운영체제의 기초: Processes and Threads

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Agenda

I. Process Concepts
II. Process Scheduling
III. Context Switching
IV. Process Creation and Termination
V. Multithreading

I. Process Concepts

Process Concepts (1)

- What is a process and why is it useful?

- Why?
  - With many things happening at once in a system, need some way of separating them all out cleanly
  - Important concept: "*Decomposition*"
    - Solve a hard problem by chopping it into several simpler problems that can be solved separately

Process Concepts (2)

- What?
  - Definition of a process
    - *Program in execution*, or
    - An *execution stream* in the context of a particular *process state*
  - What is an "*execution stream*" and what is a "*process state*"?
    - Process state is everything that can affect, or be affected by the process
      - code, data values, open files, etc.
    - Execution stream is a sequence of instructions performed in a process state
      - Key simplifying feature of a process
      - Only one thing happens at a time within a process

Process Concepts (3)

- Process *state* or *context*
  - Collection of three types of contexts
    - Memory context
      - Code segment, data segment, stack segment, heap
    - Hardware context
      - CPU registers, I/O registers
    - System context
      - Process table, open file table, page table
  - *Realization* of the notion of process

Process Concepts (4)

- Multiprogramming vs. multiprocessing
  - *Uniprogramming*
    - Only one process in memory at a time
    - Mostly old PC OS
    - Makes some parts of OS easier, but others hard
  - Multiprogramming
    - Multiple processes in memory
    - Most systems support multiprogramming
  - Multiprocessing
    - Multiple processes are running together at the same time
    - CPU is multiplexed

Process Concepts (5)

- *Design-time* entity vs. *run-time entity*
  - *System design* is an activity of
    - Accepting the *system requirements*
    - Generating a collection of *tasks*
      - Design by decomposition
  - Task is a design-time entity
  - Process is a run-time entity
    - Target of CPU scheduling and resource allocation
  - *Implementation* is
    - A mapping from design-time entities onto run-time entities

Process Control Block

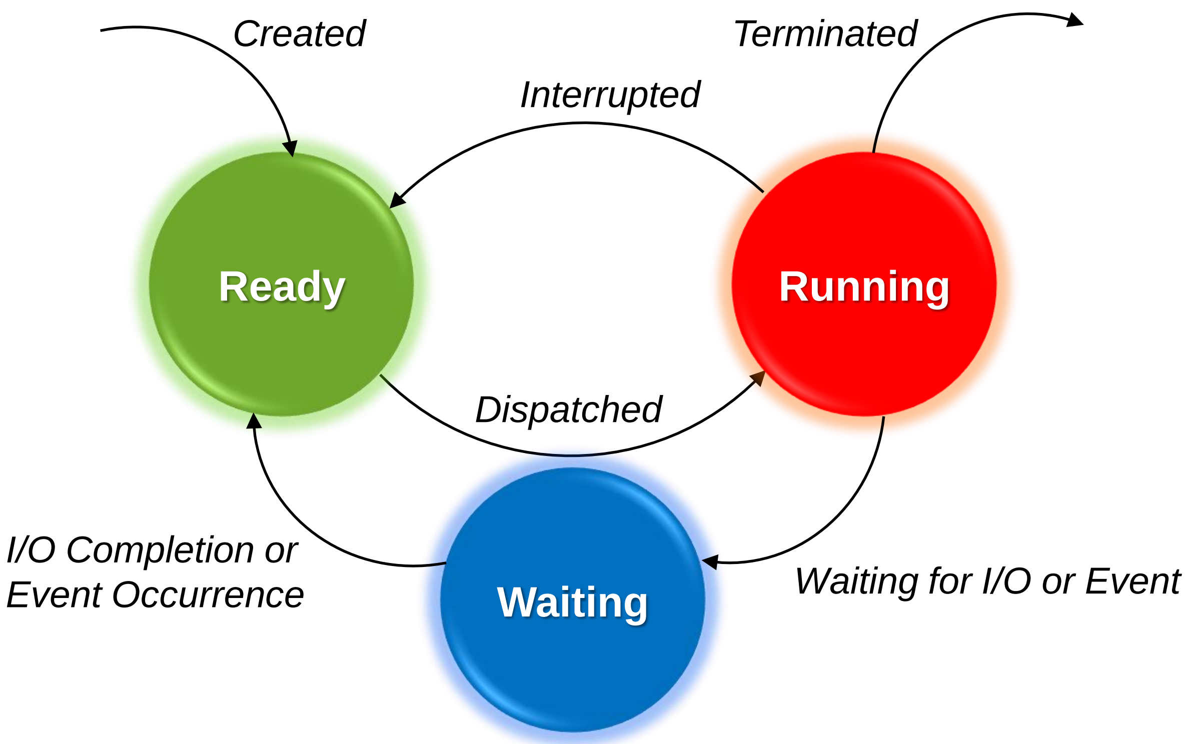
- With multiprocessing, OS must keep track of processes
  - For each process, a process control block (PCB) holds
    - Execution state (saved registers, etc.)
    - Scheduling information (priority)
    - Accounting and other misc. information (open files)
  - System-wide table of PCB
    - Process table
  - Unix
    - Fixed-size array of PCB's

State Transition (1)

- As a process executes, it changes state
  - New
    - Process is being created
  - Running
    - Instructions are being executed
  - Waiting
    - Process is waiting for some event to occur
  - Ready
    - Process is waiting to be assigned to CPU
  - Terminated
    - Process has finished execution

State Transition (2)

- State transition diagram



State Transition (3)

- State transitions and scheduling queues
  - Queues in different states
    - Ready queue
      - Set of all processes residing in main memory, ready and waiting to execute
    - Device queues (I/O waiting queues)
      - Set of processes waiting for an I/O device
  - State transition
    - Migrating processes between various queues

II. Process Scheduling

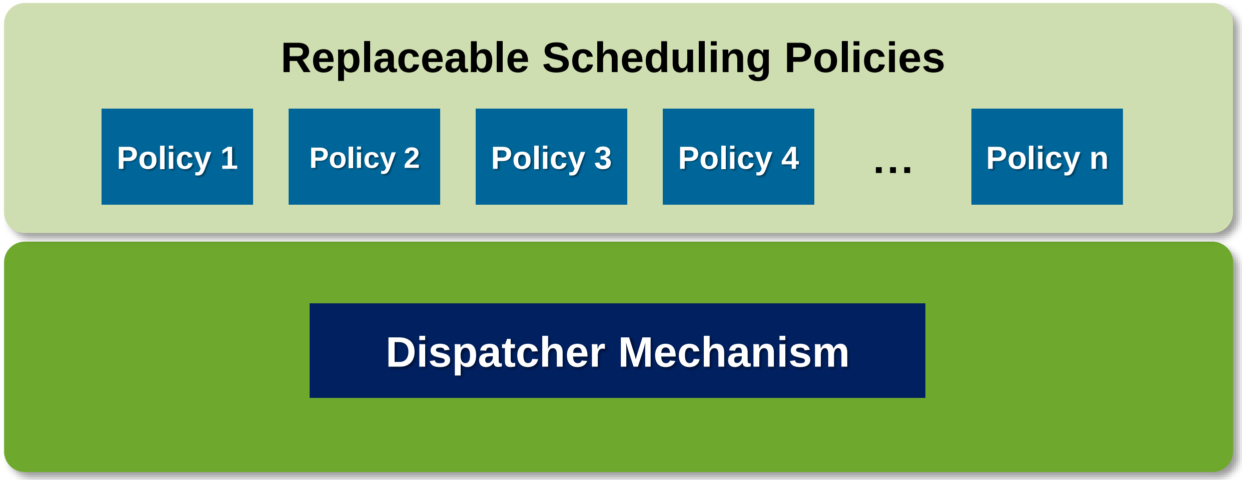
Process Scheduling

- Goal
  - For several processes to share a CPU, OS must select a process to run next

- Constraints
  - OS must offer
    - Fair scheduling
      - Make sure each process gets a chance to run
    - Protection
      - Making sure processes don't trash each other

Scheduler Design Principle

- Principle in designing system software
  - *Separation of policy and mechanism*
    - Separation of *scheduling policies* and *dispatching mechanisms*
  - Leads to two-level architecture



Dispatcher (1)

- Inner-most portion of OS that runs processes

```
loop forever
{
    run the process for a while
    stop it and save its state
    load state of another process
}
```

Dispatcher (2)

- Challenges
  1. How does the dispatcher regain control?
     - CPU can only be doing one thing at a time
     - User process running means that dispatcher isn't.
  2. Which process is executed next?
     - Need to locate runnable processes efficiently

1. Entering and Leaving the Kernel (1)

- How does the dispatcher regain control?
  - Trust the process to wake up the dispatcher
    - On a voluntary basis – "*non-preemptive*" way
    - Problem: Sometimes processes misbehave
  - Provide the dispatcher with an alarm clock
    - On a compulsory basis – "*preemptive*" way
    - Timer hardware and interrupts

