Operating Systems and Concurrency

Processes 3: Threads

COMP2007

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Recap

Last Lecture

- **Types of schedulers**: preemptive/non-preemptive, long/medium/short term)
- Performance **evaluation criteria**
- Scheduling **algorithms**: FCFS, SJF, Round Robin, Priority Queues

Goals for Today

Overview

1. Threads vs. processes
2. Different thread implementations
3. POSIX Threads (PThreads)

- A process consists of two **fundamental units**
  - **Resources**: all related resources are grouped together
    - A logical address space containing the process image (program, data, heap, stack)
    - Files, I/O devices, I/O channels, . . .
  - **Execution trace**, i.e., an entity that gets executed
- A process can **share its resources** between **multiple execution traces**, i.e., multiple threads running in the same resource environment

Threads from an OS Perspective (Cont'ed)

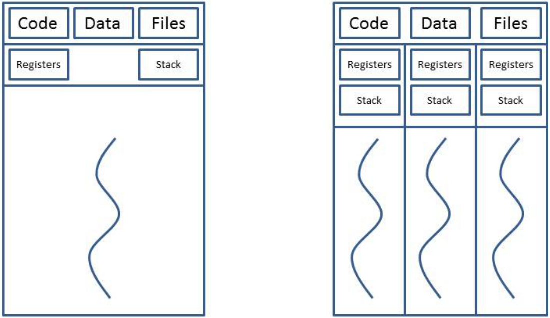


Figure: Single threaded process (left), multi-threaded process (right)

- Every thread has its own **execution context** (e.g. program counter, stack, registers)
- All threads have **access** to the process' **shared resources**
  - E.g. files, one thread opens a file, all threads of the same process can access the file
  - Global variables, memory, etc. ($\Rightarrow$ synchronisation!)
- Similar to processes, threads have:
  - **States** and **transitions** (new, running, blocked, ready, terminated)
  - A **thread control block (TCB)**

Threads

Threads from an OS Perspective (Cont'ed)

Processes	Threads
Address space	Program Counter
Global variables	Registers
Open files	Stack
Child processes	State
Pending alarms	Local vars
Signals and signal handlers	
Accounting information	

Table: Shared resources left, private resources right

Threads

Threads from an OS Perspective (Cont'ed)

- Threads incur **less overhead** to create/terminate/switch (address space remains the same for threads of the same process)
- Some CPUs have direct **hardware support** for **multi-threading**
  - Typically, they can offer up to 8 hardware threads per core

- **Inter-thread communication** is easier/faster than **interprocess** communication (threads share memory by default)
- **No protection boundaries** are required in the address space (threads are cooperating, belong to the same user, and have a common goal)
- **Synchronisation** has to be considered carefully!

- Multiple **related activities** apply to the **same resources**, these resources should be accessible/shared
- Processes will often contain multiple **blocking tasks**
  - I/O operations (thread blocks, **interrupt** marks completion)
  - Memory access: pages faults are result in blocking
- Such activities should be carried out in **parallel/concurrently**
- **Application examples**: webservers, make program, spreadsheets, word processors, processing large data volumes

- **User** threads
- **Kernel** threads
- **Hybrid** implementations

User Threads

Many-to-One

- **Thread management** (creating, destroying, scheduling, thread control block manipulation) is carried out **in user space** with the help of a **user library**
- The process maintains a **thread table** managed by the **runtime system** without the **kernel's knowledge**
  - Similar to **process table**
  - Used for **thread switching**
  - Tracks thread related information

User Threads
Many-to-One

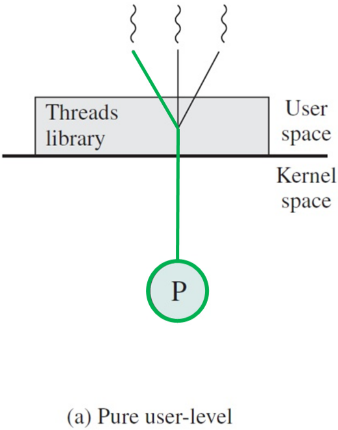
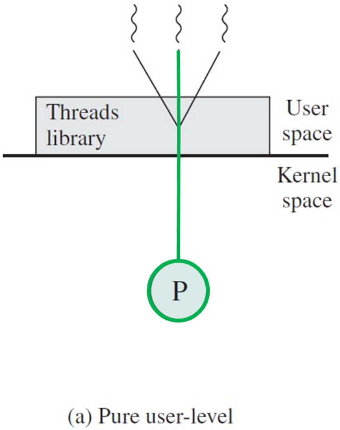


