Chapter 4: Multithreaded Programming

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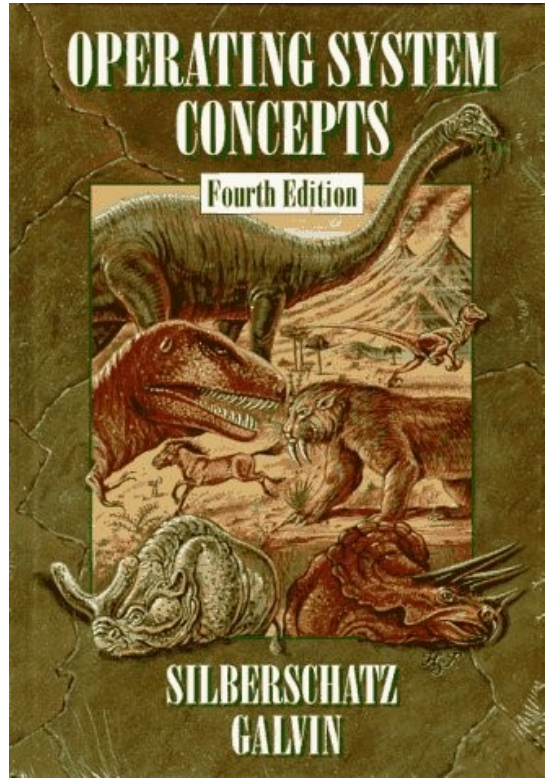


Chapter 4: Multithreaded Programming

- Overview
- Benefits of Multithreading
- Multithreading Models
- Thread Libraries
- Process vs. Thread

Objectives

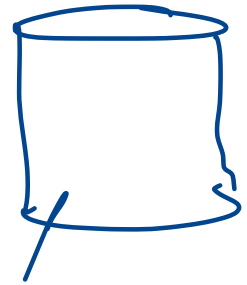
쓰레드 → 기본적 단위

- To introduce the notion of a **thread**—a fundamental unit of **CPU utilization** that forms the basis of multithreaded computer systems

- To discuss the APIs for the Pthreads and Java thread libraries

Multi-Process (Multi-tasking)

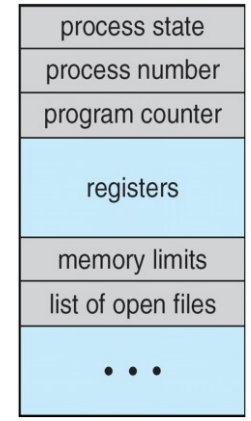
- User opens the same program two times
  - e.g., opens two web browsers, opens two Word files, Web server executes similar tasks for each user
- The two programs will be
  - executing **same code**,
  - may want to **share data**

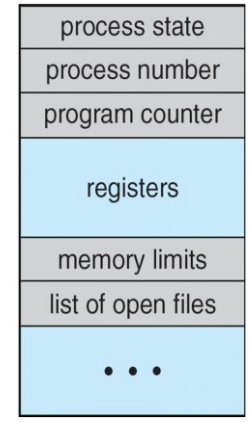


같은 프로그램이 같은 코드, 같은 데이터를 사용할 경우...!

Multi-Process (Multi-tasking)

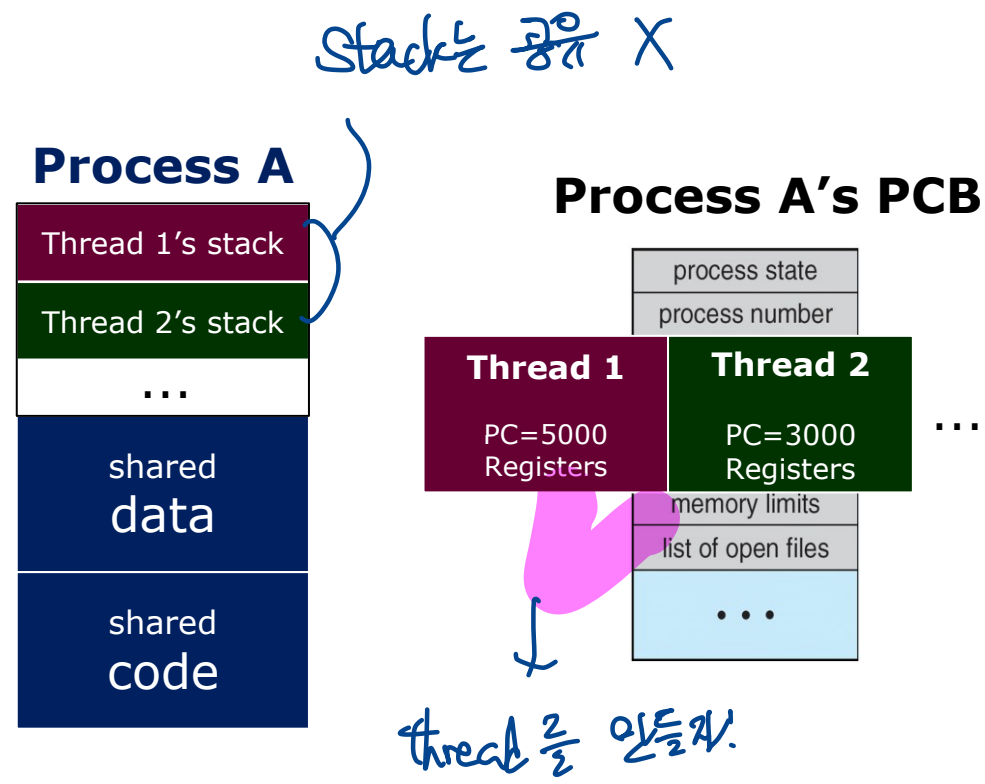
- Processes are not very efficient
  - Each process has its own PCB and OS resources
- Processes don't (directly) share memory
  - Each process has its own address space
  - Need IPC (shared memory, message passing)
- Can make it more efficient by **sharing**?