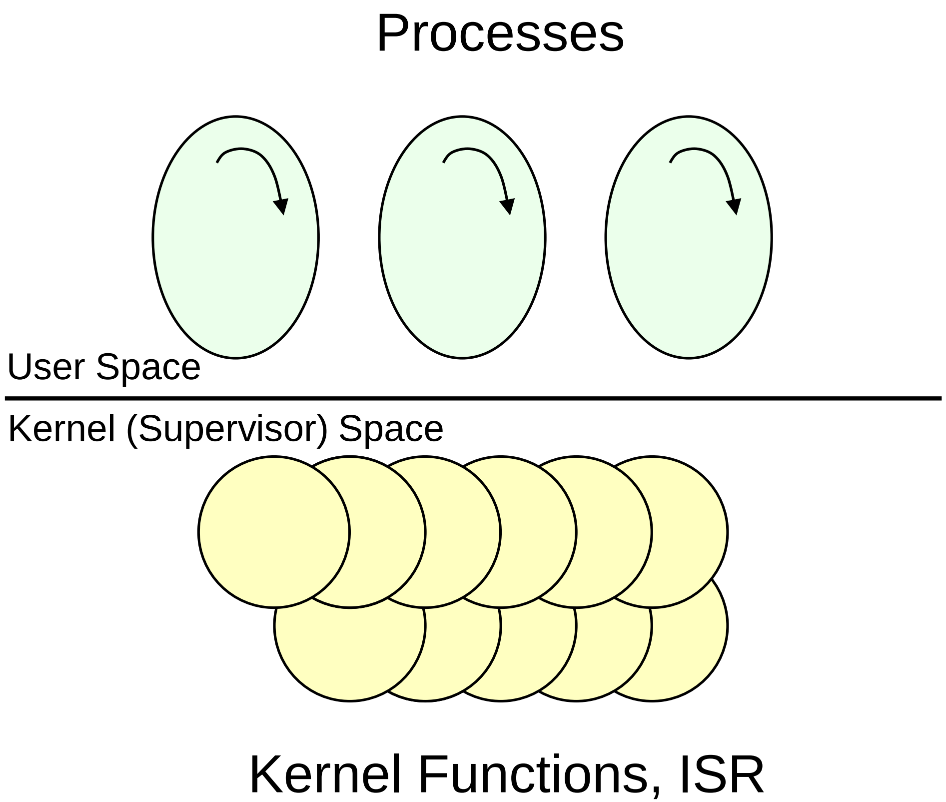
1. Entering and Leaving the Kernel (2)

- "*Misconceptions*" about the kernel
  - Like a user process, the kernel is an active and independent entity possessing a thread of control
  - The kernel is continuously monitoring user processes while they are running

- In reality
  - The kernel is a passive entity consisting of *kernel functions* and *interrupt service routines*
  - It's like a library

1. Entering and Leaving the Kernel (3)

- In reality (cont'd)
  - A *collection of functions* running in kernel space



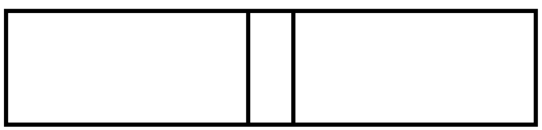
1. Entering and Leaving the Kernel (4)

- Kernel space (mode)
  - Has elevated system state compared to normal user applications
    - Protected memory space
    - Full access to the hardware
  - *Elevated system state + unrestricted memory access*
- User space (mode)
  - Has restricted system state compared to the kernel
    - A subset of the machine's available resources
    - Limited privilege
      - Unable to perform certain system functions
  - *Restricted system state + restricted memory access*

1. Entering and Leaving the Kernel (5)

- Execution modes in protected MMU machine

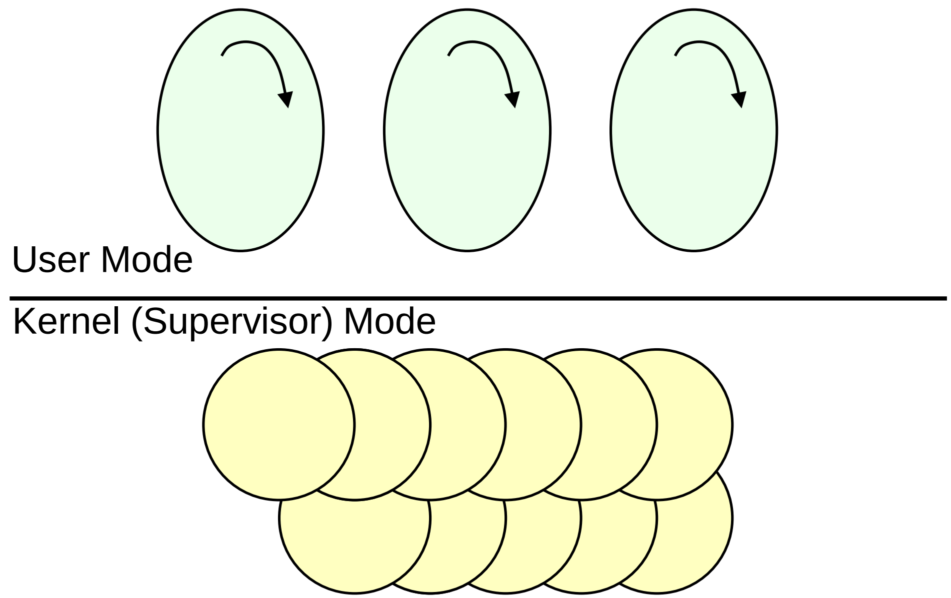
Processor Status Word (PSW)



Mode bit = 0: kernel mode

1: user mode

Processes



Kernel Functions, ISR

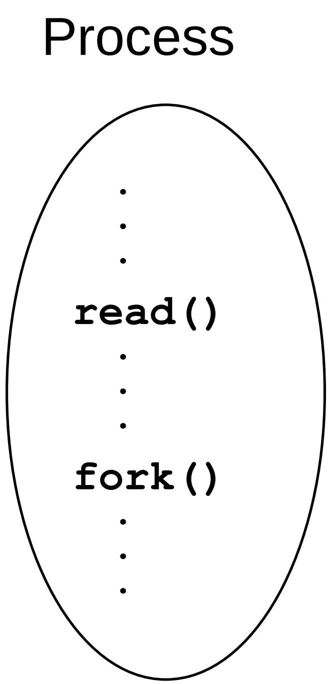
1. Entering and Leaving the Kernel (6)

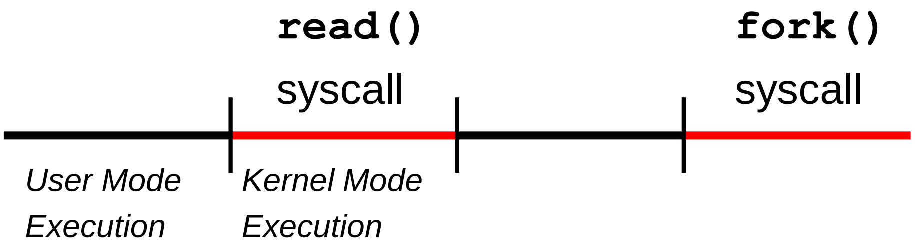
- Dispatcher is a kernel function after all

- Control returns to OS on
  - Traps: events internal to user processes
    - System calls
    - Errors (illegal instructions, address error, etc)
    - Page faults
  - Interrupts: events external from user processes
    - Character typed at a terminal
    - Completion of a disk transfer
    - Timer to make sure OS eventually gets control

1. Entering and Leaving the Kernel (7)

- Mode change of a process





1. Entering and Leaving the Kernel (8)

- *System call* vs. *function call*
  - Common properties
    - *Transfer* control to another routine
    - *Maintain* the context of the process
  - Differences
    - Syscall incurs *mode change* but function call doesn't
    - Syscall is more *expensive* than function call

2. Scheduling Policy (1)

- Once the dispatcher gets control, how to decide who's next?
  - Possibilities
    - Scan process table for first runnable process:
      - Might spend much time searching
      - Results in weird priorities: Small PIDs better
      - Question: How do you know a process is runnable?
    - Link together the runnable processes into a queue
      - Dispatcher takes from the head of the queue
      - Runnable processes are inserted at back of queue
      - Called "*ready list*" or "*run queue*"
    - Assign priorities to processes
      - Keep the queue sorted by priority
      - Separate queue per priority

2. Scheduling Policy (2)

- Who decides priorities and how are priorities chosen?
  - Who?
    - Separate part of OS: the scheduler
  - Question: Why not by the dispatcher?
    - Concept: Separation of policy and mechanism
  - How? Subject of the next topic

