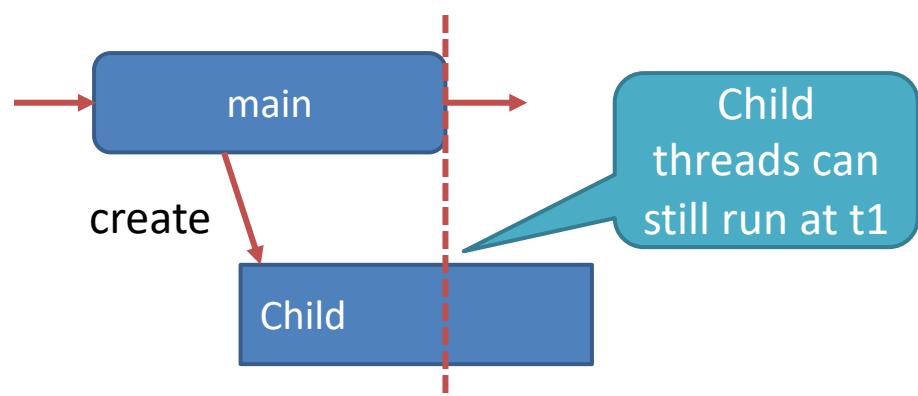
## pthread\_exit (status)

- If main() finishes before the threads it has created, and exists with the pthread\_exit(), the other threads will continue to execute. Otherwise, they will be automatically terminated when main() finishes

w/o pthread\_exit()



w/ pthread\_exit()



# 1, Termination example

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

void *myThread1(void)
{
    int i;
    for (i=0; i<10; i++)
    {
        printf("This is the 1st pthread.\n");
        sleep(1);
    }
}

int main()
{
    int ret=0;
    pthread_t id1;

    printf("This is main thread!\n");

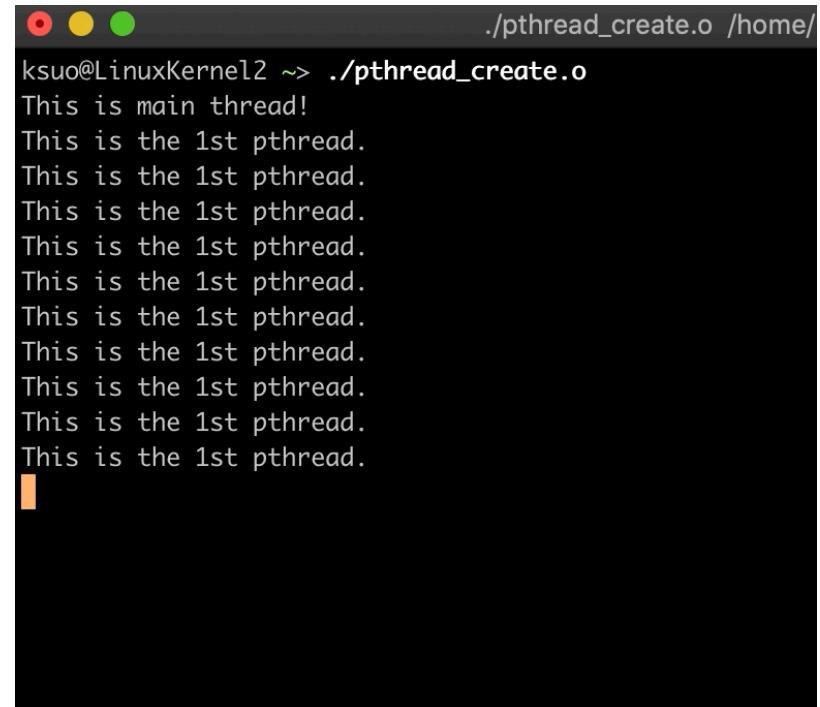
    ret = pthread_create(&id1, NULL, (void*)myThread1, NULL)
    if (ret)
    {
        printf("Create pthread error!/n");
        return 1;
    }

    pthread_exit(NULL);

    return 0;
}
```

[https://github.com/kevinsuo/CS3502  
/blob/master/pthread\\_create.c](https://github.com/kevinsuo/CS3502/blob/master/pthread_create.c)

```
gcc pthread_create.c -o
pthread_create.o -pthread
```



```
./pthread_create.o /home/
ksuo@LinuxKernel2 ~> ./pthread_create.o
This is main thread!
This is the 1st pthread.
```

With it: Child threads will continue to run when the main thread ends.

# 1, Termination example

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

void *myThread1(void)
{
    int i;
    for (i=0; i<10; i++)
    {
        printf("This is the 1st pthread.\n");
        sleep(1);
    }
}

int main()
{
    int ret=0;
    pthread_t id1;

    printf("This is main thread!\n");

    ret = pthread_create(&id1, NULL, (void*)myThread1, NULL);
    if (ret)
    {
        printf("Create pthread error!/n");
        return 1;
    }

    // pthread_exit(NULL);

    return 0;
}
```

[https://github.com/kevinsuo/CS3502  
/blob/master/pthread\\_create.c](https://github.com/kevinsuo/CS3502/blob/master/pthread_create.c)

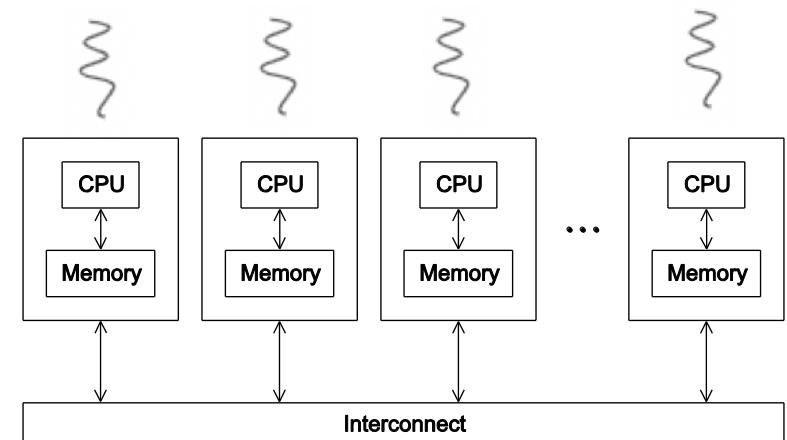
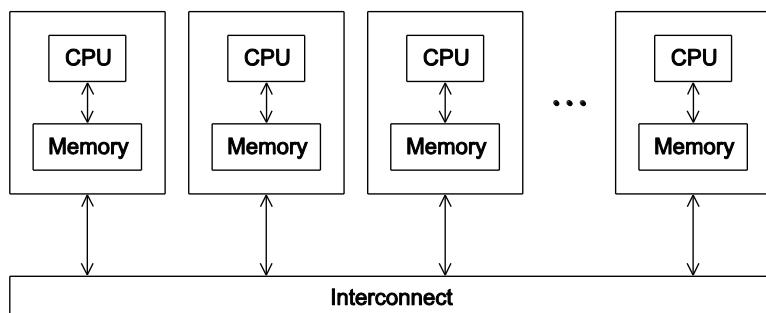
```
gcc pthread_create.c -o
pthread_create.o -pthread
```

```
ksuo@LinuxKernel2 ~> ./pthread_create.o
This is main thread!
ksuo@LinuxKernel2 ~> [ ]
```

Without it: Child threads will end if  
the main thread ends.

# 2, identification

Pthread\_create



how to differentiate them?

# 2, identification

---

**pthread\_self (void)**

- returns the ID of the thread in which it is invoked.

- A thread can obtain its own thread ID by calling the **pthread\_self()** function



# 2, identification

[https://github.com/kevinsuo/CS3502/blob/master/pthread\\_id.c](https://github.com/kevinsuo/CS3502/blob/master/pthread_id.c)

```
#include <pthread.h>
#include <stdio.h>
#include <stdlib.h>
#define NUM_THREADS      5

void *doSomeThing(void *threadid)
{
    long tid = (long)pthread_self();
    printf("id is %ld\n", tid);
    pthread_exit(NULL);
}

int main(int argc, char *argv[])
{
    pthread_t threads[NUM_THREADS];
    int t;
    for(t=0;t<NUM_THREADS;t++){
        pthread_create(&threads[t], NULL, doSomeThing, (void *)t);
    }
    pthread_exit(NULL);
}
```

gcc pthread\_id.c -o self.o -pthread

```
ksuo@LinuxKernel2 ~> ./self.o
id is 140603160495872
id is 140603135317760
id is 140603143710464
id is 140603152103168
id is 140603126925056
```