What can we do? Let us share...

- What can we **share** across all of these processes?
  - Same code: generally running the same or similar programs
  - Same data
- What is private to each process? (i.e., what can we **not share**?)
  - Execution context: CPU registers, stack, and program counter (PC)

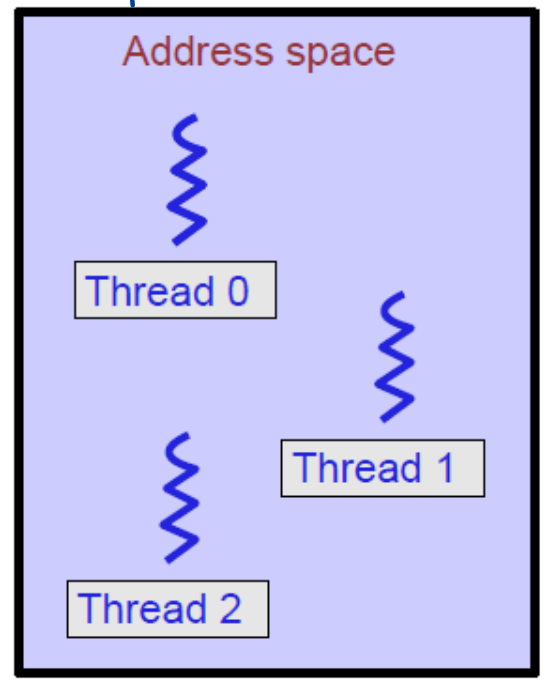


CPU register, stack, program comter

→ NOT SHARE!

Processes and Threads

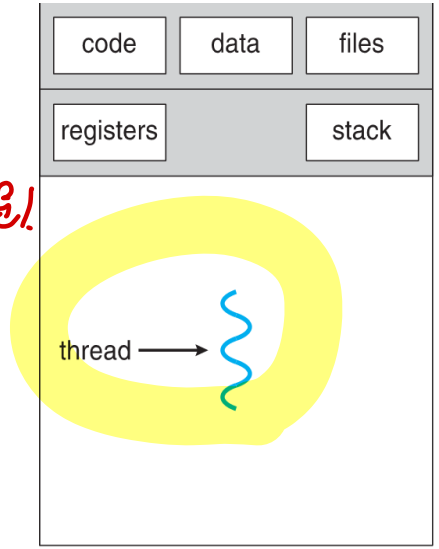
- **Thread**?
  - A thread (or lightweight process) is a basic unit of **CPU scheduling**
  - A process is just a "container" for its threads
  - Each thread is bound to its containing process
- Each thread has its own (**not share**)
  - **stack, CPU registers, PC**
- All threads within a process **share** memory space
  - **text, data, and OS resources**
  - **Threads in same process** can communicate directly via shared memory (no need for IPC)



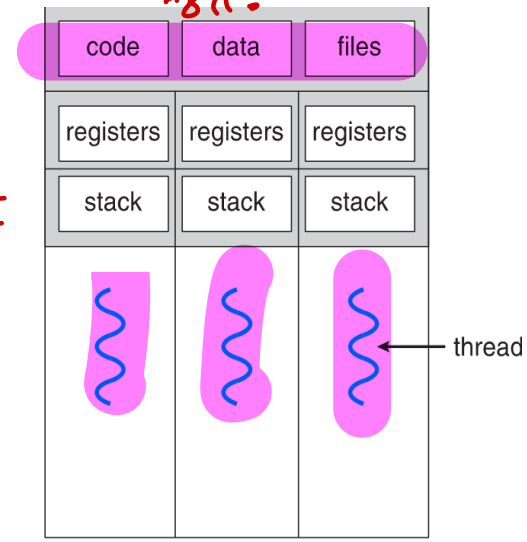
Process

Single-threaded vs. Multi-threaded Process

- Simple programs can have one thread per process
  - ***single-threaded*** *process*
- Complex programs can have multiple threads
  - ***multi-threaded*** *process*
  - Multiple threads running in same process's address space



single-threaded process



multithreaded process

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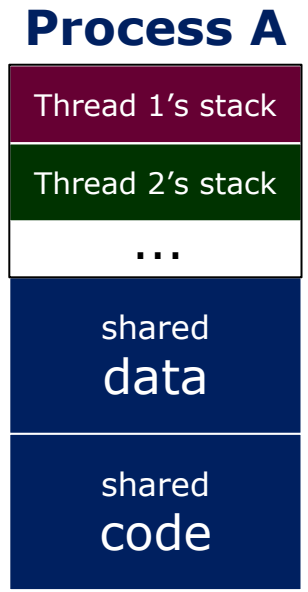
Benefits of Multithread

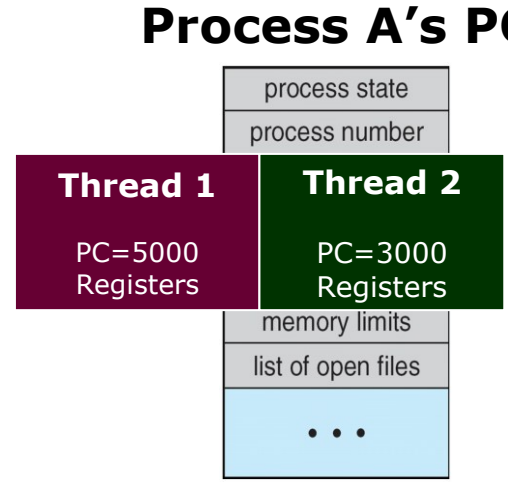
- **Resource Sharing**
  - All threads in one process share memory resources (code, data) of process
  - easier to share than IPC

