Department of Physics,
Computer Science & Engineering

CPSC 410 – Operating Systems I

Chapter 4:Threads

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Adapted from original slides by Dr. Roberto A. Flores

Chapter 4 Topics

- Processes & Threads
  - Approaches, States, Processes vs. Threads, Benefits
- Types of Threads
  - User-level, Kernel-level, Hybrid
- Multi-core & Multi-threading
  - Performance, Winners
- Examples
  - ~~Windows 7~~
  - Linux

Multi-Threading

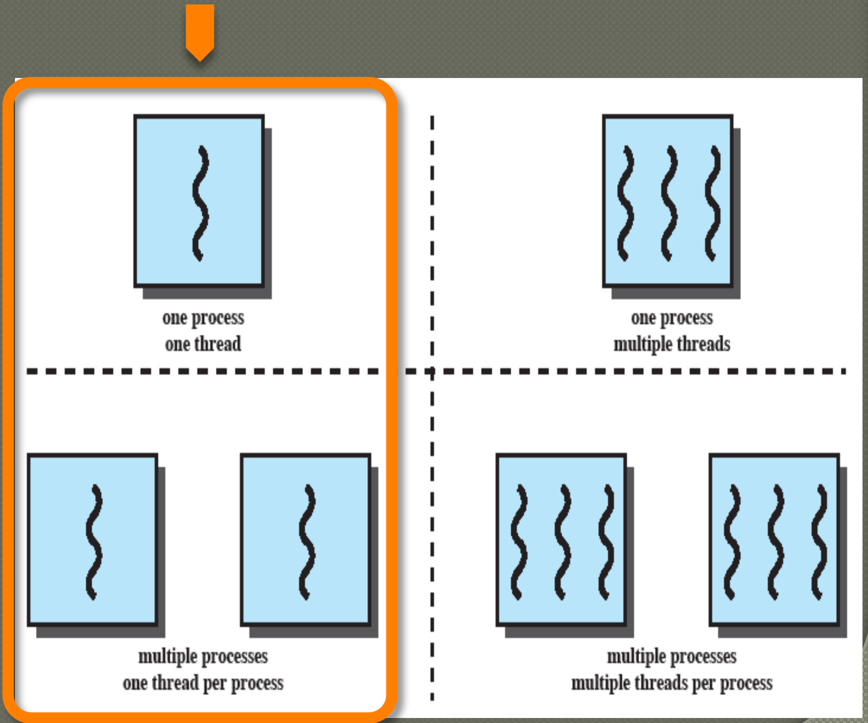
- A process has 2 characteristics
  - Resource ownership
    - virtual address space holding the process image
  - Scheduling & Execution
    - execution state (Running, Ready, etc.) a
    - dispatching priority

- Multi-threading
  - ability of an OS to support multiple concurrent paths of execution within a single process

