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
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)

(b)
Key Idea (3)

![Diagram showing the difference between single-threaded and multithreaded processes.](image-url)
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.
### Concurrent Servers: Threads

#### 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

- **Code (text segment)**
- **Static data (data segment)**
- **Heap (dynamically allocated mem)**
- **Stack (dynamically allocated mem)**

Address space boundaries:
- \(0x00000000\)
- \(0xFFFFFFFF\)
Address Space with Threads

- Address space
  - 0xFFFFFFFF
  - 0x00000000

- Stack
  - thread 1 stack
  - thread 2 stack
  - thread 3 stack

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

- Memory regions
  - Code (text segment)
  - Static data (data segment)
  - Heap (dynamically allocated mem)

- Program counter
  - 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 Early Macintosh</td>
<td>Traditional UNIX</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.