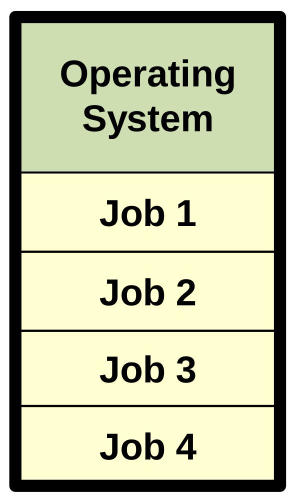
III. Context Switching

Context Switching (1)

- How does the dispatcher save and restore state?
  - Mechanism: "*context switch*"
- What must get saved?
  - Everything that next process could or will damage:
    - Program counter
    - Processor status word (condition codes, etc.)
    - General purpose registers, floating-point registers
    - All of memory?
      - Swapping
        - Memory could be large so saving it could be expensive

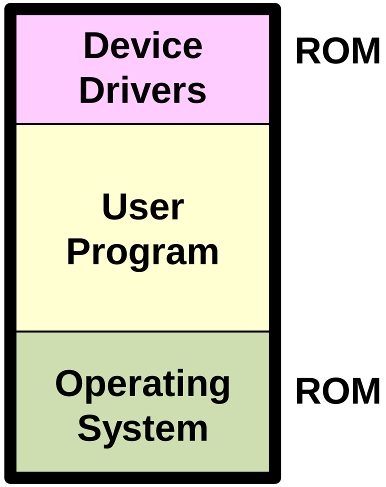
Context Switching (2)

- What must get saved? (cont'd)
  - Possibilities:
    1. Don't save memory at all
       - No dynamic memory management
         - Memory is allocated to entire batch
       - Old batch processing system: multiprogrammed batch monitor
       - Context switching in multithreaded process



Context Switching (3)

- What must get saved? (cont'd)
  - Possibilities: (cont'd)
    2. Save all memory to disk (roll-in/roll-out swapping)
       - Bringing in each process entirely, running it and then putting it back on the disk, so that another program may be loaded into that space
       - Early personal computer/workstation: DOS
       - Effective but very slow



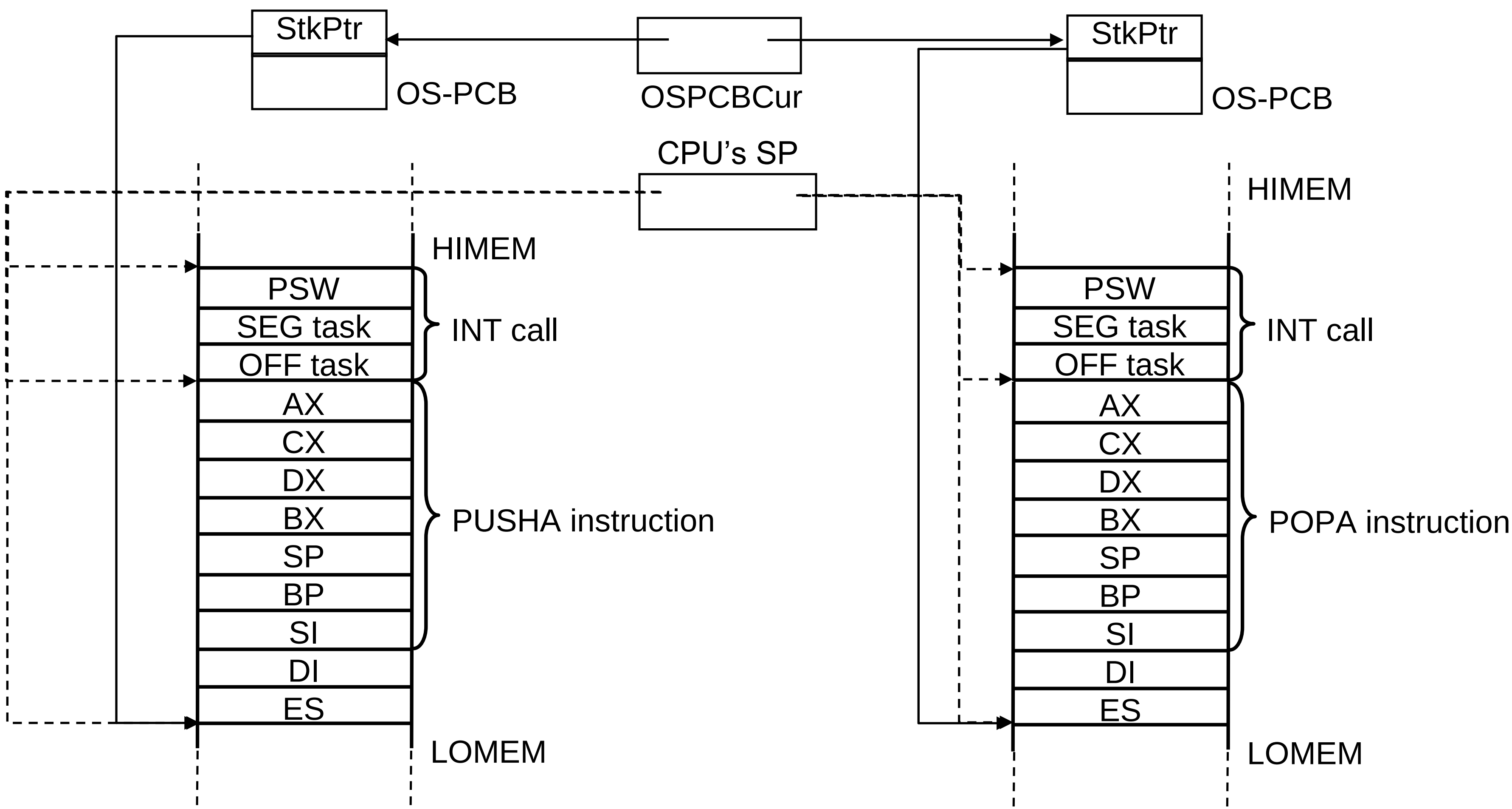
Context Switching (4)

- What must get saved? (cont'd)
  - Possibilities: (cont'd)
    3. Save some part memory to disk (swapping)
       - Moving memory blocks of process between RAM and disk
         - Swap file, swap device
       - Implemented with memory complex management mechanisms
       - Used in most of the modern OSes
         - Unix or Unix-like systems: Linux, OS X

Implementation

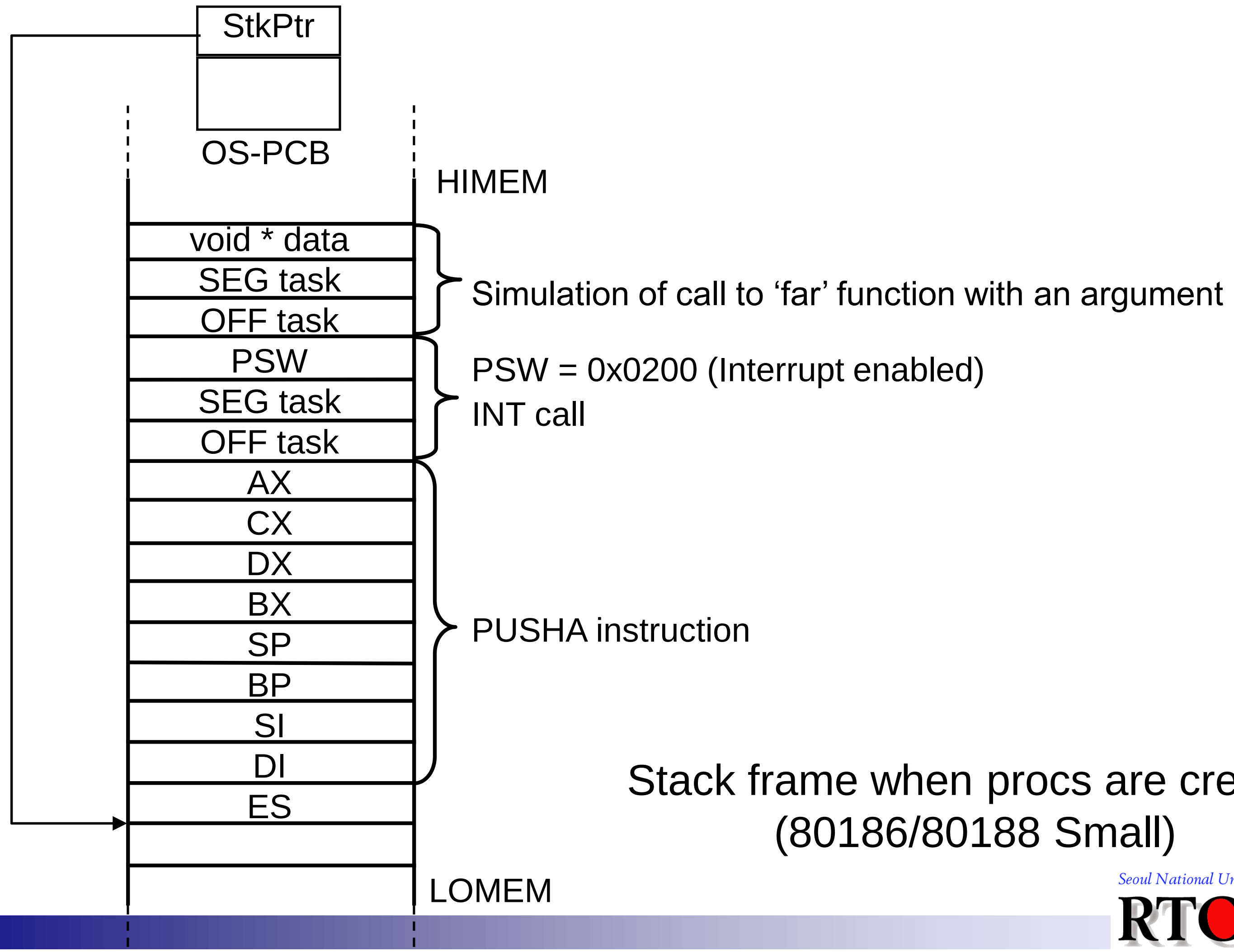
- Machine dependent
  - Different for MIPS, SPARC, x86, etc.
- Tricky
  - OS must execute code to save state without changing the process' state
- Requires some special hardware support
  - Example: "*Save PC and PSR on trap or interrupt*"

