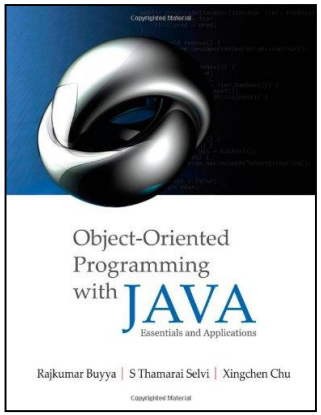
中国科学院深圳先进技术研究院
SHENZHEN INSTITUTE OF ADVANCED TECHNOLOGY
CHINESE ACADEMY OF SCIENCES

# OS Support for Building Distributed Applications: Multithreaded Programming using Java Threads

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四山旗似晴霞卷，万马蹄如骤雨来。
——（清）徐珽

# Review


Sockets

Q1. Briefly discuss three aspects of the Socket interface.

# Review

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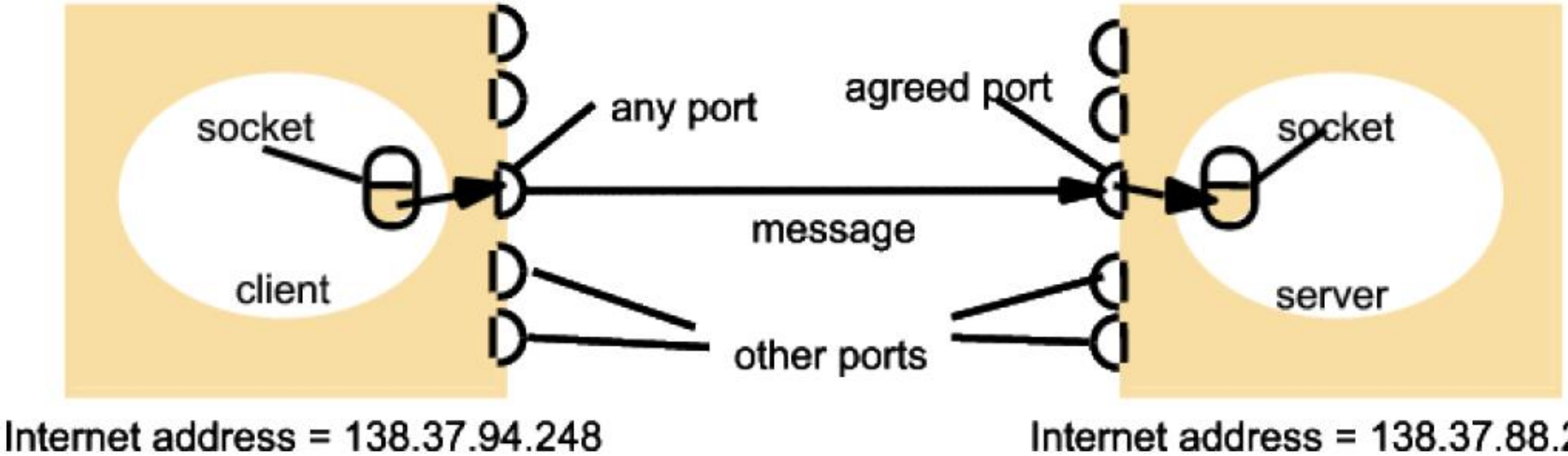

# Review


## Sockets

Q1. Briefly discuss three aspects of the Socket interface.

- Receiver process is bound to a local port.
- Socket can be used for sending and receiving.
- Each socket is associated with a protocol (UDP or TCP).

# Review

UDP vs TCP

# Review


## UDP vs TCP

## UDP: User Datagram Protocol

- Provides a message passing abstraction.
- Is the simplest form of Interprocess Communication (IPC).
- Transmits a single message (called a datagram) to the receiving process.

## TCP: Transmission Control Protocol

- Provides an abstraction for a two-way stream.
- Streams do not have message boundaries.
- Stream provide the basis for producer/consumer communication.
- Data sent by the producer are queued until the consumer is ready to receive them.
- The consumer must wait when no data is available.

# Review

UDP vs TCP

Q2. Briefly explain three possible failures that can happen when using UDP for communication.

# Review

UDP vs TCP

Q2. Briefly explain three possible failures that can happen when using UDP for communication.

- Data Corruption.
- Omission failures.
- Order.

# Review

UDP vs TCP

Q3. Briefly explain three aspects of TCP that address issues not addressed by UDP.