Multi-Threading

- Approaches
  - Single-Threaded

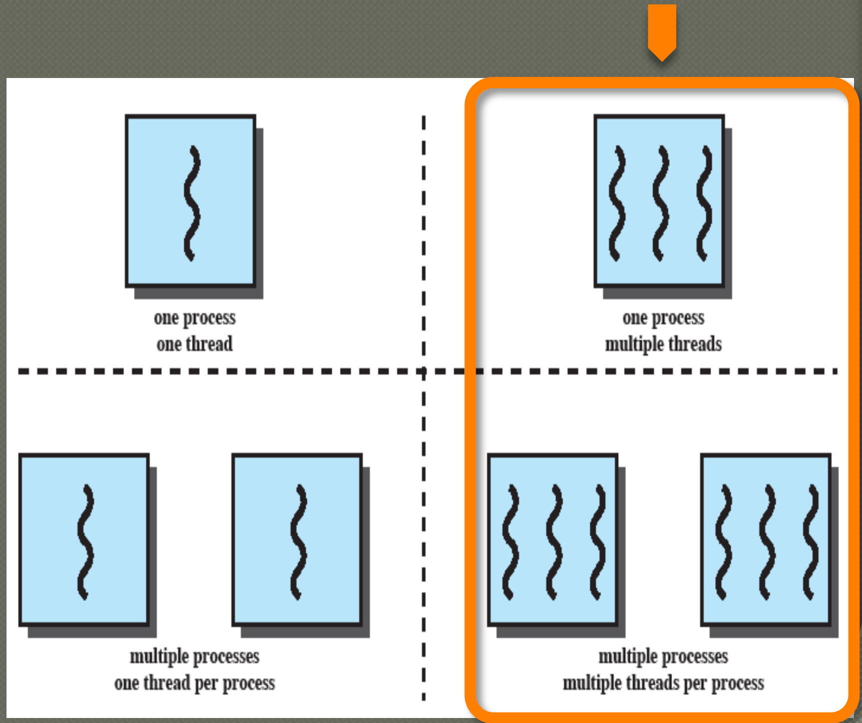
    1 thread per process…



Multi-Threading

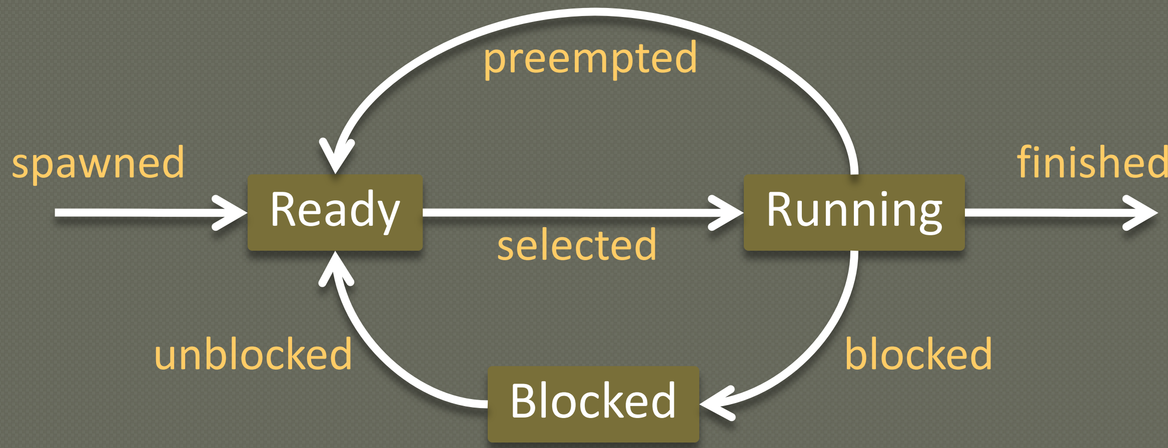
- Approaches
  - Multi-Threaded

    1+ threads per process



Threads

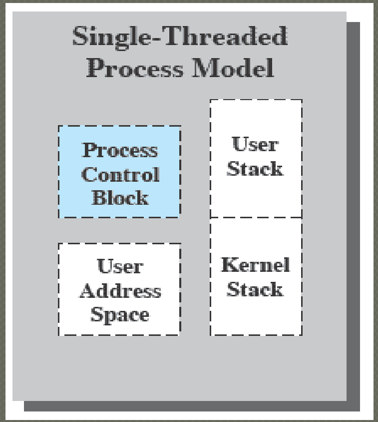
- States



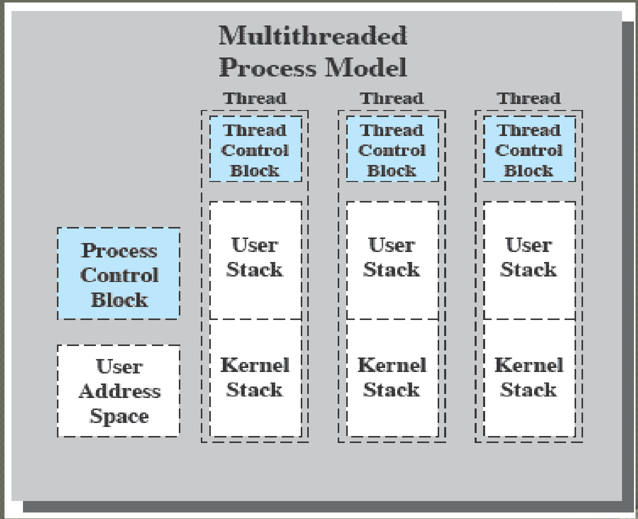
- That all thread info is stored in a process means that…
  - suspending/terminating a process suspends/terminates all its threads.

Processes vs. Threads

- A process has data structures to run in 1 thread
  - PCB, memory space, user/kernel stacks



- A thread duplicates (most of) them to run in its own terms
  - except PCB (replaced by TCB) & memory (which is shared among threads)
  - All in the host process space

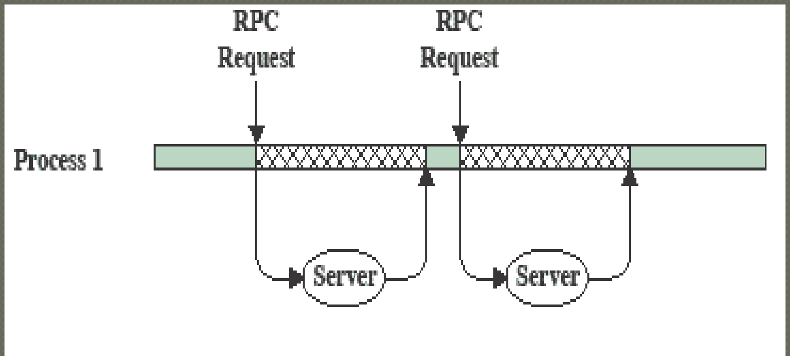


Benefits of Threads

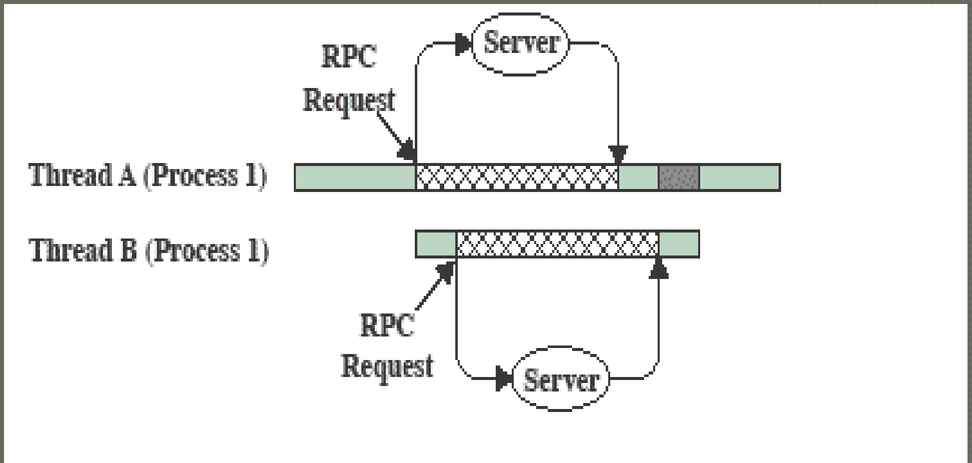
- Takes less time to create a new thread than a process
- Less time to terminate a thread than a process
- Switching between two threads takes less time than switching between processes
- Threads enhance efficiency in communication between programs

Threads

- Why multi-threading?
  - improved utilization – concurrent waiting rather than sequential



(a) RPC Using Single Thread



(b) RPC Using One Thread per Server (on a uniprocessor)

Threads

- Why multi-threading?
  - Improves efficiency in asynchronous execution
    Responsiveness
    - 1 thread handles GUI, another background processing
  - Speed of execution (depends on if you can parallelize tasks)
    - e.g., in video games: rendering, AI, physics
  - Modular programming (SE)
    - programmers design modular code

Thread synchronization
- Needed because:
  - all threads of a process share the same memory/resources
    - i.e., any changes by one thread affects other threads in process

