# EEE8068: Concurrent Programming

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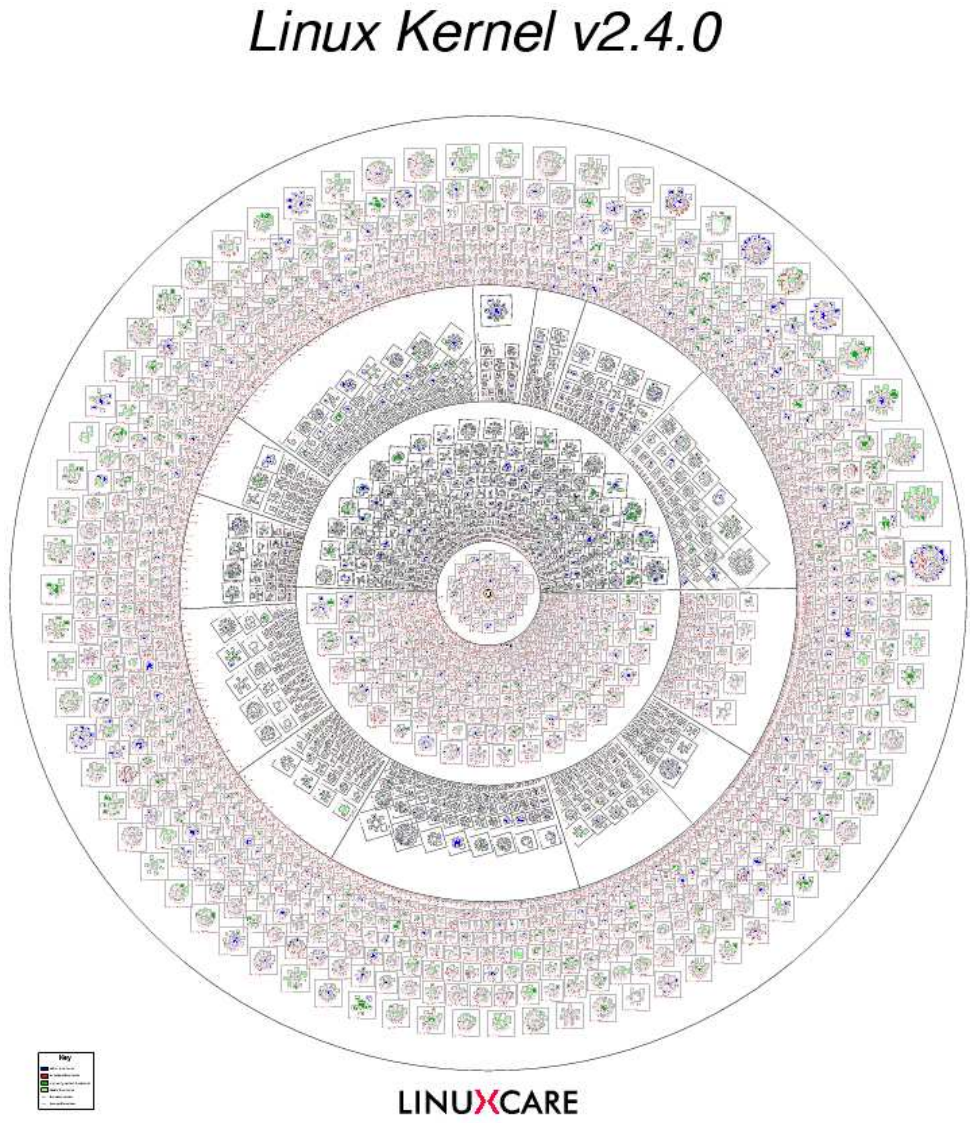
# Schedulers – Embedded OS



# Concurrent programming

- Process
  - Concept
  - Modelling
  - Examples
- Threads (underlined topics examined)
  - Concept
  - Modelling
  - Examples
- Shared data
  - Mutex
  - Condition variables
  - Semaphores

# Concurrent programming – baseline

The baseline idea is very simple:

- CPU switches fast between the concurrent activities (tasks, threads or processes)
- mechanisms and libraries for task control
- means for data communication
- means of protecting the shared data from access conflicts

The details are not simple and need to be discussed...

