**CS 370: OPERATING SYSTEMS**
**[THREADS]**

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## Frequently asked questions from the previous class survey

- When a process is waiting, does it get penalized later on when it executes?
- Difference between tasks and processes?
- Pipes
  - In memory file? Is that why it is fast?
  - The shell example, how do the child communicated using the pipe? [child-child?]
  - Does a process group have a default pipe to communicate over?
  - Garbage collected when the process terminates?
- How are rights transferred between queues?
- Distributed objects and RPCs: Sockets



## Topics covered in this lecture

- Background
- Rationale for threads
- Thread model
- Benefits of multithreaded programming



Many hands make light work.
—John Heywood (1546)

## THREADS



## Some background on threading

- Exploited to make programs **easier** to write
  - Split programs into separate tasks
- Took off when GUIs became standard
  - User **perceives** better performance
    - Programs did not run faster: this was an illusion
    - Dedicated thread to service input OR display output
- Growing trend to **exploit** available processors on a machine



## What are threads?

- Miniprocesses or lightweight processes
- Deja vu all over again?
  - Why would anyone want to have a *kind of process* **within** a process?

## The main reason for using threads

- In many applications *multiple activities* are going on at once
  - Some of these may block from time to time
- Decompose application into multiple sequential threads
  - Running in **quasi-parallel**



## Isn't this precisely the argument for processes?

- Yes, *but* there is a new dimension …
- Threads have the ability to **share the address space** (and all of its data) among themselves
- For several applications
  - Processes (with their *separate* address spaces) don't work



## Threads are also lighter weight than processes

- **Faster** to create and destroy than processes
- In many systems thread creation is 10-100 times faster
- When number of threads that are needed changes dynamically and rapidly?
  - Lightweight property is very useful



## Threads: The performance argument

- When all threads are CPU bound all the time?
  - Threads yield **no** performance gain
- But when there is substantial computing ***and substantial I/O***
  - Having threads allows activities to **overlap**
  - Speeds up the application



## An Example Application
## Word Processor



## Our Word Processor

- Displays document being created on the screen
- Document formatted exactly as it will appear on a printed page

## Let's take a look at someone editing a 800-page document

- User deletes one sentence from Page-1 of an 800-page document
- Now user wants to make a change on page 600
  - Either go to that page or search for term that only appears there



## Page 600 after the edit on Page 1

- Word processor *does not know* what's the first line on page 600
- Word processor has to **reformat** entire book up to page 600
- Threads could help here …



## Suppose the word processor is written as a 2-threaded program

- One thread **interacts** with the user
- The second thread handles **formatting** in the background
- As soon as the sentence is deleted
  - Interactive thread tells formatter thread to format the book



## While we are at it, why not add a third thread?

- Automatically save file every few minutes
- Handle disk backups *without interfering* with the other 2 threads



## What if the program were single threaded?

- Whenever disk backup started
  - Commands from keyboard/mouse would be **ignored** till backup was finished
  - User perceives sluggish performance
- Alternatively, keyboard/mouse events could *interrupt* the disk backup
  - Good performance
  - Complex, interrupt-driven programming



## With 3 threads the programming model is simpler

- First thread **interact**s with the user
- Second thread **reformat**s when told to
- Third thread **write**s contents of RAM on to disk periodically

## Three separate processes WOULD NOT work here

- **All three** threads need to operate on document
- By having 3 threads instead of 3 processes
  1. The threads share a **common memory**
  2. Have access to document being edited



## Applications are typically implemented as a process with multiple threads of control

- Perform different tasks in the application
  - Web browser
    - Thread A: Render images and text
    - Thread B: Fetch network data
- Assist in the performance of several similar tasks
  - Web Server: Manages requests for web content
    - Single threaded model: One client at a time
      - Poor response times
    - Multithreaded model: Multiple clients served *concurrently*



## Classical Thread Model



## The process model is based on two independent concepts

- Resource grouping
- Execution



## A process can be thought of as a way to group related resources together

- **Address space** containing program text and data
- Other resources
  - Open files, child processes, signal handlers, etc.



## A process also has a thread-of-execution

- Usually shortened to just **thread**
- The thread has
  1. Program counter
  2. Registers: Current working variables
  3. Stack: Contains execution history
     - One **frame** for each procedure **called, but not returned from**

## Although a thread must execute in some process

- The process and thread are *different* concepts
  - Can be treated separately
- Processes are used to group resources together
- Threads are entities scheduled for execution on the CPU

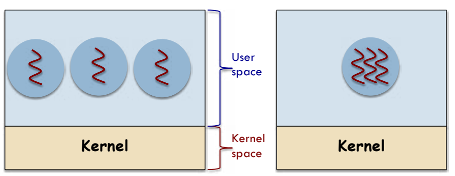


## Threads & Processes

- Threads extend the process model by allowing *multiple executions* in the **same process**
- Multiple threads in parallel in one process?
  - Analogous to multiple processes running in parallel on one computer



## Threads and Processes




Three processes, each with one thread — One process with three threads



## Different threads in a process are NOT AS INDEPENDENT as different processes

- All threads within a process have the **same address space**
  - Share the same global variables
- Every thread can access **every** memory address within the process' address space
  - Read
  - Write
  - Wipe out another thread's stack



## There is no protection between threads, because …

① It is **impossible**
② It *should not* be necessary



## Unlike processes which may be from different users

- A process is always owned by a single user
- The user created threads so that they can cooperate … not fight

