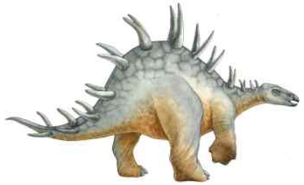
Chapter 4: Threads

Chapter 4: Threads

- Overview
- Multithreading Models
- Threading Issues
- Pthreads
- Windows XP Threads
- Linux Threads
- Java Threads



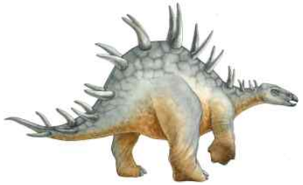
Threads 개요

- A *thread* (or *lightweight process*) is a basic unit of CPU utilization; it consists of (보유)
  - thread ID
  - program counter
  - register set
  - stack space

- A thread shares with its peer threads its(공유)
  - code section
  - data section
  - operating-system resources(files …)

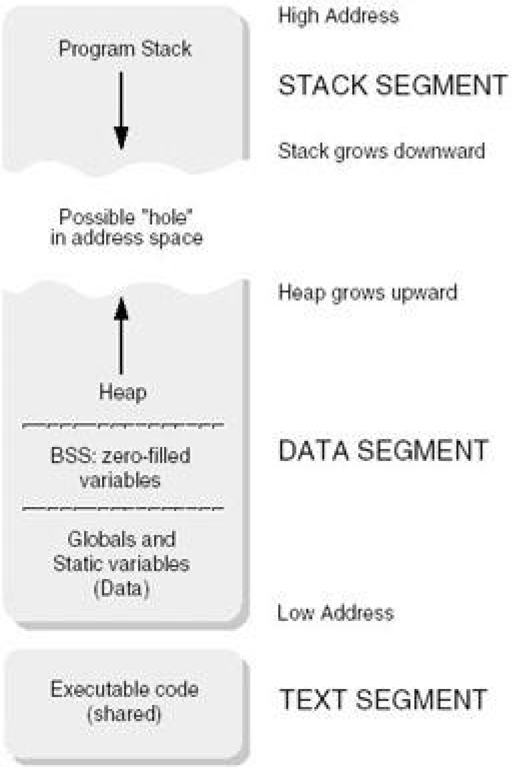
  collectively known as a *task*.

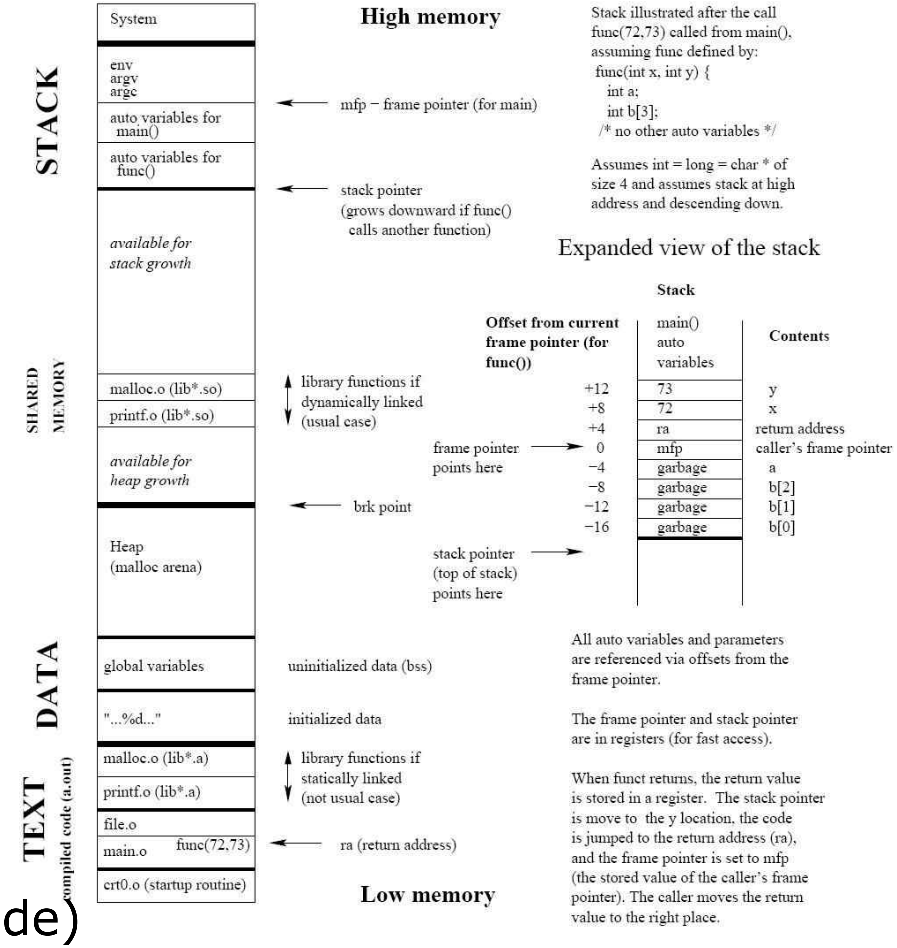
- 프로세스 : 중량 프로세스(HWP;Heavy Weight Process)
  - 하나의 스레드를 가진 작업(task)



Threads 개요

- Process의 메모리 구조(상세)





Stack illustrated after the call func(72,73) called from main(), assuming func defined by:

```
func(int x, int y) {
   int a;
   int b[3];
 /* no other auto variables */
```

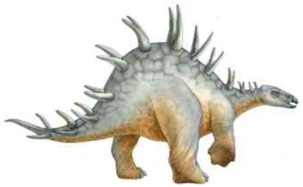
Assumes int = long = char * of size 4 and assumes stack at high address and descending down.

All auto variables and parameters are referenced via offsets from the frame pointer.

The frame pointer and stack pointer are in registers (for fast access).

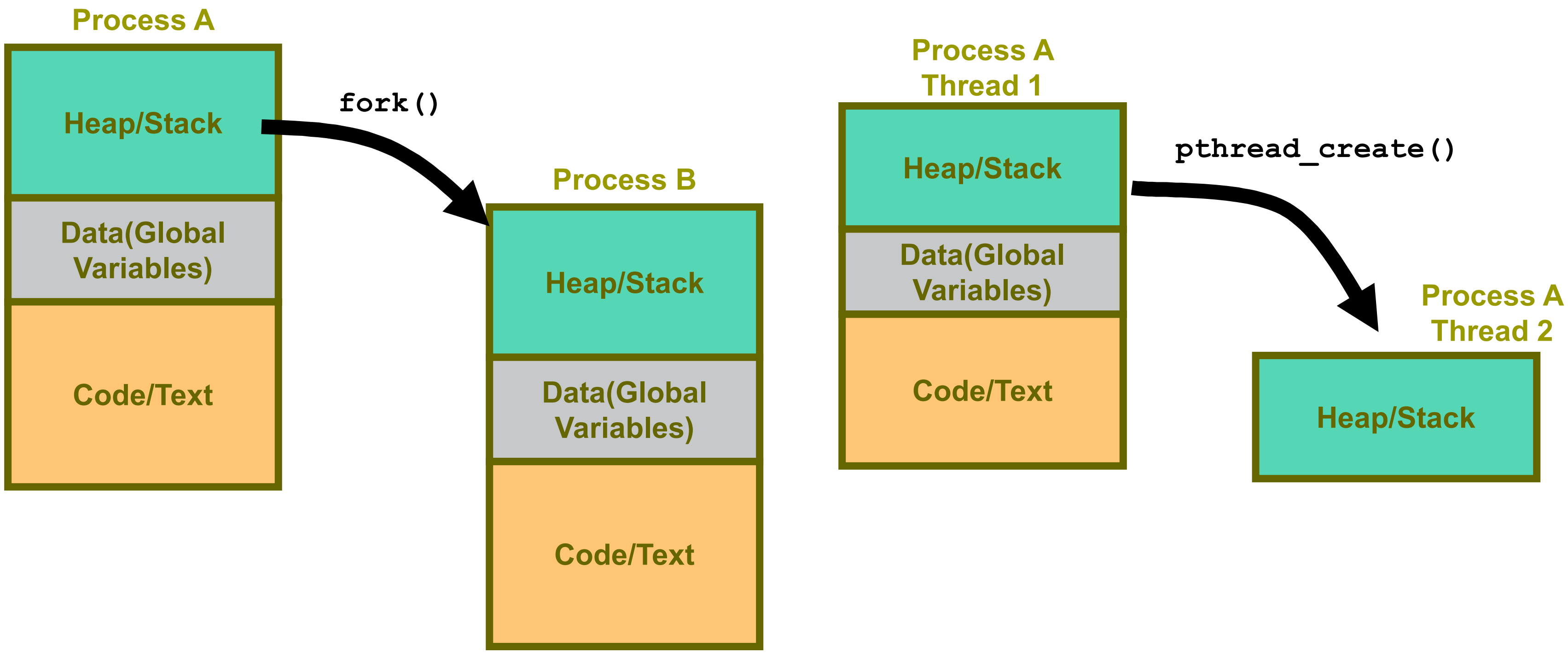
When funct returns, the return value is stored in a register. The stack pointer is move to the y location, the code is jumped to the return address (ra), and the frame pointer is set to mfp (the stored value of the caller's frame pointer). The caller moves the return value to the right place.

(code)