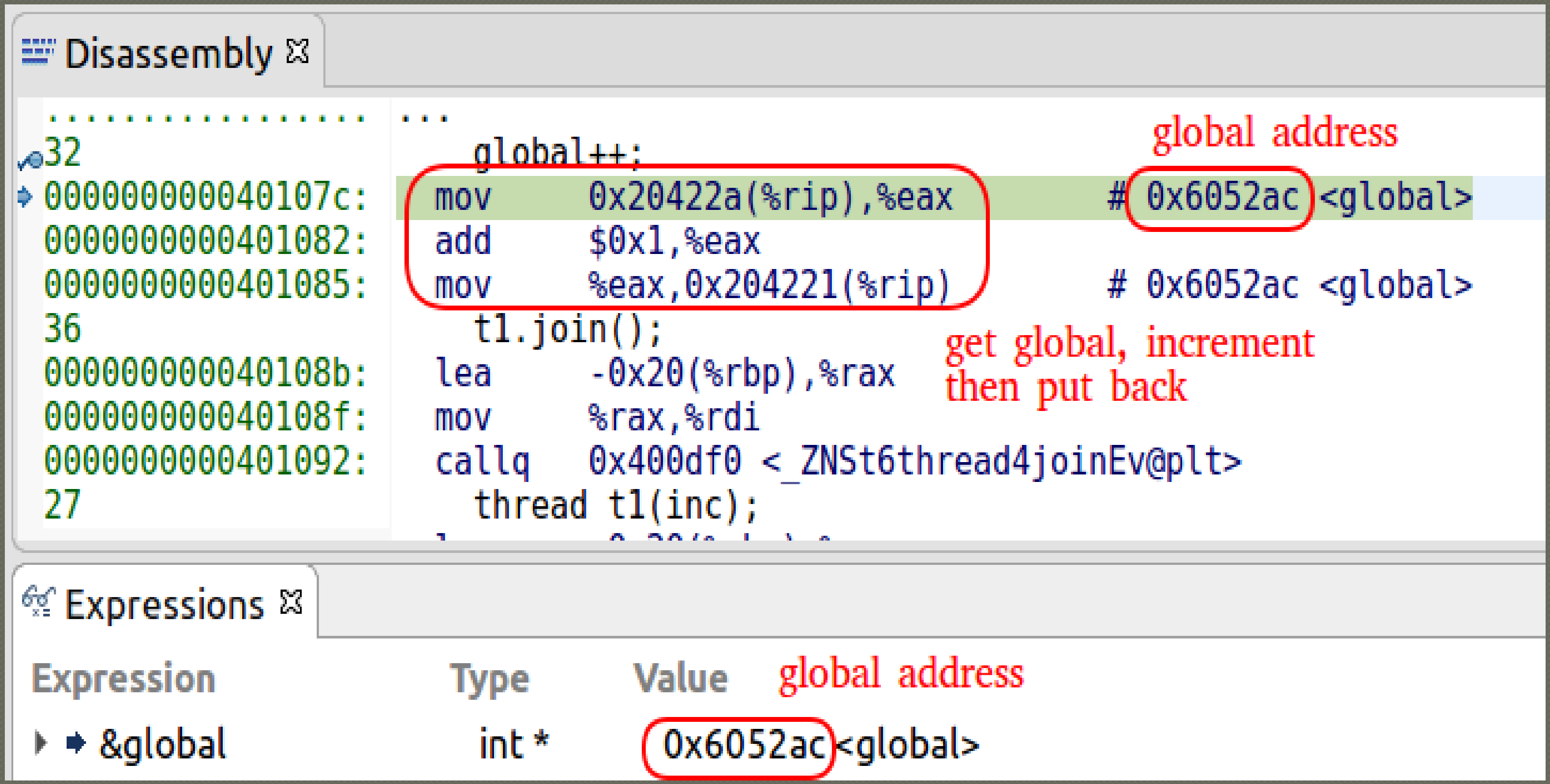
Board Demo

- Show process space
- Show stack frames
- Show thread

My first thread (Eclipse)

```
int global = 0;

void inc()
{
    global++;
}

void thread1()
{
    // constructs threads and runs it
    //it starts by executing function task_inc
    thread t1(inc);

    //Show dissasembly view (window->Show View->Other->debug->Disassembly
    //the following instruction = 3 assembly instructions
    //interrupt can happen after any of those, what happens if
    global++;

    // Makes the main thread wait for the new thread to finish execution,
    // therefore blocks its own execution.
    t1.join();
}
```

Under the hood (Eclipse)



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  - Approaches, States, Processes vs. Threads, Benefits
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  - User-level, Kernel-level, Hybrid
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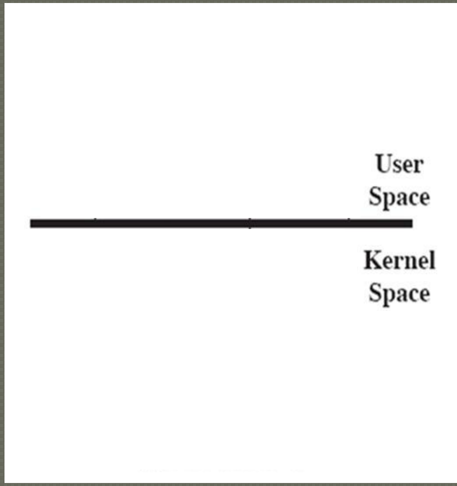
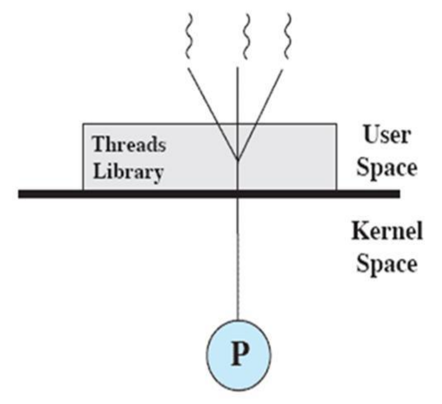
Types of Threads