## Contrasting items unique & shared across threads

| Per process items {Shared by threads within a process} | Per thread items {Items unique to a thread} |
|---|---|
| Address space | Program Counter |
| Global variables | Registers |
| Open files | Stack |
| Child Processes | State |
| Pending alarms | |
| Signals and signal handlers | |
| Accounting Information | |



## A thread is a basic unit of CPU utilization

- Thread ID
- Program Counter
- Register Set
- Stack
- State

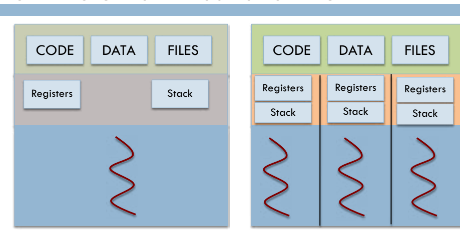


## Sharing among threads belonging to a given process

- Code section
- Data section
- OS resources
  - Open files
  - Signals



## A process with multiple threads of control can perform more than 1 task at a time




Traditional Heavy weight process    Process with multiple threads



## Why each thread needs its own stack [1/2]

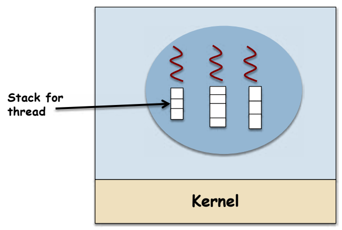
- Stack contains one **frame** for each procedure *called but not returned from*
- Frame contains
  - Local variables
  - Procedure's return address



## Why each thread needs its own stack [2/2]

- Procedure **X** calls procedure **Y**, **Y** then calls **Z**
  - When **Z** *is executing*?
    - Frames for **X**, **Y** and **Z** will be on the stack
- Each thread calls *different* procedures
  - So has a *different execution* history

## Each thread has its own stack






## Thread states are similar to processes

- Running
- Blocked
- Ready
- Terminated



## Benefits of Multithreaded Programming



## The rationale for threads

- Process creation is
  - Time consuming
  - Resource intensive
- If new process performs same tasks as existing process
  - Why incur this overhead?
- Much more efficient to use multiple threads in the process



## Threads have made inroads into the OS itself

- Most OS kernels are now multithreaded
  - Perform specific tasks
  - Interrupt handling
  - Device management
- Solaris OS
  - Multiple threads in the kernel for interrupt handling
- Linux
  - Kernel thread manages system's free memory



## Benefits of multithreaded programming

1. Responsiveness
2. Resource Sharing
3. Economy
4. Scalability

## Multithreaded programming: Benefit #1 Responsiveness

- Shifting work to run in the background
- Interactive multithreaded application
  - **Parts** of program may be blocked or slow
  - **Remainder** of program may still chug along
  - E.g., Web browser
    - You may read text, while high-resolution image is being downloaded



## Multithreaded programming: Benefit #2 Resource Sharing

- Programmer **arranges sharing** between processes
  - Shared memory & message passing
- Threads within a process **share** its resources
  - Memory, code, and data
  - Allows several different threads of activity within the same process



## Multithreaded programming: Benefit #3 Economy

- Process creation is memory and resource intensive
- Threads share process' resources
  - Economical to **create** and **context-switch** threads

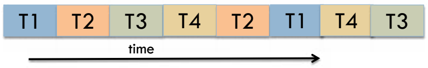


## Multithreaded programming: Benefit #4 Scalability

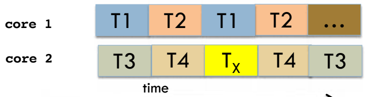
- A single threaded process can ONLY run on 1 processor
  - Regardless of how many are available
  - Underutilization of compute resource
- Programs can use threads on a multiprocessor to do work in parallel
  - Do the same work in less time OR
  - Do more work in the same elapsed time



## Comparing thread executions on single core and dual core systems




**Single core: Thread executions are interleaved on a single core**




**True concurrency: Threads execute in parallel on different cores**



## Demand pulls of multicore systems

- OS designers
  - Scheduling algorithms to harness multiple cores
- Application Programmers
  - Modify existing non-threaded programs
    - Daunting!
  - Design multithreaded programs

## Going about writing multithreaded programs [1/2]

- The key idea is to write a **concurrent program** — one with many simultaneous activities
  - As a set of sequential streams of execution, or threads, that interact and share results in very precise ways
- **Subdivide** functionality into multiple separate & concurrent tasks
- Threads let us define a set of tasks that run concurrently while the code for each task is sequential.



## Going about writing multithreaded programs [2/2]

- Managing **data** manipulated by tasks
  - Split to run on separate cores. BUT
    - Examine data dependencies between the tasks
- Threaded programs on many core systems have many different **execution paths**
  - Which may or may not reveal **bugs**
  - Testing and debugging is inherently harder



## The contents of this slide-set are based on the following references

- *Avi Silberschatz, Peter Galvin, Greg Gagne. Operating Systems Concepts, 9th edition. John Wiley & Sons, Inc. ISBN-13: 978-1118063330. [Chapter 4]*
- *Andrew S Tanenbaum and Herbert Bos. Modern Operating Systems. 4th Edition, 2014. Prentice Hall. ISBN: 013359162X/ 978-0133591620. [Chapter 2].*
- *Kay Robbins & Steve Robbins. Unix Systems Programming, 2nd edition, Prentice Hall ISBN-13: 978-0-13-042411-2. [Chapter 12]*
- *Thomas Anderson and Michael Dahlin. Operating Systems: Principles and Practice, 2nd Edition. Recursive Books. ISBN: 0985673524/978-0985673529. [Chapter 4]*