Figure: User threads (Stallings)

User Threads

Many-to-One



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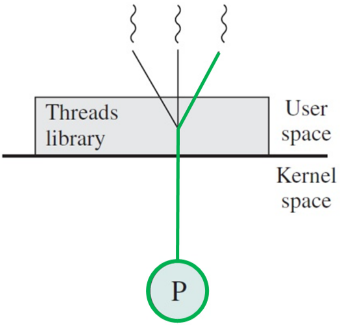

(a) Pure user-level

Figure: User threads (Stallings)

User Threads

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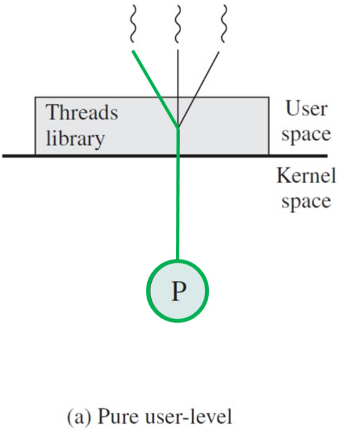

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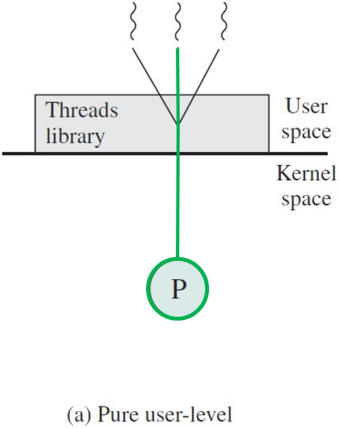

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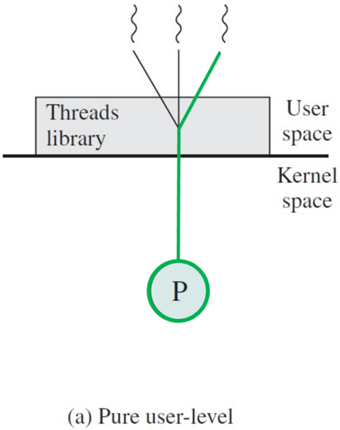

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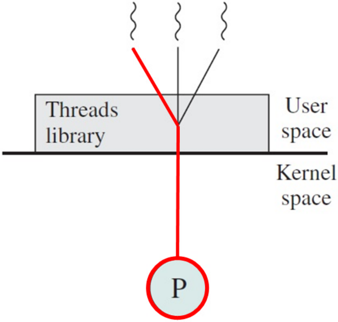

(a) Pure user-level

Figure: User threads (Stallings)

User Threads

Many-to-One

- Advantages:
  - Threads are in user space (i.e., **no mode switches** required)
  - **Full control** over the thread scheduler
  - **OS independent** (threads can run on OS that do not support them)
- Disadvantages:
  - **Blocking system calls** suspend the entire process (user threads are mapped onto a single process, managed by the kernel)
  - **No true parallelism** (a process is scheduled on a single CPU)
  - **Clock interrupts** are non-existent (i.e. user threads are non-preemptive)
  - **Page faults** result in blocking the process

User Threads

Many-to-One

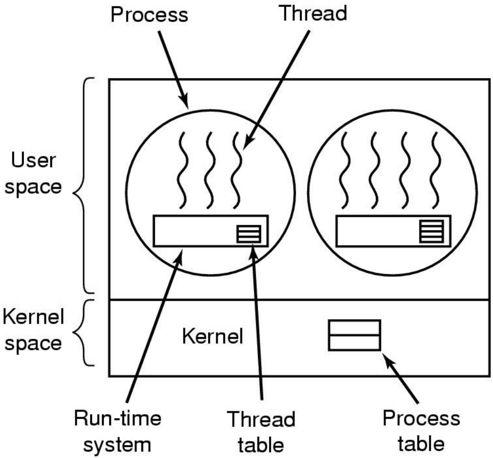

Figure: User threads (Tanenbaum 2014)

Kernel Threads

One-to-One

- The **kernel manages** the threads, user application accesses threading facilities through **API** and **system calls**
  - **Thread table** is in the kernel, containing thread control blocks (subset of process control blocks)
  - If a **thread blocks**, the kernel chooses thread from same or different process
- Advantages:
  - **True parallelism** can be achieved
  - No run-time system needed
- Frequent **mode switches** take place, resulting in lower performance
- Windows and Linux apply this approach