# Review

## UDP vs TCP

# Q3. Briefly explain three aspects of TCP that address issues not addressed by UDP.

- **Message sizes:** There is no limit on data size applications can use.
- **Lost messages:** TCP uses an acknowledgment scheme unlike UDP. If acknowledgments are not received the messages are retransmitted.
- **Flow control:** TCP protocol attempts to match the speed of the process that reads the message and writes to the stream.
- **Message duplication or ordering:** Message identifiers are associated with IP packets to enable the recipient to detect and reject duplicates and reorder messages in case messages arrive out of order.
- **Message destinations:** The communicating processes establish a connection before communicating. The connection involves a connect request from the client to the server followed by an accept request from the server to the client.

# Review

UDP vs TCP

Q4. List the steps involved at the client and at the server to establish a TCP stream socket connection.

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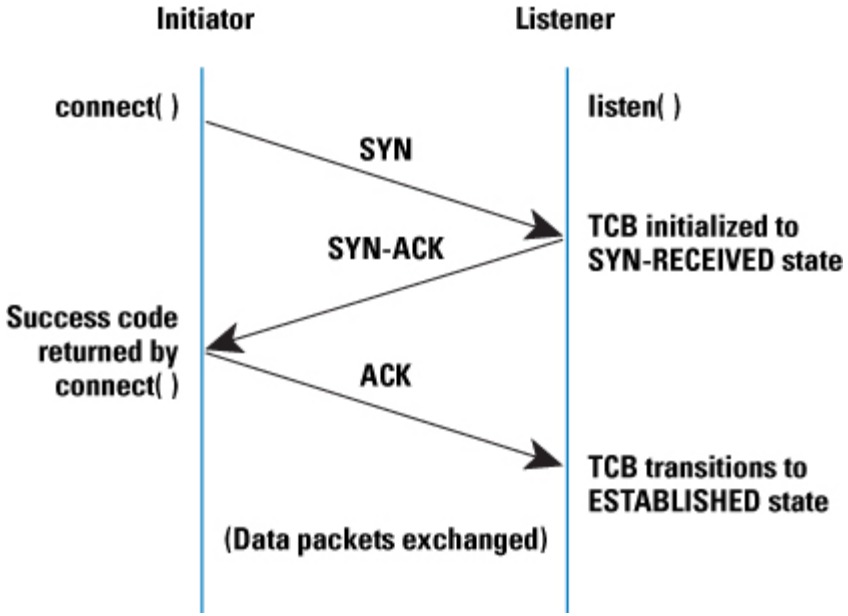
UDP vs TCP

Q4. List the steps involved at the client and at the server to establish a TCP stream socket connection.

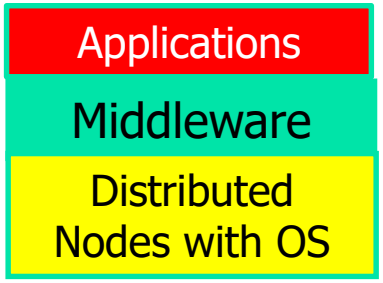


# Outline


- Introduction to Middleware
- Thread Applications
- Defining Threads
- Java Threads and States
- Architecture of Multithreaded servers
- Threads Synchronization
- Summary

# Introduction

- Middleware is a layer of software (system) between Applications and Operating System (OS) powering the nodes of a distributed system.
- The OS facilitates:
  - Encapsulation and protection of resources inside servers;
  - Invocation of mechanisms required to access those resources including concurrent access/processing.