- Types
  - Thread management is done at
    - The application level (User-level threads)
      - Kernel is aware of process only not its multiple threads (library manages them)
    - The OS level (Kernel-level threads)
      - processes use an OS API to access threads
      - approach favored by MS Windows



Types of Threads

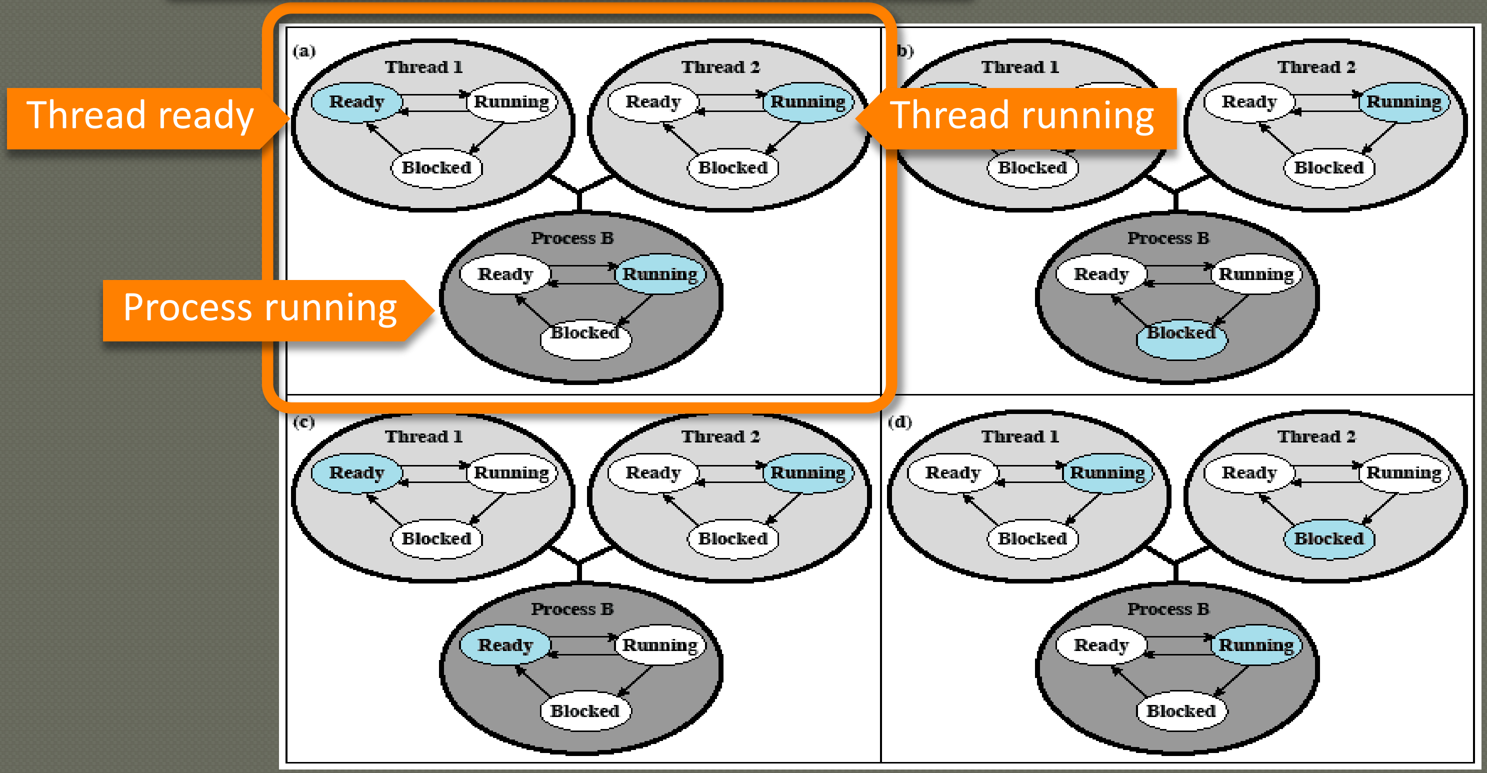
- User-level Threads (ULT)
  - All management done by a threads library
    - Program & library run in a one-thread process.
    - A program spawning a new thread (within the same process) invokes the library, which creates data structures for the thread.
    - When the library is given control, it executes threads using its own scheduling algorithm, saving threads states as it switches execution from one to the next.



