Operating Systems 2020/2021

TP Class 04 – Threads and synchronization (1/2)

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Slides based on previous versions from Bruno Cabral, Paulo Marques and Luis Silva.

operating system
noun
the collection of software that directs a computer's operations, controlling and scheduling the execution of other programs, and managing storage, input/output, and communication resources.

Abbreviation: OS

Source: Dictionary.com

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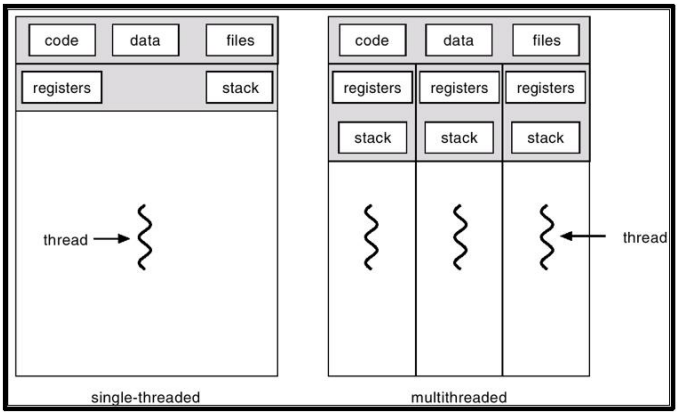
THREADS

Threads

- Single vs multithreaded process



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

Threads

- Why use threads?
  - Very light weight compared to processes
  - Light context switches
  - Fast to create and terminate
  - Fast to synchronize
  - Resource sharing

Be careful to synchronize the access to shared resources!

POSIX Threads – Thread Management

- POSIX Thread management functions summary

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

  - Create a new thread

```
int pthread_create(pthread_t *thread,
    const pthread_attr_t *attr,
     void*(*start_function)(void*), void *arg);
```

  - Terminate the current thread and return a pointer to a value

```
void pthread_exit(void * retval);
```

  - Cancel a thread

```
int pthread_cancel(pthread_t thread);
```

  - Wait for the termination of a given thread

```
int pthread_join(pthread_t thread, void** retval);
```

  - Return the identifier of the current thread

```
pthread_t pthread_self(void);
```

All Pthreads functions return 0 on success or a positive value on failure

POSIX Threads – Thread Management

- Thread creation

```
#include <pthread.h>
int pthread_create(pthread_t *thread,
     const pthread_attr_t *attr,
     void*(*start_function)(void*), void *arg);
```

  - Creates a new thread;
  - The function prototype for Pthread creation (the start function) is:

```
void * start_function(void * arg);
```

  - The new thread starts execution by calling function `start_function` with arguments `arg` (`start_function(arg)`);
  - If multiple arguments are needed, then `arg` should point to a structure
  - If `attr` is specified as `NULL`, then the thread is created with default attributes; (use NULL)
  - After a call to `pthread_create()`, a program has no guarantees about which thread will next be scheduled.

POSIX Threads – Thread Management

- Thread termination
  - The execution of a thread terminates in one of the following ways:
    - The thread's start function performs a return specifying a return value for the thread.
    - The thread calls `pthread_exit()`
    - The thread is canceled using `pthread_cancel()`
    - Any of the threads calls `exit()`, or the main thread performs a return (in the `main()` function), which causes all threads in the process to terminate immediately.

POSIX Threads – Thread Management

- Thread termination (2)

```
#include <pthread.h>
int pthread_exit(void* retval);
```

  - Terminates the calling thread;
  - The `retval` argument specifies the return value for the thread;
  - If the main thread calls `pthread_exit()` instead of calling `exit()` or performing a `return`, then the other threads continue to execute.

POSIX Threads – Thread Management

- Thread termination (3)

```
#include <pthread.h>
int pthread_cancel(pthread_t thread);
```

  - Requests a thread cancellation;
  - Having made the cancellation request, `pthread_cancel` returns immediately, it doesn't wait for the target thread to terminate;
  - What happens to the target thread, and when it happens, depends on that thread's cancellation state (specifies if a specific thread is cancelable or not) and type (the thread can be cancelable at any time or remains pending until a cancellation point – a call to some specific functions);
  - By default a new thread is cancelable.