IPC보다 공유하기 쉽다

- **Lighter weight**
  - lighter weight than process
    - creation/deletion, context-switching faster
  - Easier to create/delete 10 threads than 10 processes

프로세스를 만드는 것보다 Thread를 만드는 것이 훨씬 효율적이다

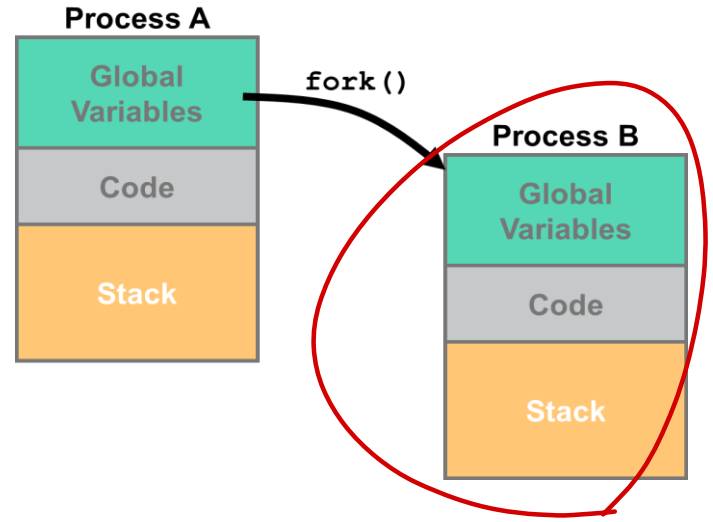




Thread vs. Process creation

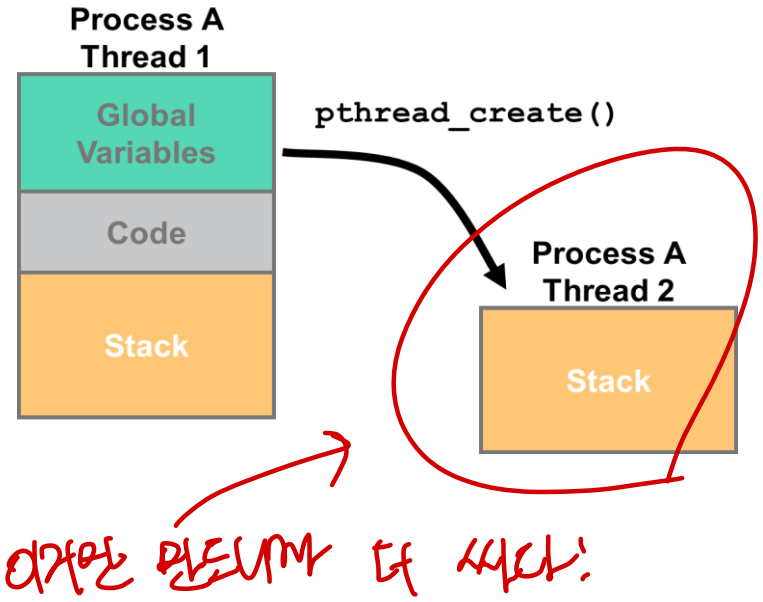
Creation of a new process using *fork()* is *expensive* (time & memory).

Need new PCB



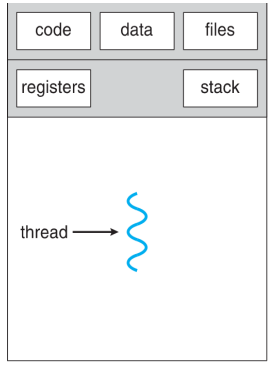
A thread creation using pthread_create() does ***not*** require a lot of memory or startup time.

No need for new PCB

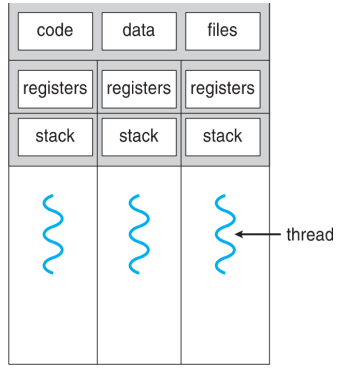


Benefits of Multithread

- **Non-blocking System Call (Responsiveness)**
  - may allow continued execution if part of **process** is blocked
    - why blocked? – time consuming operation (e.g., I/O such as printing, network)
    - single-threaded process: **wait** until I/O operation is complete
    - multithreaded process: one thread must wait, but another thread in same process can continue



single-threaded process



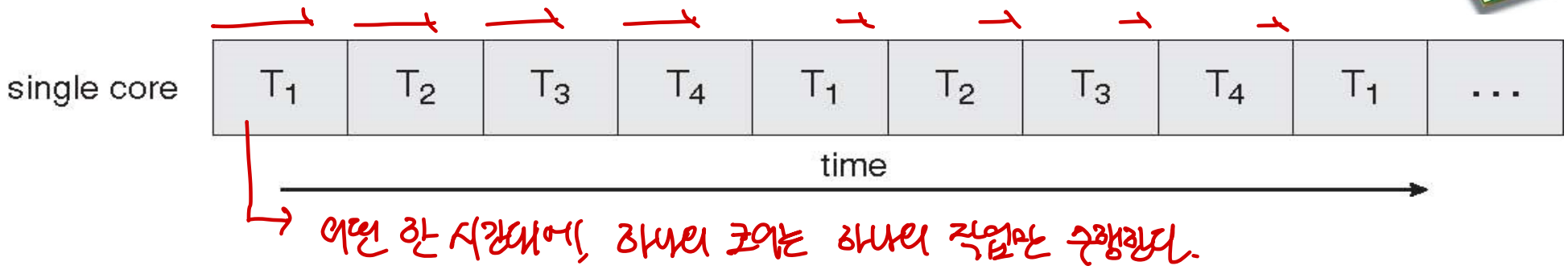
multithreaded process

Single ?