(a) Pure user-level

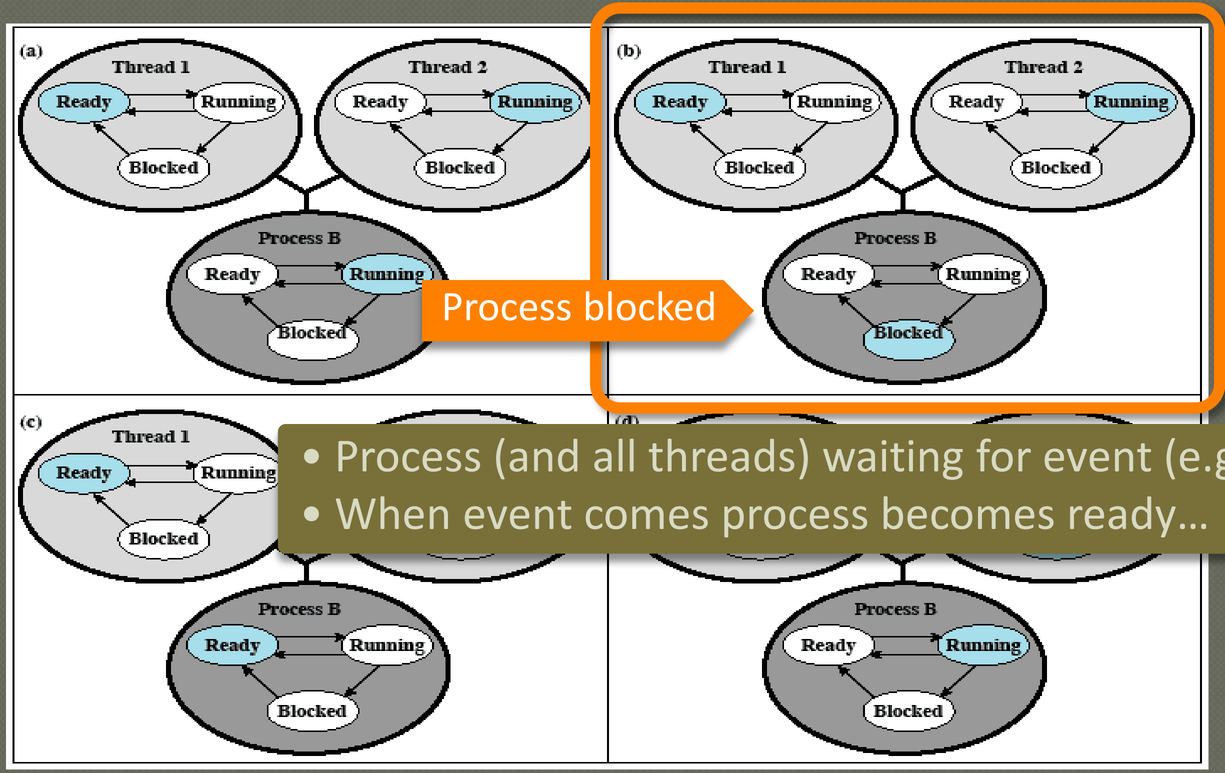
Types of Threads

- User-level Threads (ULT) in context
  - Thread requests system call (e.g., I/O)
  - Entire process is blocked by OS



Types of Threads

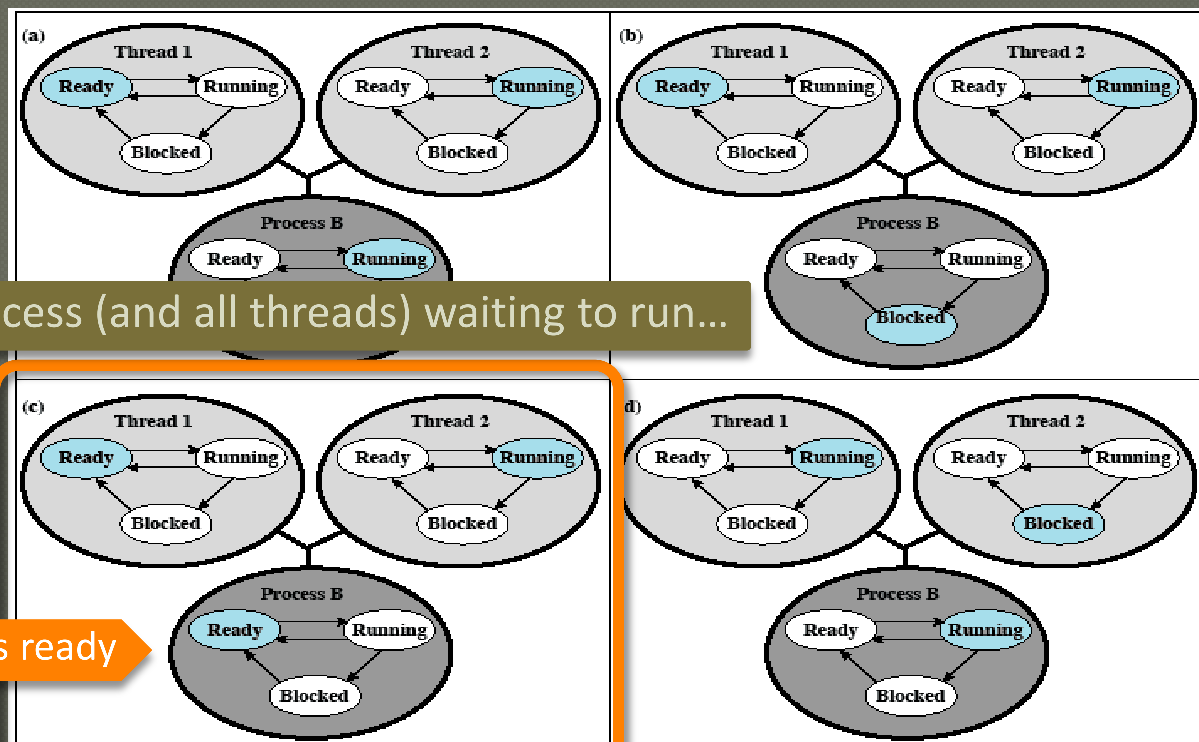
- User-level Threads (ULT) in context



- Process (and all threads) waiting for event (e.g., I/O interrupt)
- When event comes process becomes ready…