Threads 개요

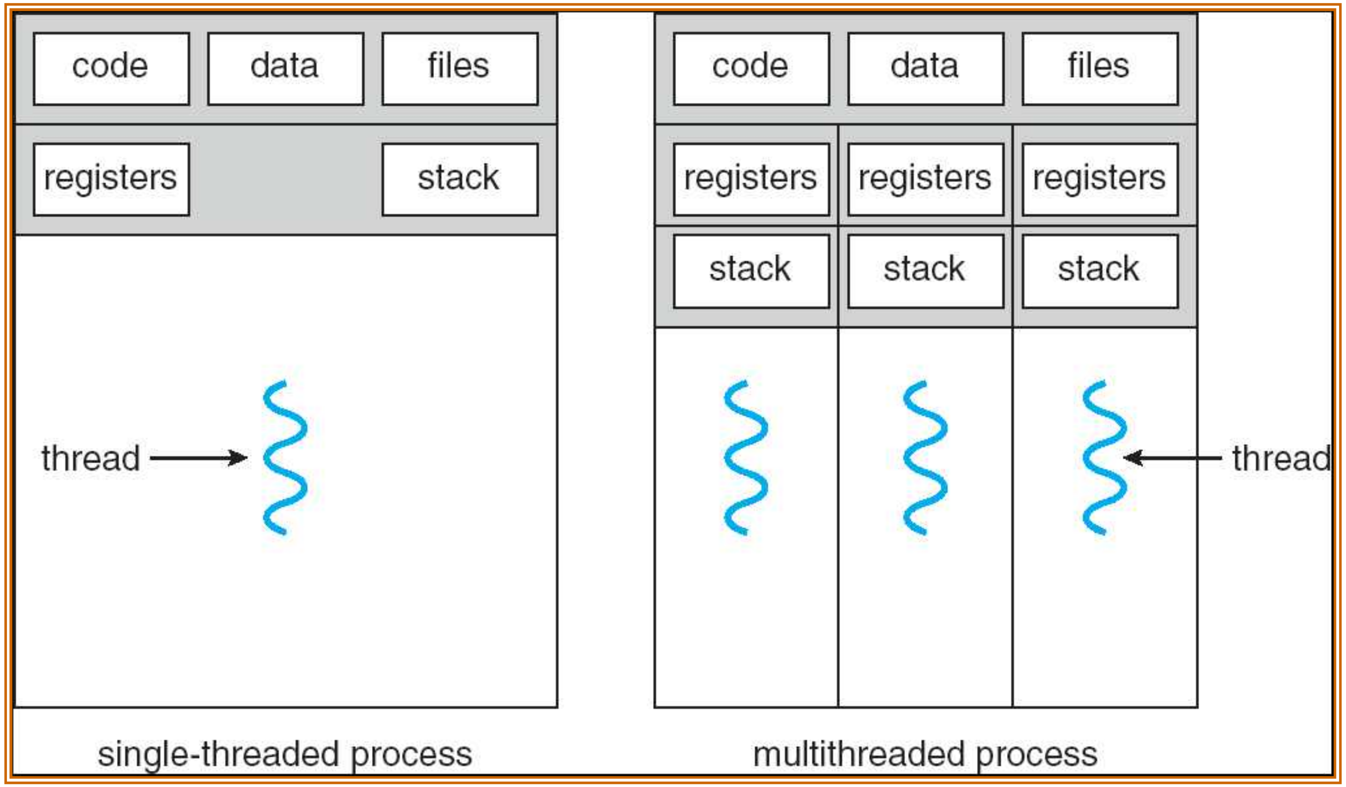
- Process와 Thread의 차이



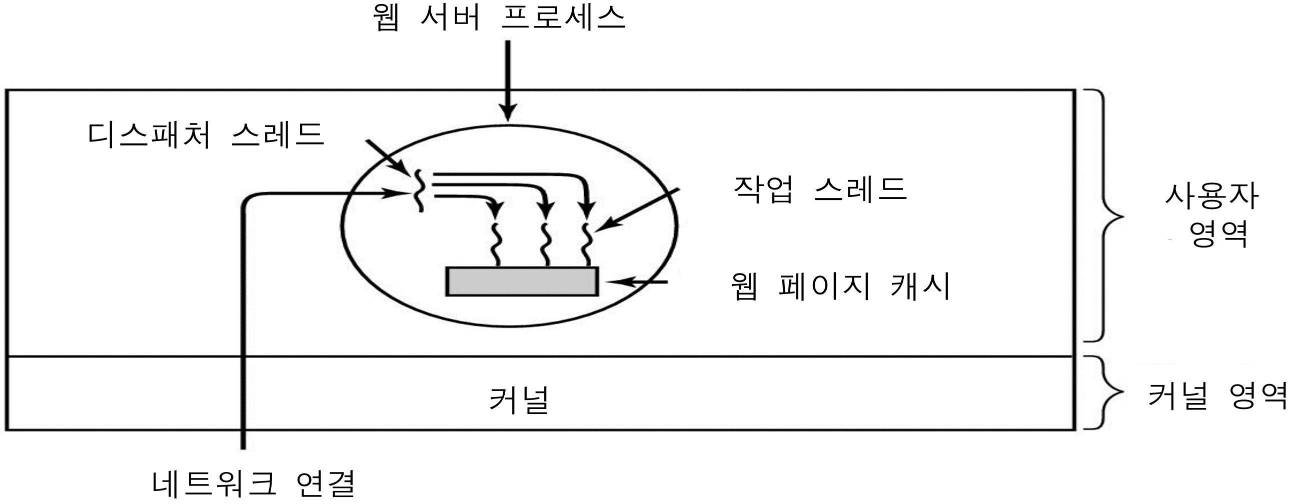
Process

Thread

Single and Multithreaded Processes



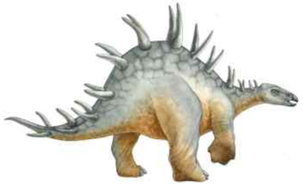
쓰레드의 이용 예 : 웹 서버



출처: 그림으로 보는 운영체제

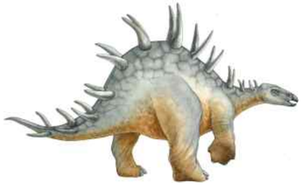
Benefits

- Responsiveness
  - eg) multi-threaded Web - if one thread is blocked (eg network) another thread continues (*eg display)*
- Resource Sharing
  - n threads can share binary code, data, resource of the process (files, crt, …)
- Economy
  - *creating* and *context switching* *thread* (rather than a *process)*
  - Solaris: 30배 5배
- Utilization of MP Architectures
  - *each thread* may be running in *parallel* on a *different processor*



User and Kernel Threads

- User Thread
  - Thread management done by user-level threads library
  - 라이브러리는 커널의 지원없이 쓰레드의 생성과 스케쥴링, 관리를 지원
  - 커널을 통하지 않으므로, 생성과 관리가 빠르나 봉쇄형 시스템 콜을 수행하는 사용자 수준의 쓰레드는 다른 쓰레드와 함께 스케쥴링 되지 않음



User and Kernel Threads

- Kernel Thread
  - Supported by the Kernel
  - 커널 수준에서 관리되어 생성과 관리가 느리나 다른 쓰레드와 함께 스케쥴링 될 수 있음
  - Examples

    - Windows 95/98/NT/2000

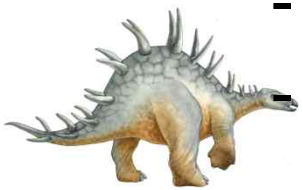
    - Solaris

    - Tru64 UNIX

    - BeOS

    - Linux

Java는 JVM에 의해 지원되므로,
커널 쓰레드와 사용자 쓰레드의 중간 형태



User and Kernel Threads

- Some are supported by *kernel*

  eg) Windows 95/98/NT

  Solaris

  Digital UNIX

→ *Kernel Threads*

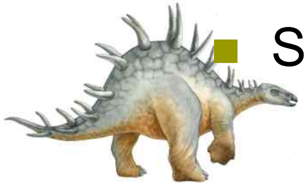
- Others are supported by *library*

  eg) POSIX *Pthreads*

  Mach *C-threads*

  Solaris *threads*

→ *User Threads*

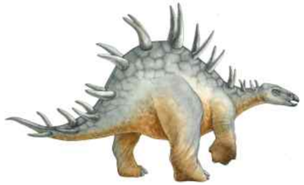


- Some are real-time threads

Multithreading Models

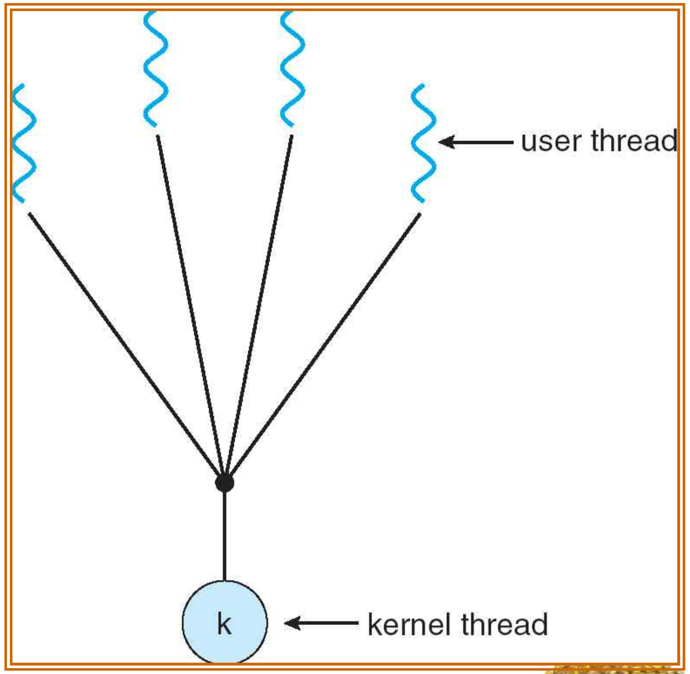
Mapping user threads to kernel threads:

- Many-to-One
- One-to-One
- Many-to-Many
  - Two-level Model : Many-to-Many 모델의 변형



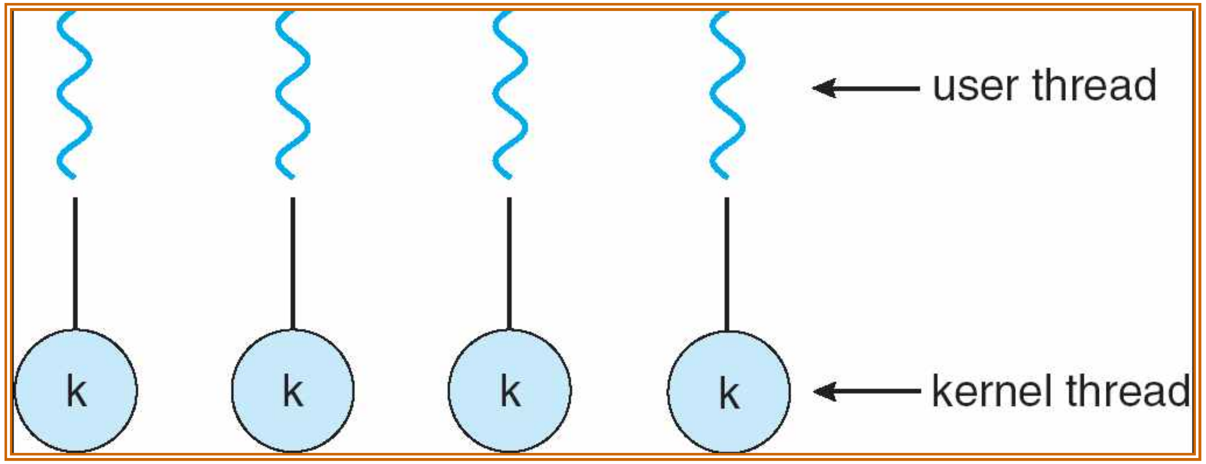
Many-to-One

- Many user-level threads mapped to single kernel thread
- Examples:
  - Solaris Green Threads
  - GNU Portable Threads



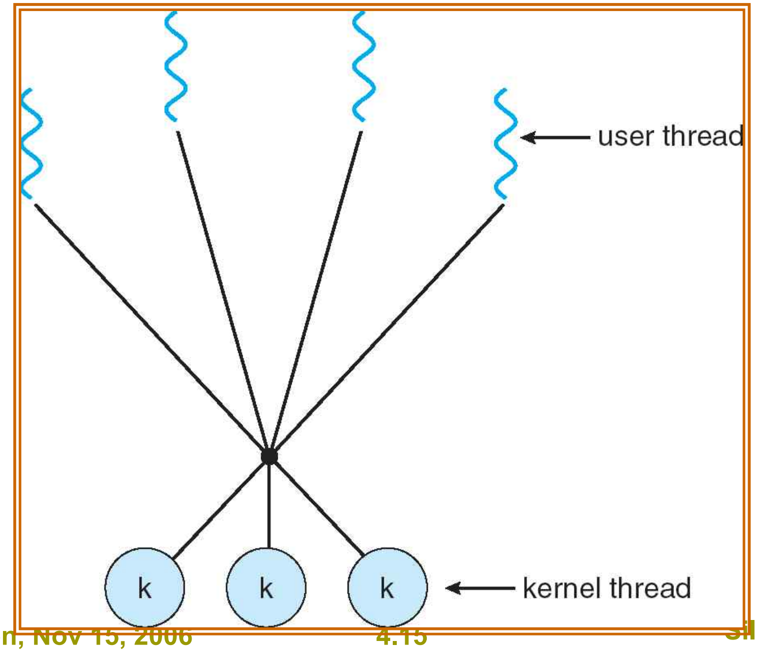
One-to-One

- Each user-level thread maps to kernel thread
- Examples
  - Windows NT/XP/2000
  - Linux
  - Solaris 9 and later