# Process

- Process as an instance of the executed program.
- The same program can be started several times before any instance of it finishes.
- serial or sequential execution
  - operator “;”
  - shell script examples:
    - `ls ; ls ../`
    - `echo "process_1" ; echo "process_2"`
- Parallel (concurrent) execution
  - operator “&”

```
(sleep 1; echo "proc_1") & echo "proc_2" &
```

# Fork-join example

```
# Define functions
process_model()
 {
  xterm -e "echo $1 ; echo press Ctl-c to finish ; sleep 1h"
  return 0
 }

# Start process_1 first
process_model process_1

# Once it has finished start
# process_2 and process_3 concurrently
process_model process_2 &
pid_process_2=$!
process_model process_3

# After both processes are finished start process_4
wait $pid_process_2
process_model process_4
```

# Processes in C

**fork** – creates a new child process, the exact copy of the parent process;

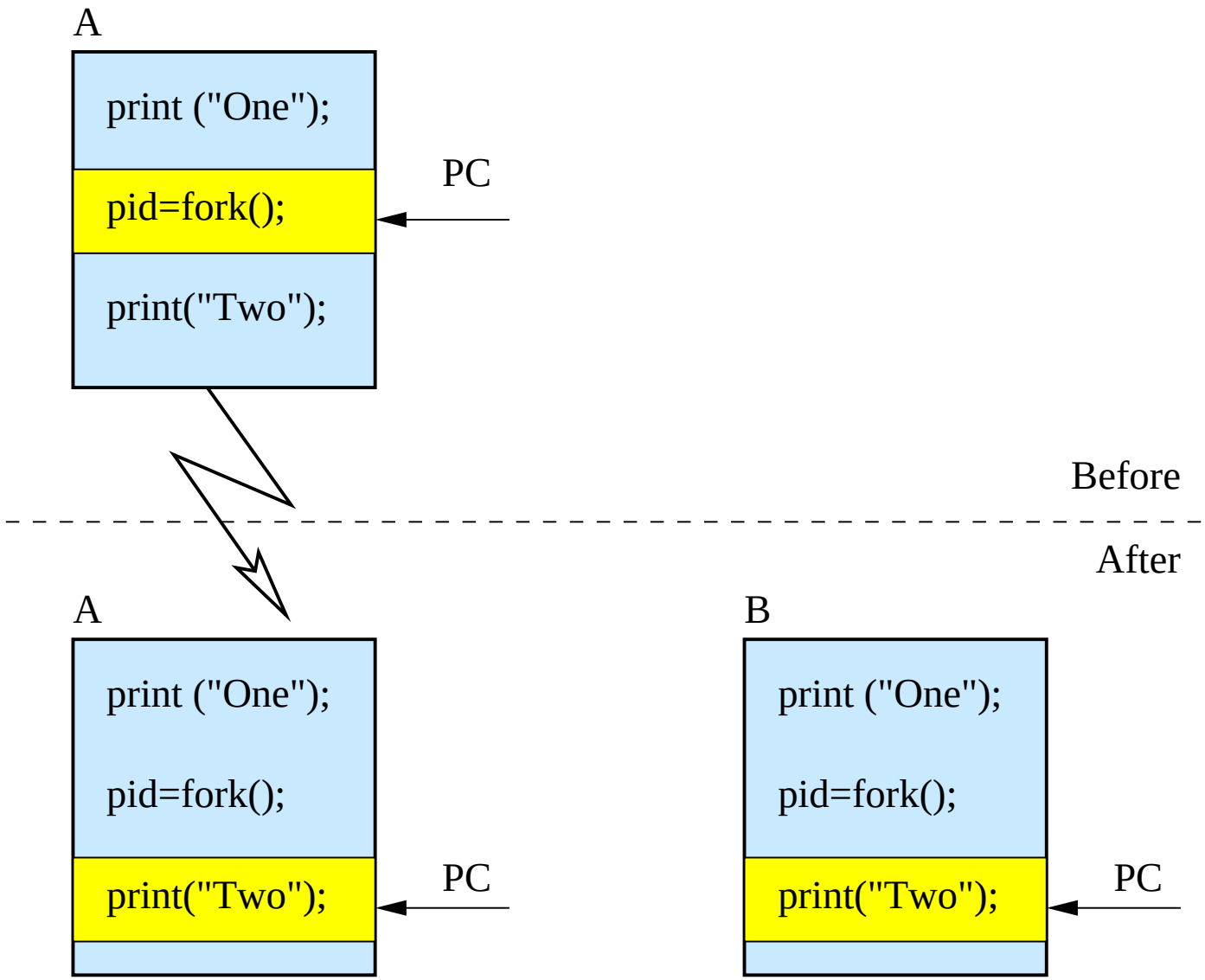
**exec** – replaces the task of the process by overwriting it;

