Sistemas de Operação / Fundamentos de Sistemas Operativos

Threads, mutexes and condition variables in Unix/Linux

Artur Pereira <artur@ua.pt>

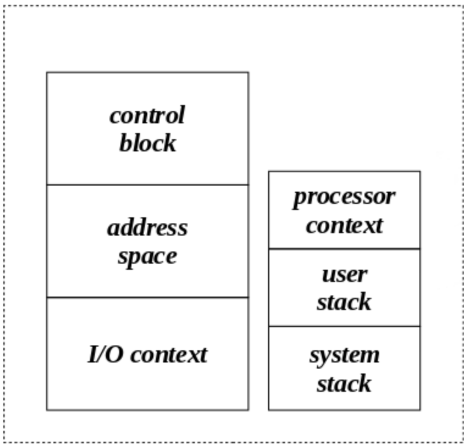
DETI / Universidade de Aveiro

Outline

1. Threads and multithreading
2. Threads in Linux
3. Monitors
4. POSIX support for monitors

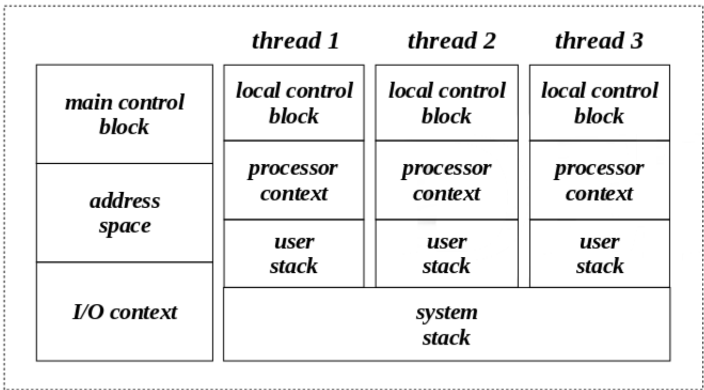
Threads
Single threading

- In traditional operating system, a process includes:
  - an address space (code and data of the associated program)
  - a set of communication channels with I/O devices
  - a single thread of control, which incorporates the processor registers (including the program counter) and a stack
- However, these components can be managed separetely
- In this model, thread appears as an execution component within a process



Single threading

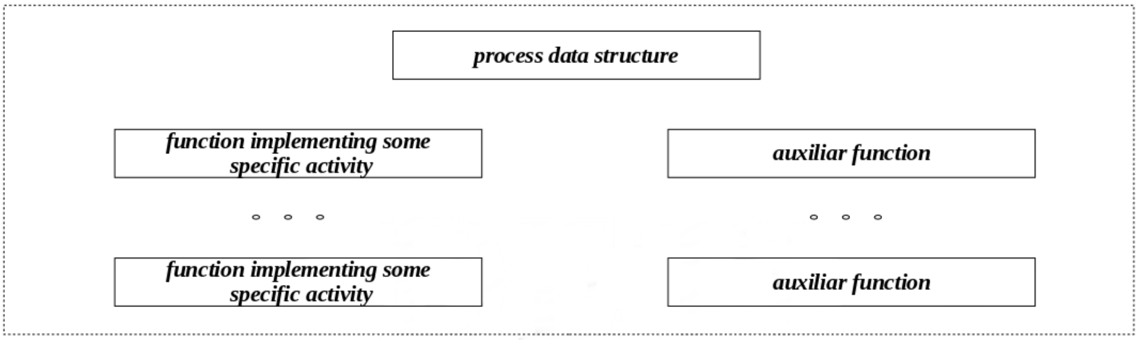
Threads
Multithreading



Multithreading

- Several independent threads can coexist in the same process, thus sharing the same address space and the same I/O context
  - This is referred to as *multithreading*
- Threads can be seen as *light weight processes*