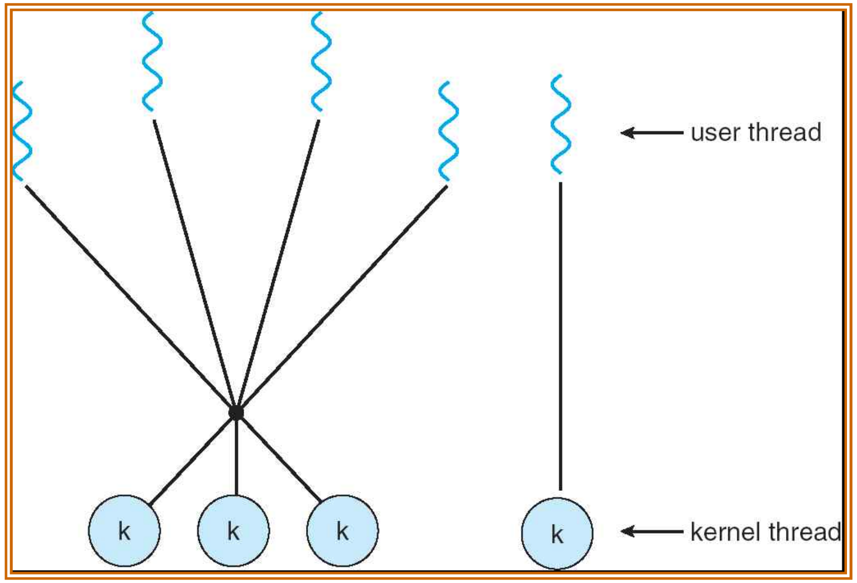
Many-to-Many Model

- Allows many user level threads to be mapped to many kernel threads
- Allows the operating system to create a sufficient number of kernel threads
  - Solaris prior to version 9
  - Windows NT/2000 with the *ThreadFiber* package



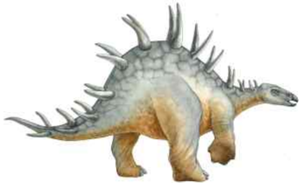
Two-level Model

- Similar to M:M, except that it allows a user thread to be **bound** to kernel thread
- Examples
  - IRIX, HP-UX, Tru64 UNIX, Solaris 8 and earlier



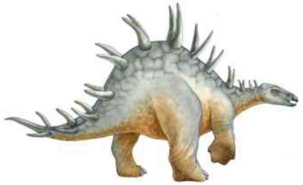
Thread Library

- POSIX Pthread
- Wind32 Thread API
- Java thread API
- Linux



Thread Library : Pthread

- POSIX Pthread
  - POSIX(IEEE 1003.1c)가 쓰레드 생성과 동기화를 위해 제정한 표준 API
    - Solaris, Linux, Mac OS X, Tru64 Unix에서 구현
    - 사용자 또는 Kernel 수준 라이브러리로 제공가능
    - 각 Thread는 stack의 크기와 스케쥴링 정보를 가짐



Thread Library : Pthread의 예

```
/*-----------------------------------------------------------------*/
/*--- main - setup server and await connections (no need to clean  ---*/
/*--- up after terminated children.                                 ---*/
/*-----------------------------------------------------------------*/
int main(void)
{   int sd;
    struct sockaddr_in addr;

    if ( (sd = socket(PF_INET, SOCK_STREAM, 0)) < 0 )
        PANIC("Socket");
    addr.sin_family = AF_INET;
    addr.sin_port = htons(9999);
    addr.sin_addr.s_addr = INADDR_ANY;
    if ( bind(sd, (struct sockaddr*)&addr, sizeof(addr)) != 0 )
        PANIC("Bind");
    if ( listen(sd, 20) != 0 )
        PANIC("Listen");
    while (1)
    {   int client, addr_size = sizeof(addr);
        pthread_t child;

        client = accept(sd, (struct sockaddr*)&addr, &addr_size);
        printf("Connected: %s:%d\n", inet_ntoa(addr.sin_addr), ntohs(addr.sin_port));
        if ( pthread_create(&child, NULL, Child, &client) != 0 )
            perror("Thread creation");
        else
            pthread_detach(child);  /* disassociate from parent */
    }
    return 0;
}
```

Thread Library : Win32 Thread

- Win32 Thread
  - Windows System의 Kernel 수준 라이브러리
  - Pthread 기법과 유사
    - 기본적으로 one-to-one 매핑

Thread Library : Win32 Thread

```
#include <windows.h>
#include <iostream>

DWORD WINAPI myThread(LPVOID lpParameter)
{
        unsigned int& myCounter = *((unsigned int*)lpParameter);
        while(myCounter < 0xFFFFFFFF) ++myCounter;
        return 0;
}

int main(int argc, char* argv[])
{
        using namespace std;

        unsigned int myCounter = 0;
        DWORD myThreadID;
        HANDLE myHandle = CreateThread(0, 0, myThread, &myCounter, 0, &myThreadID);
        char myChar = ' ';
        while(myChar != 'q') {
                cout << myCounter << endl;
                myChar = getchar();
        }

        CloseHandle(myHandle);
        return 0;
}
```

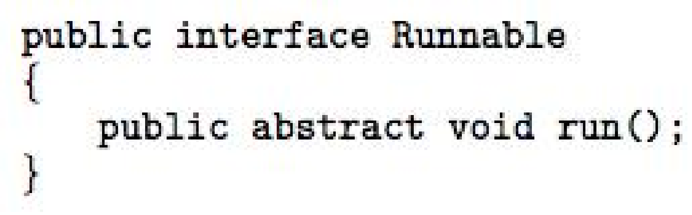
The output is:

```
0
868171493
1177338657
3782005161
4294967295
4294967295
...
```

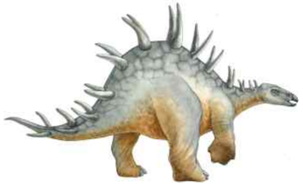
Thread Library : Java Threads

- Java threads are managed by the JVM

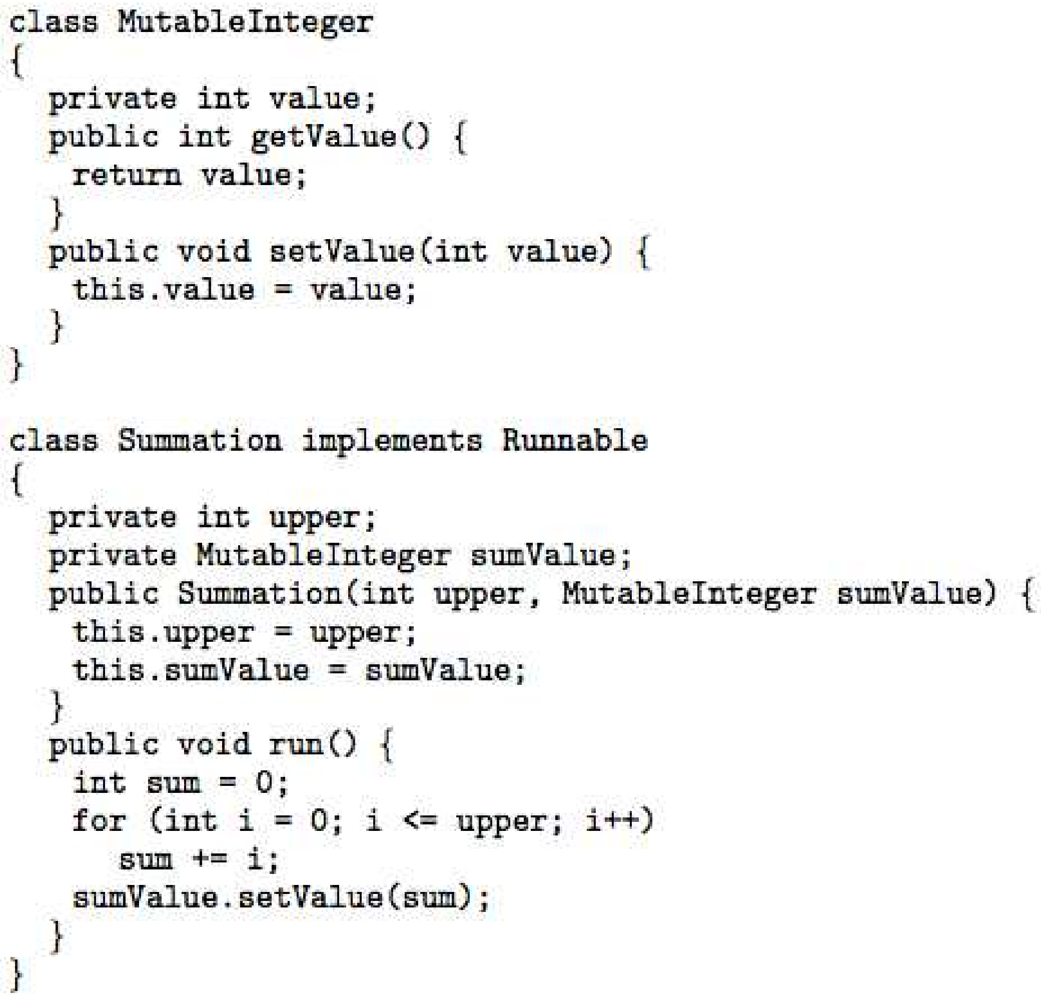
- Java threads may be created by:
  - Implementing the Runnable interface



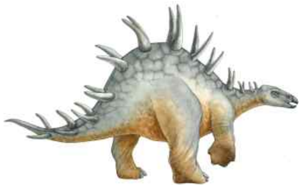
```
public interface Runnable
{
    public abstract void run();
}
```