**wait** – primitive synchronisation by waiting for the process to finish;

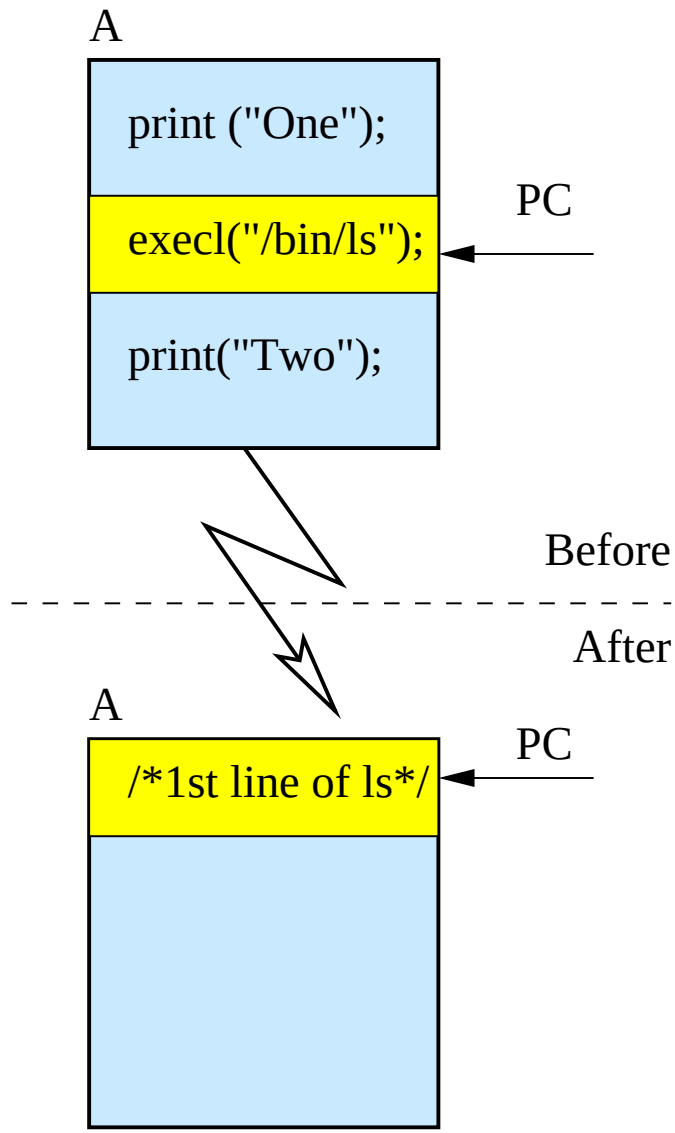
**exit** – stops the process.

**fork + exec** – creates a new process, different from the parent.

# fork()


A
print ("One");
pid=fork();
print("Two");
PC
Before
After
A
print ("One");
pid=fork();
print("Two");
PC
B
print ("One");
pid=fork();
print("Two");
PC

# Exec


A
print ("One");
execl("/bin/ls");
print("Two");
PC
Before
After
A
/*1st line of ls*/
PC

# Example

```c
#include <unistd.h>
main ()
{
  pid_t pid;

  switch (pid = fork ())
    {
    case -1:
      perror ("fork error");
      exit (1);
    case 0:
      execl ("/bin/ls", "ls", "-l", (char *) 0);
      perror ("exec error");
      exit (1);
    default:
      wait ((int *) 0);
      printf ("program ls finished\n");
      exit (0);
    }
}
```

# Threads

Read YoLinux Tutorial: POSIX thread (pthread) libraries
http://www.yolinux.com/TUTORIALS/LinuxTutorialPosixThreads.html

- The POSIX threads standard API for C/C++.
- Spawning a concurrent process flow.
- Most effective on multiprocessor systems;
  - gaining speed through parallel processing.
- Less overhead than "forking" or spawning a new process
  - the system does not initialise a new system virtual memory space and environment
  - threads within a process share the same address space.