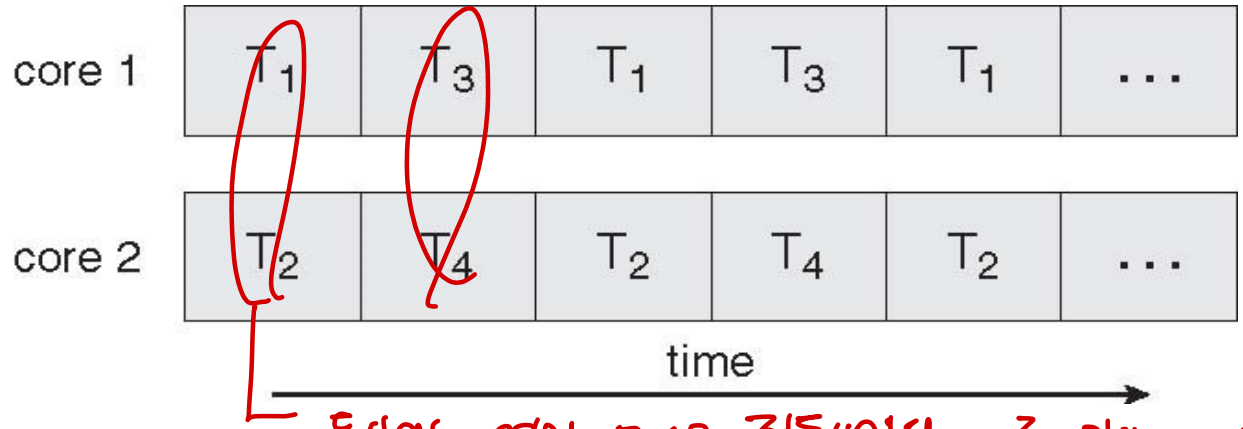
프로세스 속 thread 중 하나가 waiting / blocking 상태일 때, process 자체가 멈추게 된다. 그래서 multi thread 사용시, 기존에 사용하고 있던 나머지 thread 들은 멈추지 않고 계속 일을 할 수 있게 된다

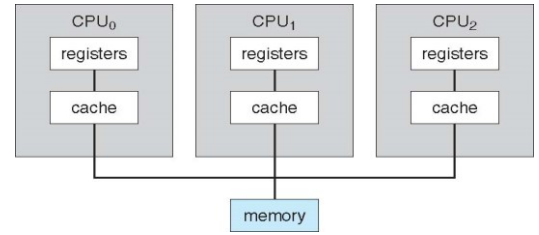
Benefits of Multithreading: Multicore Programming

- ***Concurrent*** Execution on a Single-core System



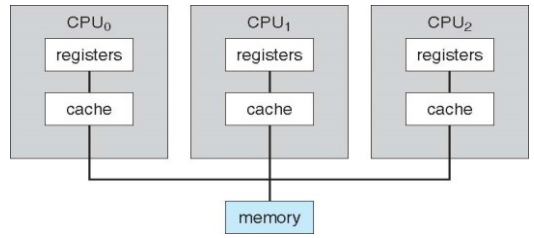
- ***Parallel*** Execution on a Multicore System





Multicore Programming

- Multicore Programming provides parallelism!
  - ***Concurrency*** supports more than one task making progress – *Single-core* processor can provide concurrency
  - ***Parallelism*** implies a system can perform more than one task simultaneously – Need *Multi-core* processor



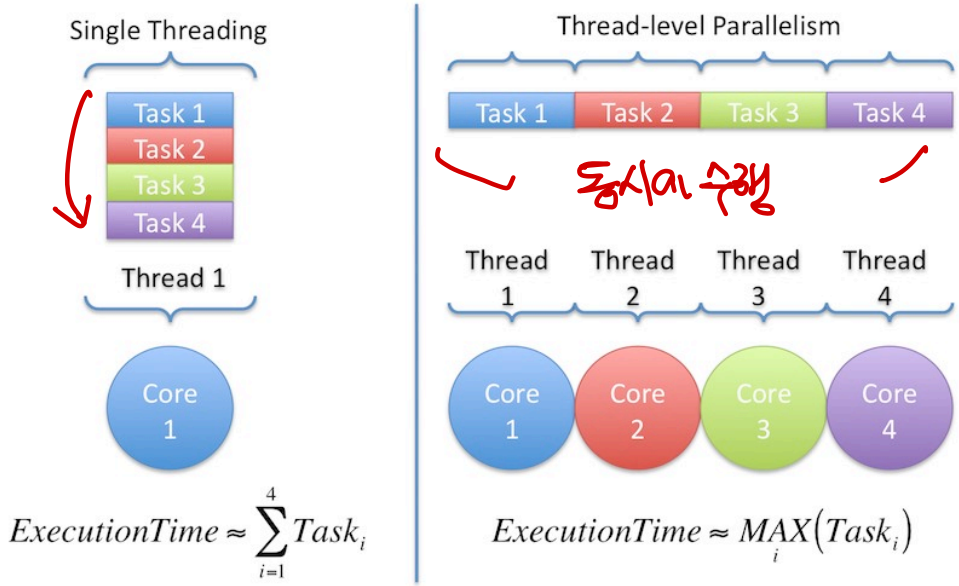
- By using multithreading, **one** process can use multiple cores!
  - Q: Multithreading gives (concurrency/parallelism) to a single process

Multicore Programming

하나의 프로세스가 멀티코어를 사용할 수 있다!

