Process Management

Thread Model. Process Scheduling

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April 08, 2020

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The purpose of this subchapter

- Defines threads and the way they can be used
- Presents scheduling principles and algorithms

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Bibliography

- A. Tanenbaum, *Modern Operating Systems*, 2nd Edition, 2001, Chapter 2, Processes, pg. 71 – 100, pg. 132 – 151

Outline

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Thread Definition

- describes a **sequential**, **independent execution** within a process
  - execution = the memory path followed in the code by the IP register
- **there could be more**
  - simultaneous and independent executions in the same process
  - ⇒ **threads in a process**

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Modeling The Execution

- **process** model
  - models "**an entire computer**" used for executing some user application
  - composed by both
    - process' resources
    - process' execution
  - **isolates resources** of one process by that of others
- **thread** model
  - models **the processor(s)** given to a process
  - makes distinction between the two components of a process
    - the process describes the resources
    - the thread describes the (an) execution
  - if multiple independent executions could be identified in a process
    - there could be more threads in that process
    - one thread for one execution
  - threads of a process **share resources** of that process
  - threads of a process (normally) **not visible to other processes**

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Multiprogramming and Multithreading

- multiprogramming = multiple processes managed simultaneously
- multithreading = multiple threads in the same process managed simultaneously

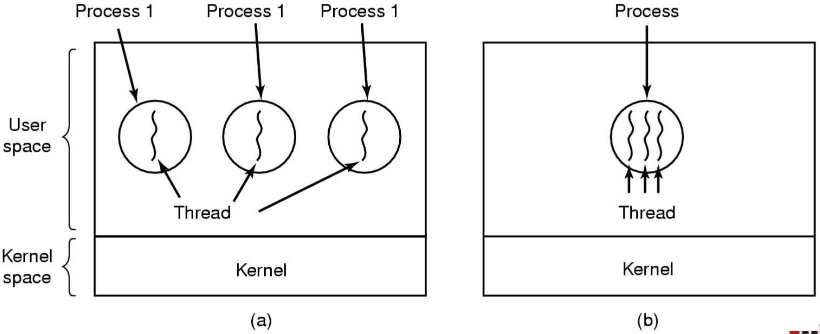

Figure: Taken from Tanenbaum

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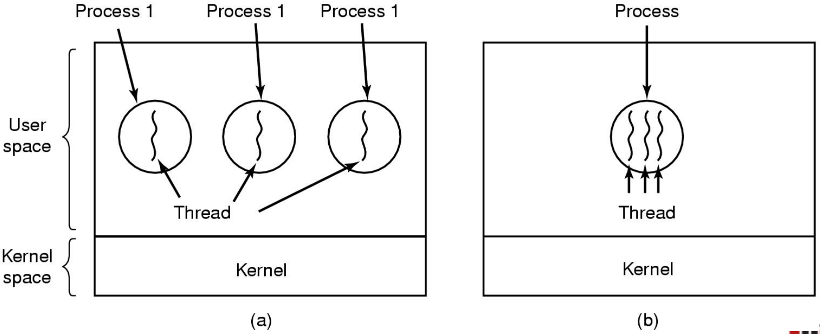

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Thread's Components. Description

- **threads** of the same process
  - **share all the resources of** that **process**: memory, open files etc.
  - ⇒ anything (i.e. inside the process) is accessible to all threads (of that process)
- each thread is an independent execution
  - ⇒ **each thread has also its own resources**
  - that describe the corresponding independent execution
- thread's specific resources
  - **machine registers** (e.g. the IP register)
  - **the stack**

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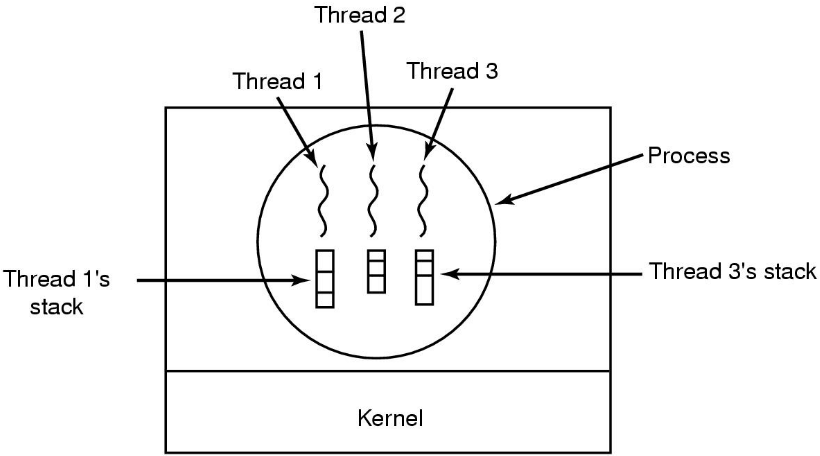
Thread's Components. Illustration



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Threads Relationship

Paraphrase a rule from "Animal Farm" by George Orwell

Threads Relationship (cont.)