# Thread Basics

- Thread operations include
  - thread creation,
  - termination,
  - synchronisation (joins,blocking),
  - scheduling,
  - data management and
  - process interaction.
- A thread does not maintain a list of created threads, nor does it know the thread that created it.
- pthread functions return "0" if OK.

# Threads share

Threads in the same process share:

- address space;
- process instructions;
- most data;
- open files (descriptors);
- signals and signal handlers;
- current working directory;
- user and group id.

Exiting the process ends all its threads!

# Threads don’t share

Each thread has a unique:

- thread ID;
- set of registers, stack pointer;
- stack for local variables, return addresses;
- signal mask;
- priority;
- return value: `errno`.

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

# Thread joining

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

`pthread_join` suspends the execution of the calling thread until the thread identified by `th` terminates, either by calling `pthread_exit` or by being cancelled.

The joined thread `th` must be in the joinable state: it must not have been detached.

`pthread_join` must be called once for each joinable thread created to avoid memory leaks.

At most one thread can wait for the termination of a given thread.

# Fork-join example

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

void
thread_func (void *ptr)
{
  printf ("%s \n", (char *) ptr);
}

main ()
{
  pthread_t t1, t2;
  char *msg1 = "Thread 1";
  char *msg2 = "Thread 2";
  int t_id1, t_id2;

  t_id1 = pthread_create (&t1, NULL, (void *) &thread_func, (void *) msg1);
  t_id2 = pthread_create (&t2, NULL, (void *) &thread_func, (void *) msg2);

  pthread_join (t1, NULL);
  pthread_join (t2, NULL);

  printf ("Threads finished with %d/%d codes\n", t_id1, t_id2);

  exit (0);
}
```

# Thread synchronisation

The threads library provides three synchronisation mechanisms (we focus on the first two):

**join** – Make a thread wait until others are completed (illustrated earlier).

**mutex** – Mutual exclusion lock: Block access to variables by other threads. This enforces exclusive access by a thread to a variable or set of variables.

**condition variables** – data type `pthread_cond_t`

# Mutexes

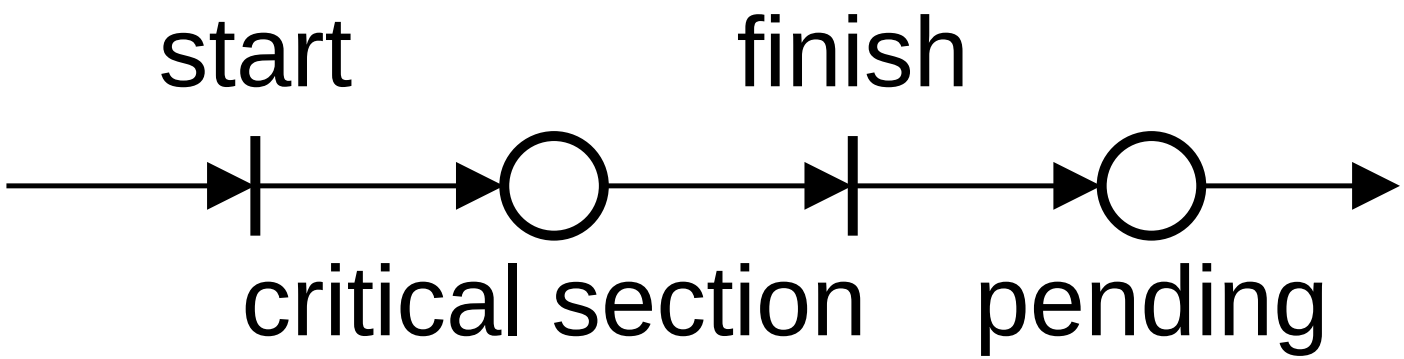
- Mutexes are used to prevent data inconsistencies due to race conditions.
- A race condition often occurs when two or more threads need to perform operations on the same memory area, but the results of computations depends on the order in which these operations are performed.
- Mutexes are used for serialising shared resources.
- Anytime a global resource is accessed by more than one thread the resource should have a Mutex associated with it.
- One can apply a mutex to protect a segment of memory ("critical region") from other threads.

# Mutex example

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

int counter = 0;
pthread_mutex_t mutex1 = PTHREAD_MUTEX_INITIALIZER;

void
thread_func (void *ptr)
{
  pthread_mutex_lock (&mutex1);
  counter++;
  printf ("Thread %d, counter = %d \n", pthread_self (), counter);
  pthread_mutex_unlock (&mutex1);
}

main ()
{
  pthread_t t1, t2;
  int t_id1, t_id2;

  t_id1 = pthread_create (&t1, NULL, (void *) &thread_func, NULL);
  t_id2 = pthread_create (&t2, NULL, (void *) &thread_func, NULL);

  pthread_join (t1, NULL);
  pthread_join (t2, NULL);

  exit (0);
}
```