Mechanism (1)



Stack frames during a context Switch (80186/80188 Small)

Mechanism (2)



Stack frame when procs are created
(80186/80188 Small)

IV. Process Creation and Termination

Process Creation (1)

- Creating new processes in a full-fledged OS
  - Build one from scratch (Ex: Unix Process 0)
  - Clone an existing one (Ex: Unix **`fork()`** syscall)

Process Creation (2)

- From scratch
  1. Load code and data into memory
  2. Create (empty) call stack
  3. Create and initialize a process control block
  4. Put the process on ready list

  - Intuitive and natural – This is what Windows OS does

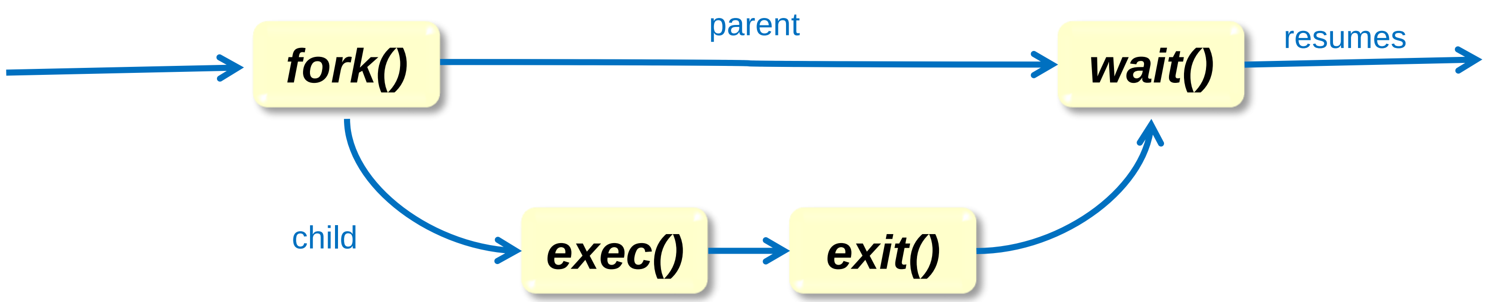
Process Creation (3)

- Cloning
  1. Stop the current process and save its state
  2. Create a new one by making a copy of code, data, stack, and PCB
  3. Put the new process on ready list

  - Not quite right – What's missing?
    - Process creation in Unix with **`fork()`** and **`exec()`**

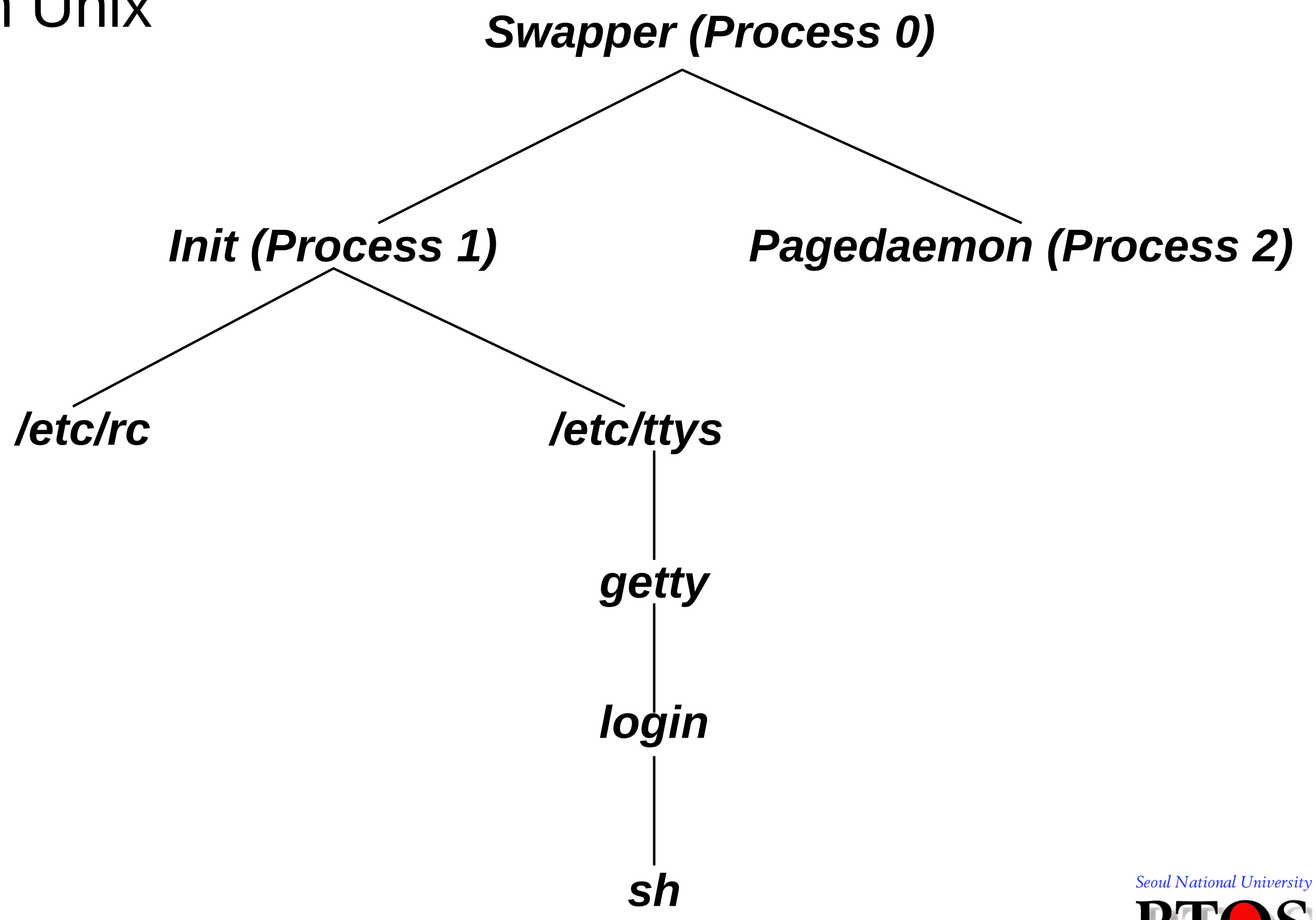
Process Creation (4)

- Process life cycle in Unix



Process Creation (5)

- In Unix



Process Creation (6)