All threads are equal, but the "main" thread is "*more equal than the others!*"

Threads Relationship (cont.)

All threads are equal,
but the "main" thread is "*more equal than the others!*"

Threads Relationship (cont.)

All threads are equal, but the "main" thread is "*more equal than the others!*"

Consequences of "All threads are equal"

- **there is no protection between threads of the same process**
  - there is no need, actually
  - created by the application itself to execute code inside the application
- **there is no restriction on them regarding their scheduling**
  - any one could be scheduled any time, depending on the system's scheduling policy
  - we have no control on thread scheduling
  - if needed, **we must synchronize the threads**

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Consequences of "All threads are equal" (cont.)

- ... **but the main one is "*more equal than the others*"**
  - it is the first one created: **executes the *main()* function**
  - it is the ancestor of all other threads, i.e. initiates creation of the other threads
  - if it terminates returning from the "`main()`" function
    - the entire process (and all threads) terminates
    - ⇒ it make sense for it to **wait for the termination of all other threads**
  - **though**, if it terminates using the thread termination syscall, the other threads survive
    - see difference between `exit()` and `pthread_exit()` in Linux
    - see a discussion about this at `https://devblogs.microsoft.com/oldnewthing/20100827-00/?p=13023`

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    - see difference between `exit()` and `pthread_exit()` in Linux
    - see a discussion about this at `https://devblogs.microsoft.com/oldnewthing/20100827-00/?p=13023`

Consequences of "All threads are equal" (cont.)

- **. . . but the main one is "*more equal than the others*"**
  - it is the first one created: **executes the *main()* function**
  - it is the ancestor of all other threads, i.e. initiates creation of the other threads
  - if it terminates returning from the "`main()`" function
    - the entire process (and all threads) terminates
    - ⇒ it make sense for it to **wait for the termination of all other threads**
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Outline

1. Threads
   - Definition of Concepts
   - Thread Usage
2. Scheduling
   - Concepts
   - Scheduling Algorithms
3. Conclusions

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When Do Threads Prove Themselves Useful?

- **useful** in applications
  - where **different actions can happen concurrently** (in the same time) → **logical parallelism**
  - and use **different "independent" system resources** (e.g. CPU, HDD, etc.) → **physical parallelism**
- **NOT useful** in applications
  - using only the single CPU (our considered context)
    - though useful, if multiple CPUs are available
  - in which possible concurrent executions need all the time (compete for) the same single shared resource

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Examples of Multi-threaded Apps: A Word Processor

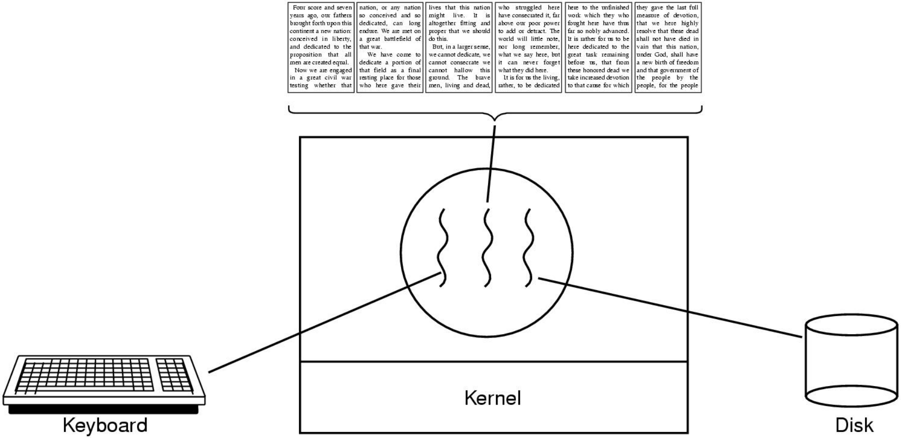
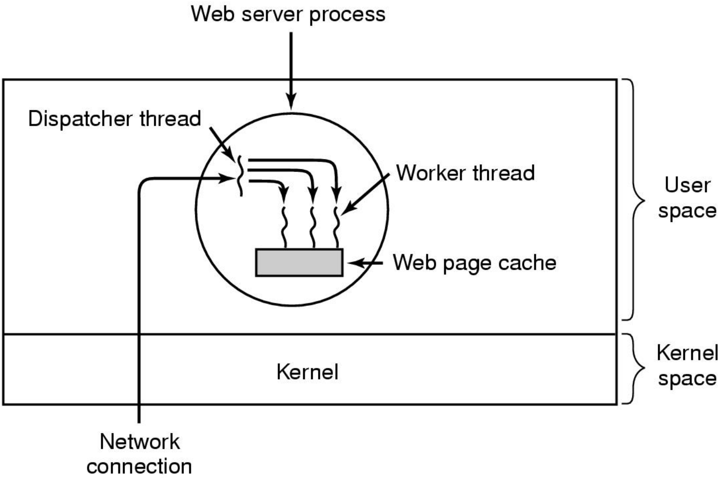