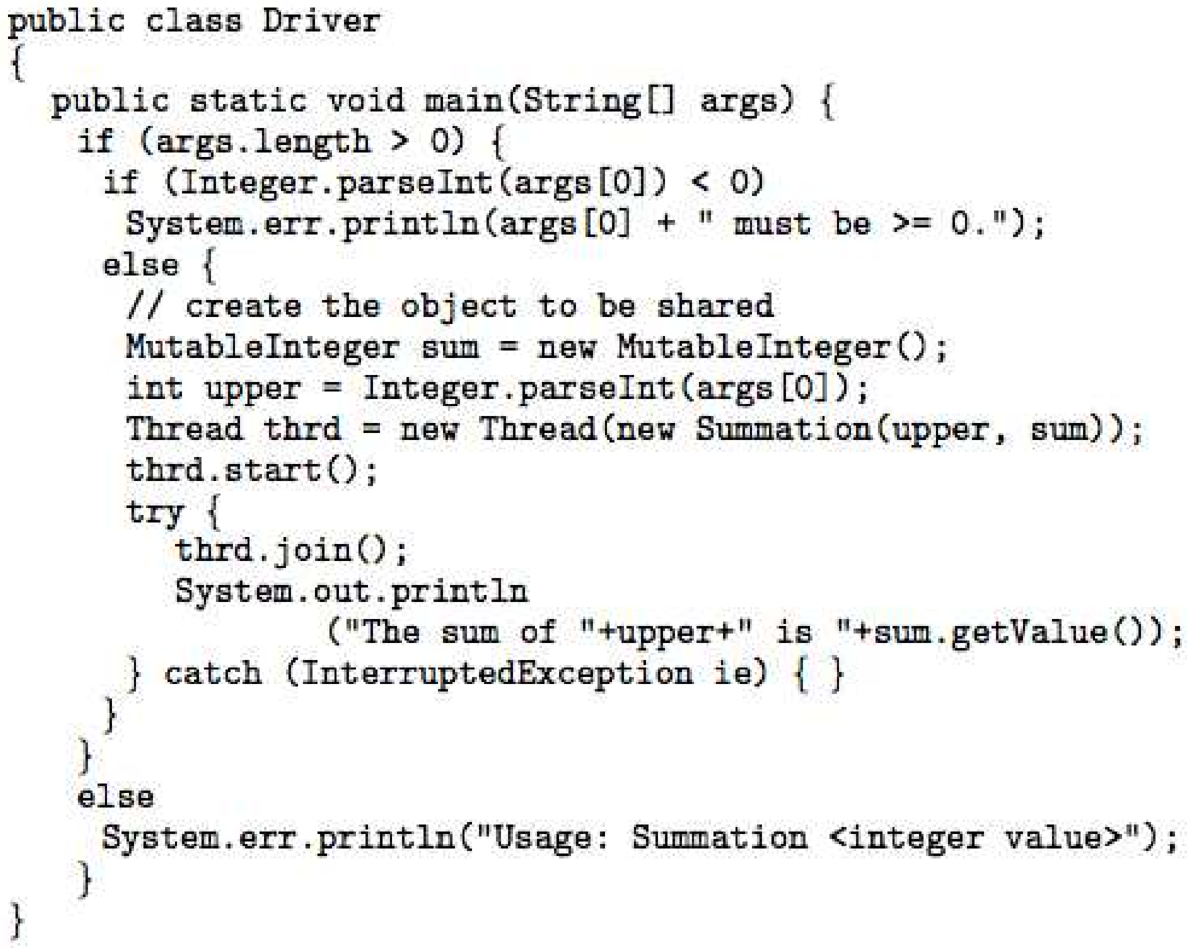
Java Threads - Example Program



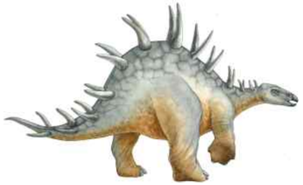
```
class MutableInteger
{
  private int value;
  public int getValue() {
   return value;
  }
  public void setValue(int value) {
   this.value = value;
  }
}

class Summation implements Runnable
{
  private int upper;
  private MutableInteger sumValue;
  public Summation(int upper, MutableInteger sumValue) {
   this.upper = upper;
   this.sumValue = sumValue;
  }
  public void run() {
   int sum = 0;
   for (int i = 0; i <= upper; i++)
     sum += i;
   sumValue.setValue(sum);
  }
}
```



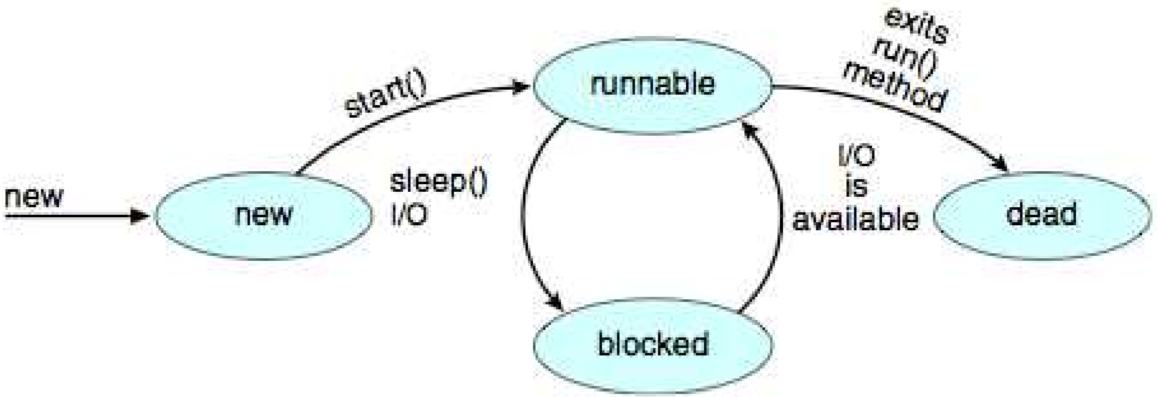
Java Threads - Example Program

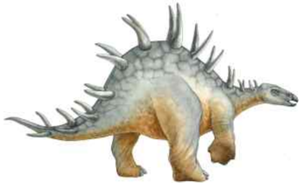


```
public class Driver
{
  public static void main(String[] args) {
    if (args.length > 0) {
     if (Integer.parseInt(args[0]) < 0)
      System.err.println(args[0] + " must be >= 0.");
     else {
      // create the object to be shared
      MutableInteger sum = new MutableInteger();
      int upper = Integer.parseInt(args[0]);
      Thread thrd = new Thread(new Summation(upper, sum));
      thrd.start();
      try {
         thrd.join();
         System.out.println
                ("The sum of "+upper+" is "+sum.getValue());
      } catch (InterruptedException ie) { }
     }
    }
    else
     System.err.println("Usage: Summation <integer value>");
    }
}
```

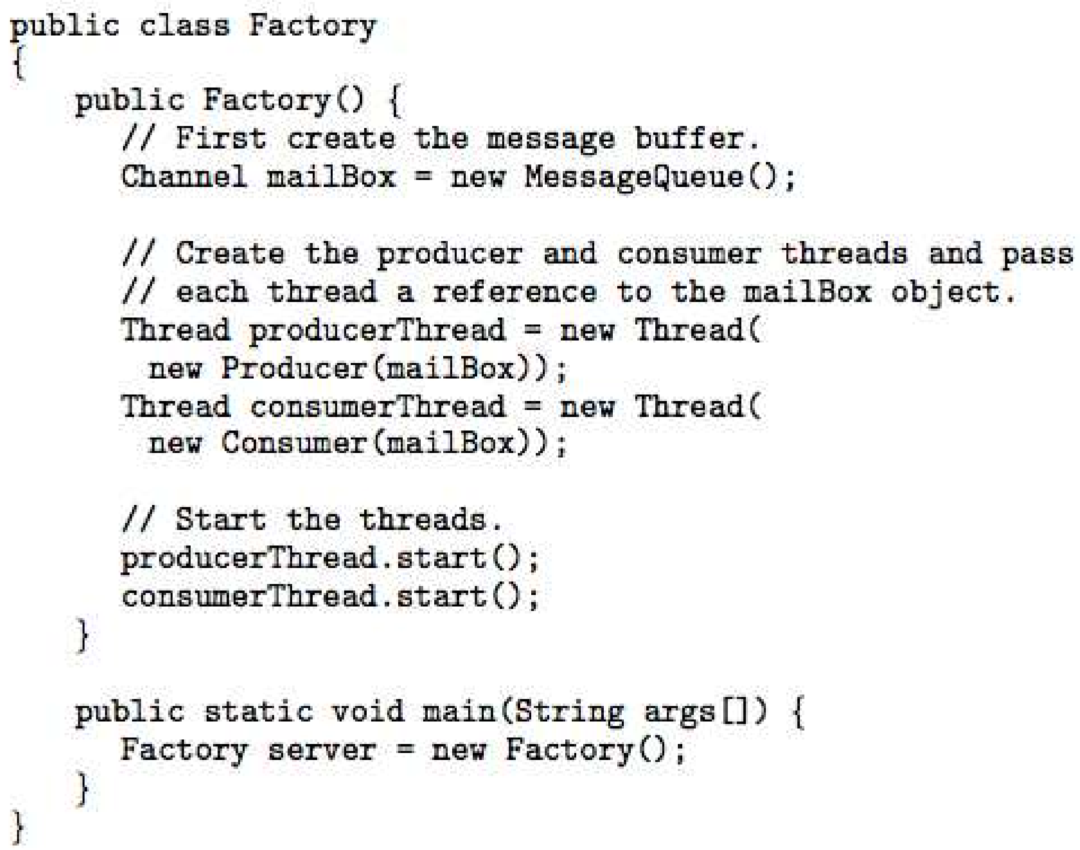


Java Thread States

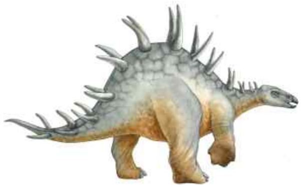




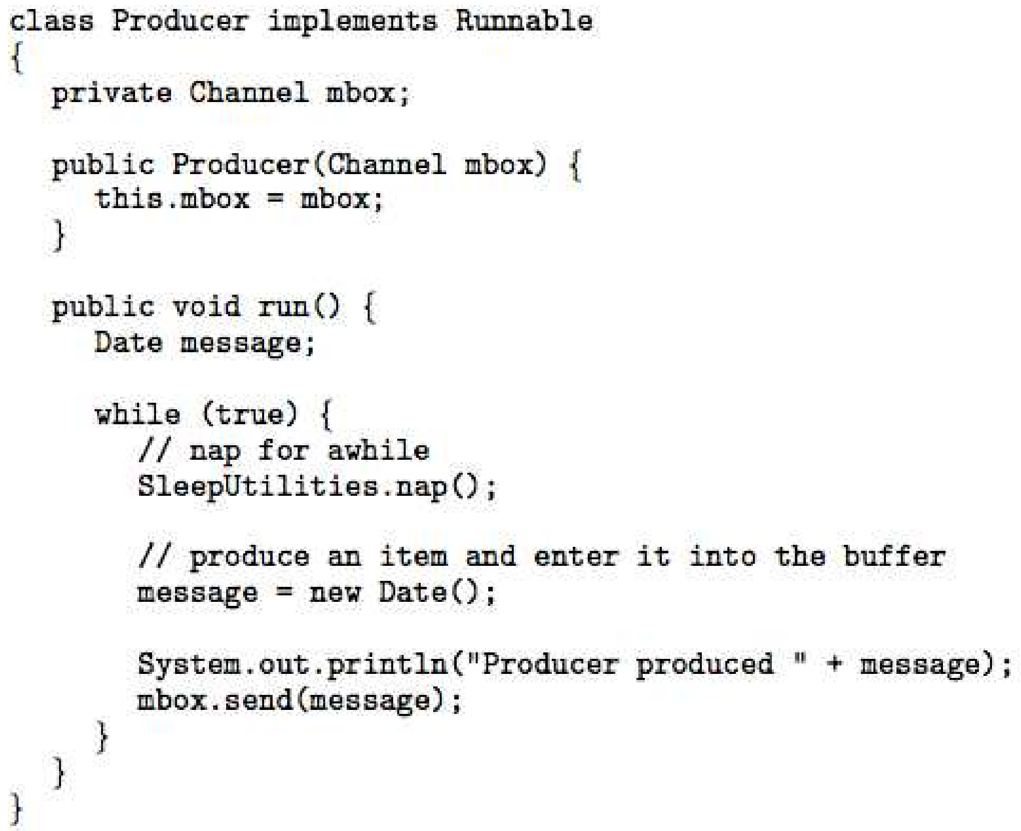
Java Threads - Producer-Consumer



```
public class Factory
{
    public Factory() {
      // First create the message buffer.
      Channel mailBox = new MessageQueue();

      // Create the producer and consumer threads and pass
      // each thread a reference to the mailBox object.
      Thread producerThread = new Thread(
        new Producer(mailBox));
      Thread consumerThread = new Thread(
        new Consumer(mailBox));

      // Start the threads.
      producerThread.start();
      consumerThread.start();
    }

    public static void main(String args[]) {
      Factory server = new Factory();
    }
}
```