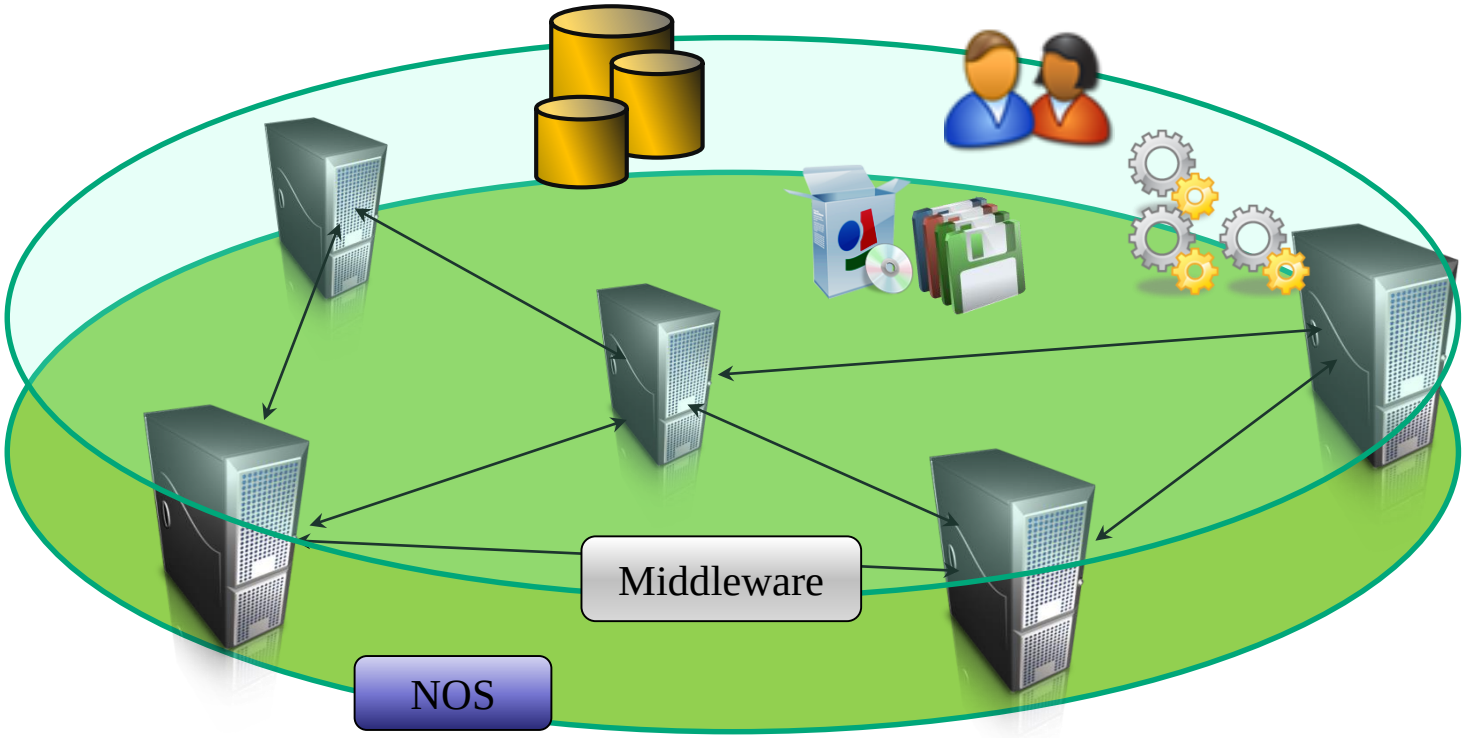


# Middleware and Network Operating System (NOS)

- Many DOS (Distributed OS) have been investigated, but there are none in general/wide use. But NOS are in wide use for various reasons both technical and non-technical.
  - Users have much invested in their application software; they will not adopt a new OS that will not run their applications.
  - Users tend to prefer to have a degree of autonomy of their machines, even in a closely knit organisation.
- A combination of middleware and NOSs provides an acceptable balance between the requirement of autonomy and network transparency.
  - NOS allows users to run their favorite word processor.
  - Middleware enables users to take advantage of services that become available in their distributed systems.