- Shell example

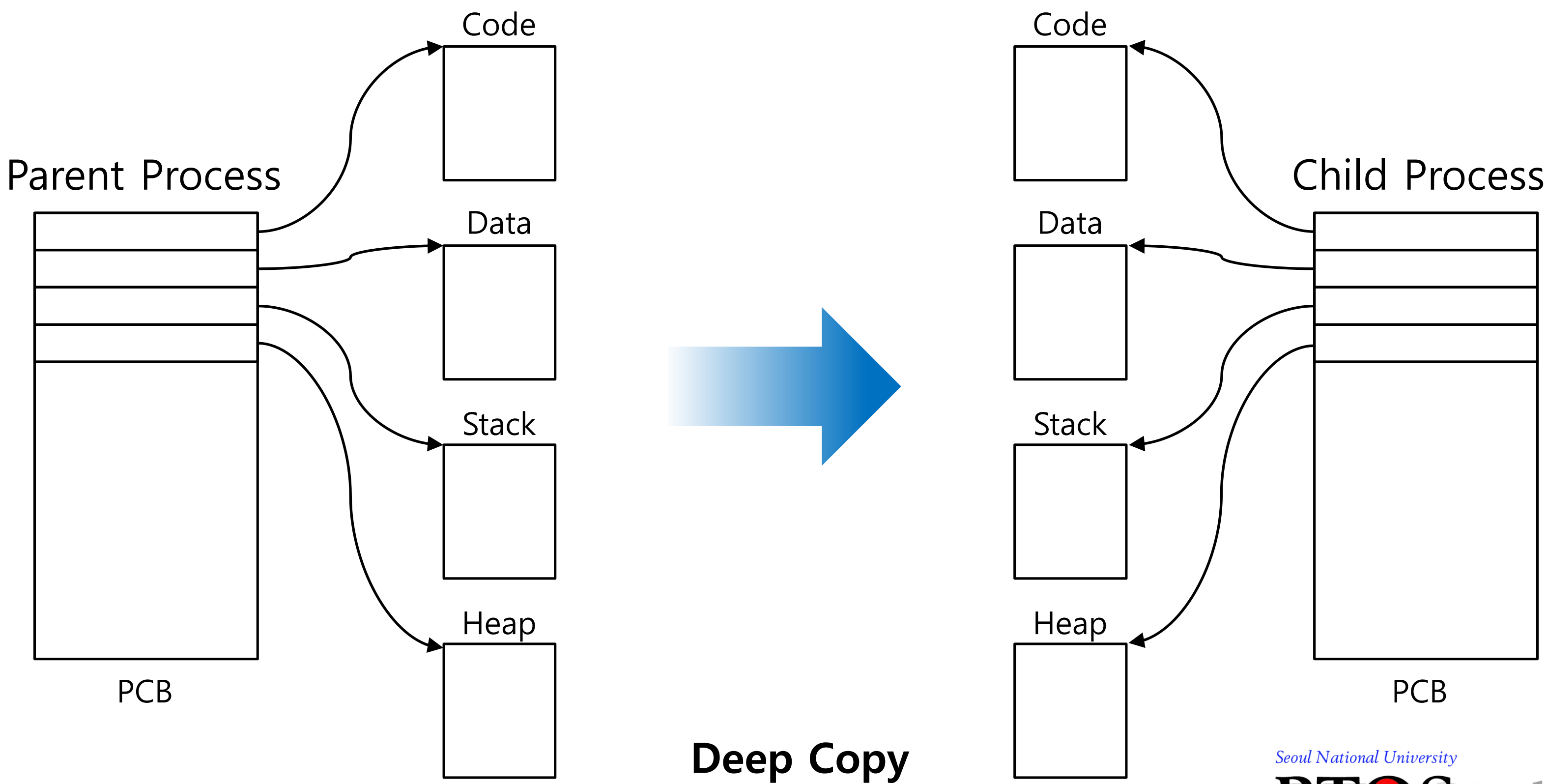
```
for(;;) {
    cmd = readcmd();
    pid = fork();
    if(pid < 0){
      perror("fork failed");
      exit(-1);
    } else if(pid == 0) {
      // Child - Setup environment
      if(exec(cmd) < 0) perror("exec failed");
      exit(-1); // Exit on exec failure
    } else {
      // Parent - Wait for command to finish
      wait(pid);
    }
 }
```

Process Creation (7)

- Questions surrounding the **`fork()`** mechanism
  1. What were the drawbacks of the original **`fork()`**?
  2. Why did early Unix adopt it after all?
  3. Why is it still used in Linux?

Process Creation (8)

1. What were the drawbacks of the original `fork()`?
   - *Deep copy*-based cloning was simply too expensive



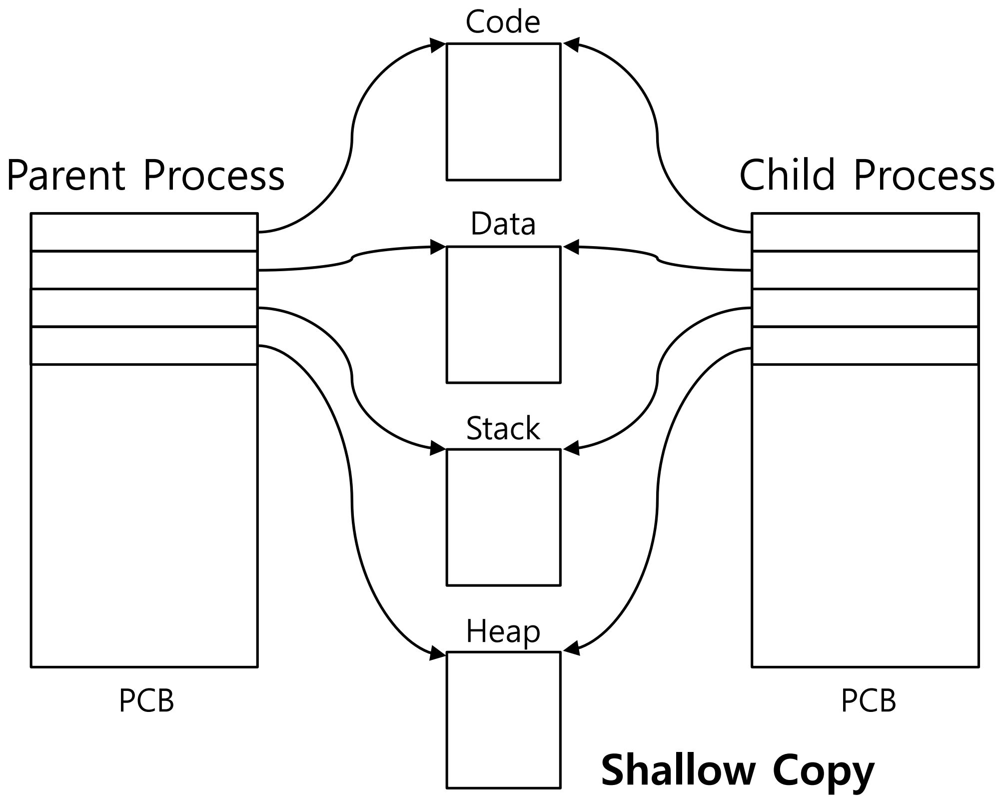
Process Creation (9)

2. Why did early Unix adopt **`fork()`** after all?
   - Due to the lack of inter-process communication mechanisms

```
ipc_proc()
{
    fd = open("./fifo_pipe", O_RDWR);

    pid = fork();
    if(pid > 0){
      // Parent - write data to the pipe
      write(fd, data, size);
    } else if(pid == 0) {
      // Child - read data from the pipe
      read(fd, data, size);
    }
}
```

Process Creation (10)

3. Why is it still used in Linux?
   - Thanks to *shallow copy* and *copy-on-write* (COW)



Process Termination

- Process executes last statement and asks the OS to decide it (**`exit()`**)
  - Outputs data from child to parent (via **`wait()`**)
  - Deallocates process' resources
- Parent may terminate execution of children processes (**`abort()`**)
  - Child has exceeded allocated resources
  - Task assigned to child is no longer required
  - Parent is exiting
    - OS does not allow child to continue if its parent terminates
    - Cascading termination

V. Multithreading

Traditional Process Model

- Two characteristics in one process
  - Unit of *resource ownership*
    - Assigned virtual address space to hold the process image
    - Has the control of some resources (files, I/O devices, ...)
  - Unit of *dispatching*
    - Has a thread of control
    - Has execution state and dispatching priority
      - Process execution may be interleaved with other processes

- *How about separating the two*?