- **Allows one process to use multiple cores**
  - A multithreaded process can take advantage of Multicore CPU architectures
  - A process can run many threads **in parallel** on different processor **cores**

하나씩 실행



- Task: Add 1 to 4,000,000
  - Divide into 4 subtasks
    - Task1: add 1 to 1,000,000
    - Task2: add 1,00,001 to 2,000,000
    - Task3: add 2,00,001 to 3,000,000
    - Task4: add 3,00,001 to 4,000,000
- Say a core takes 10 seconds to add 1 million numbers
- Single threading: Give all 4 tasks to 1 core
  - Takes 40 seconds
- Multithreading: Give one task to each core (core 1~4)
  - Takes 10 seconds

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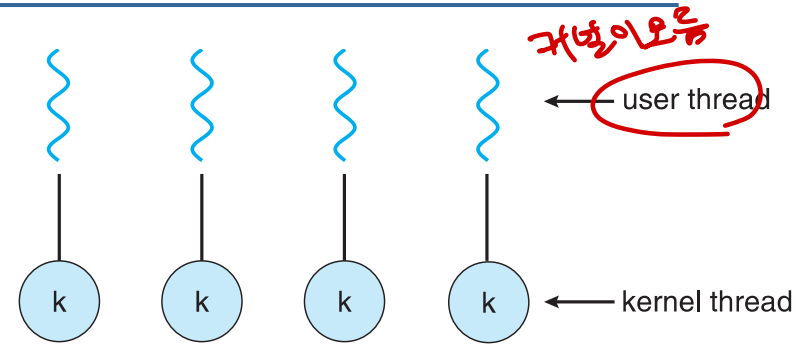
Kernel Threads

커널이 알고 있는 thread = Kernel Thread

- **Kernel threads**
  - Threads supported by the **Kernel**
    - created by `thread_create` system call
    - each thread needs **thread control block (TCB)**
  - **Pros**: kernel knows the thread, so…
    - **Parallelism**: Can run multiple threads on **multi-core**
    - **Concurrency**: another thread can run when one thread makes blocking system call (e.g., I/O request)
  - **Cons**: kernel knows the thread, so…
    - every thread operation must go through kernel; heavy weight
    - Syscall 10x-30x slower than user threads



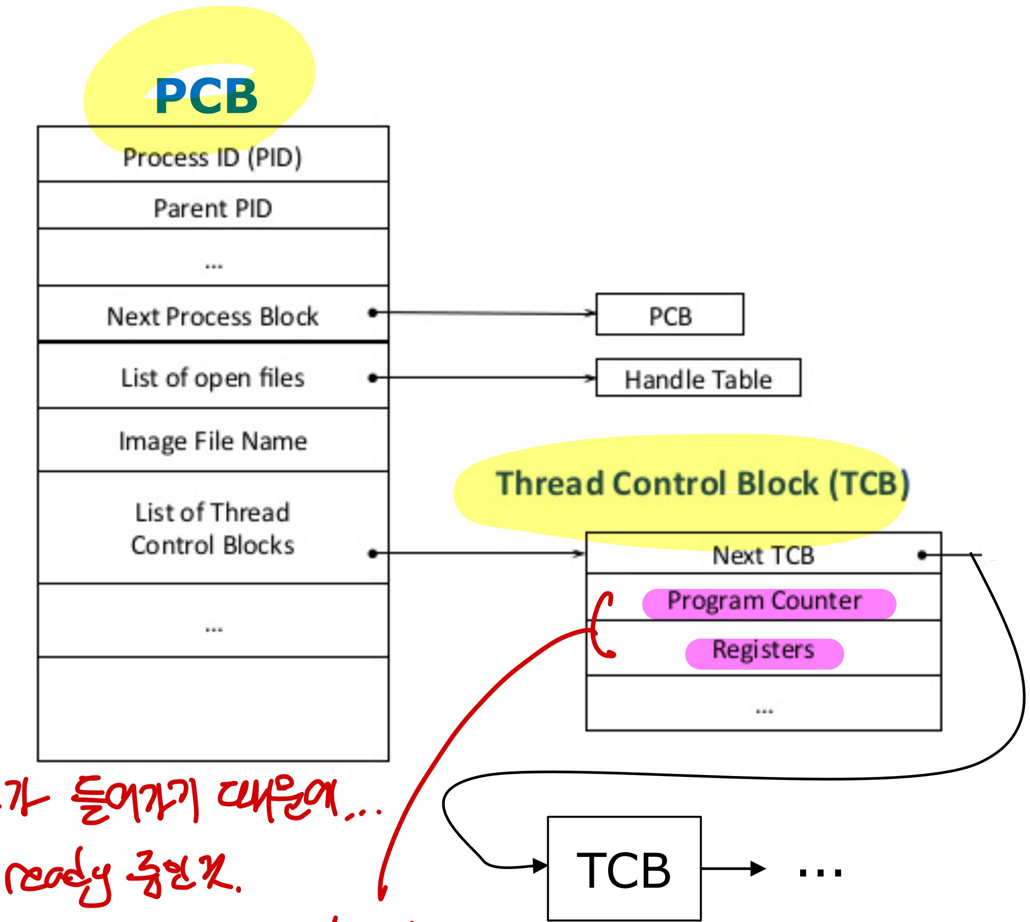
Control Blocks

Thread Control Block (TCB)

Created for each kernel thread

Contains Program Counter (PC), and registers

Other resources shared



thread끼리 공유되지 않는 값

- **Ready queue** is now a list of **TCB**s waiting for CPU resource

사실, Ready queue 에는 thread가 들어가기 때문에... TCB가 ready 중인거.