# Introducing a middleware

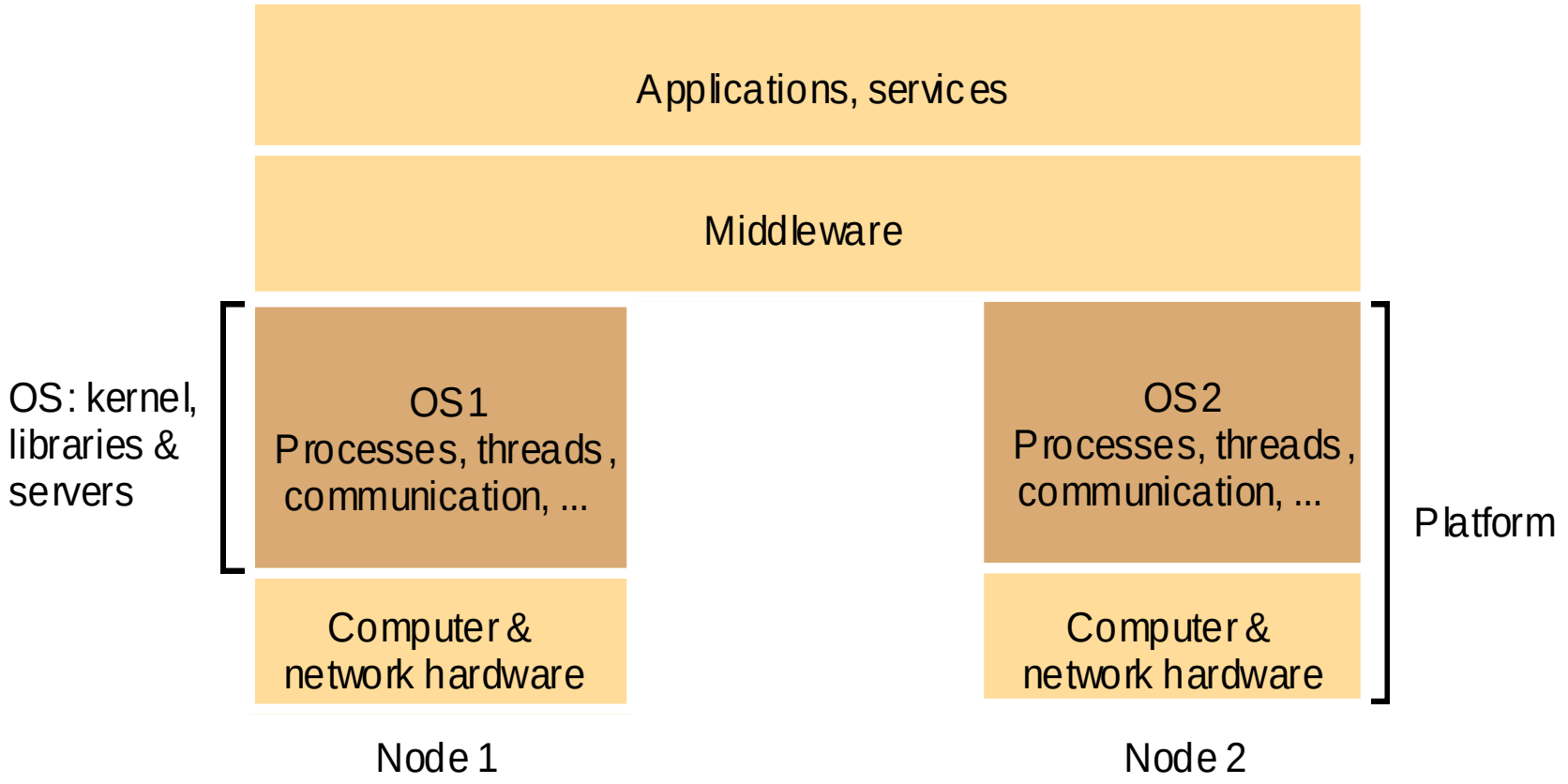
- Building Distributed Systems
  - DOS or NOS are not enough to build a DS!
  - NOS are a good starting point but ….
  - … we need an additional layer "gluing" all together