# 2, identification example

[https://github.com/kevinsuo/CS3502/blob/master/pthread\\_id\\_2.c](https://github.com/kevinsuo/CS3502/blob/master/pthread_id_2.c)

```
#include <pthread.h>
#include <stdio.h>
#include <stdlib.h>
#define NUM_THREADS      5

void *doSomeThing(void *t)
{
    long tid = (long)t;
    printf("id is %ld\n", tid);
    pthread_exit(NULL);
}

int main(int argc, char *argv[])
{
    pthread_t threads[NUM_THREADS];
    int t;
    for(t=0;t<NUM_THREADS;t++){
        pthread_create(&threads[t], NULL, doSomeThing, (void *)t);
    }
    pthread_exit(NULL);
}
```

gcc  
pthread\_id\_2.c –o pthread\_id\_2.o –pthread

arg can be used to differentiate threads



# 2, identification example

[https://github.com/kevinsuo/CS3502/blob/master/pthread\\_id\\_2.c](https://github.com/kevinsuo/CS3502/blob/master/pthread_id_2.c)

```
#include <pthread.h>
#include <stdio.h>
#include <stdlib.h>
#define NUM_THREADS      5

void *doSomeThing(void *t)
{
    long tid = (long)t;
    printf("id is %ld\n", tid);
    pthread_exit(NULL);
}

int main(int argc, char *argv[])
{
    pthread_t threads[NUM_THREADS];
    int t;
    for(t=0;t<NUM_THREADS;t++){
        pthread_create(&threads[t], NULL, doSomeThing, (void *)t);
    }
    pthread_exit(NULL);
}
```

Run:

./pthread\_id\_2.o

Compile:

```
gcc pthread_id_2.c -o
pthread_id_2.o -pthread
```

arg can be used to  
differentiate threads

```
ksuo@LinuxKernel2 ~> ./pthread_id_2.o
id is 0
id is 1
id is 3
id is 4
id is 2
```

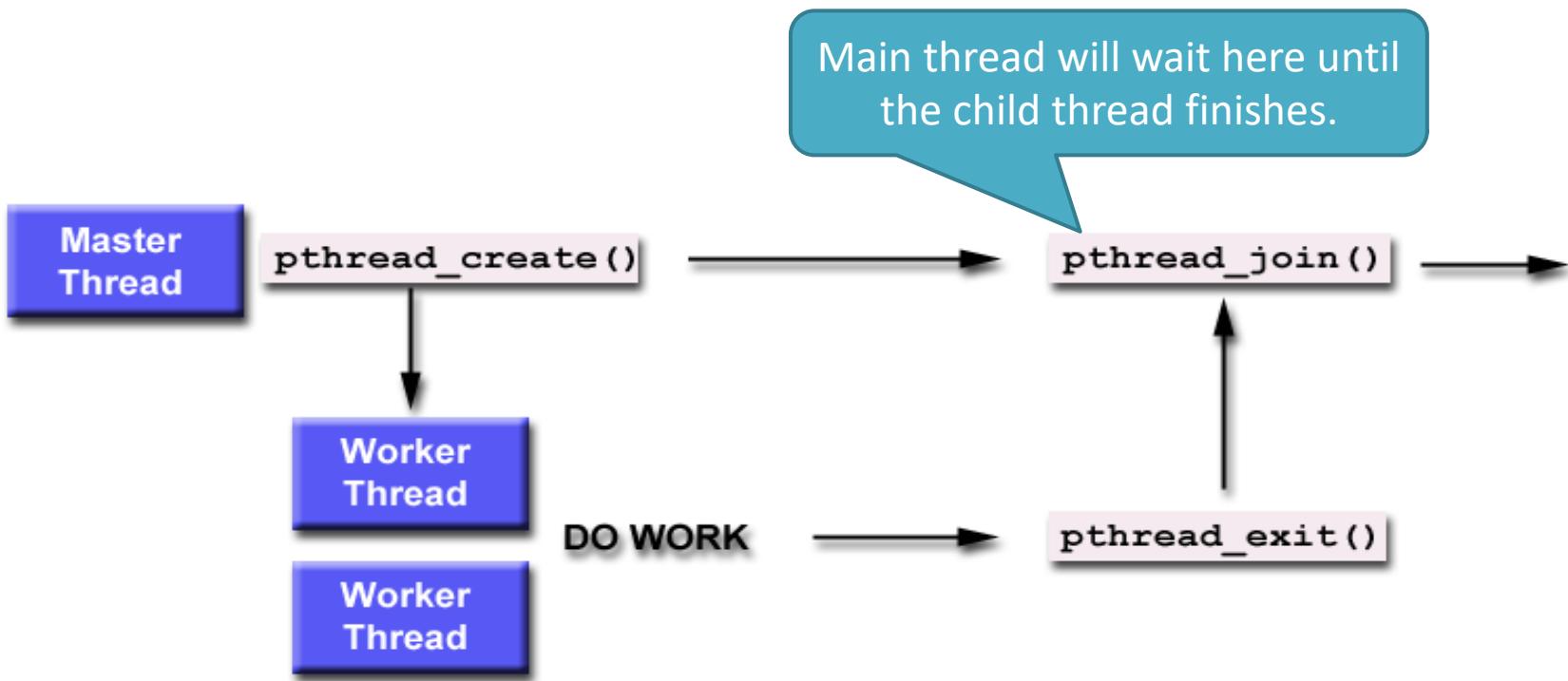


# 3, join

## pthread\_join (threadid, status)

\* Joining is one way to accomplish synchronization between threads: The `pthread_join()` subroutine blocks the calling thread until the specified `threadid` thread terminates.

The main thread will be blocked here to wait the child thread to finish



# 3, join example

[https://github.com/kevinsuo/CS3502  
/blob/master/pthread\\_join.c](https://github.com/kevinsuo/CS3502/blob/master/pthread_join.c)

```
int count = 0;

void *myThread1(void)
{
    int i;
    for (i=0; i<3; i++)
    {
        printf("This is the 1st pthread.\n");
        count++;
        sleep(1);
    }
}

int main()
{
    int ret=0;
    pthread_t id1;

    printf("This is main thread!\n");

    ret = pthread_create(&id1, NULL, (void*)myThread1, NULL);
    if (ret)
    {
        printf("Create pthread error!/\n");
        return 1;
    }

    // pthread_join(id1, (void *)ret);

    printf("count:%d\n", count);
    pthread_exit(NULL);

    return 0;
}
```

Compile:

```
gcc pthread_join.c -o
pthread_join.o -pthread
```

Run:

```
./pthread_join.o
```

```
pi@raspberrypi ~/Downloads> ./test.o
This is main thread!
This is the 1st pthread.
count:0
This is the 1st pthread.
This is the 1st pthread.
```

Count is 0 as the main thread  
keeps executing.

# 3, join example

[https://github.com/kevinsuo/CS3502  
/blob/master/pthread\\_join.c](https://github.com/kevinsuo/CS3502/blob/master/pthread_join.c)

```
int count = 0;

void *myThread1(void)
{
    int i;
    for (i=0; i<3; i++)
    {
        printf("This is the 1st pthread.\n");
        count++;
        sleep(1);
    }
}

int main()
{
    int ret=0;
    pthread_t id1;

    printf("This is main thread!\n");

    ret = pthread_create(&id1, NULL, (void*)myThread1, NULL);
    if (ret)
    {
        printf("Create pthread error!\n");
        return 1;
    }

    pthread_join(id1, (void *)ret);

    printf("count:%d\n", count);
    pthread_exit(NULL);

    return 0;
}
```

Compile:

```
gcc pthread_join.c -o
pthread_join.o -pthread
```

Run:

```
./pthread_join.o
```

```
pi@raspberrypi ~/Downloads> ./test.o
This is main thread!
This is the 1st pthread.
This is the 1st pthread.
This is the 1st pthread.
count:3
```

Count is 3 as the main thread is blocked here until child thread finished.

# 3, join example

```
int count = 0;

void *myThread1(void)
{
    int i;
    for (i=0; i<3; i++)
    {
        printf("This is the 1st pthread.\n");
        count++;
        sleep(1);
    }
}

int main()
{
    int ret=0;
    pthread_t id1;

    printf("This is main thread!\n");

    ret = pthread_create(&id1, NULL, (void*)myThread1, NULL);
    if (ret)
    {
        printf("Create pthread error!\n");
        return 1;
    }

//    pthread_join(id1, (void *)ret);

    printf("count:%d\n", count);
    pthread_exit(NULL);

}

```

```
int count = 0;

void *myThread1(void)
{
    int i;
    for (i=0; i<3; i++)
    {
        printf("This is the 1st pthread.\n");
        count++;
        sleep(1);
    }
}

int main()
{
    int ret=0;
    pthread_t id1;

    printf("This is main thread!\n");

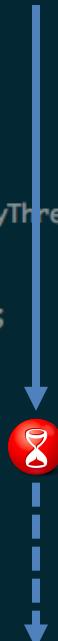
    ret = pthread_create(&id1, NULL, (void*)myThread1, NULL);
    if (ret)
    {
        printf("Create pthread error!\n");
        return 1;
    }

    pthread_join(id1, (void *)ret);

    printf("count:%d\n", count);
    pthread_exit(NULL);

}