Kernel Threads

One-to-One

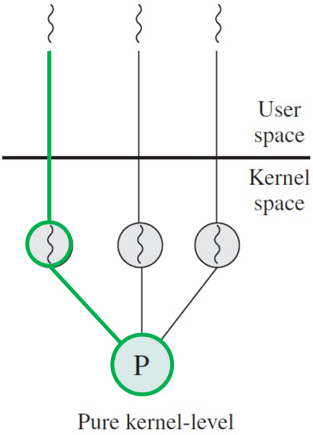

Figure: Kernel threads (Stallings 2014)

Kernel Threads

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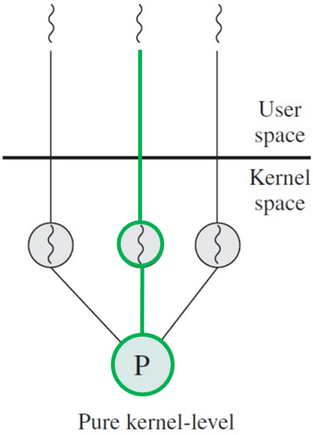

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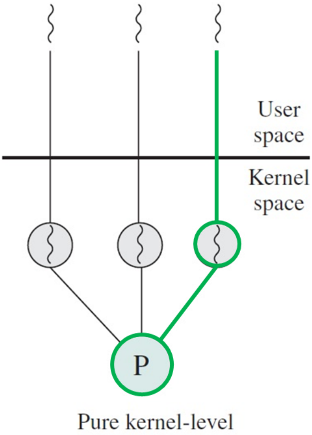

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Kernel Threads

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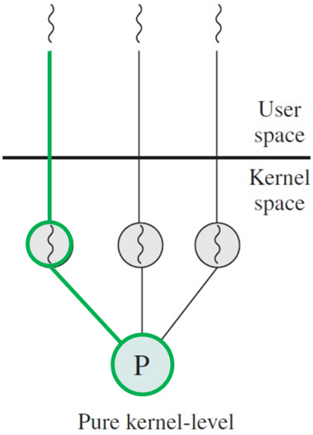

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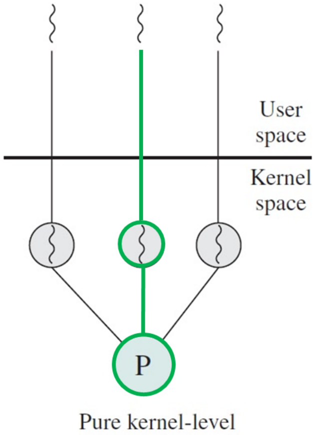

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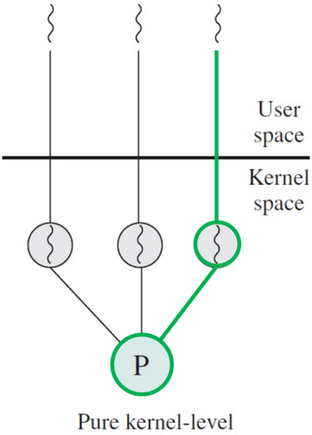

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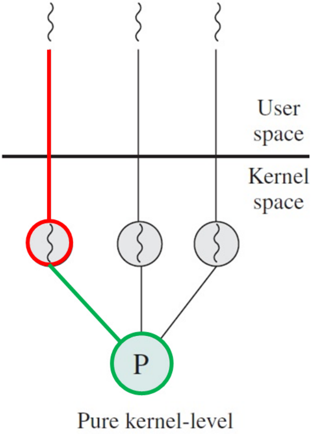

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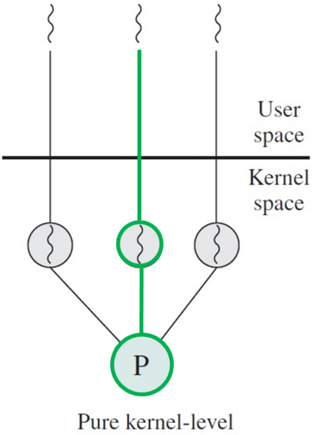

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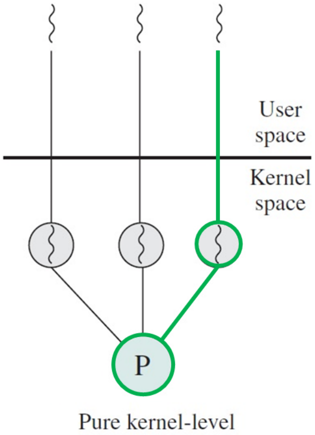