# Building Distributed Systems

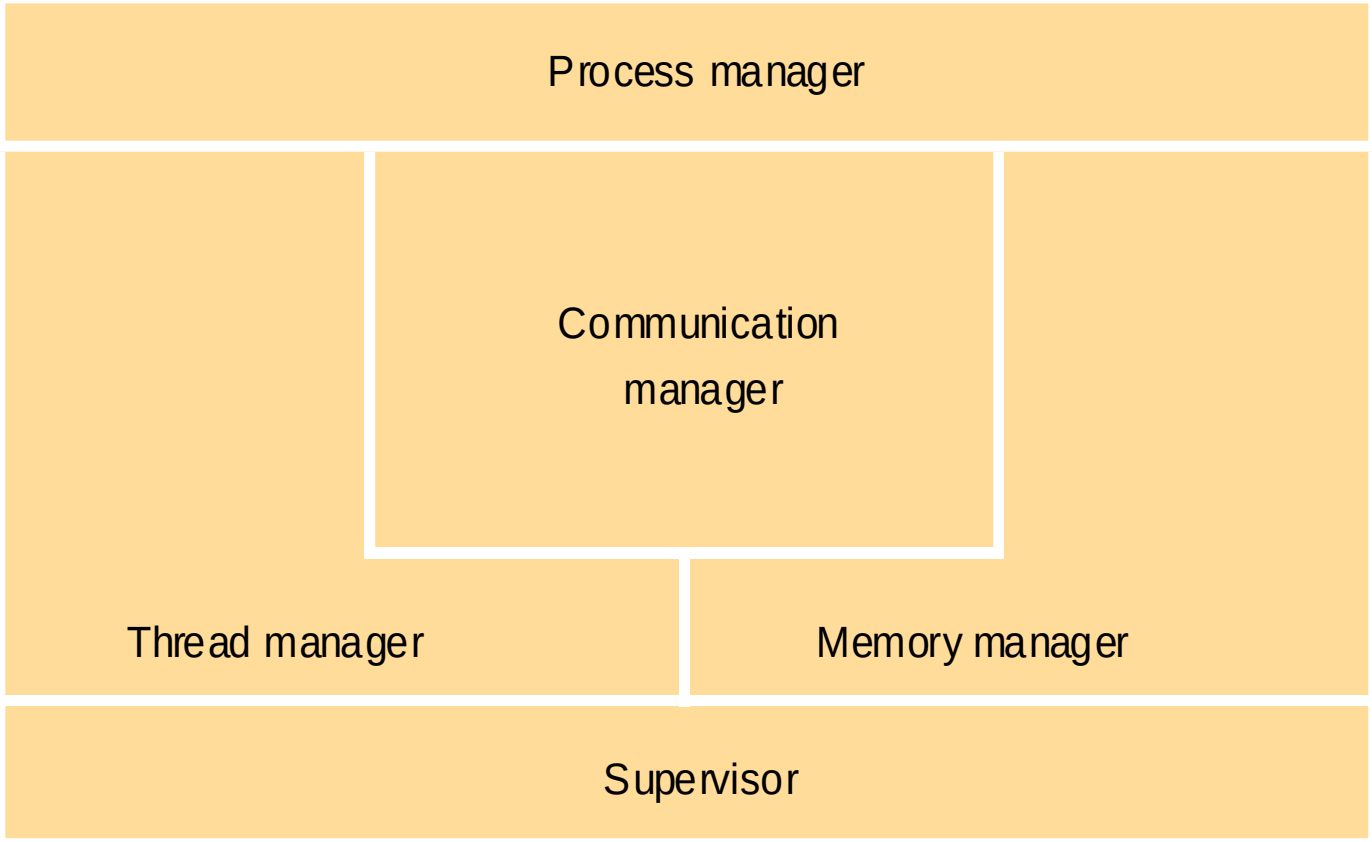

- Middleware
  - High-level features for DS
    - Communication
    - Management
    - Application specific
  - Uniform layer where to build DS services
  - Runtime environment of applications
- Operating System
  - Low / medium level (core)  features
    - Process / threads management
    - Local hardware (CPU, disk, memory)
    - Security (users, groups, domain, ACLs)
    - Basic networking

# Operating system layers and Middleware




- Unix and Windows are two examples of Network Operating Systems – have a networking capability built into them and so can be used to access remote resources using basic services such as rlogin, telnet.