POSIX Threads – Thread Management

- Thread join

```
#include <pthread.h>
int pthread_join(pthread_t thread, void** retval);
```

  - Waits for the thread identified by `thread` to terminate;
  - If `retval` is a non-NULL pointer, it receives the terminated thread reurn value (the value that was specified when the thread performed a return or called `pthread_exit()`).
  - Detached threads cannot be joined
    - Detached threads are threads from which we do not want to receive the return status; the system automatically cleans up and removes the thread when it terminates.
    - A thread can be marked as detached by using `pthread_detach()` (not covered in these slides)

POSIX Threads – Thread Management

- Thread ID

```
#include <pthread.h>
pthread_t pthread_self(void);
```

  - Returns the thread ID of the calling thread;
  - Each thread in a process is uniquely identified by a thread ID.

Simple thread creation example
simple_thread.c

```
// Ids used by the threads
pthread_t my_thread[N];
int       id[N];

// Worker thread
void* worker(void* idp) {
  int my_id = *((int*) idp);

  printf("Hello, I'm thread %d\n", my_id);
  sleep(rand()%3);
  printf("Hello, I'm thread %d, going away!\n", my_id);

  pthread_exit(NULL);
  return NULL;
}

int main()
{
  // Creates N threads
  for (int i=0; i<N; i++) {
    id[i] = i;
    pthread_create(&my_thread[i], NULL, worker, &id[i]);
  }

  // Waits for them to die
  for (int i=0; i<N; i++)
    pthread_join(my_thread[i], NULL);

  return 0;
}
```

Compiling with threads

- Linux

```
gcc –lpthread –D_REENTRANT –Wall fich.c –o fich
```

- -D_REENTRANT is quite important in LinuxThreads (Kernel 2.4) but gcc calls it implicitly
  - It instructs the compiler to use special re-entrant routine functions
  - If you don't... it ONLY appears to work, until you get in trouble!
  - In some systems –pthread is sufficient

Beware: Many routines are not re-entrant, they cannot be directly used with threads since they use common storage in an unsynchronized way (e.g. stktok())!

In some cases, there are re-entrant versions (e.g. strtok_r()). Check the manual! Don't trust common sense.

Example of non-reentrant routine

```
char buffer[MAX_SIZE];

void send_to_network(const char* msg)
{
  strcpy(buffer, "START_MSG | ");
  strcat(buffer, msg);
  strcat(buffer, " | END_MSG");
}
```

What happens if this is called from two different threads at the same time??

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

Example of reentrant/non-reentrant funcs

```
// An example where func1() and func2() are non-reentrant
int i;
int func1() {   // func1() is NOT reentrant because it uses global variable i
     return i * 2;
}

int func2() {  // func2() is NOT reentrant because it calls a non-reentrant function
   return func1() * 2;
}

// An example where func1() and func2() are reentrant
int func1(int i) {
     return i * 2;
}

int func2(int i) {
     return func1(i) * 2;
}
```


Other things to beware of...

```
// Creates N threads
for (int i=0; i<N; i++) {
  pthread_create(&my_thread[i], NULL, worker, &i);
}
```

Doesn't work, "i" is on the stack an constantly changing

```
int main()
{
  // Ids used by the threads
  pthread_t my_thread[N];
  int       id[N];

  // Creates N threads
  for (int i=0; i<N; i++) {
    id[i] = i;
    pthread_create(&my_thread[i], NULL, worker, &id[i]);
  }

  return 0;
}
```

Doesn't work!
(1) after main() dies, its variables disappear – race condition with the starting threads;
(2) main() dies everything dies!

If you need to terminate the main() thread...

```
// Ids used by the threads
pthread_t my_thread[N];
int       id[N];

int main()
{
  // Creates N threads
  for (int i=0; i<N; i++) {
    id[i] = i;
    pthread_create(&my_thread[i], NULL, worker, &id[i]);
  }

  // Kill the main thread
  pthread_exit(NULL);
  return 0;
}
```

This is OK!

