Concurrency: Threads, Address Spaces, and Processes

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Why **Concurrency**?

- Allows multiple applications to run at the same time
  - Analogy: juggling
Benefits of Concurrency
Benefits of Concurrency

- Ability to run multiple applications at the same time
- Better resource utilization
  - Resources unused by one application can be used by the others
- Better average response time
  - No need to wait for other applications to complete
Benefits of Concurrency

- Better performance
  - One application uses only the processor
  - One application uses only the disk drive
  - Completion time is shorter when running both concurrently than consecutively
Drawbacks of Concurrency
Drawbacks of Concurrency

- Applications need to be protected from one another
- Additional coordination mechanisms among applications
- Overhead to switch among applications
- Potential performance degradation when running too many applications
**Thread**

- A sequential execution stream
  - The smallest CPU scheduling unit
  - Can be programmed as if it owns the entire CPU
    - Implication: an infinite loop within a thread won’t halt the system
  - Illusion of multiple CPUs on a single machine
Thread States

- Program counter
- Register values
- Execution stacks
Thread Benefits

- Simplified programming model per thread

- Example: Microsoft Word
  - One thread for grammar check; one thread for spelling check; one thread for formatting; and so on...
  - Can be programmed independently
  - Simplifies the development of large applications
Address Space

Contains all states necessary to run a program

- Code, data, stack
- Program counter
- Register values
- Resources required by the program
- Status of the running program
Process

- An address space + at least one thread of execution
  - Address space offers protection among processes
  - Threads offer concurrency
- A fundamental unit of computation
Process = ? Program

- **Program**: a collection of statements in C or any programming languages
- Process: a running instance of the program, with additional states and system resources
Two processes can run the same program
  - The code segment of two processes are the same program
A program can create multiple processes

- Example: compilers (like gcc), web browsers
Analogy

- Program: a recipe
- Process: everything needed to cook
  - e.g., kitchen
- Two chefs can cook the same recipe in different kitchens
- One complex recipe can involve several chefs
Some Definitions

- **Uniprogramming**: running one process at a time

- **Multiprogramming**: running multiple processes on a machine
Some Definitions

- **Multithreading**: having multiple threads per address space

- **Multiprocessing**: running programs on a machine with multiple processors

- **Multitasking**: a single user can run multiple processes
## Classifications of OSes

<table>
<thead>
<tr>
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<th>Single address space</th>
<th>Multiple address spaces</th>
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<tbody>
<tr>
<td>Single thread</td>
<td>MS DOS, Macintosh</td>
<td>Traditional UNIX</td>
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<tr>
<td>Multiple threads</td>
<td>Embedded systems</td>
<td>Windows 8, Linux, OSX</td>
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Threads & Dispatching Loop

- A thread owns a *thread control block*
  - Execution states of the thread
  - The status of the thread
    - Running or sleeping
  - Scheduling information of the thread
    - e.g., priority
Dispatching Loop

- Threads are run from a **dispatching loop**
  - LOOP
    - Run thread → Jump to the first instruction
    - Save states
    - Choose a new thread to run → **Scheduling**
    - Load states from a different thread

**Context switch**
Simple? Not quite…

- How does the dispatcher regain control after a thread starts running?
- What states should a thread save?
- How does the dispatcher choose the next thread?
How does the dispatcher regain control?

- **Two ways:**
  1. Internal events (“Sleeping Beauty”)
     - A thread is waiting for I/O
     - A thread is waiting for some other thread
     - Yield—a thread gives up CPU voluntarily
  2. External events
     - Interrupts—a complete disk request
     - Timer—it’s like an alarm clock
What states should a thread save?

- Anything that the next thread may trash before a context switch
  - Program counter
  - Registers
  - Changes in execution stack
How does the dispatcher choose the next thread?

- The dispatcher keeps a list of threads that are ready to run
- If no threads are ready
  - Dispatcher just loops
- If one thread is ready
  - Easy
How does the dispatcher choose the next thread?

- If more than one thread are ready
  - We choose the next thread based on the scheduling policies
  - Examples
    - FIFO (first in, first out)
    - LIFO (last in, first out)
    - Priority-based policies
How does the dispatcher choose the next thread?

- Additional control by the dispatcher on how to share the CPU
  - Examples:

  **Run to completion**
  
  Time
  
  A   B   C

  **Timeshare the CPU**
  
  Time
  
  A   B   C   A   B   C   A   C   A   C
Per-thread States

Each thread can be in one of the three states

1. **Running**: has the CPU
2. **Blocked**: waiting for I/O or another thread
3. **Ready to run**: on the ready list, waiting for the CPU
Per-thread State Diagram

- Ready
- Running
- Scheduled
- Blocked

- Yield, timer
- I/O request
- I/O complete