# Core OS components and functionality

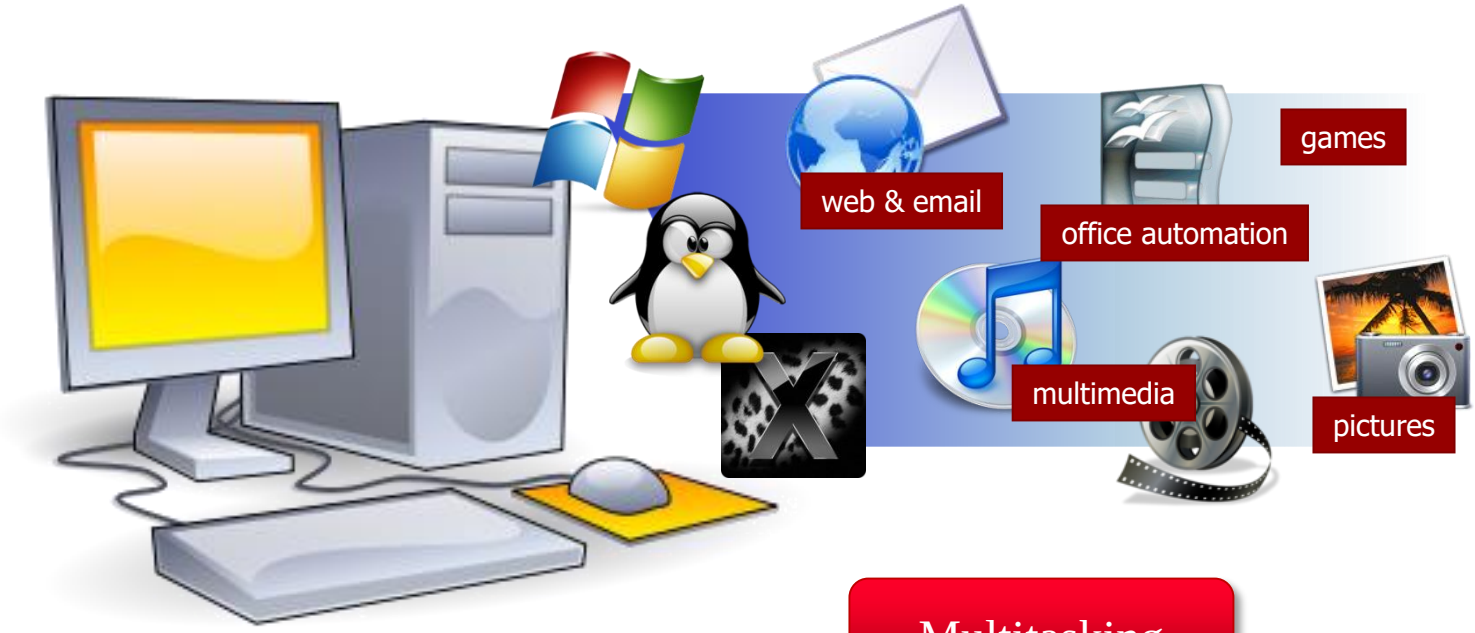


# Threaded Applications

- Modern Applications and Systems
  - Operating System Level
    - Multitasking: multiple applications running at once
  - Application Level
    - Multithreading: multiple operations performed at the same time within an application.
  - Bottom Line:
    - Illusion of concurrency

# Threaded Applications

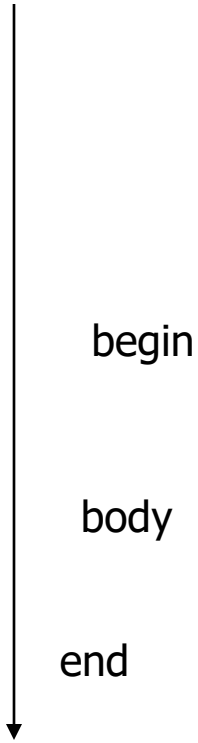
- Modern Systems
  - Multiple applications run concurrently!
  - This means that… there are multiple processes on your computer




Multitasking

# A single threaded program

```
class ABC
{
....
    public void main(..)
    {
    ...
    ..
    }
}
```



# Trade-offs involved


- Threads can increase performance
  - Create parallelism on multiprocessors
  - Intuitive way to get concurrent I/O and computation
- Natural fit for some programming paradigms
  - Event processing
  - Simulations
- Trade-off: increased complexity
  - Need to think about safety, liveness, composability
  - Shared heap, complex interleavings
  - Higher resource usage