```



# Outline

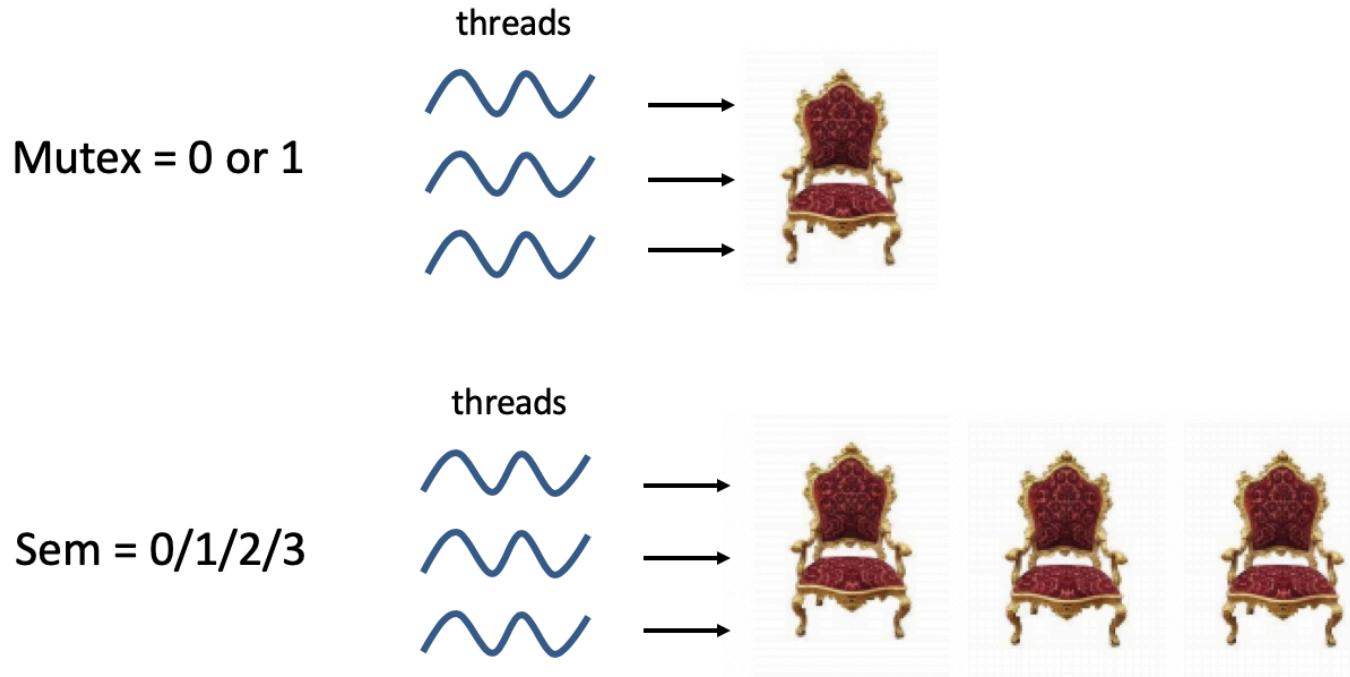
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  - Semaphore



# 4, mutex lock

- Mutex: a simplified version of the semaphores
  - A variable that can be in one of two states: unlocked or locked
  - Supports synchronization by controlling access to shared data



# 4, mutex – Creating and Destroying Mutexes

---

[pthread\\_mutex\\_init \(mutex, attr\)](#)

[pthread\\_mutex\\_destroy \(mutex\)](#)

1. Mutex variables must be declared with type pthread\_mutex\_t, and must be initialized before can be used. The mutex is initially not locked.

Statically: `pthread_mutex_t mymutex = PTHREAD_MUTEX_INITIALIZER`

Dynamically, with [pthread\\_mutex\\_init \(mutex, attr\)](#)

2. The attr object must be declared with type pthread\_mutexattr\_t
3. Programmers should free a mutex object that is no longer used



```

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

int counter = 0;
static pthread_mutex_t mlock;

void *compute()
{
    int i = 0;
//    pthread_mutex_lock(&mlock)
    while (i < 10000) {
        counter = counter + 1;
        i++;
    }
    printf("Counter value: %d\n", counter);
//    pthread_mutex_unlock(&mlock);
}

int main()
{
    pthread_t thread1, thread2, thread3, thread4, thread5;
//    if (pthread_mutex_init(&mlock, NULL) != 0)
//    {
//        printf("mutex init failed\n");
//        return 1;
//    }

    pthread_create(&thread1, NULL, compute, (void *)&thread1);
    pthread_create(&thread2, NULL, compute, (void *)&thread2);
    pthread_create(&thread3, NULL, compute, (void *)&thread3);
    pthread_create(&thread4, NULL, compute, (void *)&thread4);
    pthread_create(&thread5, NULL, compute, (void *)&thread5);

    pthread_exit(NULL);
//    pthread_mutex_destroy(&mlock);
    exit(0);
}

```

<https://github.com/kevinsuo/CS3502/blob/master/mutexlock.c>

Compile:

```
gcc mutexlock.c -o
mutexlock.o -pthread
```

Run:

```
./mutexlock.o
```

```

ksuo@LinuxKernel2 ~> ./mutexlock.o
Counter value: 10000
Counter value: 40358
Counter value: 20000
Counter value: 30358
Counter value: 47442
ksuo@LinuxKernel2 ~> ./mutexlock.o
Counter value: 10244
Counter value: 12739
Counter value: 25027
Counter value: 31032
Counter value: 40015

```

```

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

int counter = 0;
static pthread_mutex_t mlock;

void *compute()
{
    int i = 0;
    pthread_mutex_lock(&mlock);
    while (i < 10000) {
        counter = counter + 1;
        i++;
    }
    printf("Counter value: %d\n", counter);
    pthread_mutex_unlock(&mlock);
}

int main()
{
    pthread_t thread1, thread2, thread3, thread4, thread5;
    if (pthread_mutex_init(&mlock, NULL) != 0)
    {
        printf("mutex init failed\n");
        return 1;
    }

    pthread_create(&thread1, NULL, compute, (void *)&thread1);
    pthread_create(&thread2, NULL, compute, (void *)&thread2);
    pthread_create(&thread3, NULL, compute, (void *)&thread3);
    pthread_create(&thread4, NULL, compute, (void *)&thread4);
    pthread_create(&thread5, NULL, compute, (void *)&thread5);

    pthread_exit(NULL);
    pthread_mutex_destroy(&mlock);
    exit(0);
}

```

<https://github.com/kevinsuo/CS3502/blob/master/mutexlock.c>

Compile:

gcc mutexlock.c -o  
mutexlock.o -pthread

Run:

./mutexlock.o

Init the mutex lock

```

pi@raspberrypi ~/Downloads> ./mutexlock.o
Counter value: 10000
Counter value: 20000
Counter value: 30000
Counter value: 40000
Counter value: 50000

```

destroy the mutex lock

# 5, mutex – Locking and Unlocking of Mutexes

---

`pthread_mutex_lock` (mutex) ; P(down)

`pthread_mutex_trylock` (mutex)

`pthread_mutexattr_unlock` (mutex) ; V(up)

1. `pthread_mutex_lock` (mutex) is a blocking call.
2. `pthread_mutex_trylock` (mutex) is a non-blocking call, useful in preventing the deadlock conditions (priority-inversion problem)
3. If you use multiple mutexes, the order is important;



```

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

int counter = 0;
static pthread_mutex_t mlock;

void *compute()
{
    int i = 0;
    pthread_mutex_lock(&mlock);
    while (i < 10000) {
        counter = counter + 1;
        i++;
    }
    printf("Counter value: %d\n", counter);
    pthread_mutex_unlock(&mlock);
}

int main()
{
    pthread_t thread1, thread2, thread3, thread4, thread5;
    if (pthread_mutex_init(&mlock, NULL) != 0)
    {
        printf("mutex init failed\n");
        return 1;
    }

    pthread_create(&thread1, NULL, compute, (void *)&thread1);
    pthread_create(&thread2, NULL, compute, (void *)&thread2);
    pthread_create(&thread3, NULL, compute, (void *)&thread3);
    pthread_create(&thread4, NULL, compute, (void *)&thread4);
    pthread_create(&thread5, NULL, compute, (void *)&thread5);

    pthread_exit(NULL);
    pthread_mutex_destroy(&mlock);
    exit(0);
}

```

Lock the “counter”

Unlock the “counter”