- **CPU Context switching** is done for **Threads**

마찬가지. CPU switch도 process X thread O

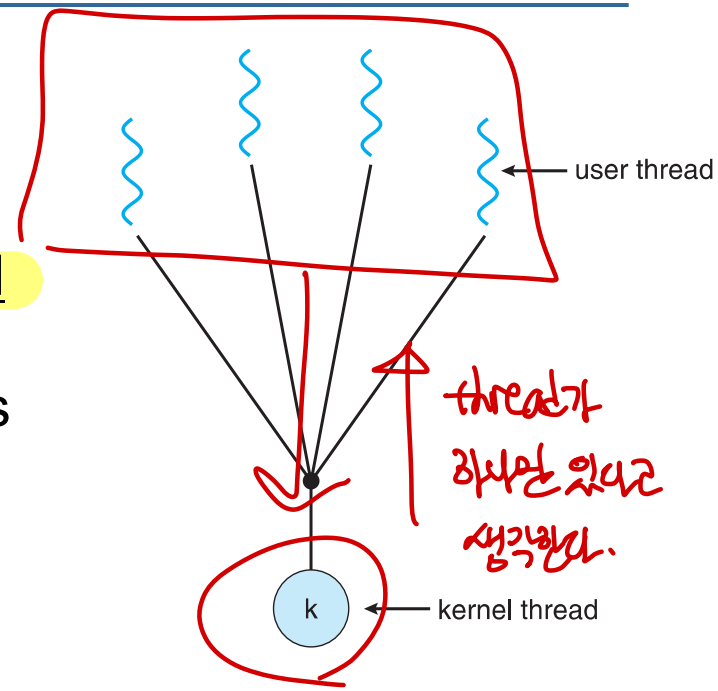
User thread

- **User Thread (=green threads)**
  - Implement thread in **user library**
  - created/managed *without* kernel support: **no need for system call**
  - One kernel thread per process, many user threads mapped to single kernel thread

  Pros: kernel doesn't know the user thread, so…

  Thread management is done by the thread library in user space

  Fast and efficient (10x-30x faster than kernel thread) – no syscall
- **Cons**: kernel doesn't know the user thread, so…
  - A thread makes a system call - one thread blocking causes all threads in process to **block**
  - Multiple user-level threads may ***not*** run in parallel on multicore system



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Pthreads

- A POSIX standard (IEEE 1003.1c) API for thread creation and synchronization
- Common in UNIX operating systems (Linux & Mac OS)

Multithreaded C program using the Pthreads API

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

int sum;          /* this data is shared by the thread(s) */
void *runner( void * param ); /* the thread */

int main( int argc, char * argv[] )
{
   pthread_t tid;              /* the thread identifier */
   pthread_attr_t attr;     /* set of thread attributes */


   /* set the default attributes */
   pthread_attr_init( &attr );
   /* create the thread */
   pthread_create( &tid, &attr, runner, argv[1] );
   /* wait for the thread to exit */
   pthread_join( tid, NULL );

   printf( "sum = %d\n", sum );
}
```

data 영역에 저장되고 thread 사이에서 공유됨

$$sum = \sum_{i=0}^{N} i$$

Separate Thread does this..

① 쓰레드 생성

②

③

① Thread Creation

Unique thread identifier (ID) returned from call

Attributes structure (NULL for defaults)