Threads
Structure of a multithreaded program



- Each thread is typically associated to the execution of a function that implements some specific activity
- Communication between threads can be done through the process data structure, which is global from the threads point of view
  - It includes static and dynamic variables (heap memory)
- The main program, also represented by a function that implements a specific activity, is the first thread to be created and, in general, the last to be destroyed

Threads
Implementations of multithreading

- user level threads – threads are implemented by a library, at user level, which provides creation and management of threads without kernel intervention
  - versatile and portable
  - when a thread calls a blocking system call, the whole process blocks
    - because the kernel only sees the proccess
- kernel level threads – threads are implemented directly at kernel level
  - less versatile and less portable
  - when a thread calls a blocking system call, another thread can be schedule to execution

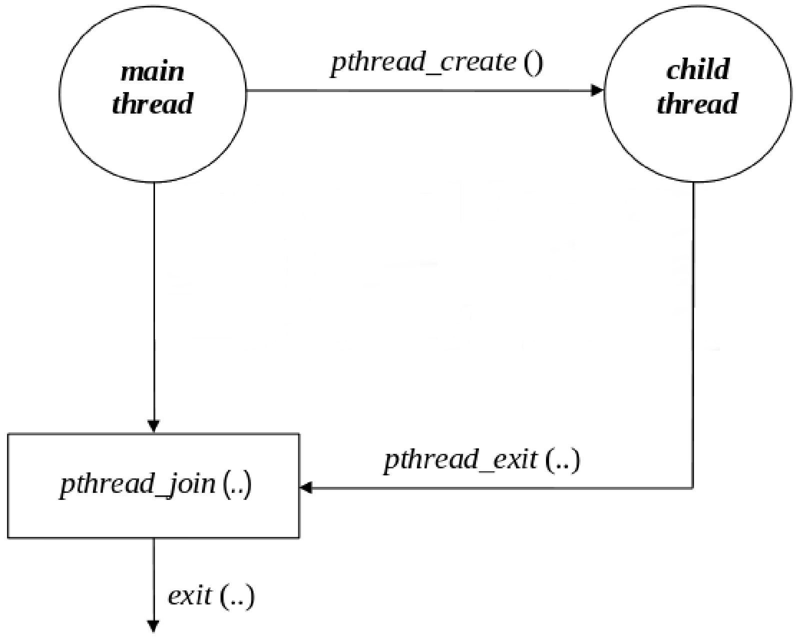
Threads
Advantages of multithreading

- easier implementation of applications – in many applications, decomposing the solution into a number of parallel activities makes the programming model simpler
  - since the address space and the I/O context is shared among all threads, multithreading favors this decomposition.
- better management of computer resources – creating, destroying and switching threads is easier then doing the same with processes
- better performance – when an application envolves substantial I/O, multithreading allows activities to overlap, thus speeding up its execution
- multiprocessing – real parallelism is possible if multiples CPUs exist

Threads in linux
The `clone` system call

- In Linux there are two system calls to create a child process:
  - fork – creates a new process that is a full copy of the current one
    - the address space and I/O context are duplicated
    - the child starts execution in the point of the forking
  - clone – creates a new process that can share elements with its parent
    - address space, table of file descriptors, and table of signal handlers are shareable.
    - the child starts execution in a specified function
- Thus, from the kernel point of view, processes and threads are treated similarly
- Threads of the same process forms a thread group and have the same thread group identifier (TGID)
  - this is the value returned by system call `getpid()`
- Within a group, threads can be distinguished by their unique thread identifier (TID)
  - this value is returned by system call `gettid()`

Threads in linux
Thread creation and termination – `pthread` library



Threads in linux
Thread creation and termination – example

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

/* return status */
int status;

/* child thread */
void *threadChild (void *par)
{
  printf ("I'm the child thread!\n");

  sleep(1);
  status = EXIT_SUCCESS;
  pthread_exit (&status);
}
```

```c
/* main thread */
int main (int argc, char *argv[])
{
  /* launching the child thread */
  pthread_t thr;
  if (pthread_create (&thr, NULL,
                 threadChild, NULL) != 0)
  {
    perror ("Fail launching thread");
    return EXIT_FAILURE;
  }