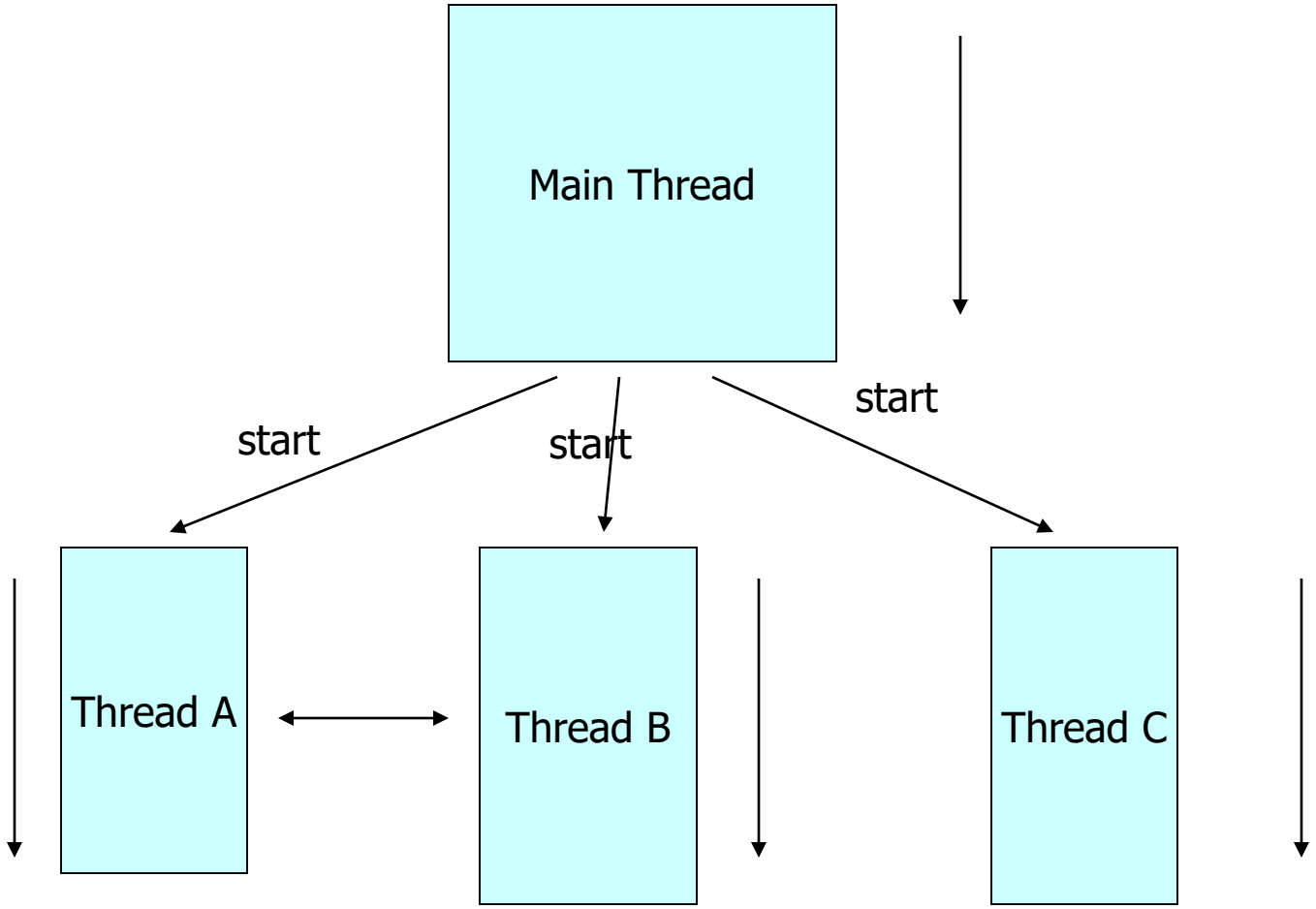
# Thread Programming Model


- Threads exist in many languages
  - C, C++, C#, Java, Smalltalk, F#, . . .
- In many languages (e.g., C, C++) threads a an add-on library
  - Not a part of the language specification
  - Java threads are part of the language specification

# Threaded Applications

- Modern Systems
  - Applications perform many tasks at once!
  - This means that… there are multiple threads within a single process.