<https://github.com/kevinsuo/CS3502/blob/master/mutexlock.c>



Critical section

```

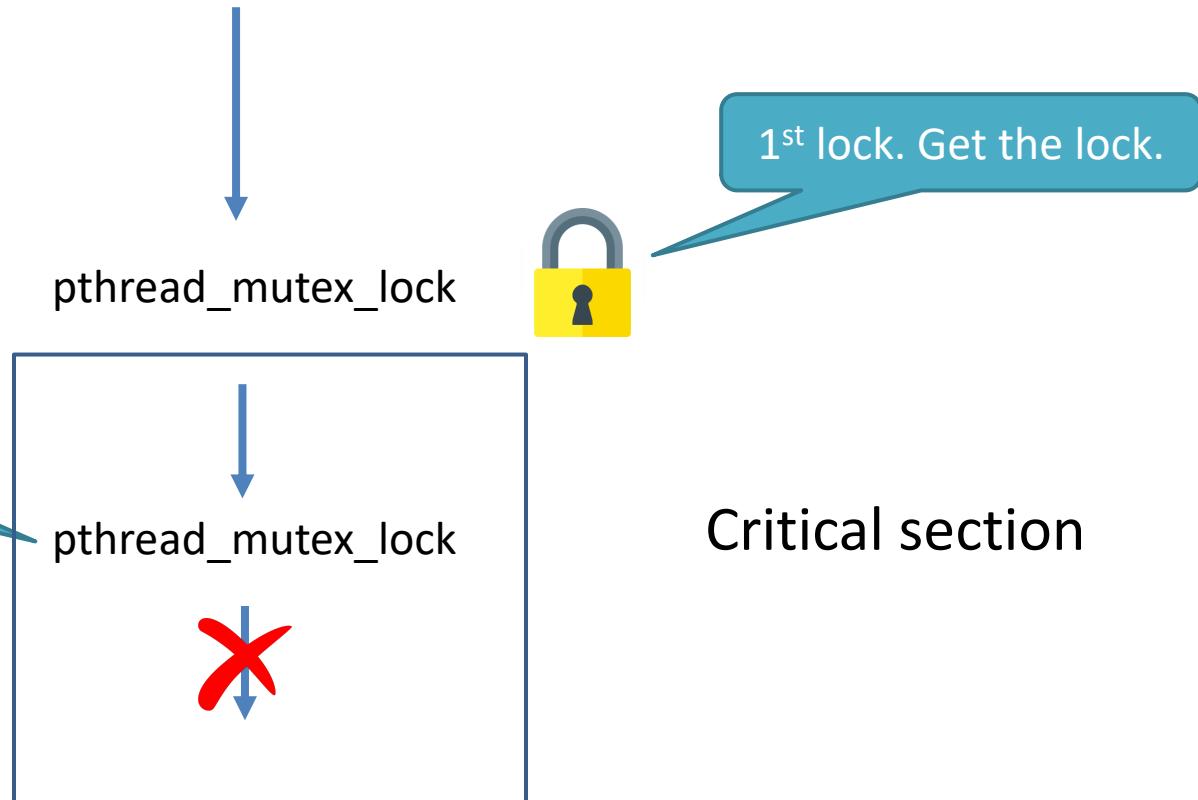
pi@raspberrypi ~/Downloads> ./mutexlock.o
Counter value: 10000
Counter value: 20000
Counter value: 30000
Counter value: 40000
Counter value: 50000

```

# pthread\_mutex\_lock vs. pthread\_mutex\_trylock

<https://github.com/kevinsuo/CS3502/blob/master/lock.c>

- `pthread_mutex_lock` (mutex) is a blocking call.



# pthread\_mutex\_lock vs. pthread\_mutex\_trylock

<https://github.com/kevinsuo/CS3502/blob/master/lock.c>

- pthread\_mutex\_lock (mutex) is a blocking call.

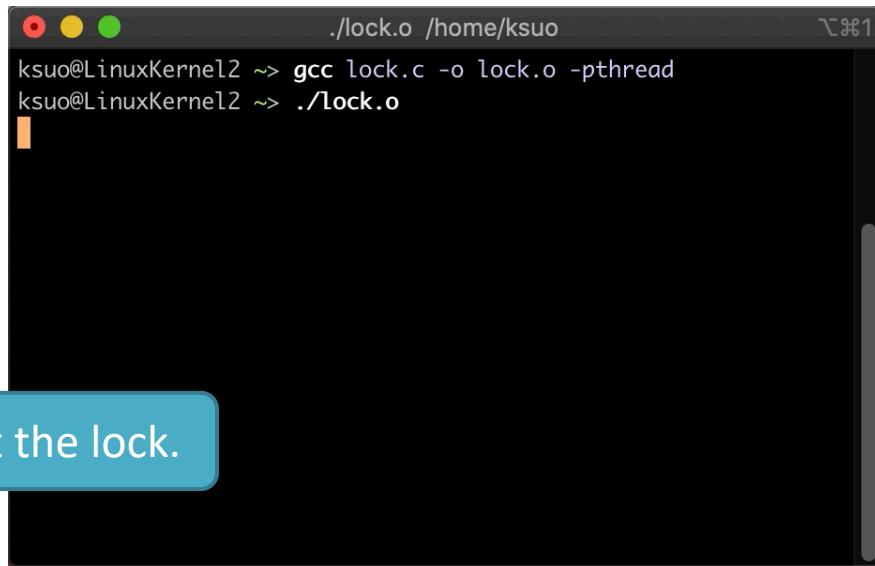
```
#include <stdio.h>
#include <stdlib.h>
#include <pthread.h>

int main(void)
{
    int i = 0;
    int res;

    pthread_mutex_t lock;
    pthread_mutex_init(&lock, NULL);

    pthread_mutex_lock(&lock);
    if((res = pthread_mutex_lock(&lock) != 0)) {
        printf("don't lock\n");
    } else {
        printf("locked\n");
    }

    return 0;
}
```



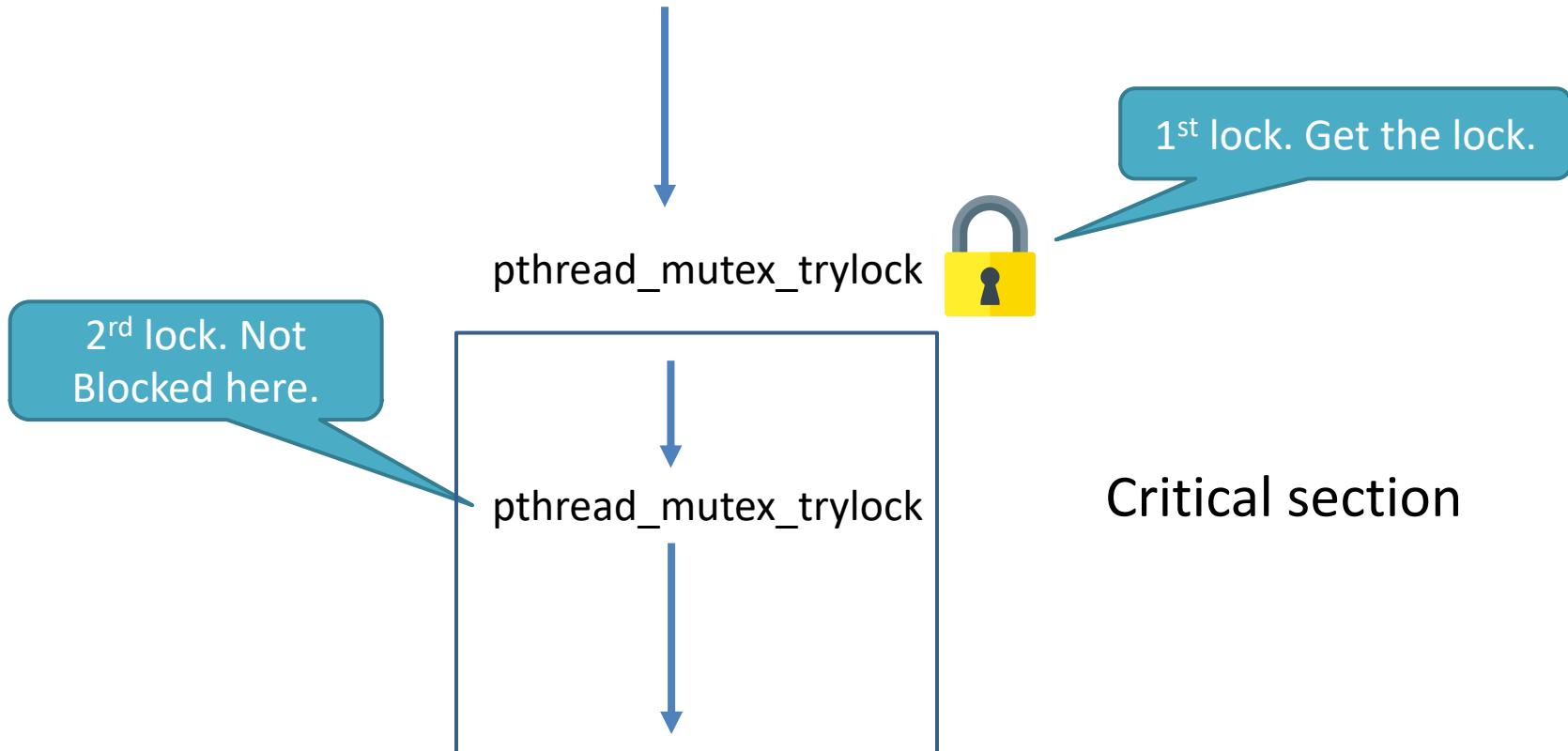
1<sup>st</sup> lock. Get the lock.

2<sup>nd</sup> lock. Blocked here.

# pthread\_mutex\_lock vs. pthread\_mutex\_trylock

<https://github.com/kevinsuo/CS3502/blob/master/lock.c>

- `pthread_mutex_lock` (mutex) is a blocking call.



# pthread\_mutex\_lock vs. pthread\_mutex\_trylock

[https://github.com/kevinsuo/CS3502  
/blob/master/trylock.c](https://github.com/kevinsuo/CS3502/blob/master/trylock.c)

- pthread\_mutex\_trylock (mutex) is a non-blocking call.