Note: the other threads continue to execute.

Beware of... shared variables

```
char **ptr;  /* global */

int main()
{
    int i;
    pthread_t tid;
    char *msgs[N] = {
        "Hello from foo",
        "Hello from bar"
    };
    ptr = msgs;
    for (i = 0; i < 2; i++)
        pthread_create(&tid,
            NULL,
            thread,
            (void *)i);
    pthread_exit(NULL);
}
```

```
/* thread routine */
void *thread(void *vargp)
{
    int myid = (int)vargp;
    static int cnt = 0;

    printf("[%d]: %s (cnt=%d)\n",
        myid, ptr[myid], ++cnt);
}
```

The new threads access the main thread's stack through **ptr**

Beware of...

- What happens when you...
  - fork() in a thread
    - When a multithreaded process calls fork(), only the calling thread is replicated in the child process.
  - exec() in thread
    - When any thread calls one of the exec() functions, the calling program is completely replaced.
- Signals are received
  - More on this later…

THREADS SYNCHRONIZATION

POSIX synchronization of threads

- Mutexes
  - Provide mutual exclusion zones between threads (processes can also use them if shared memory is used)
  - Similar to a binary semaphore, but the thread that locks the mutex must be the one to unlock it
- POSIX Semaphores (named and unnamed can be used)
  - Used to signal events across threads
  - Used to count objects in an synchronized way
- Condition Variables
  - Allow a thread to block or to notify others on any condition
  - Semaphores are a kind of condition variable:
  - the implicit condition is the semaphore being greater than 0

POSIX mutexes and semaphores

```
// Creates a new initialized semaphore to a certain value
// pshared indicates if it's going to be used between
// processes
int sem_init(sem_t *sem, int pshared, unsigned int value);

// Releases the semaphore
int sem_destroy(sem_t * sem);

// Performs a wait on the semaphore
int sem_wait(sem_t * sem);

// Signals the semaphore
int sem_post(sem_t * sem);

// Tries to perform a wait on the semaphore
int sem_trywait(sem_t * sem);

// Directly gets the current value of the semaphore
int sem_getvalue(sem_t * sem, int * sval);
```

Unnamed semaphores (POSIX named and unnamed semaphores were already seen before…)

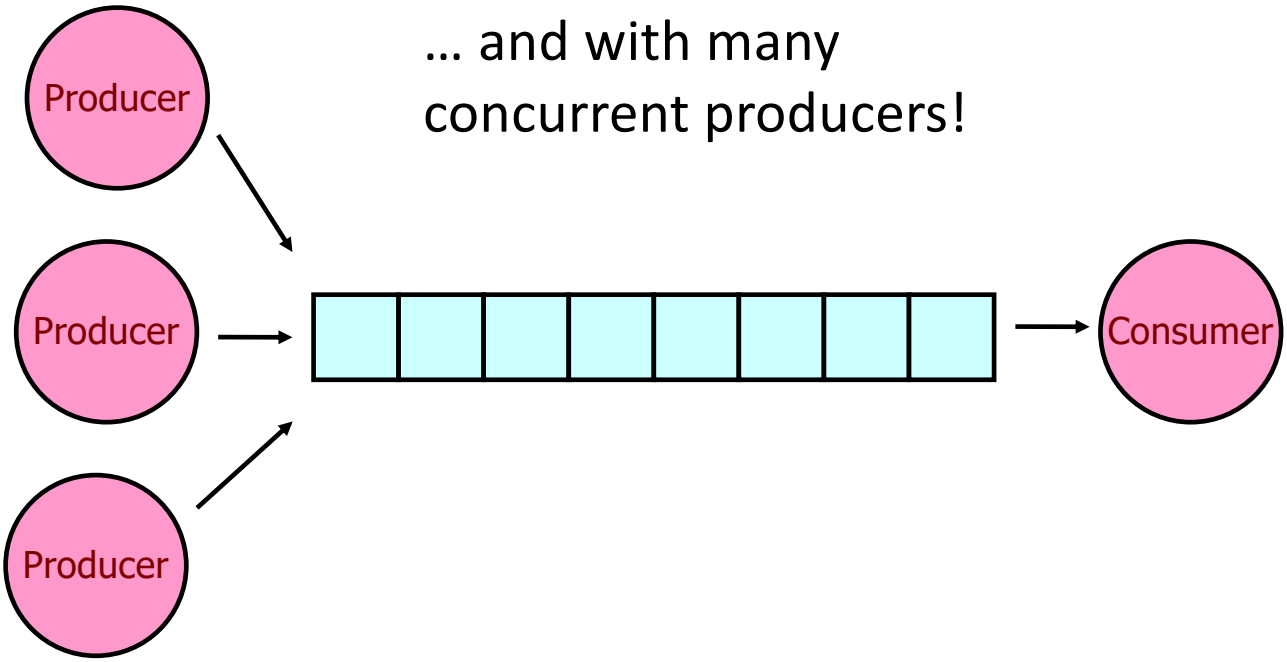
Mutexes

```
// Declares an initialized mutex
pthread_mutex_t fastmutex = PTHREAD_MUTEX_INITIALIZER;

// Performs a lock on a mutex
int pthread_mutex_lock(pthread_mutex_t* mutex);

// Performs an unlock on a mutex
int pthread_mutex_unlock(pthread_mutex_t* mutex);

// Tries to perform a lock on a mutex
int pthread_mutex_trylock(pthread_mutex_t* mutex);

// Releases a mutex
int pthread_mutex_destroy(pthread_mutex_t* mutex);
```