Figure: Taken from Tanenbaum

Examples of Multi-threaded Apps: A Concurrent Server



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Threads vs. Processes

- which are better and for which kind of applications
- **processes** → **isolation**, i.e. totally separated by one another → protection
  - ⇒ use them when isolation and protection needed
  - e.g. tabs in an Internet browser
  - e.g. document tabs in a PDF reader
  - e.g. Web server handling client sessions
- **threads** (light-wight processes) → **resource sharing** (of the same process)
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Questions (1)

On a computing system with **3 logical processors**, specify the **number of threads** needed to **get the best performance** for:

1. checking if N given numbers are prime or not, using an algorithm that divide the N numbers in equal subsets among the threads.
2. calculating the N-th element of the array generated by the rule: $x(n) = x(n\text{-}1) + x(n\text{-}2)$, $x(0)=0$, $x(1)=1$.

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Questions (2)

On a computing system with **1 logical processor**, **a HDD** and **a network card** that can act independently of the system's processors, specify the **number of threads** needed to **get the best performance** for:

1. copying a file from the local HDD to another file on the same HDD;
2. encrypting a file from the local HDD into another file on the same HDD;
3. uploading a file from the local HDD on a remote Web site.

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Outline

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Outline

Definitions

- **scheduler**: the OS component that **decides**
  - **what process / thread will be run next** and
  - **for how long**
- scheduling policy / algorithm
  - the policy (rules, requirements) / algorithm used by the scheduler
- mainly related to CPU(s)
  - but also consider other system resources
- scheduler's role (motivation)
  - mediates between the more competitors of a limited set of resources
- general classes of processes
  1. compute-bounded (CPU-bounded), i.e. CPU intensive
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Classes of Processes

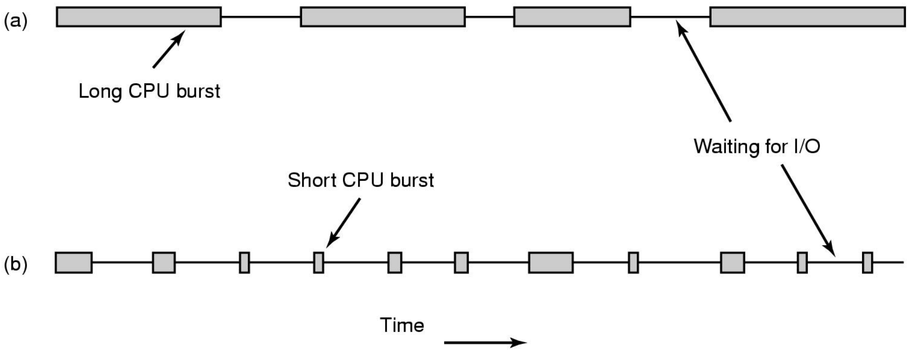

Figure: Taken from Tanenbaum

DEMO: CPU-bound vs. I/O-bound Processes/Threads

- create few I/O bound threads, just to see they let the CPU idle a lot (see the percentage they use from CPU)
  - e.g. threads that display very often something on the screen
  - e.g. threads that mostly all the time read something from a file
- create just one CPU-bound thread, just to see that the CPU will be in use all the time
  - e.g. a simple, unrealistic "`while(1);`" thread

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Questions (3)

Which threads in the following code are CPU-bound and IO-bound respectively?

```
thread_1 (int n)
{
    int i, x;
    for (x =1, i = 1; i <= n; i++)
        x = x * i;
}

thread_2 ()
{
    char c;
    while (1) {
        read  (0, &c, 1);
        write (1, &c, 1);
    }
}
```

Scheduling Situations

- any time something is changed regarding the CPU's competitors
    - **process creation**
    - **process termination**
    - **process blocking**, e.g. sleeping for a while, waiting for an event etc.
- external events
    - generally, **interrupt occurrences**
    - particularly, the **clock interrupt occurrence**
        - used to implement CPU (time) sharing between processes

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- depends on the way the clock interrupt occurrence is used by scheduler
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Preemptive vs. Non-preemptive Scheduler

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  - do not interact with the users, usually performing long running jobs
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  - **fit better non-preemptive scheduling algorithms**
  - or preemptive algorithms with long time quanta
  - reduce the no of process switches ⇒ increase overall performance
- **interactive systems** (processes)
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Outline

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First-Come First-Served (FCFS)