Multithreaded Process Model

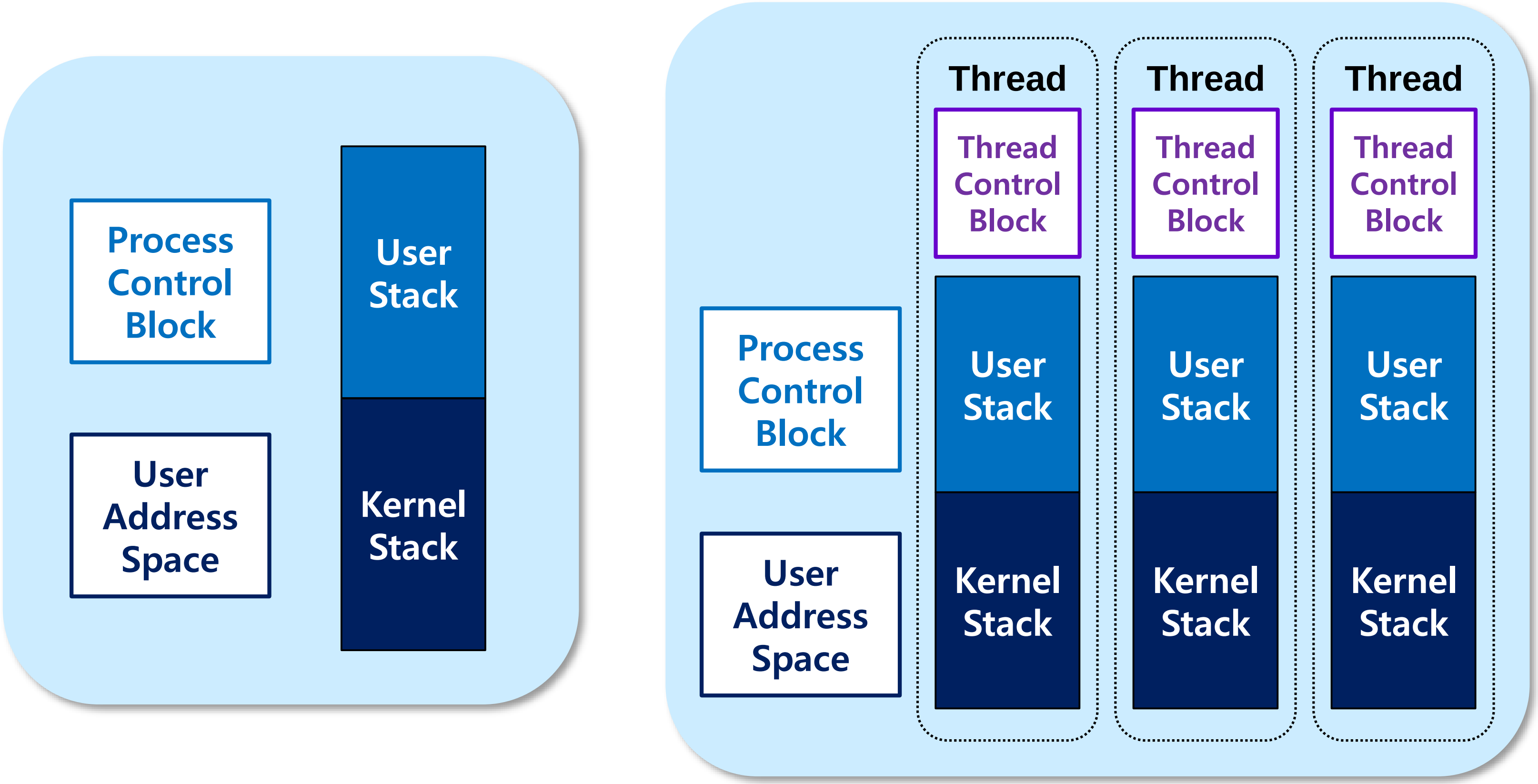
- Most modern OSes treat these two characteristics independently
  - Unit of resource ownership is usually referred to as "*process*" or "*task*"
  - Unit of dispatching is usually referred to as "*thread*" or "*lightweight process*"

Multithreading: Basics (1)

- Characteristics of threads
  - Has an execution state (running, ready, stopped)
    - Saves thread context when not running
  - Has a *runtime stack* for local variables and some *per-thread static memory*
  - Has access to the memory address space and resources of its process
    - All threads of a process share these
    - When one thread alters a (non-private) memory item, all other threads (of the process) see that
    - A file opened by a thread is available to others

Multithreading: Basics (2)

- Single threading vs. multithreading



Multithreading: Basics (3)

- Various thread supports in OS
  - MS-DOS
    - Supports a single user process and a single thread
  - Old Unix
    - Supports multiple user processes
      but only supports one thread per process
  - Solaris
    - Supports multiple user processes possessing multiple threads

Multithreading: Basics (4)

- State transition of threads
  - Three key states
    - Running, ready, blocked
  - They have no *suspended* (i.e., swapped-out) state
    - All threads of the same process share the same address space
    - Suspending a single thread involves suspending all threads in the same address space
  - Termination of a process terminates all threads within the process

Why Multithreading? (1)

- Effective concurrent programming (original goal)
  - Straightforward mapping from threads onto multiprocessors
- Resource sharing
  - Can pass data via shared memory
    - No need for IPC
    - Need to synchronize the activities of various threads so that they do not obtain inconsistent views of the data

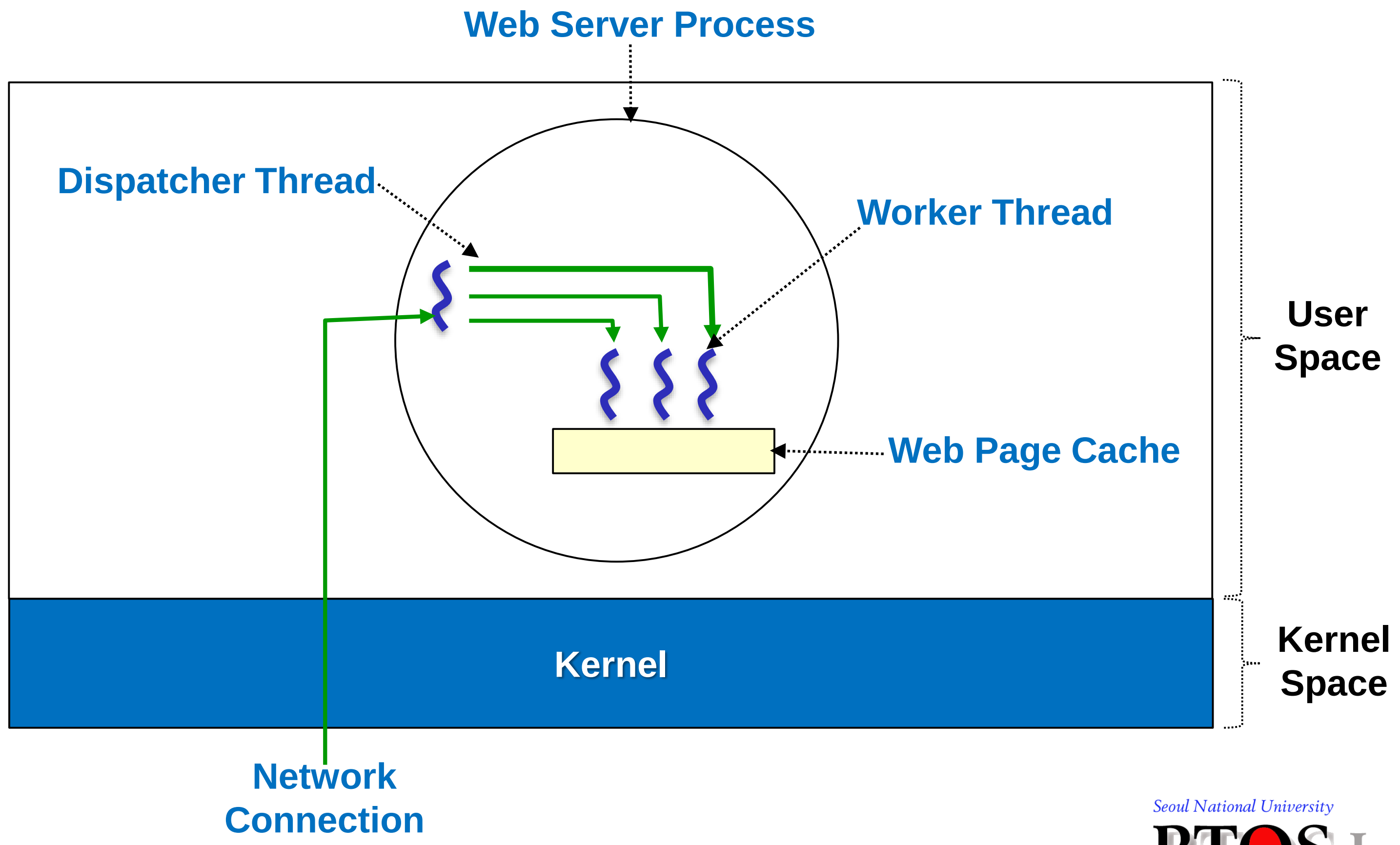
Why Multithreading? (2)

- Economy – cheap to implement
  - Takes less time
    - To create a new thread than a process
    - To terminate a thread than a process
    - To switch between two threads within the same process
  - Uses very little resource
    - Only stack and per-thread static memory

- Agility in responses (good for reactive systems)
  - *Concurrent server* architecture for interactive applications
    - A process has one server thread and multiple worker threads
      - Even if one worker blocks, possibly on a read, others still continue executing and produce outputs to users

Why Multithreading? (3)

- Multithreading fits for concurrent server architecture



Why Multithreading? (4)

- Pseudocode for concurrent server architecture

```
while (TURE){
    get_next_request(&buf);
    dispatch_work(&buf);
}
```