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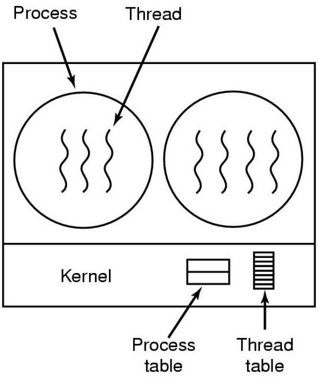

Figure: Kernel threads (Tanenbaum 2014)

Performance

User Threads vs. Kernel Threads vs. Processes

- Null fork: the overhead in creating, scheduling, running and terminating a null process/thread
- Signal wait: overhead in synchronising threads

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

Figure: Comparison, in μs (Stallings)

Hybrid Implementations

Many-to-Many

- User threads are **multiplexed** onto kernel threads
- Kernel sees and schedules the kernel threads (a limited number)
- User application sees user threads and creates/schedules these (an "unrestricted" number)

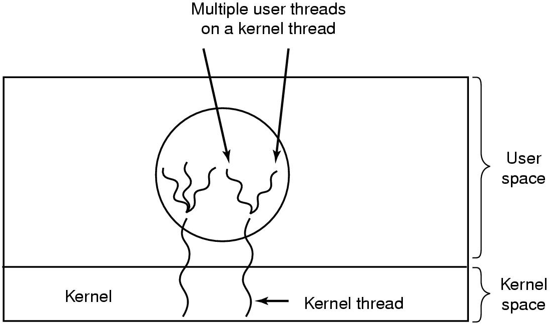

Figure: Kernel threads (Tanenbaum 2014)

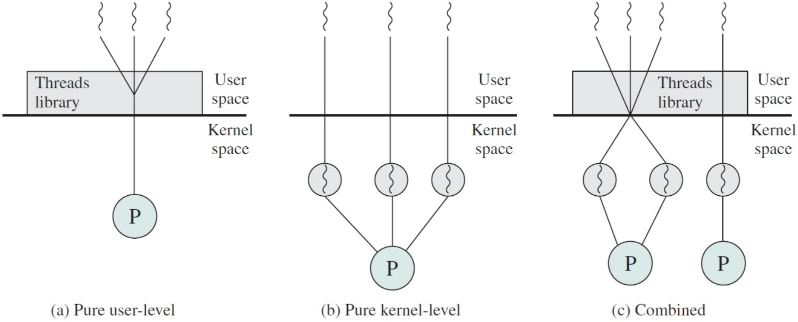

Figure: Comparison (Stallings)

Exam 2013-2014: In which situations would you favour user level threads? In which situation would you definitely favour kernel level threads?

Thread Management

Libraries

- Thread libraries provide an **API/interface for managing threads** (e.g. creating, running, destroying, synchronising, etc.)
- Thread libraries can be implemented:
  - Entirely in **user space** (i.e. user threads)
  - Based on **system calls**, i.e., rely on the kernel for thread implementations
- Examples of thread APIs include **POSIX's PThreads**, Windows Threads, and Java Threads
  - The PThread specification can be implemented as user or kernel threads

POSIX Threads

Overview

- POSIX threads are a **specification** that **“anyone” can implement**, i.e., it defines a set of APIs (function calls, over 60 of them) and what they do
- Core functions of PThreads include:

Function Call	Summary
`pthread_create`	Create new thread
`pthread_exit`	Exit existing thread
`pthread_join`	Wait for thread with ID
`pthread_yield`	Release CPU
`pthread_attr_init`	Thread Attributes (e.g. priority)
`pthread_attr_destroy`	Release Attributes

Table: PThread examples

- More detailed descriptions can be found using `man function_name` on the command line

POSIX Threads

Example

```
#include <pthread.h>
#include <stdio.h>

void* hello(void* arg) {
  printf("Hello from thread %d\n", *((int*)arg));
  return 0;
}

int main() {
  int const THREADS = 10;
  int args[THREADS] = { 0 };
  pthread_t threads[THREADS];
  for(int i = 0; i < THREADS; i++) {
    args[i] = i;
    if(pthread_create(threads + i, NULL, hello, args + i)) {
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Test your understanding

- If the threads in a process share the same memory, why do they have independent stacks?
- Is it always necessary to call `pthread_exit` when ending a thread?
- What is the minimum number of threads a process can have?
- Can user threads make good use of concurrent hardware?