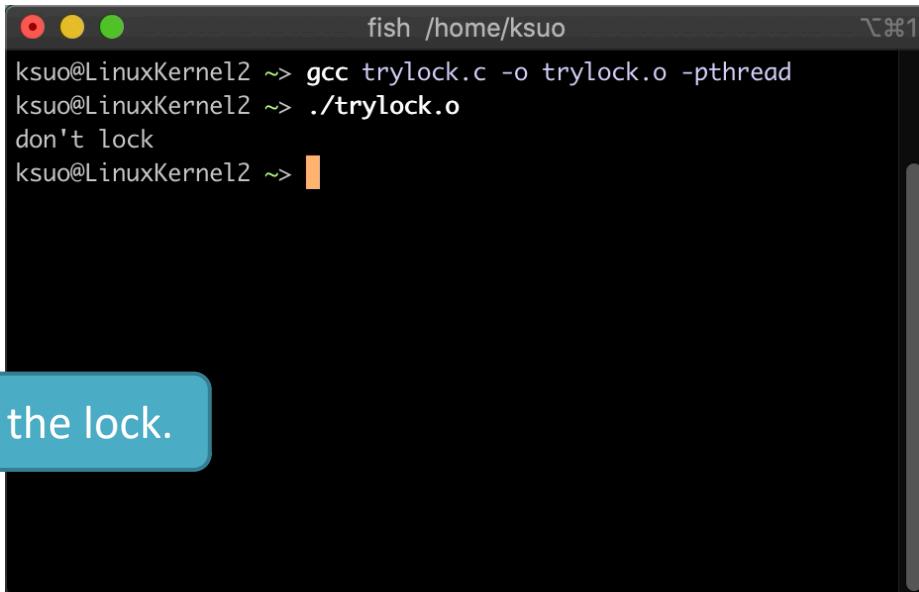
```
#include <stdio.h>
#include <stdlib.h>
#include <pthread.h>

int main(void)
{
    int i = 0;
    int res;

    pthread_mutex_t lock;
    pthread_mutex_init(&lock, NULL);

    pthread_mutex_trylock(&lock);
    if((res = pthread_mutex_trylock(&lock) != 0)) {
        printf("don't lock\n");
    } else {
        printf("locked\n");
    }

    return 0;
}
```



```
fish /home/ksuo
ksuo@LinuxKernel2 ~> gcc trylock.c -o trylock.o -pthread
ksuo@LinuxKernel2 ~> ./trylock.o
don't lock
ksuo@LinuxKernel2 ~>
```

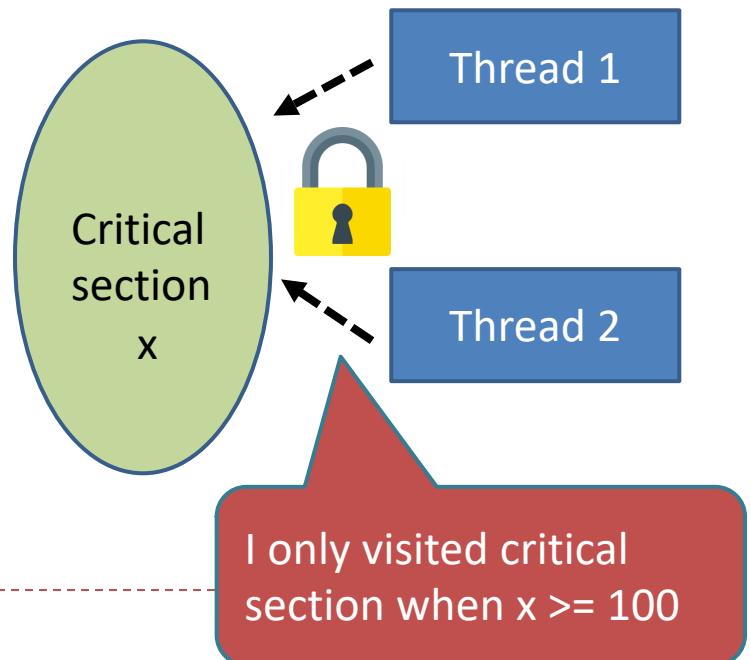
1<sup>st</sup> lock. Get the lock.

2<sup>nd</sup> lock. Not blocked here.



# 6, Condition variable

- Mutexes: support synchronization by controlling thread access to data (**without conditions**)
- Condition variables: another way for threads to synchronize (**with conditions**)
- Example:
  - T1: increase  $x$  every time;
  - T2: when  $x$  is larger than 99, then set  $x$  to 0;



# 6, condition variable example

[https://github.com/kevinsuo/CS3502/blob/master/lock\\_wo\\_condition.c](https://github.com/kevinsuo/CS3502/blob/master/lock_wo_condition.c)

- Mutex without condition

- Example: T1: increase x every time;
- T2: when x is larger than 99, then set x to 0;

```
//thread 1:  
  
while(true)  
{  
    pthread_mutex_lock(&mutex);  
    iCount++;  
    pthread_mutex_unlock(&mutex);  
}
```

```
//thread 2:  
while(true)  
{  
    pthread_mutex_lock(&mutex);  
    if(iCount >= 100)  
    {  
        iCount = 0;  
    }  
    pthread_mutex_unlock(&mutex);  
}
```

T2 needs to:  
lock;  
determine;  
unlock;  
every time to check

```

int iCount = 0;
static pthread_mutex_t mlock;

void *thread1_work(void *id) {
    long tid = (long)id;
    while (1) {
        pthread_mutex_lock(&mlock);
        iCount++;
        printf("thread: %ld iCount: %d\n", tid, iCount);
        pthread_mutex_unlock(&mlock);
        sleep(1);
    }
}

void *thread2_work(void *id) {
    long tid = (long)id;
    while (1) {
        pthread_mutex_lock(&mlock);
        if (iCount >= 100)
            iCount = 0;
        printf("thread: %ld iCount: %d\n", tid, iCount);
        pthread_mutex_unlock(&mlock);
        sleep(1);
    }
}

int main() {
    pthread_t thread1, thread2;
    int id1=1, id2=2;
    if (pthread_mutex_init(&mlock, NULL) != 0) {
        printf("mutex init failed\n");
        return 1;
    }

    pthread_create(&thread1, NULL, thread1_work, (void *)(intptr_t)id1);
    pthread_create(&thread2, NULL, thread2_work, (void *)(intptr_t)id2);

    pthread_exit(NULL);
    pthread_mutex_destroy(&mlock);
    exit(0);
}

```

[https://github.com/kevinsuo/CS3502/blob/master/lock\\_wo\\_condition.c](https://github.com/kevinsuo/CS3502/blob/master/lock_wo_condition.c)

```

//thread 1:

while(true)
{
    pthread_mutex_lock(&mutex);
    iCount++;
    pthread_mutex_unlock(&mutex);
}

```

```

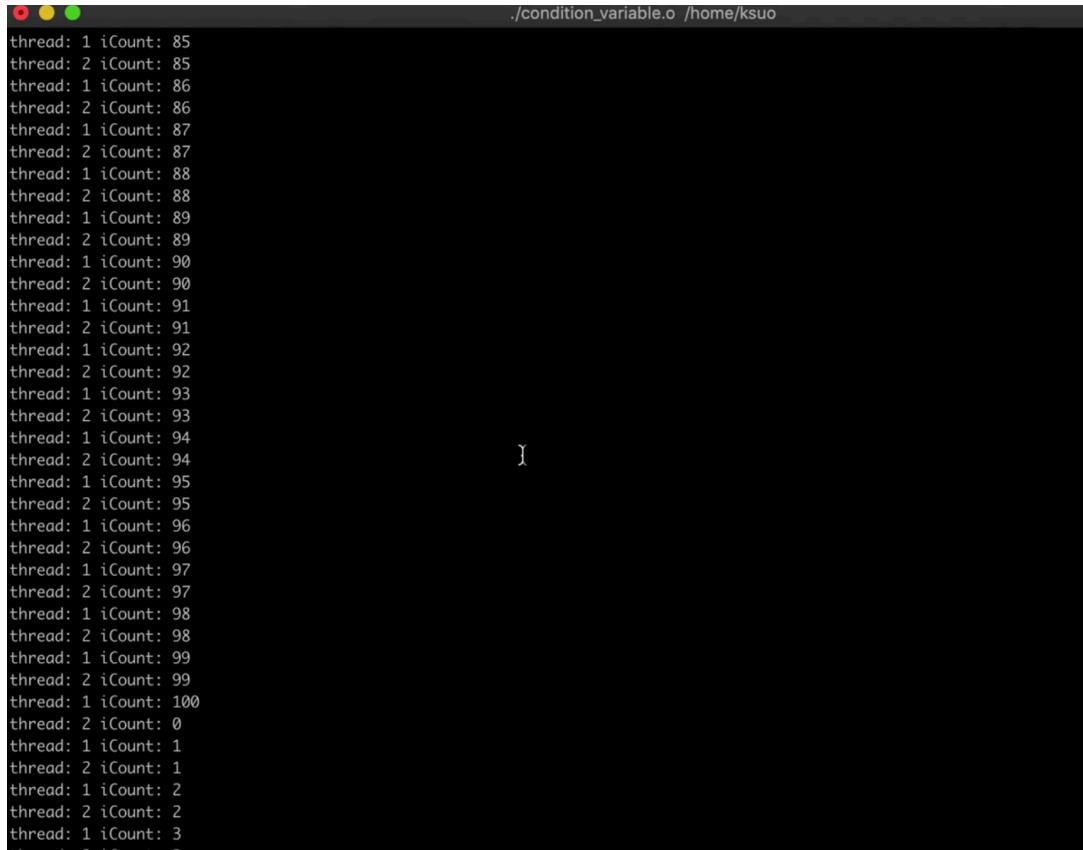
//thread 2:
while(true)
{
    pthread_mutex_lock(&mutex);
    if(iCount >= 100)
    {
        iCount = 0;
    }
    pthread_mutex_unlock(&mutex);
}