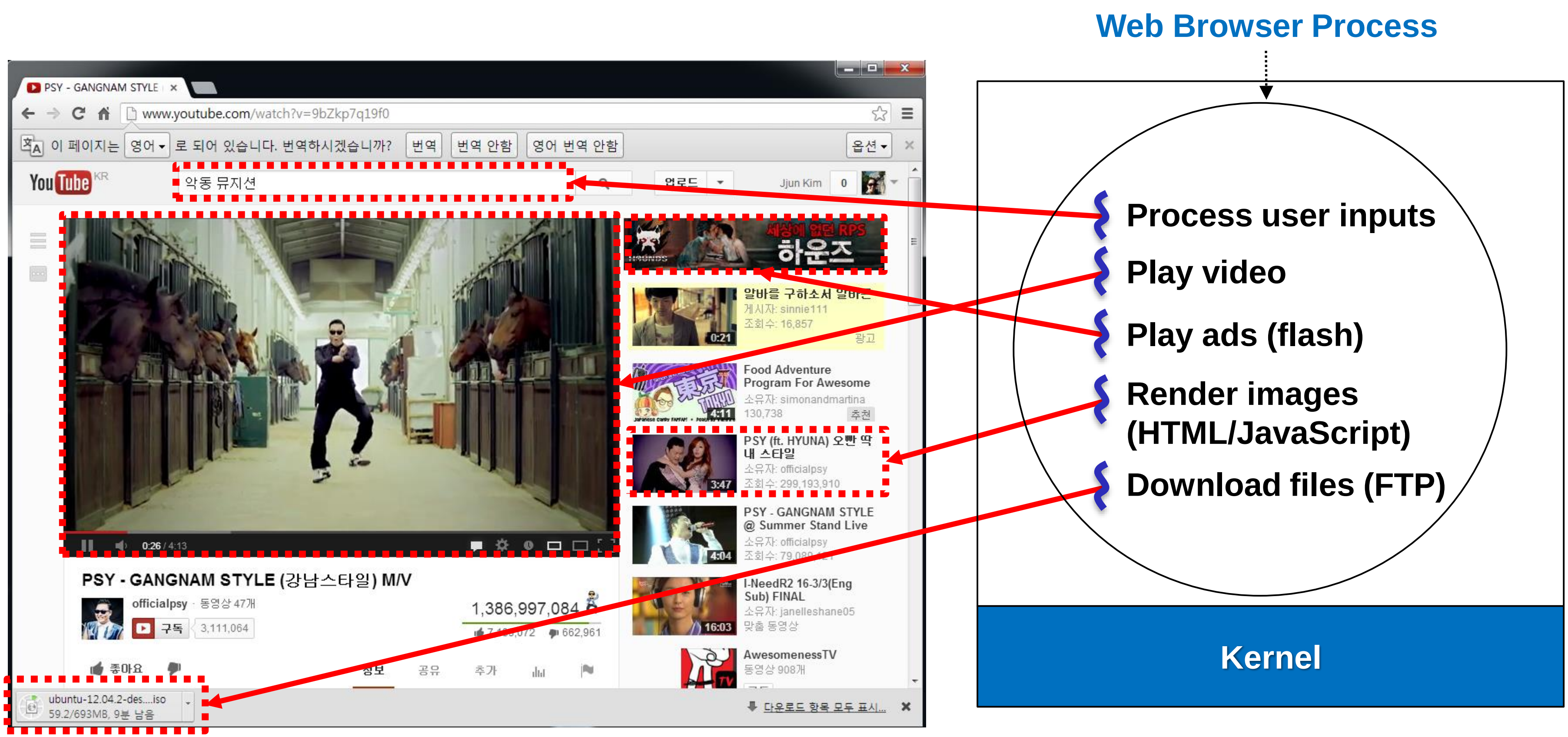
Dispatcher Thread

```
while (TURE){
    wait_for_work(&buf)
    look_for_page_in_cache(&buf, &page);
    if(page_not_in_cache(&page))
        read_page_from_disk(&buf, &page);
    return_page(&page);
}
```

Worker Thread

Why Multithreading? (5)

- Multithreaded Web browser



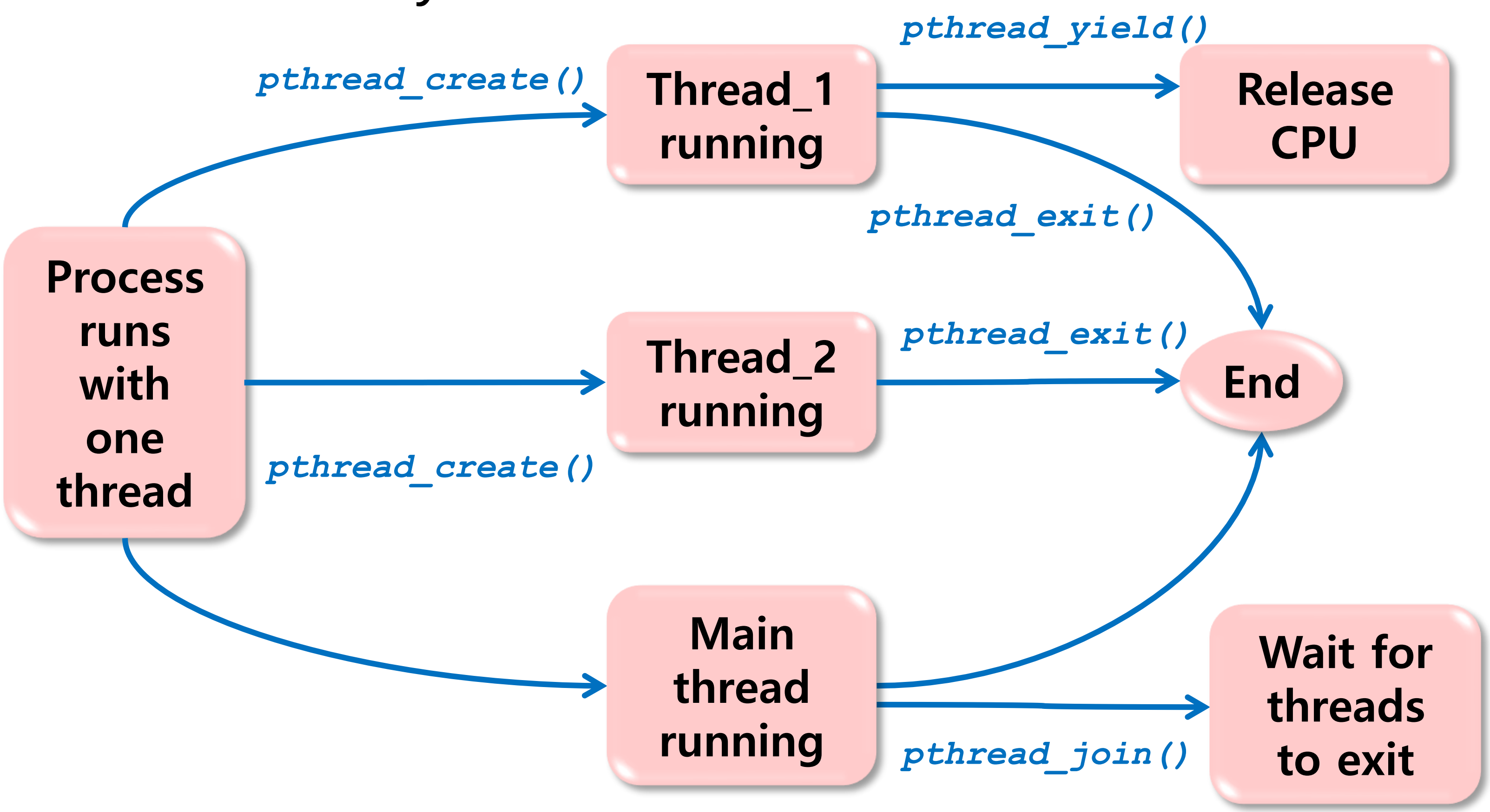
Pthreads Programming Model (1)

- Pthreads: POSIX standard for threads
  - Defines API for creating and manipulating threads
  - Implementations of the API are available on many Unix-like OSes such as Linux and Mac OS X
- Selected Pthreads functions

Pthreads API	Description
`pthread_create()`	Create a new thread
`pthread_exit()`	Terminate the calling thread
`pthread_join()`	Wait for a specific thread to exit
`pthread_yield()`	Release CPU to let another thread run

Pthreads Programming Model (2)

- Thread life cycle



Pthreads Programming Model (3)

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

#define NUM_THREADS     5

void *ThreadCode(void *argument)
{
   int tid;

   tid = *((int *)argument);
   printf("Hello World! It's me, thread %d!\n", tid);

   /* optionally: insert more useful stuff here */

   return NULL;
}
```

Source: http://en.wikipedia.org/wiki/POSIX_Threads

Pthreads Programming Model (4)

```
int main(void)
{
   pthread_t threads[NUM_THREADS];
   int thread_args[NUM_THREADS];
   int rc, i;