Types of Threads

- User-level Threads (ULT) in context

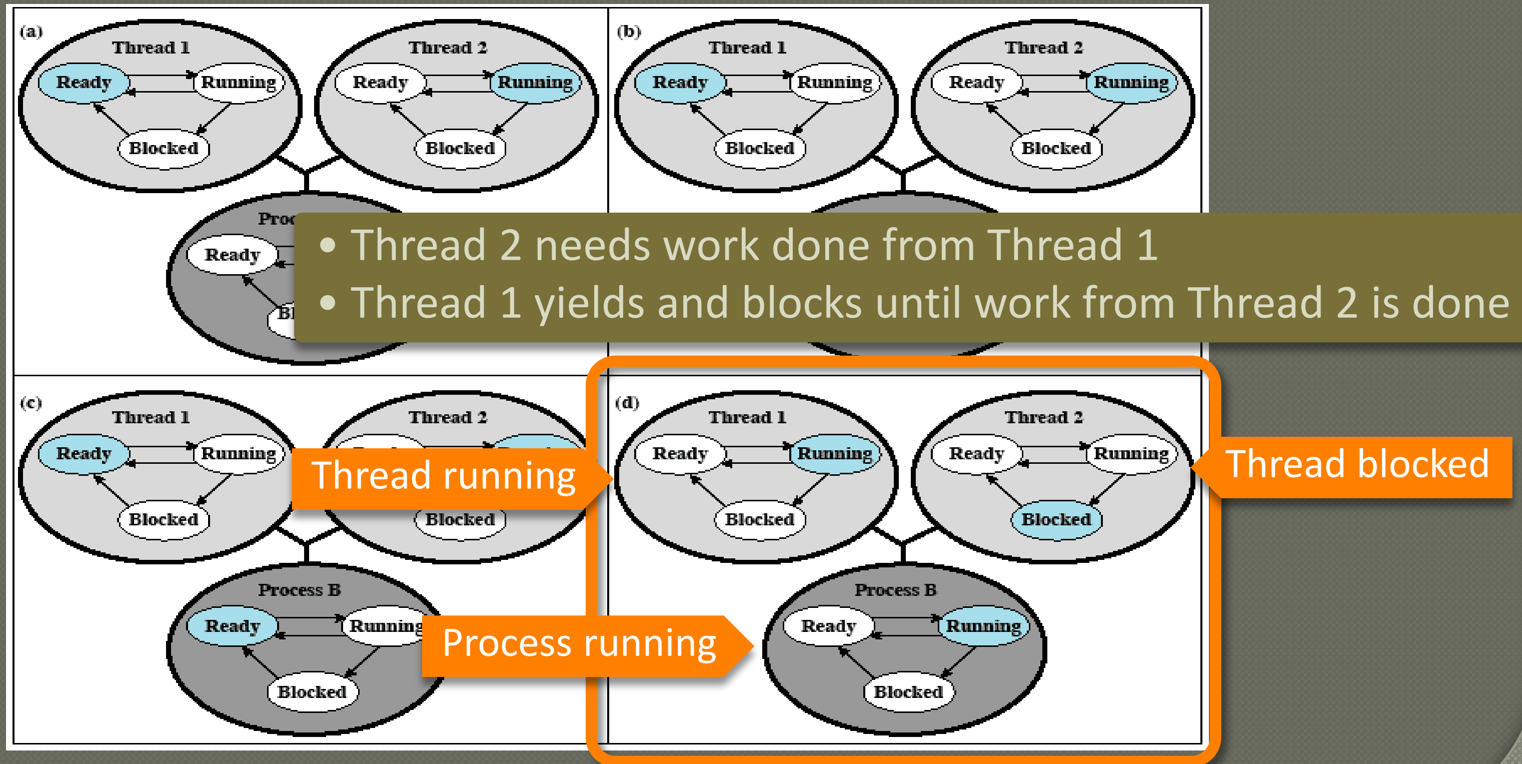


- Process (and all threads) waiting to run…

Process ready

Types of Threads

- User-level Threads (ULT) in context



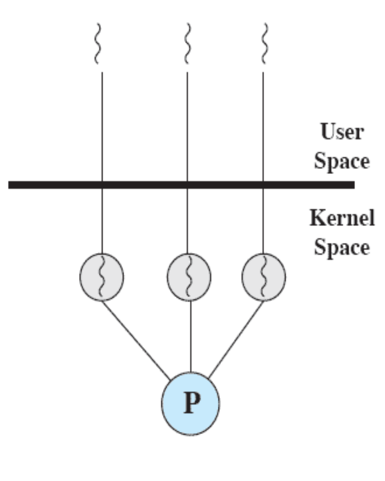
- Thread 2 needs work done from Thread 1
- Thread 1 yields and blocks until work from Thread 2 is done

Types of Threads

- User-level Threads (ULT)
  - Advantages
    - Switching threads does not require Kernel mode.
    - Scheduling can be application-specific.
    - Threads can run on any OS.
  - Disadvantages
    - If a thread requests a system call, then the process (and all threads) are blocked.
    - ULT cannot take advantage of (OS scheduled) multi-processing.
  - Overcoming Disadvantages (sorta)
    - Jacketing (technique)
      - Application level code sees if IO device is busy, if so it calls the threads library to switch to another thread

Types of Threads

- Kernel-level Threads (KLT)
  - All management done by OS
    - Threads like processes (with shared memory)
  - Advantages
    - Threads from the same process can…
      - …run on multiple processors.
      - …keep running if one gets blocked.
  - Disadvantages
    - Transferring control from one thread to another (even from the same process) requires a switch to kernel mode.

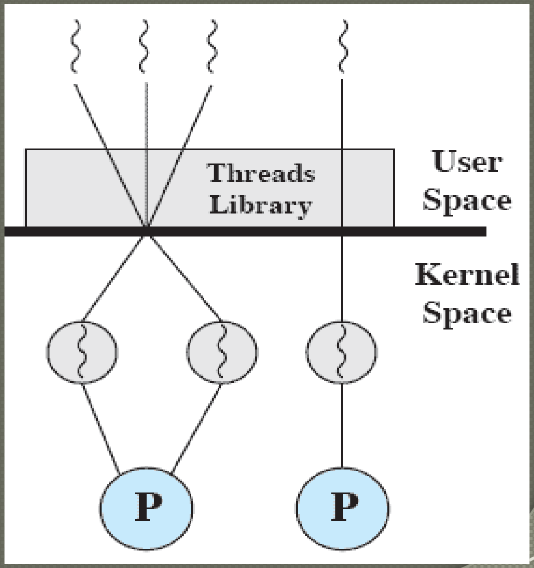


(b) Pure kernel-level

Operation	User-Level Threads	Kernel-Level Threads	Processes
Null Fork	34	948	11,300
Signal Wait	37	441	1,840

Types of Threads

- Combined Approach (Hybrid)
  - All management done by a threads library, which takes advantage of OS multithreading capabilities
    - (if library properly implemented) Threads from the same process could run in parallel on multiple processors.
      - Combines advantages of ULT & KLT…
        - Scheduling can be application-specific.
        - Threads could run on any OS, and on multiple processors.
        - Threads (same process) are not blocked.
      - …while minimizing disadvantages
        - Switching threads may not need Kernel mode.



