Threads

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Today’s Topics

- Why threads?
- Threading issues
Processes

- **Heavy-weight**
  - A process includes many things:
    - An address space (all the code and data pages)
    - OS resources (e.g., open files) and accounting info.
    - Hardware execution state (PC, SP, registers, etc.)
  - Creating a new process is costly because all of the data structures must be allocated and initialized
    - Linux: over 100 fields in task_struct
      (excluding page tables, etc.)
  - Inter-process communication is costly, since it must usually go through the OS
    - Overhead of system calls and copying data
Concurrent Servers: Processes

- Web server example
  - Using fork() to create new processes to handle requests in parallel is overkill for such a simple task.

```c
While (1) {
    int sock = accept();
    if ((pid = fork()) == 0) {
        /* Handle client request */
    } else {
        /* Close socket */
    }
}
```
Cooperating Processes

- **Example**
  - A web server, which forks off copies of itself to handle multiple simultaneous tasks
  - Any parallel program on a multiprocessor

- **We need to:**
  - Create several processes that execute in parallel
  - Cause each to map the same address space to share data (e.g., shared memory)
  - Have the OS schedule these processes in parallel

- **This is very inefficient!**
  - Space: PCB, page tables, etc.
  - Time: creating OS structures, fork and copy address space, etc.
Rethinking Processes

What’s similar in these cooperating processes?

- They all share the same code and data (address space)
- They all share the same privilege
- They all share the same resources (files, sockets, etc.)

What’s different?

- Each has its own hardware execution state: PC, registers, SP, and stack.
Key Idea (1)

- Separate the concept of a process from its execution state
  - Process: address space, resources, other general process attributes (e.g., privileges)
  - Execution state: PC, SP, registers, etc.
  - This execution state is usually called
    - a thread of control,
    - a thread, or
    - a lightweight process (LWP)
Key Idea (2)

(a) Process 1
(a) Process 1
(a) Process 1

User space

Kernel space

Kernel

(b) Process
(b) Thread

Kernel

Thread
Key Idea (3)

Single-threaded process:
- Code
- Data
- Files
- Registers
- Stack
- Thread

Multithreaded process:
- Code
- Data
- Files
- Registers
- Registers
- Registers
- Stack
- Stack
- Stack
- Thread
What is a Thread?

- A thread of control (or a thread)
  - A sequence of instructions being executed in a program.
  - Usually consists of
    - a program counter (PC)
    - a stack to keep track of local variables and return addresses
    - registers
  - Threads share the process instructions and most of its data.
    - A change in shared data by one thread can be seen by the other threads in the process
  - Threads also share most of the OS state of a process.
● Using threads
  • We can create a new thread for each request.

```c
webserver ()
{
    While (1) {
        int sock = accept();
        thread_fork (handle_request, sock);
    }
}
handle_request (int sock)
{
    /* Process request */
    close (sock);
}
```
Multithreading

- **Benefits**
  - Creating concurrency is cheap.
  - Improves program structure.
  - Throughput
    - By overlapping computation with I/O operations
  - Responsiveness (User interface / Server)
    - Can handle concurrent events (e.g., web servers)
  - Resource sharing
  - Economy
  - Utilization of multiprocessor architectures
    - Allows building parallel programs.
Processes vs. Threads

- A thread is bound to a single process.
- A process, however, can have multiple threads.
- Sharing data between threads is cheap: all see the same address space.
- Threads become the unit of scheduling.
- Processes are now containers in which threads execute.
- Processes become static, threads are the dynamic entities.
Process Address Space

- **0xFFFFFFFF**
- **address space**
- **0x00000000**

- **stack** *(dynamically allocated mem)*
- **heap** *(dynamically allocated mem)*
- **static data** *(data segment)*
- **code** *(text segment)*

- **PC**
- **SP**
Address Space with Threads

- Address space: 0x00000000 to 0xFFFFFFFF
- Code (text segment)
- Static data (data segment)
- Heap (dynamically allocated memory)

Thread stacks:
- Thread 1 stack
- Thread 2 stack
- Thread 3 stack

Stack pointers:
- SP (T1)
- SP (T2)
- SP (T3)