- it is a non-preemptive algorithm
- simple to understand and implement
- the average waiting time (a.w.t.) depends on the thread order and execution time
  - see Gantt diagram, i.e. graphical illustration of chronological time intervals each thread was scheduled

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First-Come First-Served (FCFS). Example 1

- `T1:23, T2:2, T3:3` (`thread` : `execution time`)
- waiting time for T1 is 0 ms, for T2 is 23 ms, and for T3 is 25 ms
- $a.w.t. = \frac{0+23+25}{3} = 16ms$

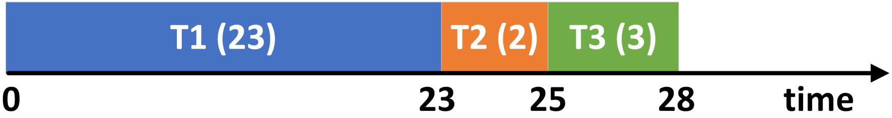

Figure: Gantt diagram of process scheduling

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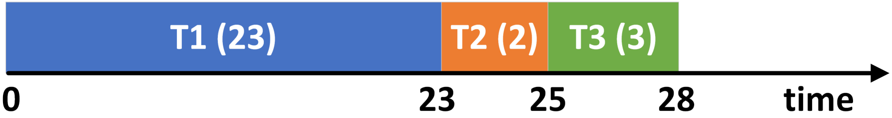

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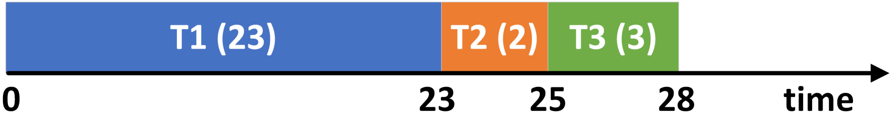

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- `T2:2, T3:3, T1:23` (`thread : execution time`)
- waiting time for T1 is 5 ms, for T2 is 0 ms, and for T3 is 2 ms
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Shortest Job First (SJF)

- runtime should be known in advance
- is the optimal algorithm when all the ready threads are available simultaneously
- non-preemptive
  - `0:P1:8,1:P2:4, 2:P3:9, 3:P4:5` (submit time : process : run time)
  - `a.w.t. = (0 + (8-1) + (17-3) + (12-2))/4 = 7.75`
- preemptive (*shortest remaining time next*)
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Round-Robin (RR)

- each thread is assigned a time interval
  - time quantum or slice
- it is a preemptive algorithm
- maintain a FIFO list for ready threads
  - like FCFS, but preemptive, based on time quanta
- the length of the time quantum
  - too short $\Rightarrow$ many CPU switches $\Rightarrow$ lower the CPU efficiency, i.e. a lot of CPU is wasted for running the context switching code
  - too large $\Rightarrow$ longer wait times in ready queue $\Rightarrow$ poor response time for interactive threads
  - 20–100 msec is a reasonable compromise

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- it is a preemptive algorithm
- maintain a FIFO list for ready threads
  - like FCFS, but preemptive, based on time quanta
- the length of the time quantum
  - too short $\Rightarrow$ many CPU switches $\Rightarrow$ lower the CPU efficiency, i.e. a lot of CPU is wasted for running the context switching code
  - too large $\Rightarrow$ longer wait times in ready queue $\Rightarrow$ poor response time for interactive threads
  - 20–100 msec is a reasonable compromise

Priority Based

- each thread has a priority assigned
  - usually a number that describes the thread "importance" (from some perspective)
  - e.g. running time could be such a number: the smaller the higher thread's priority⇒ SJF
- rule: **the ready thread with the greatest priority is always run**
- give a chance also to smaller priority threads
  - i.e. **avoid starvation**
  - by changing periodically the priority of processes
- priority-based policies
  - fixed priorities
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- priority classes
  - there could be more processes with the same priority
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Questions (4)

Let us suppose that an OS' scheduler uses the **Round-Robin** algorithm with **200 ms** time-quantum. Illustrate on a **Gannt diagram** for the time interval **0 – 1 seconds** the executions of the threads whose code is given below, for the following scenarios.

1.
```
// Thread1            // Thread2

while(1){}            while(1){}
```

2.
```
// Thread1            // Thread2

usleep(300000); // 300 ms
while(1) {}           while(1) {}
```

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Outline

What we talked about

- threads
  - describe multiple, independent executions in the same process
  - share all resources of the process they belong to
- multi-threading applications
- scheduling
  - needed when there are more competitors for a limited set of resources (e.g. CPUs)
  - first-come first-served, shortest job first, round-robin, priority-based

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Lessons Learned

Multiple threads in a process are **useful** and **effective** only in particular cases:

1. **logical application parallelism** exists
2. needed **physical resources available**

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