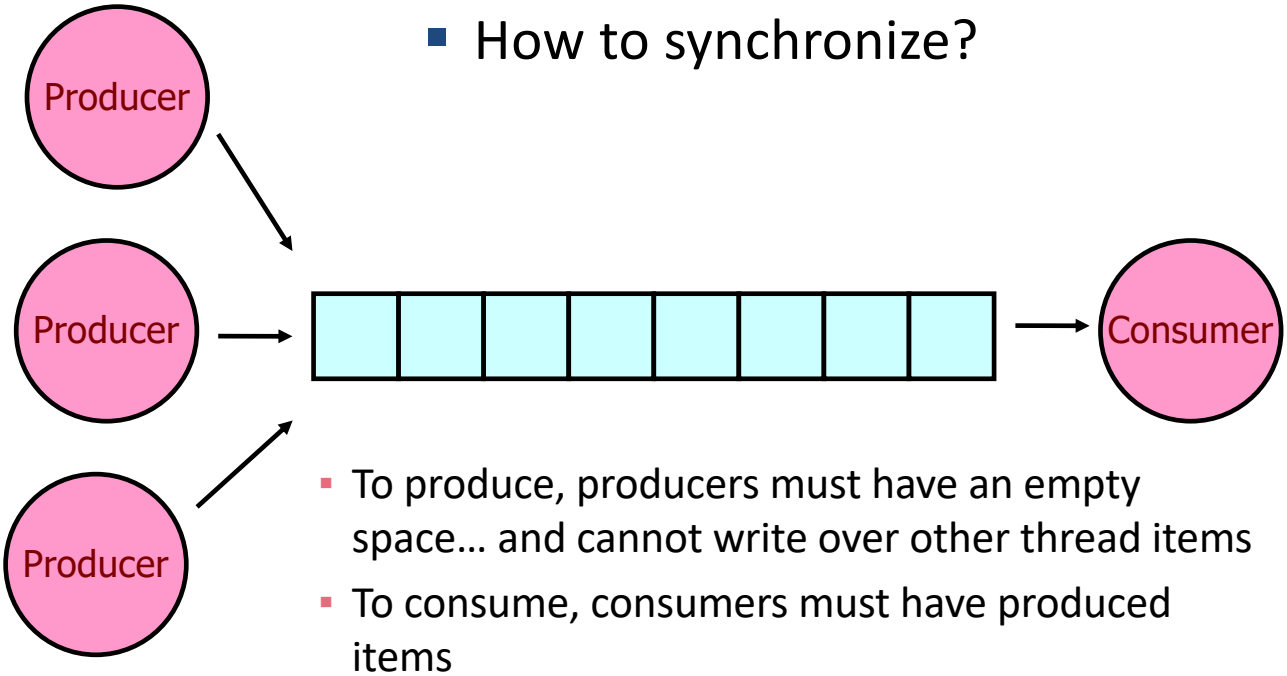
POSIX mutexes and semaphores between processes