  /* waits for child termination */
  if (pthread_join (thr, NULL) != 0)
  {
    perror ("Fail joining child");
    return EXIT_FAILURE;
  }

  printf ("Child ends; status %d.\n", status);

  return EXIT_SUCCESS;
}
```

Monitors
Introduction

- A problem with semaphores is that they are used both to implement mutual exclusion and to synchronize processes
- Being low level primitives, they are applied in a bottom-up perpective
  - if required conditions are not satisfied, processes are blocked before they enter their critical sections
  - this approach is prone to errors, mainly in complex situations, as synchronization points can be scattered throughout the program
- A higher level approach should followed a top-down perpective
  - processes must first enter their critical sections and then block if continuation conditions are not satisfied
- A solution is to introduce a (concurrent) construction at the programming level that deals with mutual exclusion and synchronization separately

- A monitor is a synchronization mechanism, independently proposed by Hoare and Brinch Hansen, supported by a (concurrent) programming language
- The `pthread` library provides primitives that allows to implement monitors (of the Lampson-Redell type)

Monitors
Definition

```
monitor example
{
   /* internal shared data structure */
   DATA data;

   cond c; /* condition variable */

   /* access methods */
   method_1 (...)
   {
      ...
   }

   method_2 (...)
   {
      ...
   }

   ...

   /* initialization code */
   ...
}
```

- An application is seen as a set of threads that compete to access the shared data structure
- This shared data can only be accessed through the access methods
- Every method is executed in mutual exclusion
- If a thread calls an access method while another thread is inside another access method, its execution is blocked until the other leaves
- Synchronization between threads is possible through condition variables
- Two operation on them are possible:
  - wait – the thread is blocked and put outside the monitor
  - signal – if there are threads blocked, one is waked up. *Which one?*

Monitors
Bounded-buffer problem – solving using monitors

```
shared FIFO fifo;     /* fixed-size FIFO memory */
shared mutex access;  /* mutex to control mutual exclusion */
shared cond nslots;   /* condition variable to control availability of slots*/
shared cond nitems;   /* condition variable to control availability of items */
```

```
/* producers - p = 0, 1, ..., N-1 */
void producer(unsigned int p)
{
   DATA data;
   forever
   {
      produce_data(&data);
      lock(access);
      if/while (fifo.isFull())
      {
         wait(nslots, access);
      }
      fifo.insert(data);
      signal(nitems);
      unlock(access);
      do_something_else();
   }
}
```

```
/* consumers - c = 0, 1, ..., M-1 */
void consumer(unsigned int c)
{
   DATA data;
   forever
   {
      lock(access);
      if/while (fifo.isEmpty())
      {
         wait(nitems, access);
      }
      fifo.retrieve(&data);
      signal(nslots);
      unlock(access);
      consume_data(data);
      do_something_else();
   }
}
```

- The mutex is the resource used to control mutual exclusion
- Critical sections are explicitly framed by the lock and unlock of a mutex

Unix IPC primitives
POSIX support for monitors

- Standard POSIX, IEEE 1003.1c, defines a programming interface (API) for the creation and synchronization of threads
  - In unix, this interface is implemented by the pthread library
- It allows for the implementation of monitors in C/C++
  - Using mutexes and condition variables
  - Note that they are of the Lampson / Redell type
- Some of the available functions:
  - `pthread_create` – creates a new thread; similar to `fork`
  - `pthread_exit` – equivalent to `exit`
  - `pthread_join` – equivalent a `waitpid`
  - `pthread_self` – equivalent a `getpid()`
  - `pthread_mutex_*` – manipulation of mutexes
  - `pthread_cond_*` – manipulation of condition variables
  - `pthread_once` – inicialization