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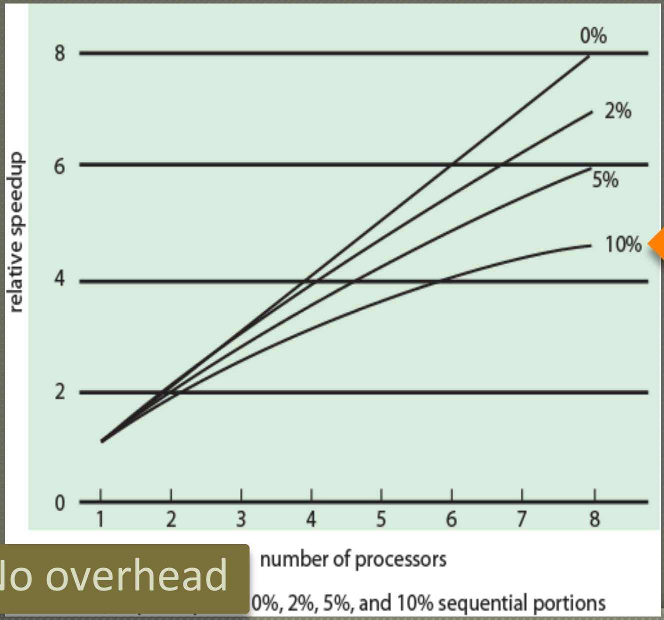
Multi-core & Multi-threading

- Performance
  - Benefits depend on program design
  - Amdahl's law

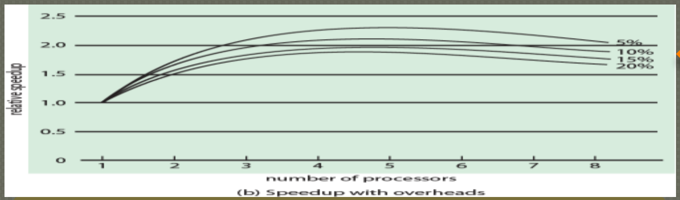
f = % parallelism

$$\text{Speedup} = \frac{\text{Time to run in 1 processor}}{\text{Time to run on N parallel processors}} = \frac{1}{(1 - f) + (f / N)}$$



f=90%, speedup=4.7

No overhead



f=90%, speedup=1.9

With synchronization overhead

Multi-core & Multi-threading

- Highest Gains
  - Multithreaded native applications
    - Programs with a small number of highly threaded processes
  - Multi-process applications
    - Programs with many single-threaded processes
      - e.g., Database management systems (transactions)
  - Java applications
    - Innate thread support
  - Multi-instance applications
    - Multiple instances of the same program running in parallel

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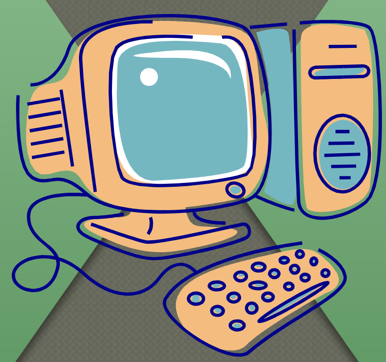
Linux Tasks

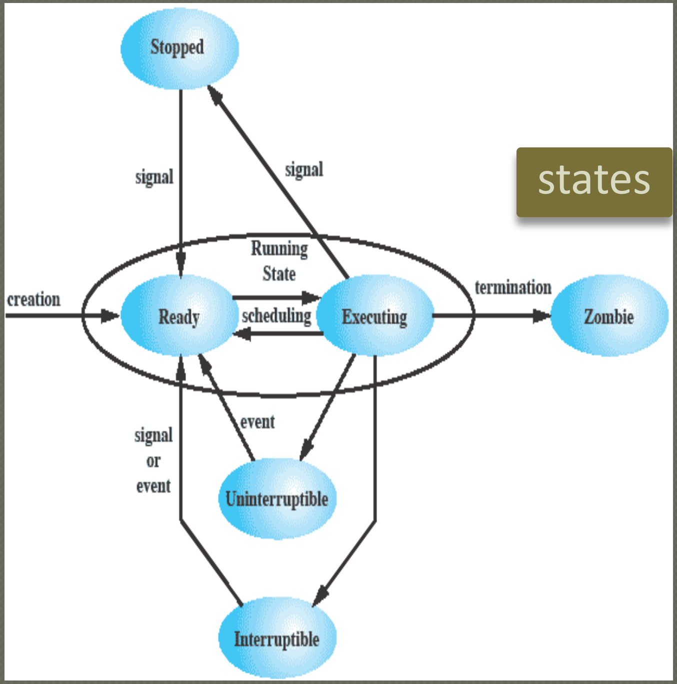
A process, or task, in Linux is represented by a task_struct data structure



This structure contains information in a number of categories

Linux

- Processes & Threads
  - No difference in Linux
  - ULT are mapped into KLT processes.
  - New processes are created…
    - …by forking or cloning
      - fork calls clone with flags cleared to create new process
      - Otherwise flags determine level of sharing
      - tgid of parent is copied
      - resources are shared
      - parent/child have separate stacks
  - When switching processes
    - If they have same ID (tgid), then Linux Does not switch address space. Just process state



states

Linux Threads

Linux does not recognize a distinction between threads and processes

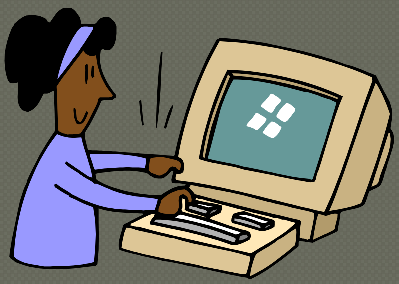
User-level threads are mapped into kernel-level processes