- POSIX unnamed semaphores and mutexes can also be used between (threads in different) processes
  - Set semaphores pshared or mutex init attributes to the appropriate value
  - Use shared memory

Producer/consumer with threads

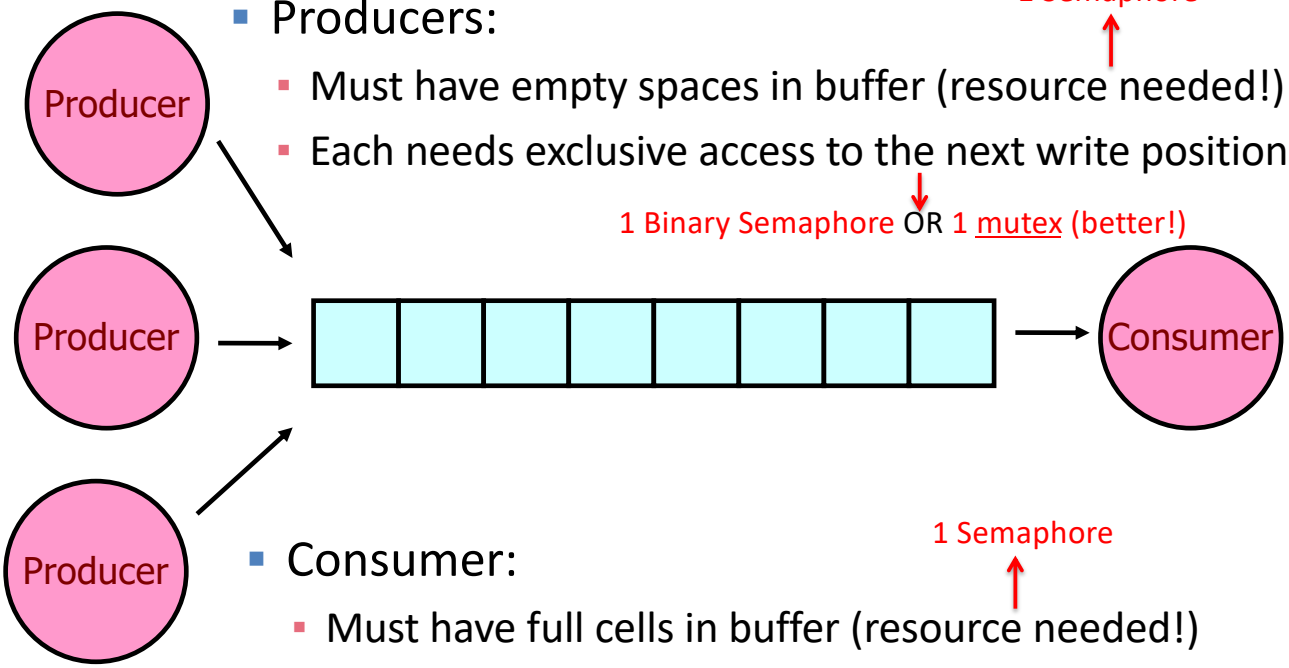


Producer/consumer with threads
synchronization



- How to synchronize?
  - To produce, producers must have an empty space… and cannot write over other thread items
  - To consume, consumers must have produced items

Producer/consumer with threads
synchronization



- Producers:
  - Must have empty spaces in buffer (resource needed!)
  - Each needs exclusive access to the next write position

1 Semaphore

1 Binary Semaphore OR 1 mutex (better!)

- Consumer:
  - Must have full cells in buffer (resource needed!)

