Processes and threads
Conceptual model

- Sequential process model
- Process $\rightarrow$ executing program
- Better think about “things” being executed in parallel rather than sequentially (too complicated)
- Switching back and forth of processes is called **multiprogramming**
Model

Reality

Our imagination

A
B
C
D

A
B
C
D

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Processes

- Should not be designed with timing issues in mind since:
  - We don’t know when a context switch occurs

- Special actions need to be taken when timing is important
Process vs. Program

- **Program**: the instructions to be executed
  - The program is “unique”

- **Process**: the actual execution
  - There might be multiple instances (processes) of the same program
Process creation

- System initialization (boot time)
- Creation (by sys call) by a running process
- A user request (shell)
- Initiation of a batch job (or scheduled job)
Interactive vs. background

- **Background processes**
  - TSR (old DOS terminology)
  - Daemons (UNIX)
  - Services (Windows)

- **Batch systems**
  - When the system decides that there are enough resources it might start a new job. Users submit (possibly remotely) jobs to the system
Process creation/termination

- **Creation**
  - Unix: `fork()` → exact copy of the caller
  - Win32: `CreateProcess()` → a brand new one

- **Termination**
  - Voluntary: normal vs. error exit `exit()`
  - Involuntary: fatal error vs. killed `TerminateProcess()`
Process hierarchy

- Root → init
- a → login process
- c, d → shells
- b → background process
Wait for process termination

- Synchronous: `waitpid()`
- Asynchronous: SIGCHLD
Process states

- Running (using the CPU)
- Ready (runnable)
- Blocked (temporarily stopped, waiting)
Scheduler

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processes

scheduler
Processes

- Associated with each process:
  - Address space (program + data + stack)
  - Entry into the process table (a list of processes)
    - Set of registers (e.g. PC, PSW, etc.)
    - MMU status, registers
- Processes can be created, terminated, signaled (SW interrupt)
- They form a tree (a hierarchy) on some systems
- Process cooperation is obtained by means of IPC (inter-process communication) mechanisms
- Processes start with the privileges of the user who starts them
Implementation

- Process table
- Scheduler is called when particular events occur (I/O interrupts, blocking calls, timers, etc.)
Threads

- **Two concepts:**
  - Shared resources: signal handlers, open files, memory, etc.
  - Thread of execution: PC, stack, etc.

- **Decoupling the two concept:**
  - Process: the container of the shared resources
  - Thread: the execution
Multiple threads

- Lightweight processes
- Multithreading

Diagram:
- Thread
- User space
- Multithreading

Kernel

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Threads (cntd.)

- Threads share the same **address space**
- No protection between thread
- A thread has a state (running, blocked, ready)
- A thread of execution is scheduled by the scheduler (depending on the implementation)
### Per process items
- Address space
- Global variables
- Open files
- Child processes
- Pending alarms
- Signals and handlers
- Accounting information

### Per thread items
- Program counter
- Registers
- Stack
- State

**Needless to say...**
Exemplar thread calls

- `thread_create()`
- `thread_exit()`

- `thread_wait()`
  - Similar to `waitpid()`

- `thread_yield()`
  - Important, since there’s no clock interrupt
Why?

- **Simpler programming model:**
  - If we need multiple quasi-parallel activities then it’s better to provide a mechanism to support them
  - Background activity within an application

- **Efficiency:**
  - Keep the CPU busy
  - Multi-processor architectures
The web server

User space

Network connection

dispatcher

workers

cache

Kernel
Many possibilities

- **Threads**: parallelism, blocking sys calls
- **Single-threaded process**: No parallelism, blocking sys calls
- **Finite state machine**: Parallelism, non-blocking sys calls (interrupt handling!)
Thread implementation

- User space
- Kernel space
- Hybrid
User space

- Each process maintain a thread table
- Threads are implemented by implementing library calls (user code, not kernel code)
- Efficient since there’s no kernel trap to call the thread code
- Switching can be easy (thread switching)
- The kernel knows nothing of threads
Issues

- How do we implement blocking sys calls?
  - Change libraries: messy
  - Use `select()` to see if a prospective call would block, requires a “wrapper” to the library

- Page fault:
  - What should a thread do while waiting for a chunk of memory from disk?

- How do we switch from thread to thread?
  - User space threads do not have a timer clock
Kernel space threads

- Since the kernel knows everything about the system it can easily take care of managing threads
- Creating/destroying threads has a cost: a system call
  - Thread recycling in the kernel
- The kernel scheduler, schedules threads instead of whole processes
Making code multithreaded

- **Access to global variables:**
  - Thread local storage (TLS), library calls
  - Example: the `errno` variable

- **Reentrant library calls:**
  - The possibility of having a second call made while a previous call has not yet finished
  - E.g. `malloc` (maintains lists of memory chunks)

- **Who should catch unspecific interrupts?**
- **Stack growth: how do we handle it?**