```
int pthread_create(&tid, &attr, runner, argv[1] );
```

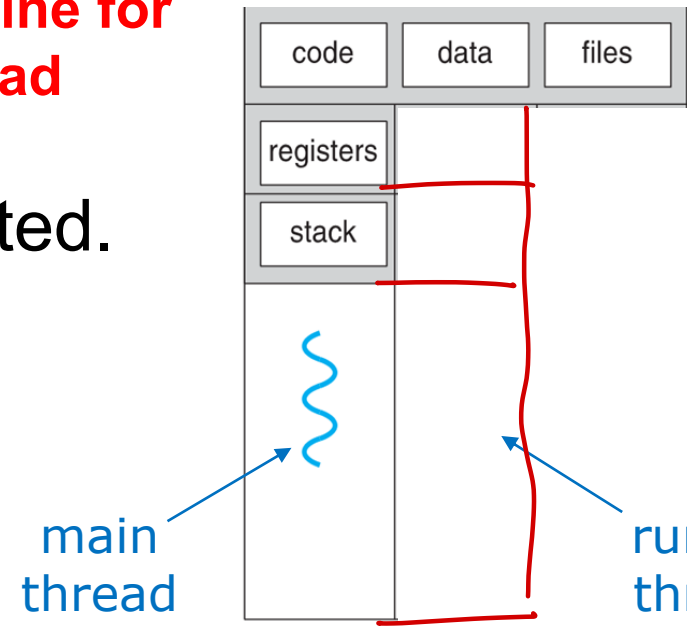
zero for success, else error number

main routine for child thread

Argument passed

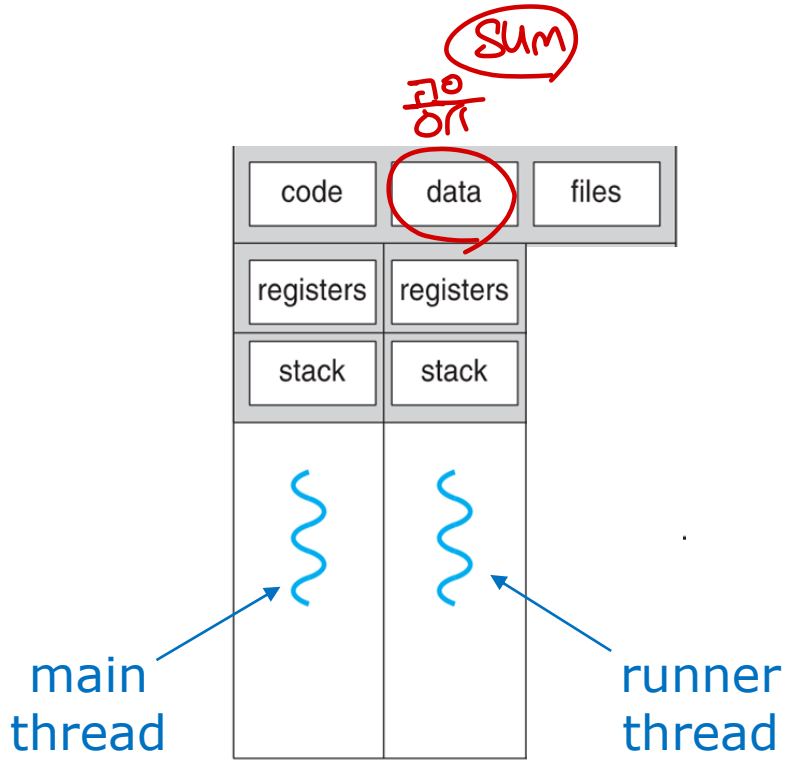
func is the function to be called.

When **func()** returns, the thread is terminated.



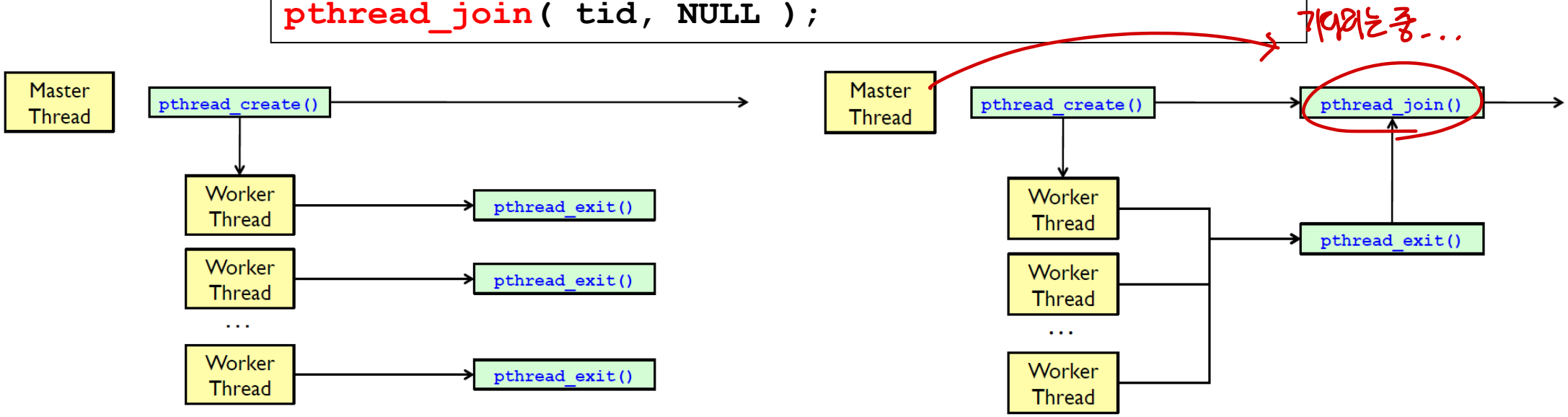
② Thread Function

```
/* The thread will begin control in this function */
void *runner( void * param )
{
   int i, upper = atoi( param );
   sum = 0;

   for( i = 1; i <= upper; i++ )
       sum += i;

   pthread_exit( 0 );
}
```



③ pthread_join()

```
pthread_create( &tid, &attr, runner, argv[1] );
/* wait for the thread to exit */
pthread_join( tid, NULL );
```



Suspends parent thread until child thread terminates

similar to wait() system call in process

Pthreads Code for Joining 10 Threads