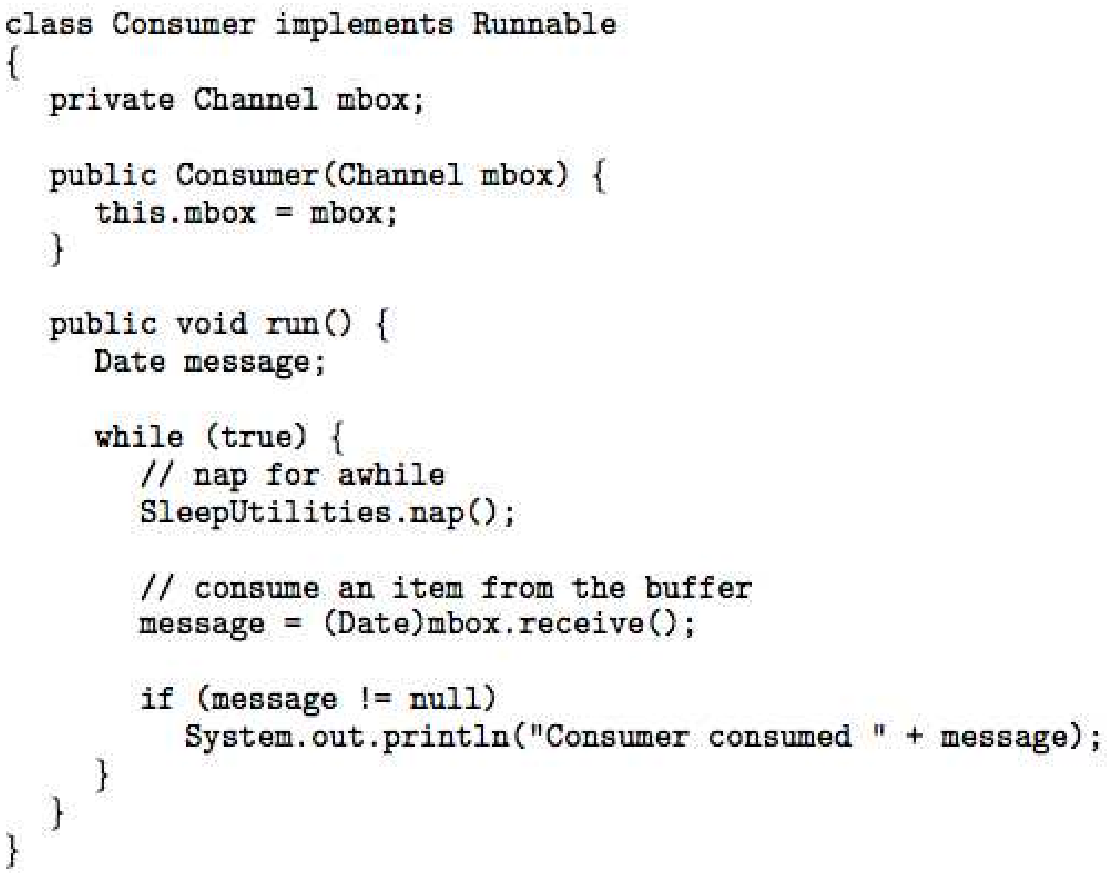


Java Threads - Producer-Consumer

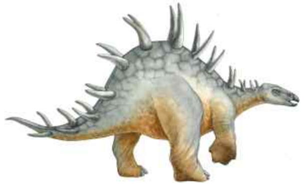


```
class Producer implements Runnable
{
   private Channel mbox;

   public Producer(Channel mbox) {
      this.mbox = mbox;
   }

   public void run() {
      Date message;

      while (true) {
         // nap for awhile
         SleepUtilities.nap();

         // produce an item and enter it into the buffer
         message = new Date();

         System.out.println("Producer produced " + message);
         mbox.send(message);
      }
   }
}
```

Java Threads - Producer-Consumer

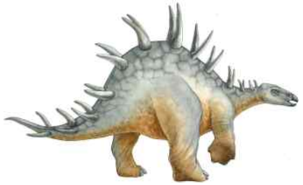


```
class Consumer implements Runnable
{
   private Channel mbox;

   public Consumer(Channel mbox) {
      this.mbox = mbox;
   }

   public void run() {
      Date message;

      while (true) {
         // nap for awhile
         SleepUtilities.nap();

         // consume an item from the buffer
         message = (Date)mbox.receive();

         if (message != null)
            System.out.println("Consumer consumed " + message);
      }
   }
}
```



Threading Issues

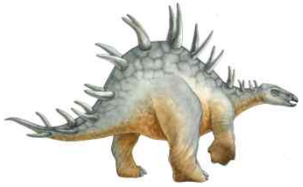
- Semantics of **fork()** and **exec()** system calls
- Thread cancellation
- Signal handling
- Thread pools
- Thread specific data
- Scheduler activations



Threading Issues – Semantics of fork() and exec()

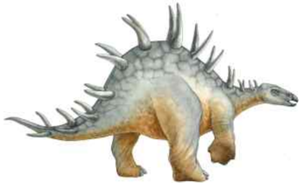
- **Multithread** 프로그램에서 **fork()**를 호출한다면**,** 한 개의 **thread**를 생성할 것인가**?** 아니면 모든 **multithread**를 모두 복사해서 생성할 것인가**?**

- 두 개 다 지원



Threading Issues – Thread Cancellation

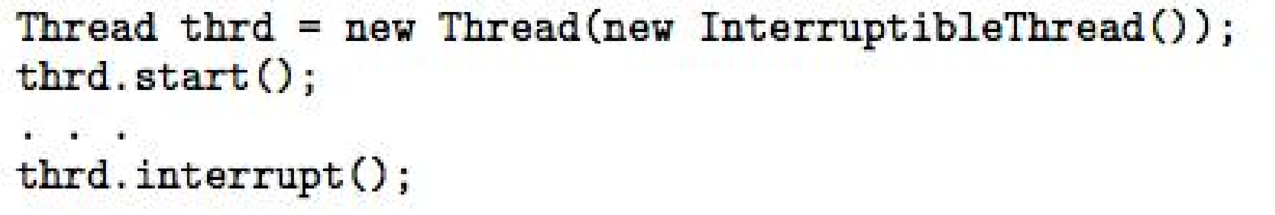
- **Terminating a thread before it has finished**
  - 예를 들면, 여러 쓰레드들이 데이터베이스를 병렬로 검색하다가 그 중 한 쓰레드가 결과를 찾은 경우,
  - 또는 웹 브라우저에서 사용자가 **stop**을 클릭한 경우
- **Two general approaches:**
  - **Asynchronous cancellation terminates the target thread immediately**
  - **Deferred cancellation allows the target thread to periodically check if it should be cancelled**



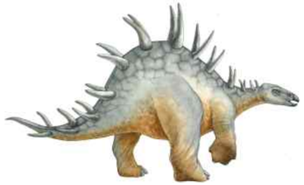
Thread Cancellation

Deferred cancellation in Java

Interrupting a thread

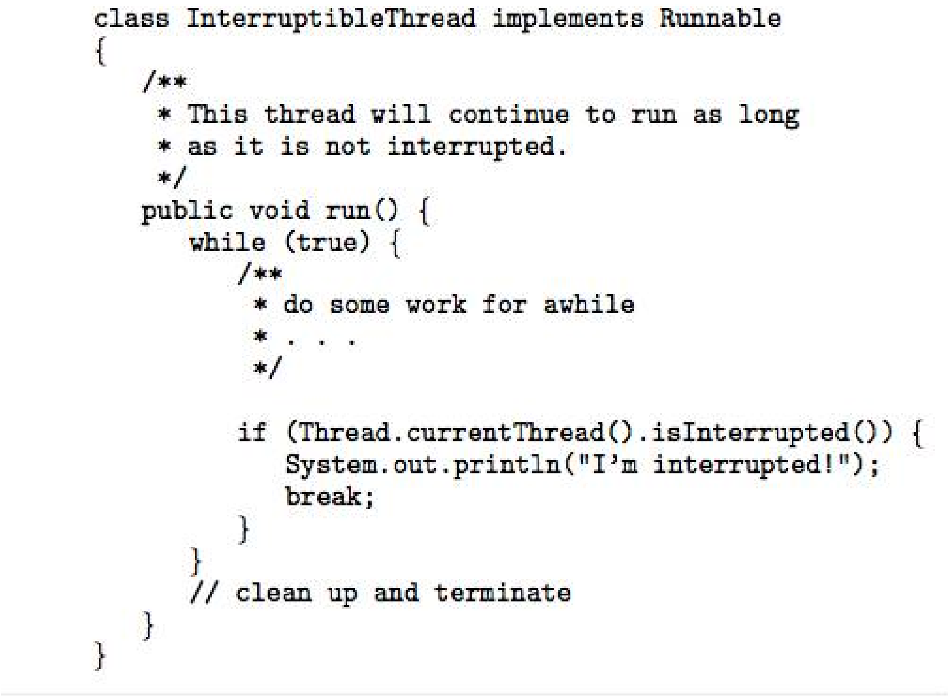


```
Thread thrd = new Thread(new InterruptibleThread());
thrd.start();
. . .
thrd.interrupt();
```

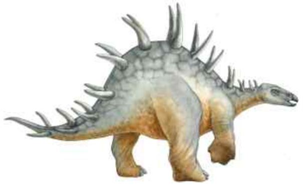


Thread Cancellation

Deferred cancellation in Java
Checking interruption status



```
class InterruptibleThread implements Runnable
{
   /**
    * This thread will continue to run as long
    * as it is not interrupted.
    */
   public void run() {
      while (true) {
         /**
          * do some work for awhile
          * . . .
          */

         if (Thread.currentThread().isInterrupted()) {
            System.out.println("I'm interrupted!");
            break;
         }
      }
      // clean up and terminate
   }
}
```

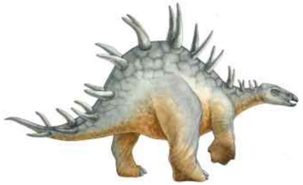


Signal Handling

- Signal
  - Unix에서 특정 Event가 일어났음을 알리기 위해 사용되는 단위(예: Windows Message)
- **signal handler의 처리 순서**
  1. Signal이 특정 event에 의해 생성됨
  2. Signal이 특정 프로세스에 전달됨
  3. Signal이 처리됨

Signal의 예
Synchronous
Devide-by-zero,
illegal-memory-access

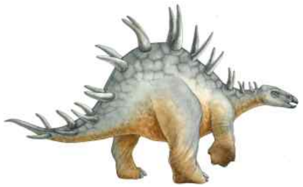
  - Process에서의 Signal 처리 선택사항
    - Signal이 적용될 특정 Thread에 전송
    - Process안에 있는 모든 Thread에 전송됨
    - Process안의 다수 Thread에게 전송됨
    - 그 Process에 전달되는 모든 Signal을 처리할 특정 Thread를 지정



Thread Pools

- 작업을 대기하는 다수의 Thread를 미리 생성해 놓는 Pool

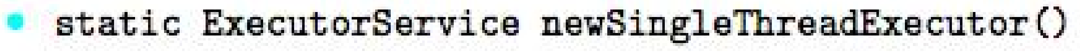
- Advantages:
  - 속도 : 보통 새로운 Thread를 생성하는 것보다 존재하는 Thread를 사용하므로 다소 빠름
  - 시스템 자원 할당의 한계 설정 : Allows the number of threads in the application(s) to be bound to the size of the pool



Thread Pools

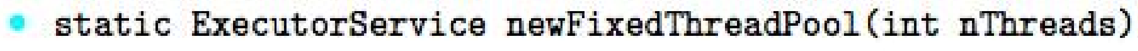
- Java provides 3 thread pool architectures:

1. **Single thread executor** - pool of size 1.