A new process is created by copying the attributes of the current process

The new process can be *cloned* so that it shares resources

The clone() call creates separate stack spaces for each process

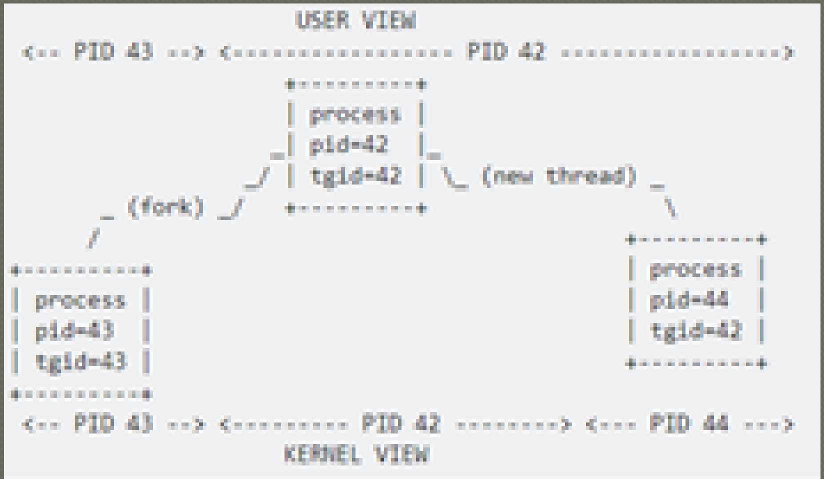
Linux Clone () Flags



CLONE_CLEARID	Clear the task ID.
CLONE_DETACHED	The parent does not want a SIGCHLD signal sent on exit.
CLONE_FILES	Shares the table that identifies the open files.
CLONE_FS	Shares the table that identifies the root directory and the current working directory, as well as the value of the bit mask used to mask the initial file permissions of a new file.
CLONE_IDLETASK	Set PID to zero, which refers to an idle task. The idle task is employed when all available tasks are blocked waiting for resources.
CLONE_NEWNS	Create a new namespace for the child.
CLONE_PARENT	Caller and new task share the same parent process.
CLONE_PTRACE	If the parent process is being traced, the child process will also be traced.
CLONE_SETTID	Write the TID back to user space.
CLONE_SETTLS	Create a new TLS for the child.
CLONE_SIGHAND	Shares the table that identifies the signal handlers.
CLONE_SYSVSEM	Shares System V SEM_UNDO semantics.
CLONE_THREAD	Inserts this process into the same thread group of the parent. If this flag is true, it implicitly enforces CLONE_PARENT.
CLONE_VFORK	If set, the parent does not get scheduled for execution until the child invokes the *execve()* system call.
CLONE_VM	Shares the address space (memory descriptor and all page tables).

Linux Processes and Threads

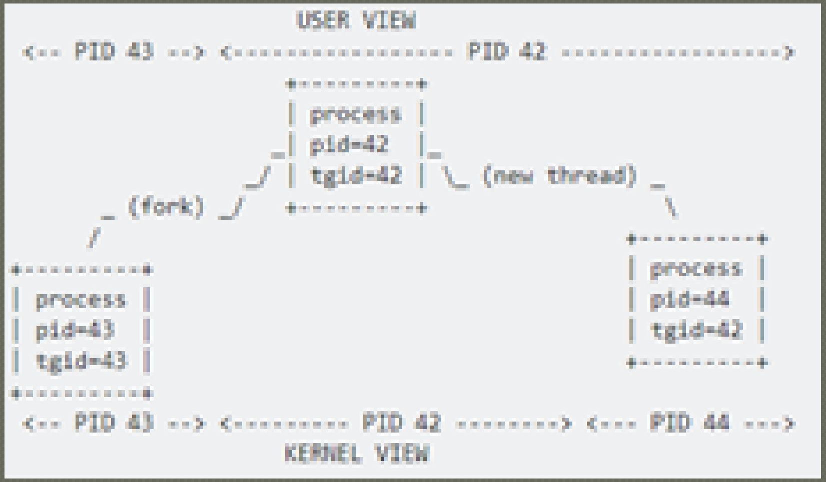
- Linux treats threads as processes
  - Parent process pid==tgid
  - Launched threads have new pid and **Parents** tgid
  - So scheduler sees different pids (for scheduling)
  - But same tgid means don’t swap memory if swapping to same tgid



Graphic from https://stackoverflow.com/questions/9305992/if-threads-share-the-same-pid-how-can-they-be-identified

Viewing

- Also means you can just show processes (not their internal threads) by displaying tgid only
- Show how HTOP tracks processes and threads
  - F2 to setup columns (PID, TGID)
  - Show tree view (Display options->to see parent process



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Stopping a Thread

- Demo cleanly stopping a thread
  - Start a bunch of threads
  - In thread func have loop
    - while(bDoWork){
      - Dowork();
  - Show passing a parameter
  - Show getting the threadID
  - Show unprotected cout
  - Show threads in HTOP

Summary 1

- User-level threads
  - created and managed by a threads library that runs in the user space of a process
  - a mode switch is not required to switch from one thread to another
  - only a single user-level thread within a process can execute at a time
  - if one thread blocks, the entire process is blocked
- Kernel-level threads
  - threads within a process that are maintained by the kernel
  - a mode switch is required to switch from one thread to another
  - multiple threads within the same process can execute in parallel on a multiprocessor
  - blocking of a thread does not block the entire process

Summary 2

Threads vs. Processes

- A thread has no data segment or heap
- A thread cannot live on its own, it must live within a process
- *There can be more than one thread in a process, the first thread calls main & has the process's stack*
- Inexpensive creation
- Inexpensive context switching
- Efficient communication
- If a thread dies, its stack is reclaimed

- A process has code/data/heap & other segments
- A process has at least one thread
- *Threads within a process share code/data/heap, share I/O, but each has its own stack & registers*
- Expensive creation
- Expensive context switching
- Interprocess communication can be expressive
- If a process dies, its resources are reclaimed & all threads die

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Done!