    /* create all threads */
   for (i=0; i<NUM_THREADS; ++i) {
      thread_args[i] = i;
      printf("In main: creating thread %d\n", i);
      rc = pthread_create(&threads[i], NULL, ThreadCode, (void *)&thread_args[i]);
      assert(0 == rc);
   }
    /* wait for all threads to complete */
   for (i=0; i<NUM_THREADS; ++i) {
      rc = pthread_join(threads[i], NULL);
      assert(0 == rc);
   }
   exit(EXIT_SUCCESS);
}
```

Source: http://en.wikipedia.org/wiki/POSIX_Threads

Pthreads Programming Model (5)

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

__thread int TLS_data;
int normal_data;

void *thread(void *param)
{
    int *data;

    data = (int *)param;
    TLS_data = *data;
    normal_data = *data;
    if (*data == 0) usleep(100000);

    printf("Thread %d, TLS_data %d, normal_data %d\n",
                            *data, TLS_data, normal_data);
}
```

Pthreads Programming Model (6)

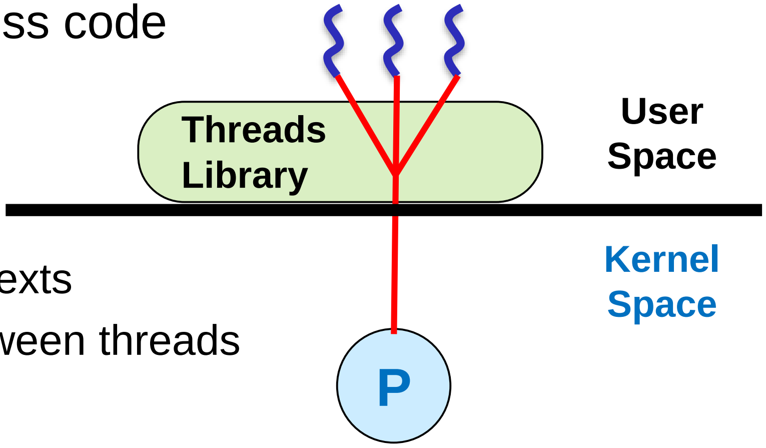
```
int main()
{
    pthread_t tcb[3];
    int thread_args[3];
    int i;

    for (i = 0; i < 3; i++)
    {
        thread_args[i] = i;
        pthread_create(&tcb[i], NULL, thread, (void *)&thread_args[i]);
    }

    for (i = 0; i < 3; i++)
    {
        pthread_join(tcb[i], NULL);
    }

    return 0;
}
```

Pthreads Programming Model (7)

```
sshong@ubuntu:~$ gcc tls.c -lpthread
sshong@ubuntu:~$ a.out
Thread 2, TLS_data 2, normal_data 2
Thread 1, TLS_data 1, normal_data 1
Thread 0, TLS_data 0, normal_data 1
```

Threads Implementation: User-Level Threads (1)

- Key entities
  - Thread:
    - 100% use-level entity
    - Kernel is not aware of the existence of threads
  - Threads library
    - User-level library linked to process code
    - Contains code for
      - Creating and destroying threads
      - Scheduling thread execution
      - Saving and restoring thread contexts
      - Passing messages and data between threads
  - Processor
    - Allocation on a process basis



Threads Implementation: User-Level Threads (2)

- Characteristics
  - Application does all the thread management via threads library
    - Thread switching does not require kernel mode privileges
    - Scheduling is application-specific
  - Kernel activities
    - Kernel is not aware of thread activity but still manages process activity
    - When a thread makes a blocking system call
      - The whole process will be blocked
      - For the thread library, that thread is still in the running state
    - Implication:
      - *Thread states are independent of process states*

Threads Implementation: User-Level Thread (3)

- Pros and cons of ULT

Advantages

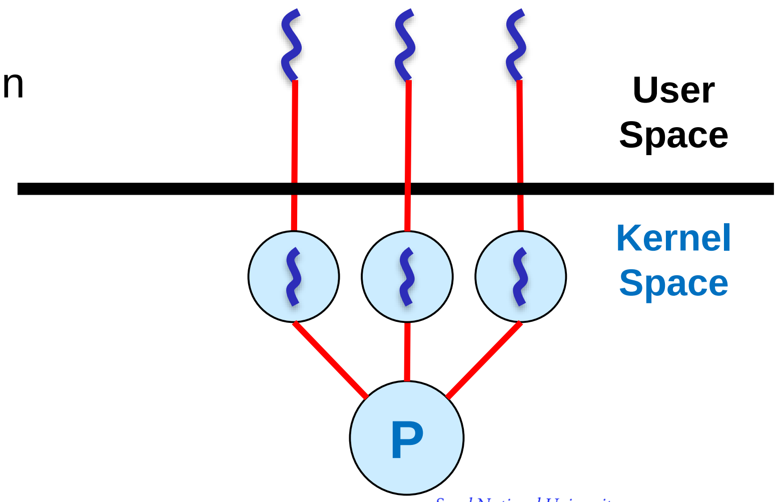
- Thread switching does not involve the kernel - no mode switching
- Scheduling can be application specific - can choose the best algorithm
- ULTs can run on any OS: only needs a thread library

Inconveniences

- Most system calls are blocking and the kernel blocks the process: all threads within the process will be blocked
- Kernel can only assign processes to processors: two threads within the same process cannot run simultaneously on two processors

Threads Implementation: Kernel-Level Threads (1)

- Key entities
  - Thread:
    - Both user-level and kernel-level entity
      - 1-to-1 mapping between user-level and kernel level thread
    - The kernel is completely aware of the existence of threads
  - System call API and kernel functions for thread facility
    - Code for
      - Maintaining context information for processes and threads
      - Switching between threads
      - Scheduling threads
      - Synchronization
  - Processor
    - Allocation on a thread basis



Threads Implementation: Kernel-Level Threads (2)

- Characteristics
  - No thread library but API to the kernel thread facility
    - Need kernel modification
  - Scheduling on a thread basis
    - Kernel-level threads are scheduling entities
  - Ex: Windows NT and OS/2

Threads Implementation: Kernel-Level Threads (3)

- Pros and cons of KLT

Advantages

- Kernel can simultaneously schedule many threads of the same process on many processors
- Blocking is done on a thread level
- Kernel routines can be multithreaded

Inconveniences

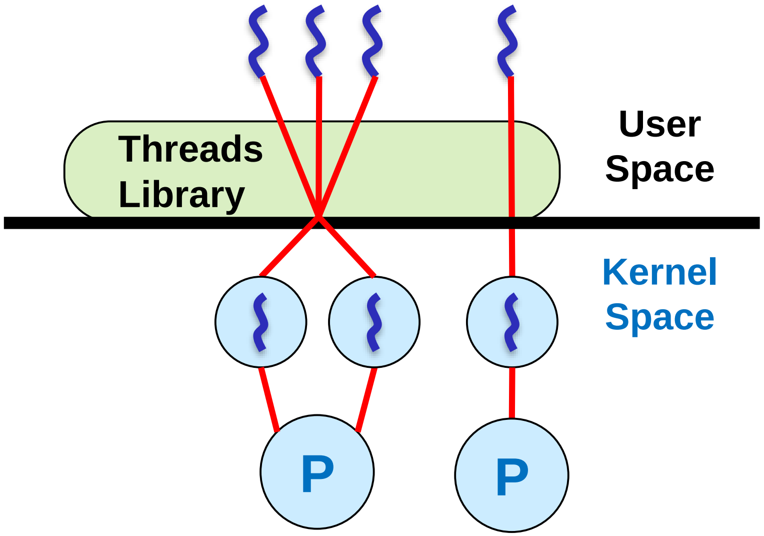
- Thread switching within the same process involves the kernel: we have two mode switches per thread switch
- This results in a significant slowdown

Threads Implementation: Combined UL/KL Threads (1)

- Key entities
  - User-level thread
    - The kernel is mostly unaware of the existence of threads
  - Kernel-level thread
    - Serves as virtual processor to user-level threads
    - Schedulable entity
  - Threads library
    - Contains code for
      - Creating/destroying user-level threads
      - Scheduling thread execution
      - Saving and restoring thread contexts
      - Passing messages and data between threads

Threads Implementation: Combined UL/KL Threads (2)

- Key entities (cont'd)
  - System call API and kernel functions for thread facility
    - Code for
      - Creating/destroying kernel-level threads
      - Mapping/unmapping between user-level and kernel level threads
      - Maintaining context information for processes and threads
      - Switching between threads
      - Scheduling threads
  - Processor
    - Allocation on a thread basis



Threads Implementation: Combined UL/KL Threads (3)

- Characteristics
  - Thread creation done in user space
  - User-level scheduling for sharing kernel-level threads
  - Kernel-level scheduling on a thread basis
  - Synchronization of threads done in user space
  - Programmer may adjust the number of KLTs
  - May combine the best of both approaches
  - Ex: Solaris