```

# 6, condition variable example

[https://github.com/kevinsuo/CS3502/blob/master/lock\\_wo\\_condition.c](https://github.com/kevinsuo/CS3502/blob/master/lock_wo_condition.c)

```
gcc lock_wo_condition.c -o lock_wo_condition.o -pthread  
./lock_wo_condition.o
```



```
./condition_variable.o /home/ksuo  
thread: 1 iCount: 85  
thread: 2 iCount: 85  
thread: 1 iCount: 86  
thread: 2 iCount: 86  
thread: 1 iCount: 87  
thread: 2 iCount: 87  
thread: 1 iCount: 88  
thread: 2 iCount: 88  
thread: 1 iCount: 89  
thread: 2 iCount: 89  
thread: 1 iCount: 90  
thread: 2 iCount: 90  
thread: 1 iCount: 91  
thread: 2 iCount: 91  
thread: 1 iCount: 92  
thread: 2 iCount: 92  
thread: 1 iCount: 93  
thread: 2 iCount: 93  
thread: 1 iCount: 94  
thread: 2 iCount: 94  
thread: 1 iCount: 95  
thread: 2 iCount: 95  
thread: 1 iCount: 96  
thread: 2 iCount: 96  
thread: 1 iCount: 97  
thread: 2 iCount: 97  
thread: 1 iCount: 98  
thread: 2 iCount: 98  
thread: 1 iCount: 99  
thread: 2 iCount: 99  
thread: 1 iCount: 100  
thread: 2 iCount: 0  
thread: 1 iCount: 1  
thread: 2 iCount: 1  
thread: 1 iCount: 2  
thread: 2 iCount: 2  
thread: 1 iCount: 3  
thread: 2 iCount: 2
```

<https://www.youtube.com/watch?v=GADpqSLHcPM>

# 6, condition variable – Waiting and Signaling

## Con. Variables

[pthread\\_cond\\_wait](#) (condition, mutex)

[pthread\\_cond\\_signal](#) (condition)

[pthread\\_cond\\_broadcast](#) (condition)

1. wait() blocks the calling thread until the specified condition is signaled. It should be called while mutex is locked
2. signal() is used to signal (or wake up) another thread which is waiting on the condition variable. It should be called after mutex is locked, and programmers must unlock mutex in order for wait() routine to complete
3. broadcast() is useful when multiple threads are in blocked waiting
4. wait() should come before signal() – conditions are not counters, signal would be lost if not waiting



# 6, condition variable example

[https://github.com/kevinsuo/CS3502/  
blob/master/lock\\_w\\_condition.c](https://github.com/kevinsuo/CS3502/blob/master/lock_w_condition.c)

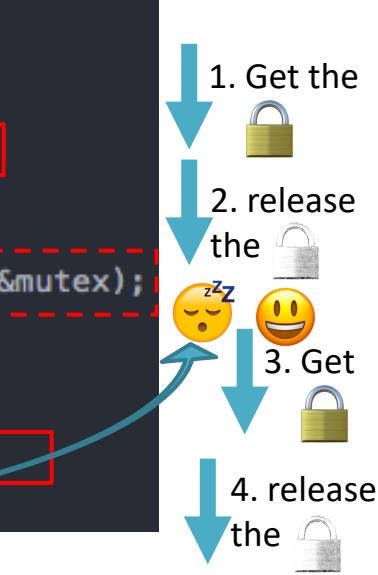
- Mutex with condition

- Example: T1: increase x every time;
- T2: when x is larger than 99, then set x to 0;

```
//thread1 :  
while(true)  
{  
    pthread_mutex_lock(&mutex);  
    iCount++;  
    pthread_mutex_unlock(&mutex);  
  
    pthread_mutex_lock(&mutex);  
    if(iCount >= 100)  
    {  
        pthread_cond_signal(&cond);  
    }  
    pthread_mutex_unlock(&mutex);  
}
```



```
//thread2:  
while(1)  
{  
    pthread_mutex_lock(&mutex);  
    while(iCount < 100)  
    {  
        pthread_cond_wait(&cond, &mutex);  
    }  
    printf("iCount >= 100\r\n");  
    iCount = 0;  
    pthread_mutex_unlock(&mutex);  
}
```



# 6, condition variable example

```
int iCount = 0;
static pthread_mutex_t mlock;
static pthread_cond_t cond = PTHREAD_COND_INITIALIZER;

void *thread1_work(void *id) {
    long tid = (long)id;
    while (1) {
        pthread_mutex_lock(&mlock);
        iCount++;
        printf("thread: %ld iCount: %d\n", tid, iCount);
        pthread_mutex_unlock(&mlock);

        pthread_mutex_lock(&mlock);
        if (iCount >= 100) {
            pthread_cond_signal(&cond);
            printf("thread: %ld iCount: %d\n", tid, iCount);
        }
        pthread_mutex_unlock(&mlock);
        sleep(1);
    }
}

void *thread2_work(void *id) {
    long tid = (long)id;
    while (1) {
        pthread_mutex_lock(&mlock);
        if (iCount < 100) {
            pthread_cond_wait(&cond, &mlock);
        }
        iCount = 0;
        printf("thread: %ld iCount: %d\n", tid, iCount);
        pthread_mutex_unlock(&mlock);
        sleep(1);
    }
}
```

[https://github.com/kevinsuo/CS3502/  
blob/master/lock\\_w\\_condition.c](https://github.com/kevinsuo/CS3502/blob/master/lock_w_condition.c)

```
//thread1 :
while(true)
{
    pthread_mutex_lock(&mutex);
    iCount++;
    pthread_mutex_unlock(&mutex);

    pthread_mutex_lock(&mutex);
    if(iCount >= 100)
    {
        pthread_cond_signal(&cond);
    }
    pthread_mutex_unlock(&mutex);
}
```

```
//thread2:
while(1)
{
    pthread_mutex_lock(&mutex);
    while(iCount < 100)
    {
        pthread_cond_wait(&cond, &mutex);
    }
    printf("iCount >= 100\r\n");
    iCount = 0;
    pthread_mutex_unlock(&mutex);
}
```

# 6, condition variable example

```
int iCount = 0;
static pthread_mutex_t mlock;
static pthread_cond_t cond = PTHREAD_COND_INITIALIZER;

void *thread1_work(void *id) {
    long tid = (long)id;
    while (1) {
        pthread_mutex_lock(&mlock);
        iCount++;
        printf("thread: %ld iCount: %d\n", tid, iCount);
        pthread_mutex_unlock(&mlock);

        pthread_mutex_lock(&mlock);
        if (iCount >= 100) {
            pthread_cond_signal(&cond);
            printf("thread: %ld iCount: %d\n", tid, iCount);
        }
        pthread_mutex_unlock(&mlock);
        sleep(1);
    }
}

void *thread2_work(void *id) {
    long tid = (long)id;
    while (1) {
        pthread_mutex_lock(&mlock);
        if (iCount < 100) {
            pthread_cond_wait(&cond, &mlock);
        }
        iCount = 0;
        printf("thread: %ld iCount: %d\n", tid, iCount);
        pthread_mutex_unlock(&mlock);
        sleep(1);
    }
}
```

[https://github.com/kevinsuo/CS3502/  
blob/master/lock\\_w\\_condition.c](https://github.com/kevinsuo/CS3502/blob/master/lock_w_condition.c)

gcc lock\_w\_condition.c -o  
lock\_w\_condition.o –  
pthread

./lock\_w\_condition.o

# 6, condition variable example

[https://github.com/kevinsuo/CS3502/  
blob/master/lock\\_w\\_condition.c](https://github.com/kevinsuo/CS3502/blob/master/lock_w_condition.c)