# Modelling a thread or a process

- a place may lose a token only after its successor becomes enabled (remember the *JOIN* structure!!!);
  - threads/processes finish when they “want”, but
- it is still possible to make the successor process wait for some concurrent process to finish. . .
  - 2 phases: a **critical section** and **pending.**



# Construct a PN model

- Fork-join example programme above
- Mutex example programme above

# Experiments on fairness

Run two threads with the following thread function. Distinguish between them by passing them different parameters.

```
void
thread_func (void *ptr)
{
   int i;
   for (i = 0; i < 10; i++)
      {
         pthread_mutex_lock (&mutex1);
         printf ("%d", *(int*)ptr);
         pthread_mutex_unlock (&mutex1);
/*       system("sleep 0.1"); */
      }
}
```

Output: 11111111112222222222
Uncomment the delay.
Output: 12121212121212121212

# Condition variables

- A condition variable is used with the appropriate functions for waiting and later, process continuation.

- A condition variable must always be associated with a mutex.
  - A deadlock when one thread is preparing to wait and another thread signals the condition. The thread will be perpetually waiting for a signal that is never sent.
  - Any mutex can be used, there is no explicit link between the mutex and the condition variable.

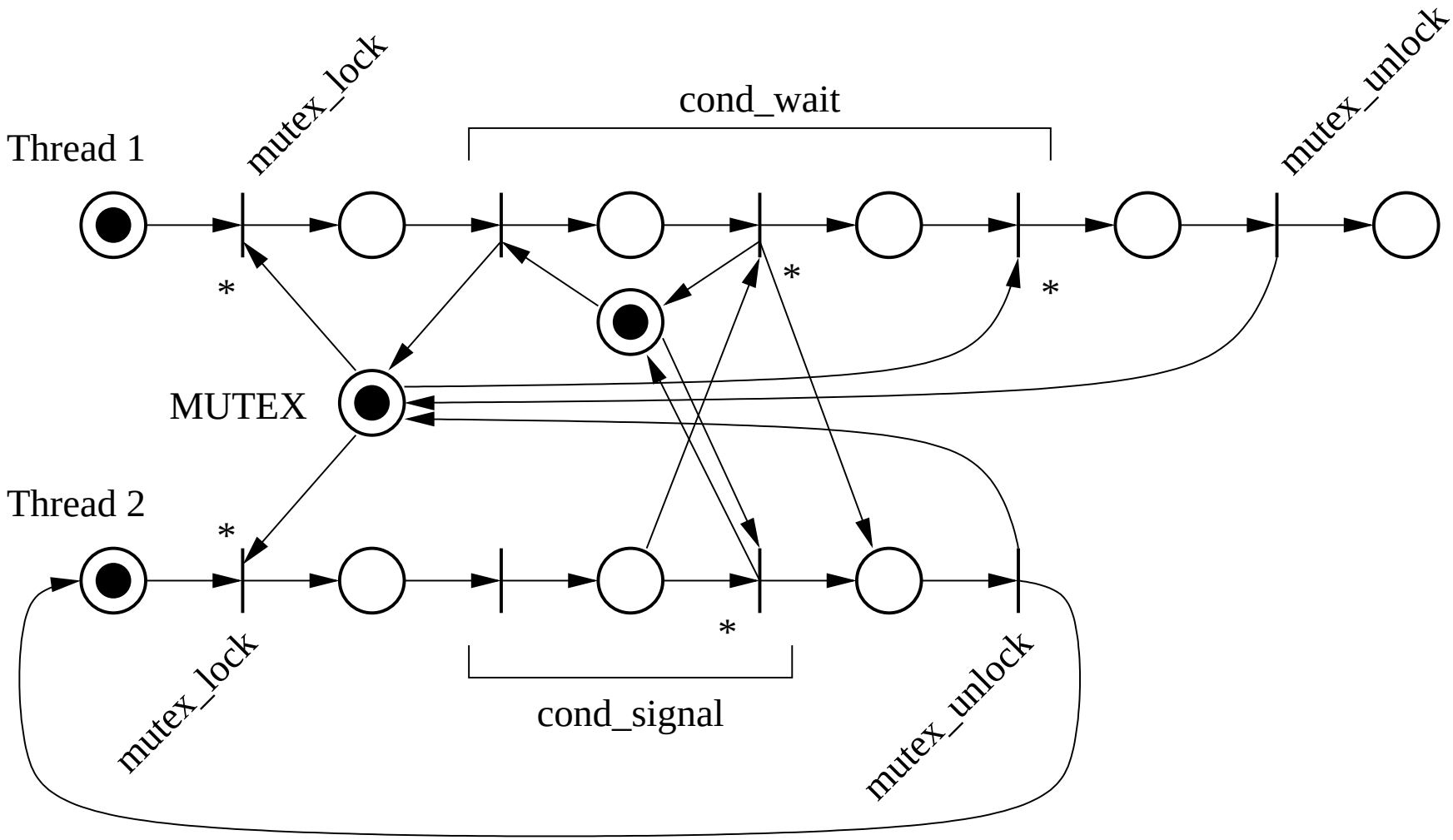
# Functions used with condition variables