Program counter (PC):
- PC (T1)
- PC (T2)
- PC (T3)
## Classification

<table>
<thead>
<tr>
<th># threads per addr space:</th>
<th># of addr spaces:</th>
<th>One</th>
<th>Many</th>
</tr>
</thead>
<tbody>
<tr>
<td>One</td>
<td>One</td>
<td>MS/DOS</td>
<td>Traditional UNIX</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Early Macintosh</td>
<td></td>
</tr>
<tr>
<td>Many</td>
<td>Many</td>
<td>Many embedded Oses (VxWorks, uClinux, ..)</td>
<td>Mach, OS/2, Linux, Windows, Mac OS X, Solaris, HP-UX</td>
</tr>
</tbody>
</table>
Threads Interface (1)

- **Pthreads**
  - A POSIX standard (IEEE 1003.1c) API for thread creation and synchronization.
  - API specifies behavior of the thread library.
  - Implementation is up to development of the library.
  - Common in UNIX operating systems.
Threads Interface (2)

- **POSIX-style threads**
  - Pthreads
  - DCE threads (early version of Pthreads)
  - Unix International (UI) threads (Solaris threads)
    - Sun Solaris 2, SCO Unixware 2

- **Microsoft-style threads**
  - Win32 threads
    - Microsoft Windows 98/NT/2000/XP
  - OS/2 threads
    - IBM OS/2
Pthreads (1)

- Thread creation/termination

```c
int pthread_create (pthread_t *tid,
                   pthread_attr_t *attr,
                   void *(start_routine)(void *),
                   void *arg);

void pthread_exit   (void *retval);

int pthread_join    (pthread_t tid,
                   void **thread_return);
```
# Pthreads (2)

## Mutexes

```c
int pthread_mutex_init
    (pthread_mutex_t *mutex,
     const pthread_mutexattr_t *mattr);

void pthread_mutex_destroy
    (pthread_mutex_t *mutex);

void pthread_mutex_lock
    (pthread_mutex_t *mutex);

void pthread_mutex_unlock
    (pthread_mutex_t *mutex);
```
Pthreads (3)

- Condition variables

```c
int pthread_cond_init
    (pthread_cond_t *cond,
     const pthread_condattr_t *cattr);

void pthread_cond_destroy
    (pthread_cond_t *cond);

void pthread_cond_wait
    (pthread_cond_t *cond,
     pthread_mutex_t *mutex);

void pthread_cond_signal
    (pthread_cond_t *cond);

void pthread_cond_broadcast
    (pthread_cond_t *cond);
```
Threading Issues (1)

- **fork() and exec()**
  - When a thread calls fork(),
    - Does the new process duplicate all the threads?
    - Is the new process single-threaded?
  - Some UNIX systems support two versions of fork().
    - In Pthreads,
      » fork() duplicates only a calling thread.
    - In the Unix International standard,
      » fork() duplicates all parent threads in the child.
      » fork1() duplicates only a calling thread.
  - Normally, exec() replaces the entire process.
Threading Issues (2)

- **Thread cancellation**
  - The task of terminating a thread before it has completed.
  - **Asynchronous cancellation**
    - Terminates the target thread immediately.
    - What happens if the target thread is holding a resource, or it is in the middle of updating shared resources?
  - **Deferred cancellation**
    - The target thread is terminated at the cancellation points.
    - The target thread periodically check if it should be cancelled.
  - Pthreads API supports both asynchronous and deferred cancellation.
### Threading Issues (3)

**Signal handling**

- Where should a signal be delivered?
  - To the thread to which the signal applies.
    - for synchronous signals.
  - To every thread in the process.
  - To certain threads in the process.
    - Typically only to a single thread found in a process that is not blocking the signal.
    - Pthreads: per-process pending signals, per-thread blocked signal mask
- Assign a specific thread to receive all signals for the process.
  - Solaris 2
Threading Issues (4)

- Using libraries
  - errno
    - Each thread should have its own independent version of the errno variable.
  - Multithread-safe (MT-safe)
    - A set of functions is said to be multithread-safe or reentrant, when the functions may be called by more than one thread at a time without requiring any other action on the caller’s part.
    - Pure functions that access no global data or access only read-only global data are trivially MT-safe.
    - Functions that modify global state must be made MT-safe by synchronizing access to the shared data.