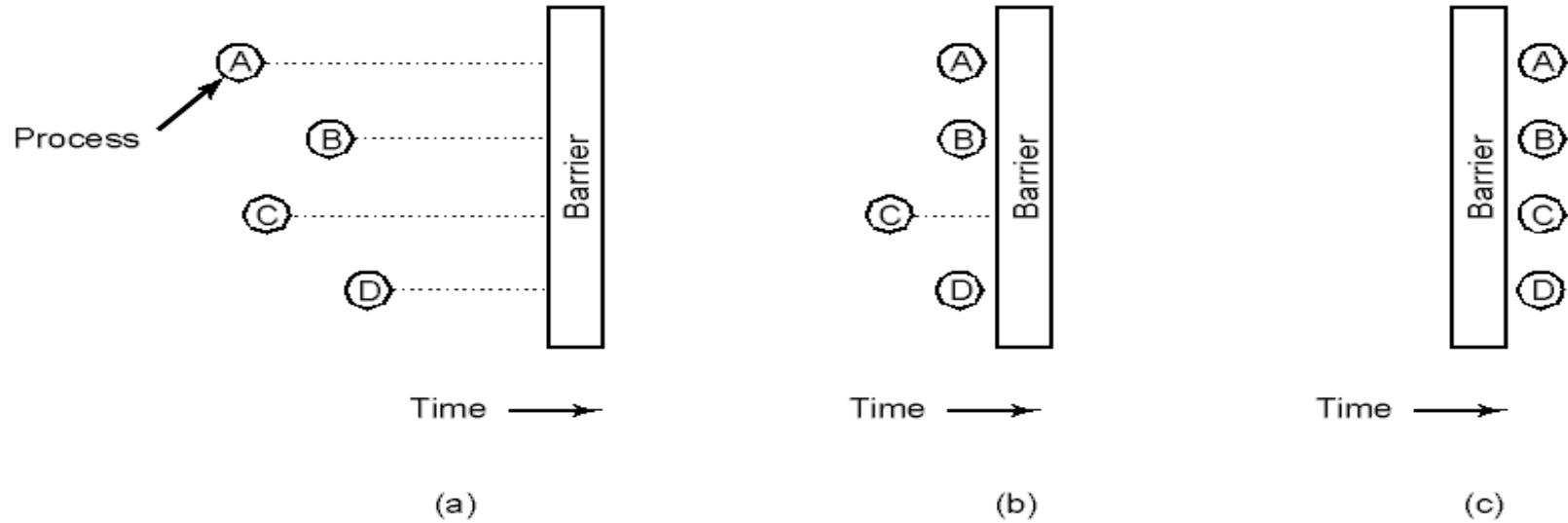
```
gcc lock_w_condition.c -o lock_w_condition.o –pthread  
../lock_w_condition.o
```

```
[1]:> ./lock_w_condition  
thread: 1 iCount: 91  
thread: 1 iCount: 92  
thread: 1 iCount: 93  
thread: 1 iCount: 94  
thread: 1 iCount: 95  
thread: 1 iCount: 96  
thread: 1 iCount: 97  
thread: 1 iCount: 98  
thread: 1 iCount: 99  
thread: 1 iCount: 100  
thread: 1 iCount: 100  
thread: 2 iCount: 0  
thread: 1 iCount: 1  
thread: 1 iCount: 2  
thread: 1 iCount: 3  
thread: 1 iCount: 4  
thread: 1 iCount: 5  
thread: 1 iCount: 6  
thread: 1 iCount: 7  
thread: 1 iCount: 8  
thread: 1 iCount: 9  
thread: 1 iCount: 10
```

[https://www.youtube.com/  
watch?v=81CFeuKRscw](https://www.youtube.com/watch?v=81CFeuKRscw)



# 7, barriers



- Use of a barrier (for programs operate in *phases*, neither enters the next phase until all are finished with the current phase) for groups of processes to do synchronization
  - (a) processes approaching a barrier
  - (b) all processes but one blocked at barrier
  - (c) last process arrives, all are let through

# 7, barriers – Initializing and waiting on barriers

[pthread\\_barrier\\_init](#)(barrier, attr, count)

[pthread\\_barrier\\_wait](#)(barrier)

[pthread\\_barrier\\_destroy](#)(barrier)

1. init() function shall allocate any resources required to use the barrier referenced by **barrier** and shall initialize the barrier with **attr**. If attr is NULL, default settings will be applied. The **count** argument specifies the number of threads that must call wait() before any of them successfully return from the call.
2. wait() function shall synchronize participating threads at the barrier.
3. destroy() function shall destroy the barrier and release any resources used by the barrier.



# 7, without barriers example

[https://github.com/kevinsuo/CS3502/blob/master/pthread\\_barrier.c](https://github.com/kevinsuo/CS3502/blob/master/pthread_barrier.c)

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

pthread_barrier_t b;

void* task(void* param) {
    int id = (int) param;
    printf("before the barrier %d\n", id);
//    pthread_barrier_wait(&b);
    printf("after the barrier %d\n", id);
}

int main() {
    int nThread = 5;
    int i;

    pthread_t thread[nThread];
//    pthread_barrier_init(&b, 0, nThread);
    for (i = 0; i < nThread; i++)
        pthread_create(&thread[i], 0, task, (void*)i);
    for (i = 0; i < nThread; i++)
        pthread_join(thread[i], 0);
//    pthread_barrier_destroy(&b);
    return 0;
}
```

Some “after” appears ahead of “before”

```
ksuo@LinuxKernel:~/Documents> ./pthread_barrier.o
before the barrier 0
before the barrier 4
after the barrier 4
before the barrier 1
after the barrier 1
before the barrier 2
after the barrier 0
before the barrier 3
after the barrier 3
after the barrier 2
```



# 7, barriers example

[https://github.com/kevinsuo/CS3502/blob/master\(pthread\\_barrier.c](https://github.com/kevinsuo/CS3502/blob/master(pthread_barrier.c)

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

pthread_barrier_t b;

void* task(void* param) {
    int id = (int) param;
    printf("before the barrier %d\n", id);
    pthread_barrier_wait(&b);
    printf("after the barrier %d\n", id);
}

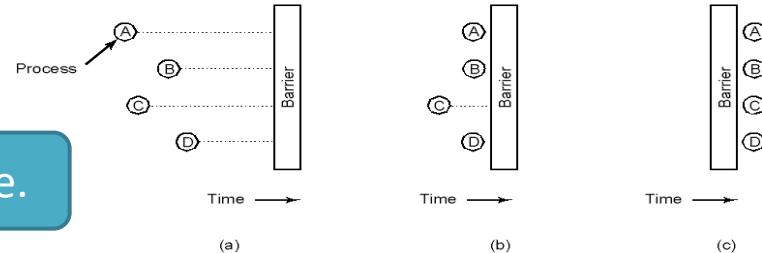
int main() {
    int nThread = 5;
    int i;

    pthread_t thread[nThread];
    pthread_barrier_init(&b, 0, nThread);
    for (i = 0; i < nThread; i++)
        pthread_create(&thread[i], 0, task, (void*)i);
    for (i = 0; i < nThread; i++)
        pthread_join(thread[i], 0);
    pthread_barrier_destroy(&b);
    return 0;
}
```

All threads are waiting here.

Create barrier

Destroy barrier

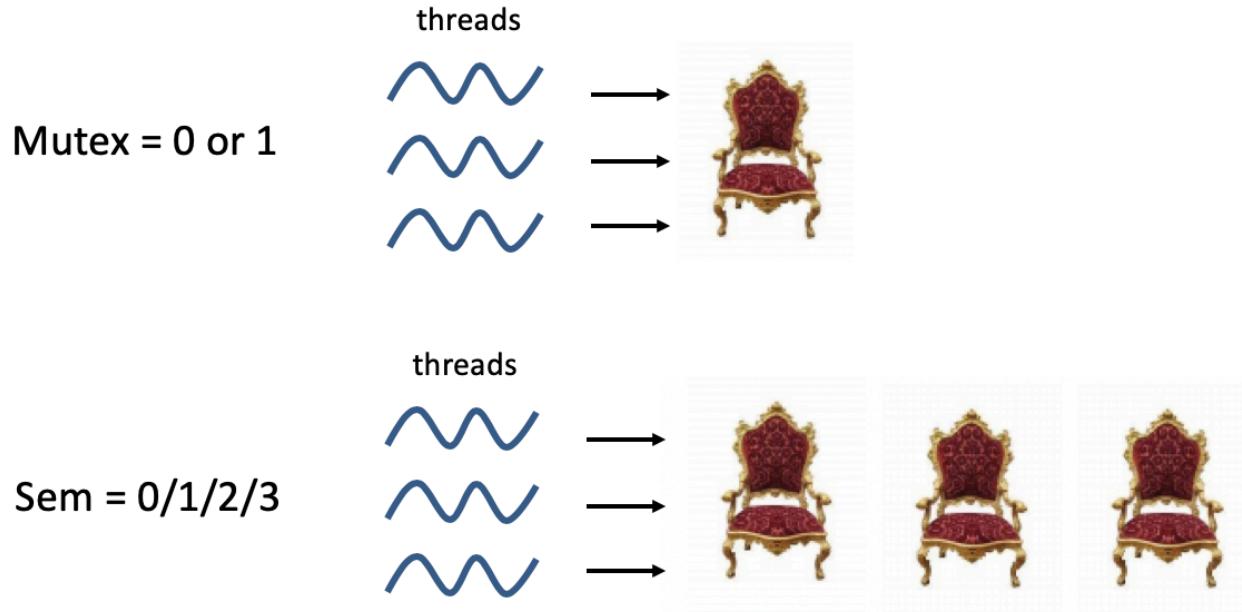


```
pi@raspberrypi ~/Downloads> ./test.o
before the barrier 1
before the barrier 0
before the barrier 2
before the barrier 3
before the barrier 4
after the barrier 0
after the barrier 2
after the barrier 3
after the barrier 1
after the barrier 4
```



# 8, semaphore

- Semaphores are **counters** for resources shared between threads. The basic operations on semaphores are: **increment** the counter atomically, and wait until the counter is non-null and **decrement** it atomically.



# Semaphore

- Down operation (P; request):
  - Checks if a semaphore is  $> 0$ ,  $\text{sem--}$ 
    - ▶ Request one unit resource and one process enters
- Up operation (V; release)
  - $\text{sem}++$ 
    - ▶ Release one unit resource and one process leaves



```
sem_init(&remain, 0, 3);
sem_init(&apple, 0, 0);
sem_init(&pear, 0, 0);
sem_init(&mutex, 0, 1);
```

# 8, semaphore

## int sem\_init(sem\_t \*sem, int pshared, unsigned int value)

//Init a sem. The **pshared** argument indicates whether this semaphore is to be shared between the threads of a process (pshared=0), or between processes (pshared≠0). The **value** argument specifies the initial value for the semaphore (how many resources).