1 Semaphore

prod_cons_threads.c

```
int write_pos, read_pos;
int buf[N];

pthread_mutex_t mutex = PTHREAD_MUTEX_INITIALIZER;
sem_t           empty;
sem_t           full;

int id[PRODUCERS];

////////////////////////////////////////

void init() {
  sem_init(&empty, 0, N);
  sem_init(&full,  0, 0);

  write_pos = read_pos = 0;
}
```

```
int main(int argc, char* argv[])
{
  // Initializes the semaphores
  init();

  // Creates all threads
  pthread_t thr;
  pthread_create(&thr, NULL, consumer, NULL);

  for (int i=0; i<PRODUCERS; i++)
  {
    id[i] = 100*i;
    pthread_create(&thr, NULL, producer, &id[i]);
  }

  pthread_exit(NULL);
  return 0;
}
```


prod_cons_threads.c (2)

```
void* producer(void* id) {
  int my_id = *((int*) id);
  int i     = my_id;

  while (1) {
    sem_wait(&empty);
    pthread_mutex_lock(&mutex);

    printf("[PRODUCER %3d] Writing %d\n", my_id, i);
    buf[write_pos] = i;
    write_pos = (write_pos+1) % N;

    sem_post(&full);
    pthread_mutex_unlock(&mutex);

    ++i;
  }
}
```

Not necessary – there is only one consumer

```
void* consumer(void* arg) {
  while (1) {
    sem_wait(&full);
    pthread_mutex_lock(&mutex);

    int e = buf[read_pos];
    read_pos = (read_pos+1) % N;
    printf("[CONSUMER    ] Read %d\n", e);

    pthread_mutex_unlock(&mutex);
    sem_post(&empty);

    sleep(1);
  }

  return NULL;
}
```

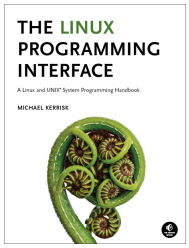
Result...

```
pmarques@null:~/IPC$ g++ -Wall -D_REENTRANT -lpthread prod_cons_threads.c -o pc
pmarques@null:~/IPC$ ./pc
[PRODUCER   0] Writing 0
[CONSUMER    ] Read 0
[PRODUCER   0] Writing 1
[PRODUCER   0] Writing 2
[PRODUCER   0] Writing 3
[PRODUCER   0] Writing 4
[PRODUCER   0] Writing 5
[CONSUMER    ] Read 1
[PRODUCER   0] Writing 6
[CONSUMER    ] Read 2
[PRODUCER 100] Writing 100
[CONSUMER    ] Read 3
[PRODUCER 200] Writing 200
[CONSUMER    ] Read 4
[PRODUCER   0] Writing 7
[CONSUMER    ] Read 5
[PRODUCER 100] Writing 101
[CONSUMER    ] Read 6
[PRODUCER 200] Writing 201
[CONSUMER    ] Read 100
[PRODUCER   0] Writing 8

pmarques@null:~/IPC$  _
```

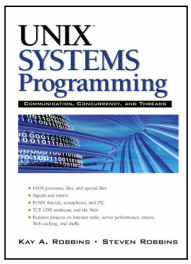

Class demos included

- demo01
  simple_thread.c
- demo02
  prod_cons_threads.c
- demo 03
  prod_cons_threads-named_semaphores.c
- demo04
  mutex_between_procs_no.c // does not work!
- demo05
  mutex_between_procs_yes.c // correct implementation

References



- [kerrisk10]
- Chapter 29: Threads: Introduction
- Chapter 30: Threads: Thread Synchronization
- Chapter 31: Threads: Thread Safety (…)
- Chapter 32: Threads: Thread Cancellation



- [Robbins03]

  Chapter 12: POSIX Threads

  Chapter 13: Thread Synchronization

  Chapter 14: Critical Sections and Semaphores

INTRODUCTION TO ASSIGNMENT 05 – "THREADS AND SYNCHRONIZATION I"

Thank you! Questions?

I keep six honest serving men. They taught me all I knew. Their names are What and Why and When and How and Where and Who.
—Rudyard Kipling