- Creating/Destroying:
  - `pthread_cond_init`
  - `pthread_cond_t cond = PTHREAD_COND_INITIALIZER;`
  - `pthread_cond_destroy`
- Waiting on condition:
  - `pthread_cond_wait`
  - `pthread_cond_timedwait` – bloking time limit
- Waking thread based on condition:
  - `pthread_cond_signal`
  - `pthread_cond_broadcast` – wake up all threads blocked by the condition variable.

# Condition wait example

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

pthread_mutex_t condition_mutex = PTHREAD_MUTEX_INITIALIZER;
pthread_cond_t condition_cond = PTHREAD_COND_INITIALIZER;

void *t_func1 ()
{
  pthread_mutex_lock (&condition_mutex);
  printf ("thread 1: waiting started\n");
  pthread_cond_wait (&condition_cond, &condition_mutex);
  printf ("thread 1: waiting finished\n");
  pthread_mutex_unlock (&condition_mutex);
  return NULL;
}

void *t_func2 ()
{
  system ("sleep 1");
  pthread_mutex_lock (&condition_mutex);
  printf ("thread 2: signal\n");
  pthread_cond_signal (&condition_cond);
  pthread_mutex_unlock (&condition_mutex);
  return NULL;
}

main ()
{
  pthread_t thread1, thread2;
```

# Condition wait model



# Semaphores

- Built upon mutexes and condition variables.
- An integer value is associated with a semaphore.

Semaphore operations:

- `semaphore_init` – create a semaphore with value 1
- `semaphore_up` – increments the semaphore
- `semaphore_down` – blocks if its value $\leq 0$, decrements the semaphore value
- `semaphore_decrement` – decrements without blocking
- `semaphore_destroy` – destroys a semaphore

# Semaphore example

```
char buffer;
Semaphore writers_turn, readers_turn;

void writer_function(void)
{
  while(1)
  {
    semaphore_down( &writers_turn );
    buffer = produce_new_item();
    semaphore_up( &readers_turn );
  }
}

void reader_function(void)
{
  while(1)
  {
    semaphore_down( &readers_turn );
    consume_item();
    semaphore_up( &writers_turn );
  }
}
```

# Conclusions

- We are now familiar with the basic concepts of concurrent programming
- The schedulers implement the mechanism of concurrency – we have started this topic and the following 4 hours of seminars will be dedicated to it.
- Fork-join, choice-merge, arbitration when accessing common resource
- Two types of dependency between threads/processes
  - imposed by start-termination control
  - imposed by data communication
- Modelling concurrent computations with Petri nets
- Interesting effects – fairness