```
#define NUM_THREADS 10

/* an array of threads to be joined upon */
pthread_t workers[NUM_THREADS];
...
for (int i = 0; i < NUM_THREADS; i++)
  pthread_join(workers[i], NULL);
```

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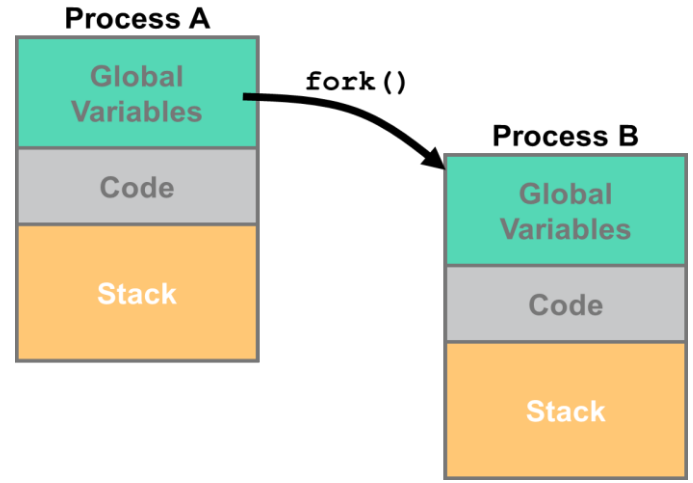
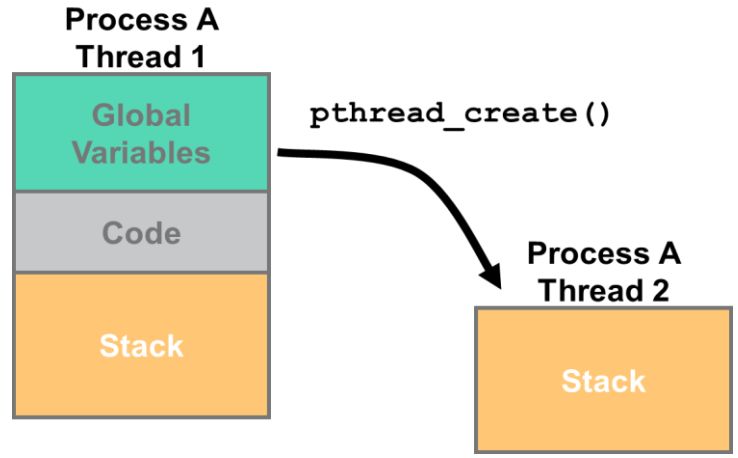
Thread vs. Process Creation

- **`fork()`** process 복사, 독립적
  - Two separate processes
  - Child process starts from same position as parent (clone)
  - Independent memory space for each process



- **`pthread_create()`**
  - Two separate threads
  - Child thread starts from a function
  - Share memory

일부만 기재함



Process vs. Thread Example

- Shared code:

```
int x = 1; //global variable
void* func(void* p){
   x = x + 1;
   printf("x is %d\n", x);
   return NULL;
}
```

- fork version:

```
main(…) {
     fork();
     func(NULL);
}
```

- threads version:

```
main(…) {
    pthread_t tid;

pthread_create(&tid,NULL,func,NULL);
    func(NULL);
}
```

Possible output: fork() case 1

parent와 child 중 어느 것이 scheduler에 의해 먼저 선택되는지, 둘 중 무엇이 먼저 실행될지는 모른다.

```
int x = 1; //global variable

void* func(void* p){
   x = x + 1;
   printf("x is %d\n", x);
   return NULL;
}
```

```
int x = 1; //global variable

void* func(void* p){
   x = x + 1;
   printf("x is %d\n", x);
   return NULL;
}
```

공유하지 않으므로, 둘 다 값은 2이다

time

Parent process **Child process**

Possible output: fork() case 2

```
int x = 1; //global variable
```

```
void* func(void* p){
   x = x + 1;
   printf("x is %d\n", x);
   return NULL;
}
```

Parent process

```
int x = 1; //global variable
```

```
void* func(void* p){
   x = x + 1;
   printf("x is %d\n", x);
   return NULL;
}
```

Case1 과 같아서. global variable은

공유하지 않는다!

time

Child process

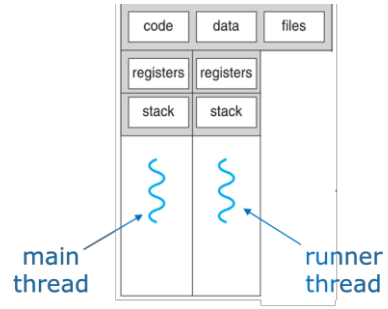
Possible output: threads case 1

```
int x = 1; //global variable
```

```
void* func(void* p){
   x = x + 1;
   printf("x is %d\n", x);
   return NULL;
}
```

2

join을 하지 않고 있으므로
우열이 없이 실행되는지 모름!



func()를 하는게 아니라, 그냥 func 내부 코드를 실행하는 것

```
void* func(void* p){
   x = x + 1;
   printf("x is %d\n", x);
   return NULL;
}
```

3

지역을 data에서 기준으로 x=2 인 상태

time

Parent thread

Child thread

Possible output: threads case 2

```
int x = 1; //global variable
```

```
void* func(void* p){
   x = x + 1;
   printf("x is %d\n", x);
   return NULL;
}
```

x=2

← Interrupt

```
void* func(void* p){
   x = x + 1;
   printf("x is %d\n", x);
   return NULL;
}
```

x=3

③

③

time

Parent thread

Child thread

Possible output: threads case 3

```
int x = 1; //global variable
```

```
void* func(void* p){
   x = x + 1;
   printf("x is %d\n", x);

   // interrupted during printf()

   printf("x is %d\n", x);

   return NULL;
}
```

① string data → kernel buffer

② kernel buffer → ~ → monitor

Interrupt!

```
void* func(void* p){
   x = x + 1;
   printf("x is %d\n", x);
   return NULL;
}
```

x is 2

x is 2

time

Parent thread

Child thread

Possible output: threads case 4

Output:
x is 2
x is 2

- Is it a possible output for this example ??
  - Hint: translate x = x + 1 into assembly instructions
    - lw $t0, 0($gp)
    - addi $t0, $t0, 1
    - sw $t0, 0($gp)

$t0: data register
$gp: memory address of x
lw: load word (from memory)
sw: store word (to memory)

- Bottom line: We cannot predict the results!
  - We need process (thread) synchronization (Ch. 6)

Up Next

- Which thread gets to go next when a thread exits running state?
  - Scheduling Algorithm (Ch. 5)

- What happens when multiple threads want to use the shared resource?
  - Synchronization (Ch. 6)

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