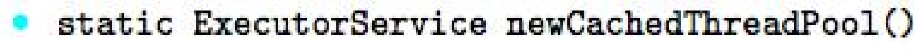
- static ExecutorService newSingleThreadExecutor()

2. **Fixed thread executor** - pool of fixed size.

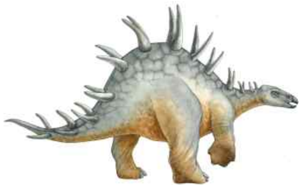


- static ExecutorService newFixedThreadPool(int nThreads)

3. **Cached thread pool** - pool of unbounded size

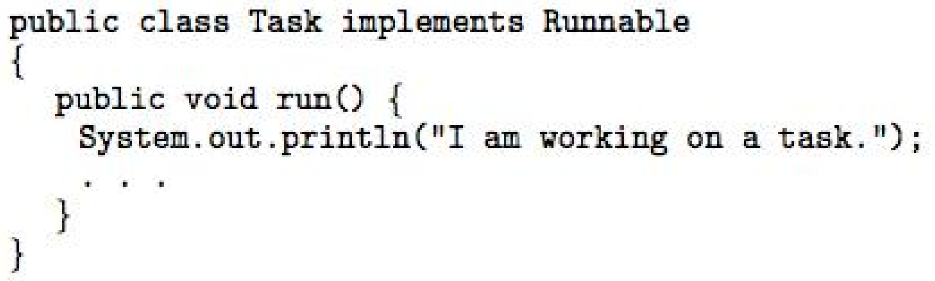


- static ExecutorService newCachedThreadPool()

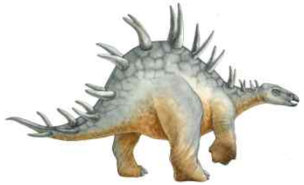


Thread Pools

A task to be serviced in a thread pool

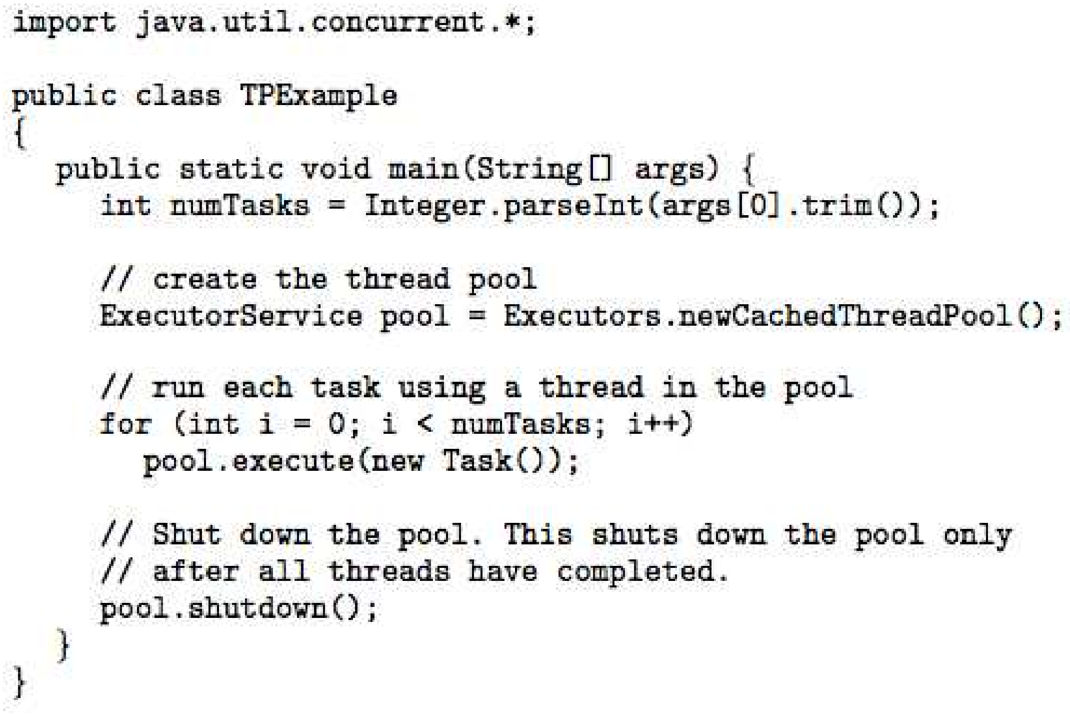


```
public class Task implements Runnable
{
   public void run() {
     System.out.println("I am working on a task.");
     . . .
   }
}
```

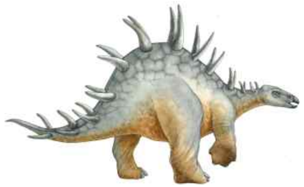


Thread Pools

Creating a thread pool in Java



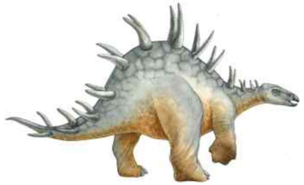
```
import java.util.concurrent.*;

public class TPExample
{
   public static void main(String[] args) {
      int numTasks = Integer.parseInt(args[0].trim());

      // create the thread pool
      ExecutorService pool = Executors.newCachedThreadPool();

      // run each task using a thread in the pool
      for (int i = 0; i < numTasks; i++)
         pool.execute(new Task());

      // Shut down the pool. This shuts down the pool only
      // after all threads have completed.
      pool.shutdown();
   }
}
```



Thread Specific Data

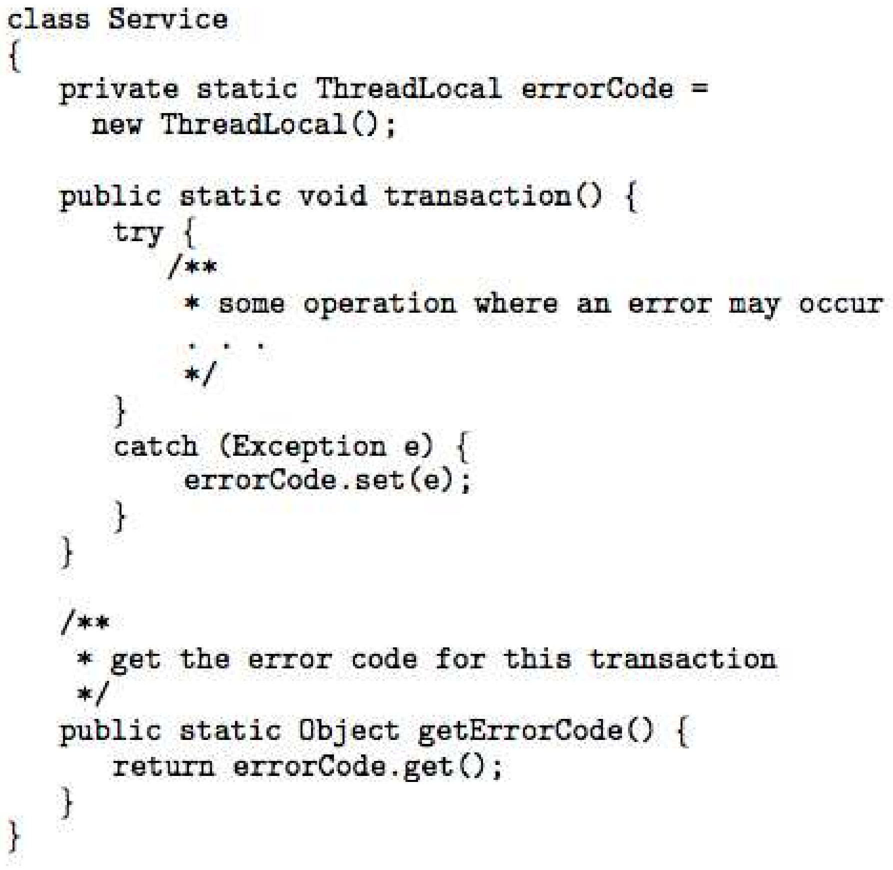
- Allows each thread to have its own copy of data

- Useful when you do not have control over the thread creation process (i.e., when using a thread pool)



Thread Specific Data

Thread-specific data in Java.

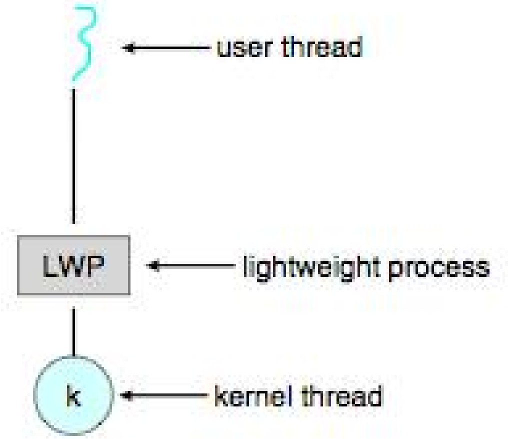


```
class Service
{
    private static ThreadLocal errorCode =
      new ThreadLocal();

    public static void transaction() {
        try {
            /**
             * some operation where an error may occur
             . . .
             */
        }
        catch (Exception e) {
             errorCode.set(e);
        }
    }

    /**
     * get the error code for this transaction
     */
    public static Object getErrorCode() {
        return errorCode.get();
    }
}
```

Scheduler Activations

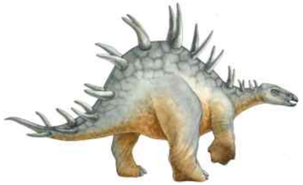
- Scheduler Activation
  - Thread library와 Kernel Thread의 통신방법
  - This communication allows an application to maintain the correct number kernel threads

- LWP 자료구조
  - M:M and Two-level model들은 다수의 Kernel



Scheduler Activations

- **upcall in scheduler activation**
  - Kernel- Thread간 종료 또는 activation을 알림
    - 특정 thread 가 종료될때 upcall이 발생
    - upcall 처리기는 이 upcall을 받아 다른 thread를 activation
  - 수행되는 thread의 수를 조절