## int sem\_destroy(sem\_t \* sem)

//Destroy a sem

## int sem\_wait(sem\_t \* sem)

//Request one unit resource, blocking call. If successful, sem--.

## int sem\_trywait(sem\_t \* sem)

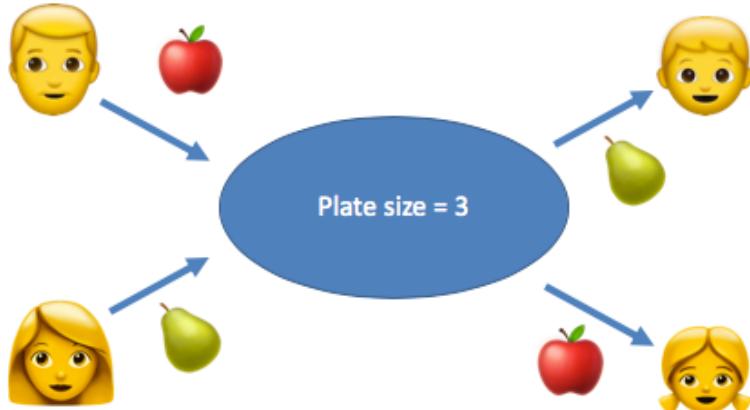
//Request one unit resource, non-blocking call. If successful, sem--.

## int sem\_post(sem\_t \* sem)

//Release one unit resource. If successful, sem++.



# Semaphore example



- **Semaphore:**

- Son: whether there is pear,  $s_1$
- Daughter: whether there is apple,  $s_2$
- Father/Mother: whether there is space,  $s_3$

Father thread:  
peel apple  
 $P(s_3)$   
put apple  
 $V(s_2)$

Mother thread:  
peel pear  
 $P(s_3)$   
put apple  
 $V(s_1)$

Son thread:  
 $P(s_1)$   
get pear  
 $V(s_3)$   
eat pear

Daughter thread:  
 $P(s_2)$   
get apple  
 $V(s_3)$   
eat apple

# Semaphore example

- Semaphore:

- Son: whether there is pear, s1
- Daughter: whether there is apple, s2
- Father/Mother: whether there is space, s3

Father thread:

    peel apple  
    P(s3)  
    put apple  
    V(s2)

Daughter thread:

    P(s2)  
    get apple  
    V(s3)  
    eat apple

```
void *father(void *arg) {
    while(1) {
        sleep(5); //simulate peel apple
        P(s3) [sem_wait(&remain)];
        sem_wait(&mutex);
        nremain--;
        napple++;
        sem_post(&mutex);
        V(s2) [sem_post(&apple)];
    }
}
```

```
void *daughter(void *arg) {
    while(1) {
        P(s2) [sem_wait(&apple)];
        sem_wait(&mutex);
        nremain++;
        napple--;
        sem_post(&mutex);
        V(s3) [sem_post(&remain)];
        sleep(10); //simulate eat apple
    }
}
```

# Semaphore example

- Semaphore:
  - Son: whether there is pear, s1
  - Daughter: whether there is apple, s2
  - Father/Mother: whether there is space, s3

Mother thread:

    peel pear  
    P(s3)  
    put apple  
    V(s1)

Son thread:

    P(s1)  
    get pear  
    V(s3)  
    eat pear

```
void *mother(void *arg) {  
    while(1) {  
        sleep(7); //simulate peel pear  
        P(s3) [sem_wait(&remain);]  
        sem_wait(&mutex);  
        nremain--;  
        npear++;  
        sem_post(&mutex);  
        V(s1) [sem_post(&pear);]  
    }  
}
```

```
void *son(void *arg) {  
    while(1) {  
        P(s1) [sem_wait(&pear);]  
        sem_wait(&mutex);  
        nremain++;  
        npear--;  
        sem_post(&mutex);  
        V(s3) [sem_post(&remain);]  
        sleep(10); //simulate eat pear  
    }  
}
```

- Semaphore:
  - Son: whether there is pear, s1
  - Daughter: whether there is apple, s2
  - Father/Mother: whether there is space, s3

```
void *father(void *arg) {
    while(1) {
        sleep(5); //simulate peel apple
        sem_wait(&remain);
        sem_wait(&mutex);
        nremain--;
        napple++;
        sem_post(&mutex);
        sem_post(&apple);
    }
}
```

```
void *daughter(void *arg) {
    while(1) {
        sem_wait(&apple);
        sem_wait(&mutex);
        nremain++;
        napple--;
        sem_post(&mutex);
        sem_post(&remain);
        sleep(10); //simulate eat apple
    }
}
```

```
void *mother(void *arg) {
    while(1) {
        sleep(7); //simulate peel pear
        sem_wait(&remain);
        sem_wait(&mutex);
        nremain--;
        npear++;
        sem_post(&mutex);
        sem_post(&pear);
    }
}
```

remain is semaphore  
nremain is an integer

```
void *son(void *arg) {
    while(1) {
        sem_wait(&pear);
        sem_wait(&mutex);
        nremain++;
        npear--;
        sem_post(&mutex);
        sem_post(&remain);
        sleep(10); //simulate eat pear
    }
}
```

[https://github.com/kevinsuo/CS3502/  
blob/master/semaphore.c](https://github.com/kevinsuo/CS3502/blob/master/semaphore.c)

# Semaphore example

```
sem_t remain, apple, pear, mutex;  
static unsigned int nremain = 3, napple = 0, npear = 0;  
  
int main() {  
    pthread_t fa, ma, so, da;  
    setlocale(LC_ALL, "en_US.utf8");  
  
    sem_init(&remain, 0, 3);  
    sem_init(&apple, 0, 0);  
    sem_init(&pear, 0, 0);  
    sem_init(&mutex, 0, 1);  
  
    pthread_create(&fa, NULL, &father, NULL);  
    pthread_create(&ma, NULL, &mother, NULL);  
    pthread_create(&so, NULL, &son, NULL);  
    pthread_create(&da, NULL, &daughter, NULL);  
  
    for(;;)  
}
```

```
void *mother(void *arg) {  
    while(1) {  
        sleep(7); //simulate peel pear  
        sem_wait(&remain);  
        sem_wait(&mutex);  
        nremain--;  
        npear++;  
        sem_post(&mutex);  
        sem_post(&pear);  
    }  
}
```

```
void *son(void *arg) {  
    while(1) {  
        sem_wait(&pear);  
        sem_wait(&mutex);  
        nremain++;  
        npear--;  
        sem_post(&mutex);  
        sem_post(&remain);  
        sleep(10); //simulate eat pear  
    }  
}
```

[https://github.com/kevinsuo/CS3502/  
blob/master/semaphore.c](https://github.com/kevinsuo/CS3502/blob/master/semaphore.c)

# Semaphore example

```
pi@raspberrypi ~/Downloads> ./semaphore.o
father 🧑 before put apple, remain=3, apple🍎=0, pear🍐=0
father 🧑 after put apple, remain=2, apple🍎=1, pear🍐=0

daughter👩 before eat apple, remain=2, apple🍎=1, pear🍐=0
daughter👩 after eat apple, remain=3, apple🍎=0, pear🍐=0

mother 🧑 before put pear , remain=3, apple🍎=0, pear🍐=0
mother 🧑 after put pear , remain=2, apple🍎=0, pear🍐=1

son 🧑 before eat pear , remain=2, apple🍎=0, pear🍐=1
son 🧑 after eat pear , remain=3, apple🍎=0, pear🍐=0

father 🧑 before put apple, remain=3, apple🍎=0, pear🍐=0
father 🧑 after put apple, remain=2, apple🍎=1, pear🍐=0

mother 🧑 before put pear , remain=2, apple🍎=1, pear🍐=0
mother 🧑 after put pear , remain=1, apple🍎=1, pear🍐=1

daughter👩 before eat apple, remain=1, apple🍎=1, pear🍐=1
daughter👩 after eat apple, remain=2, apple🍎=0, pear🍐=1

father 🧑 before put apple, remain=2, apple🍎=0, pear🍐=1
father 🧑 after put apple, remain=1, apple🍎=1, pear🍐=1

son 🧑 before eat pear , remain=1, apple🍎=1, pear🍐=1
son 🧑 after eat pear , remain=2, apple🍎=1, pear🍐=0

mother 🧑 before put pear , remain=2, apple🍎=1, pear🍐=0
mother 🧑 after put pear , remain=1, apple🍎=1, pear🍐=1

father 🧑 before put apple, remain=1, apple🍎=1, pear🍐=1
father 🧑 after put apple, remain=0, apple🍎=2, pear🍐=1

daughter👩 before eat apple, remain=0, apple🍎=2, pear🍐=1
daughter👩 after eat apple, remain=1, apple🍎=1, pear🍐=1
```

gcc -pthread semaphore.c  
-o semaphore.o

[https://youtu.be/ZIW  
wvcuROME](https://youtu.be/ZIWwvcuROME)

# Conclusion

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- What is pthread?
  - Thread model
  - Pthread overview
- Pthread management
  - Creation and termination
  - Identification
  - Join and detach
- Pthread data sharing
  - Mutex
  - Condition variable
  - Barrier
  - Semaphore