운영체제 사례

- Solaris에서 Thread와 Process의 관계

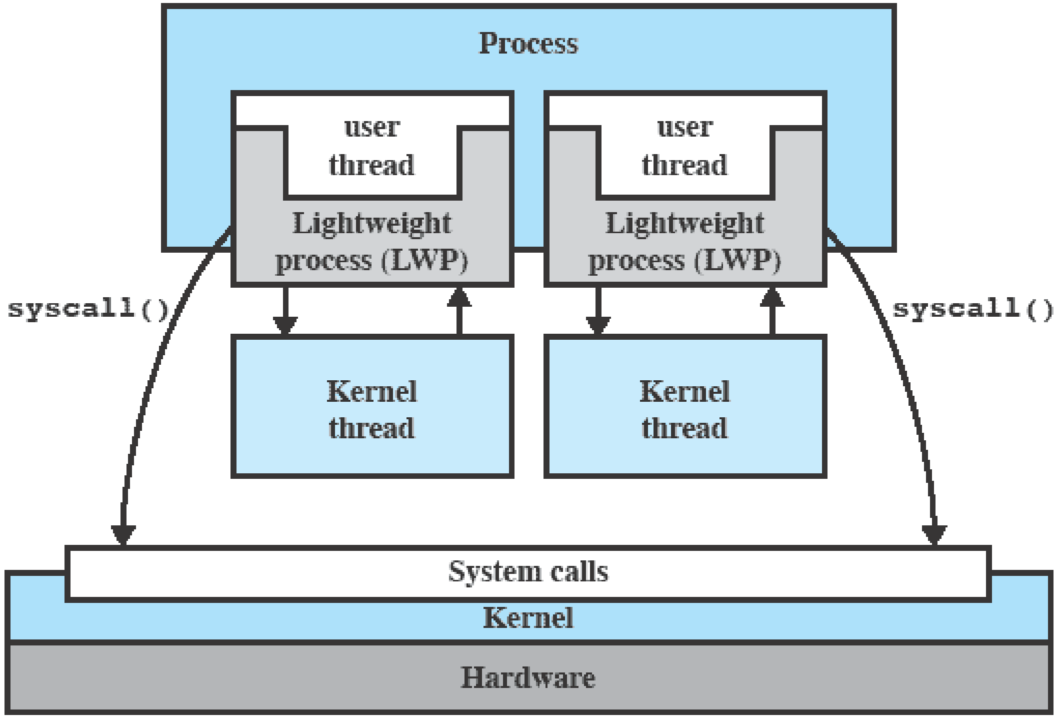
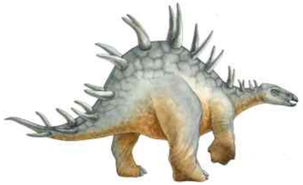
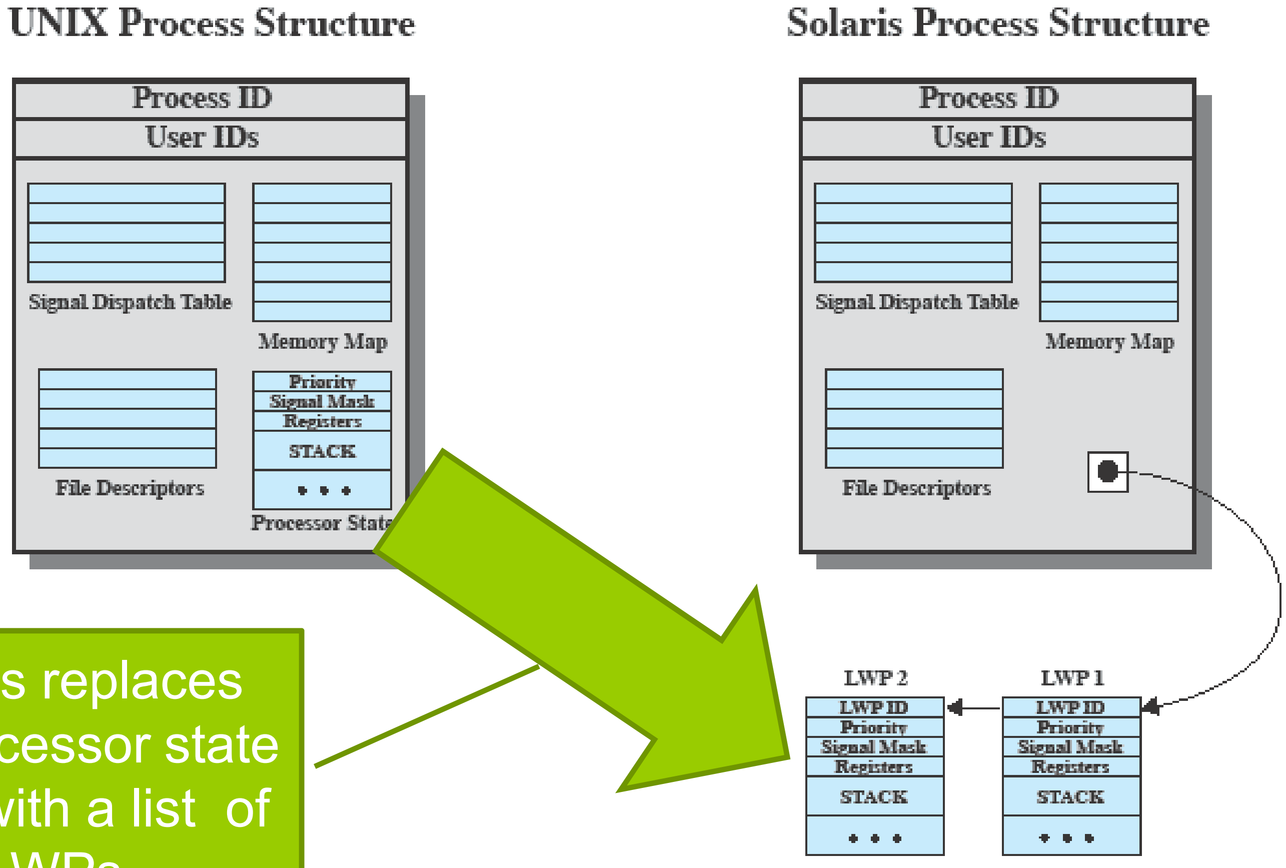


Figure 4.15 Processes and Threads in Solaris [MCDO07]



운영체제 사례

- Unix와 Solaris의 Thread 지원 Process의 비교



Solaris replaces the processor state block with a list of LWPs

Figure 4.16 Process Structure in Traditional UNIX and Solaris [LEWI96]

운영체제 사례

- Solaris에서의 Thread 모델

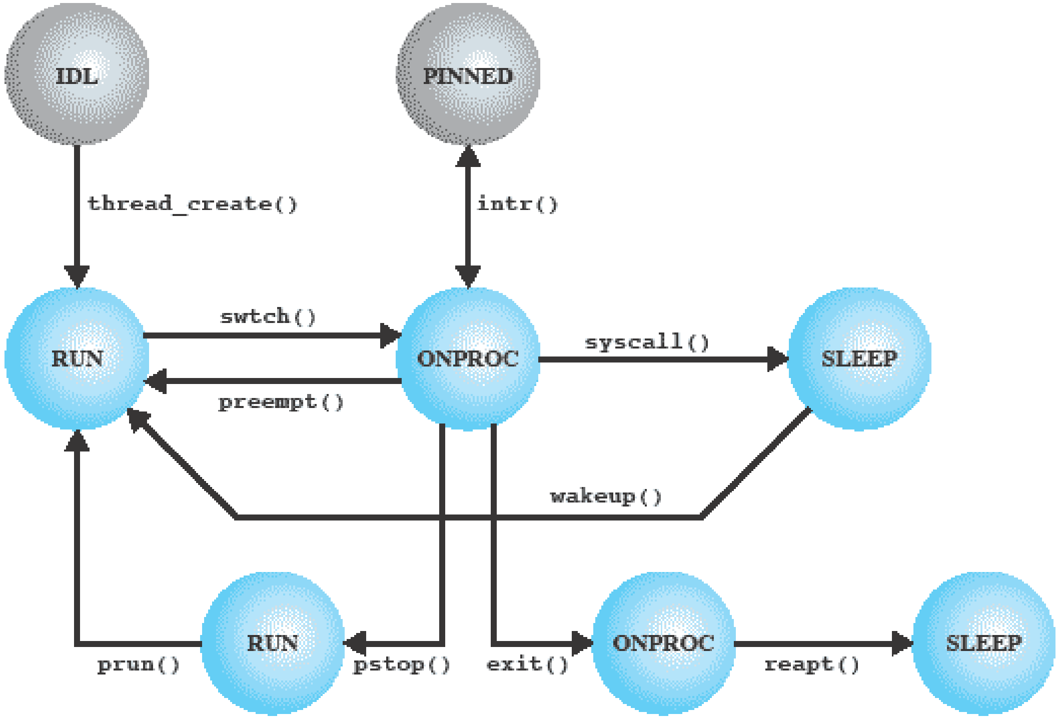


Figure 4.17 Solaris Thread States [MCDO07]

운영체제 사례

- Linux에서의 Process/Thread 모델

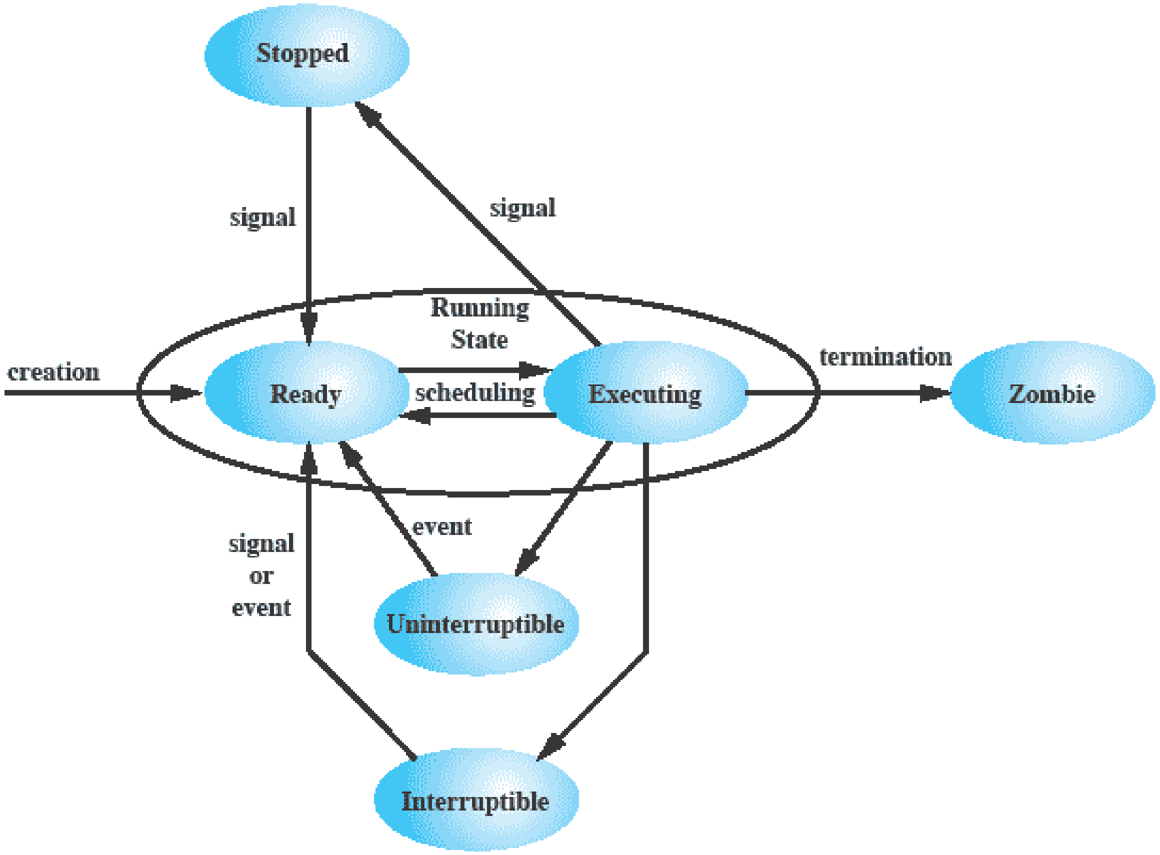
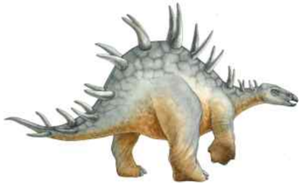
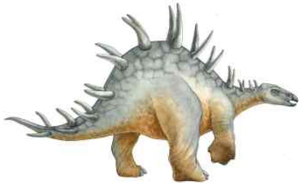


Figure 4.18 Linux Process/Thread Model

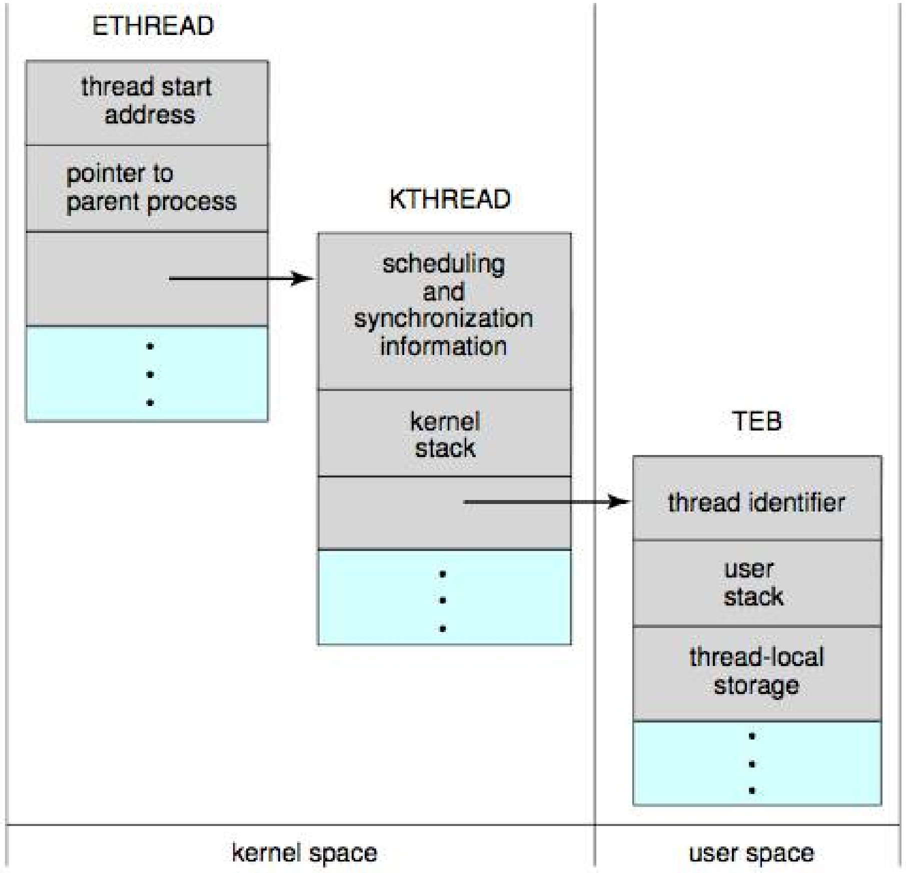


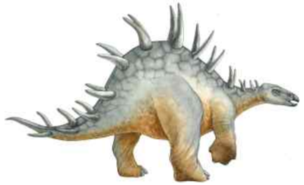
운영체제 사례: Windows XP Threads

- Implements the one-to-one mapping
- Each thread contains
  - A thread id
  - Register set
  - Separate user and kernel stacks
  - Private data storage area
- The register set, stacks, and private storage area are known as the **context** of the threads



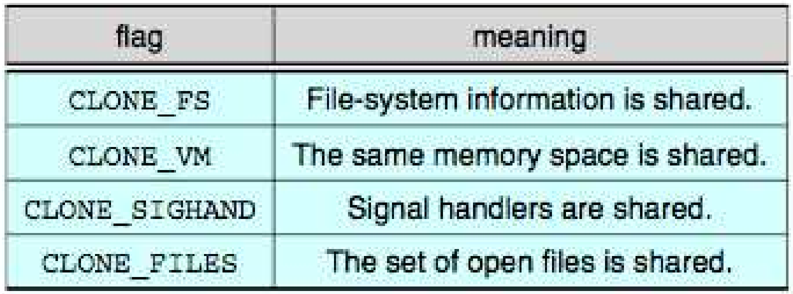
운영체제 사례: Windows XP Threads



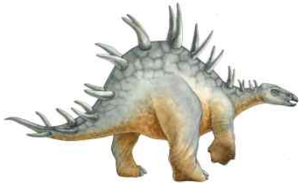


운영체제 사례: Linux Threads

- Linux refers to them as *tasks* rather than *threads*
- Thread creation is done through **clone()** system call
- **clone()** allows a child task to share the address space of the parent task (process)



flag	meaning
CLONE_FS	File-system information is shared.
CLONE_VM	The same memory space is shared.
CLONE_SIGHAND	Signal handlers are shared.
CLONE_FILES	The set of open files is shared.



Thread Programming : Windows(1)

```
#include <stdio.h>
#include <string.h>
#include <windows.h>
#include <process.h>

#define rowA 3
#define colA 4
#define rowB 4
#define colB 5

typedef struct Matrix
{
 int matrixA[rowA][colA];
 int matrixB[rowB][colB];
 int matrixC[rowA][colB];
}Matrix;
unsigned long  thread0, thread1, thread2;
unsigned __stdcall Thread0(void *pParam)//스레드 함수
{
 int nTemp=0, j, k;
 Matrix *mx = (Matrix*)pParam;

 for ( j = 0; j < colB; j++ )
 {
  for ( k = 0; k < colA; k++ )
  {
   nTemp += (mx->matrixA[0][k] * mx->matrixB[k][j]);
  }
  mx->matrixC[0][j] = nTemp;
  nTemp = 0;
 }
 thread0=1;
 return 0;
}
```

Thread Programming : Windows(2)

```
unsigned __stdcall Thread1(void *pParam)//스레드 함수
{
 int nTemp=0, j, k;
 Matrix *mx = (Matrix*)pParam;

 for ( j = 0; j < colB; j++ )
 {
  for ( k = 0; k < colA; k++ )
  {
   nTemp += (mx->matrixA[1][k] * mx->matrixB[k][j]);
  }
  mx->matrixC[1][j] = nTemp;
  nTemp = 0;
 }
 thread1=1;
 return 0;
}

unsigned __stdcall Thread2(void *pParam)//스레드 함수
{
 int nTemp=0, j, k;
 Matrix *mx = (Matrix*)pParam;

 for ( j = 0; j < colB; j++ )
 {
  for ( k = 0; k < colA; k++ )
  {
   nTemp += (mx->matrixA[2][k] * mx->matrixB[k][j]);
  }
  mx->matrixC[2][j] = nTemp;
  nTemp = 0;
 }
 thread2=1;
 return 0;
}
```

행렬곱셈
[3 * 4] * [4 * 5] -> [3*5]에서
[1*5] [1 * 5] [1 * 5]쓰레드를 통해
[3*5] 행렬 계산

Thread Programming : Windows(3)

```
void main()
{
    Matrix mx;

 int i, j;
 for(i = 0; i < rowA; i++)
 {
  for(j = 0; j < colA; j++)
   mx.matrixA[i][j] = 1;
 }

 for(i = 0; i < rowB; i++)
 {
  for(j = 0; j < colB; j++)
   mx.matrixB[i][j] = 2;
 }
 _beginthreadex(NULL, 0, Thread0, &mx, 0, NULL);//스레드 시작
 _beginthreadex(NULL, 0, Thread1, &mx, 0, NULL);//스레드 시작
 _beginthreadex(NULL, 0, Thread2, &mx, 0, NULL);//스레드 시작
 while(1)
 {
  if(thread0 && thread1 && thread2)
  {
   for(i = 0; i < rowA; i++)
   {
    for(j = 0; j < colB; j++)
     printf("%d ", mx.matrixC[i][j]);
    printf("\n");
   }
   break;
  }
 }
}
```

예제 : Thread Echo Server

```
/****************************************************************************/
/*** echo-thread.c                                                       ***/
/***                                                                   ***/
/*** An echo server using threads.                                          ***/
/****************************************************************************/
#include <stdlib.h>
#include <errno.h>
#include <unistd.h>
#include <string.h>
#include <sys/wait.h>
#include <sys/socket.h>
#include <resolv.h>
#include <arpa/inet.h>
#include <pthread.h>

void PANIC(char* msg);
#define PANIC(msg)  { perror(msg); exit(-1); }

/*---------------------------------------------------------------------*/
/*--- Child - echo servlet                                        ---*/
/*---------------------------------------------------------------------*/
void* Child(void* arg)
{   char line[100];
    int bytes_read;
    int client = *(int *)arg;

    do
    {
        bytes_read = recv(client, line, sizeof(line), 0);
        send(client, line, bytes_read, 0);
    }
    while (strncmp(line, "bye\r", 4) != 0);
    close(client);
    return arg;
}
```

예제 : Thread Echo Server

```
/*------------------------------------------------------------------*/
/*--- main - setup server and await connections (no need to clean  ---*/
/*--- up after terminated children.                         ---*/
/*------------------------------------------------------------------*/
int main(void)
{   int sd;
    struct sockaddr_in addr;

    if ( (sd = socket(PF_INET, SOCK_STREAM, 0)) < 0 )
        PANIC("Socket");
    addr.sin_family = AF_INET;
    addr.sin_port = htons(9999);
    addr.sin_addr.s_addr = INADDR_ANY;
    if ( bind(sd, (struct sockaddr*)&addr, sizeof(addr)) != 0 )
        PANIC("Bind");
    if ( listen(sd, 20) != 0 )
        PANIC("Listen");
    while (1)
    {   int client, addr_size = sizeof(addr);
        pthread_t child;

        client = accept(sd, (struct sockaddr*)&addr, &addr_size);
        printf("Connected: %s:%d\n", inet_ntoa(addr.sin_addr), ntohs(addr.sin_port));
        if ( pthread_create(&child, NULL, Child, &client) != 0 )
            perror("Thread creation");
        else
            pthread_detach(child);  /* disassociate from parent */
    }
    return 0;
}
```