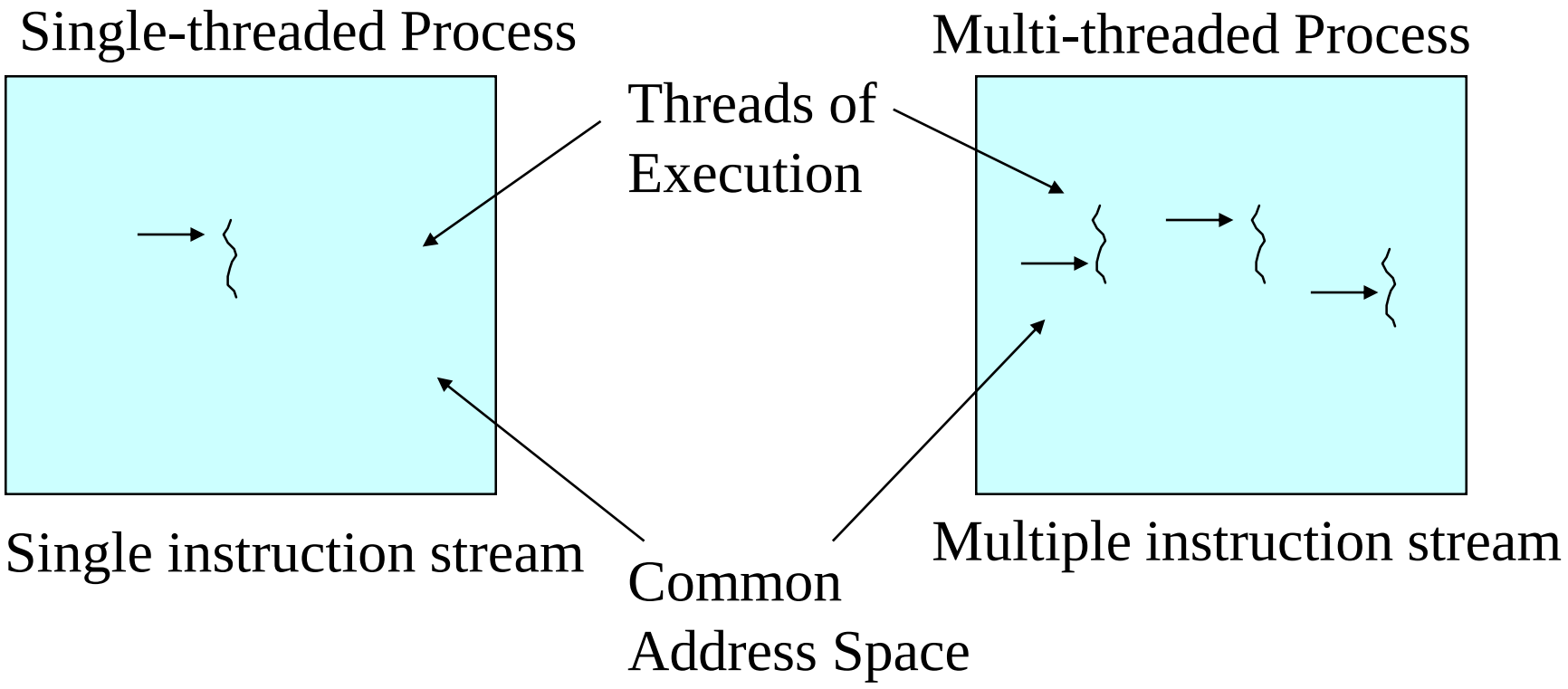
# A Multithreaded Program




Threads may switch or exchange data/results

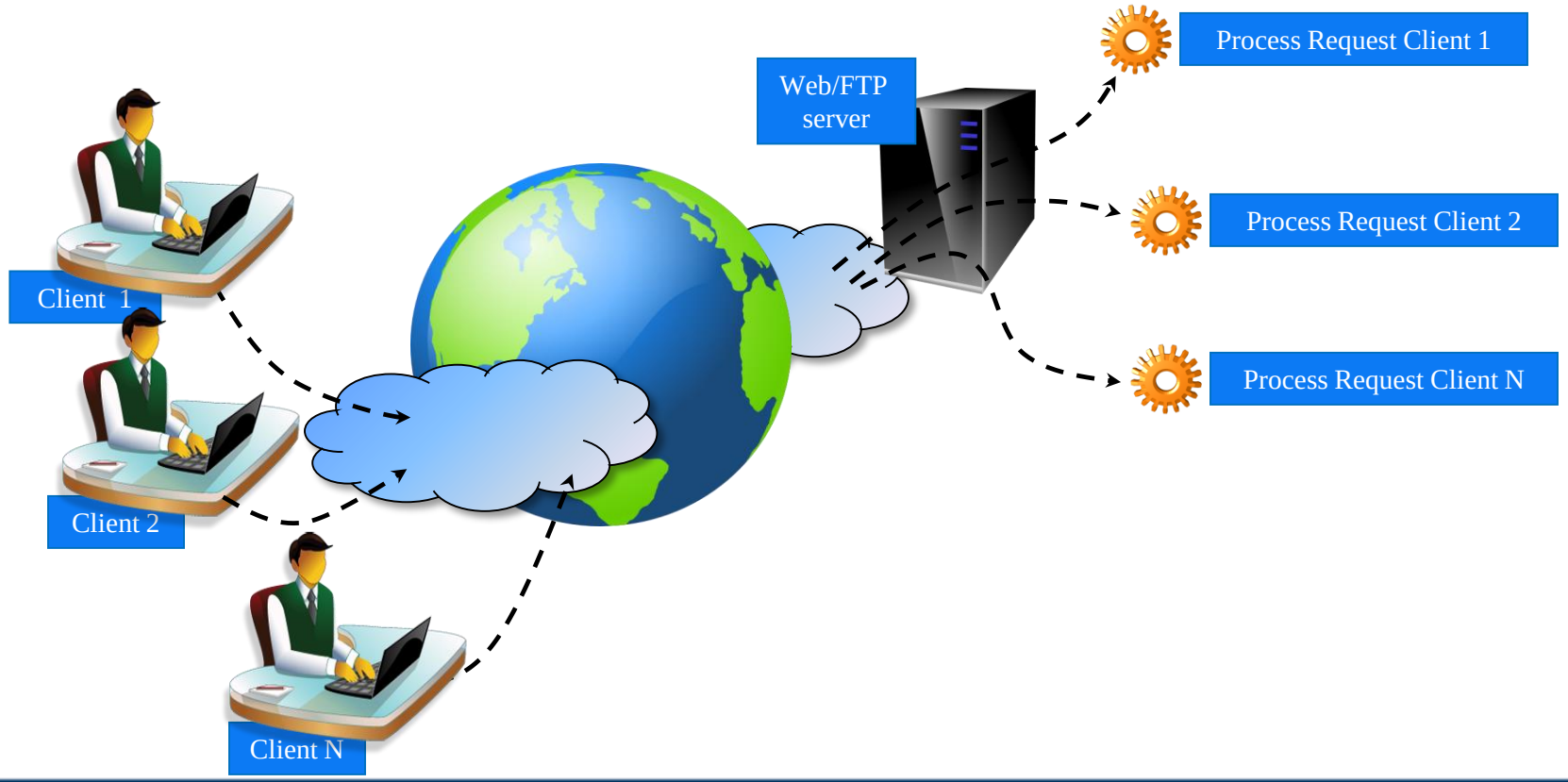
# Single and Multithreaded Processes

threads are light-weight processes within a process



# Multithreaded Server: For Serving Multiple Clients Concurrently

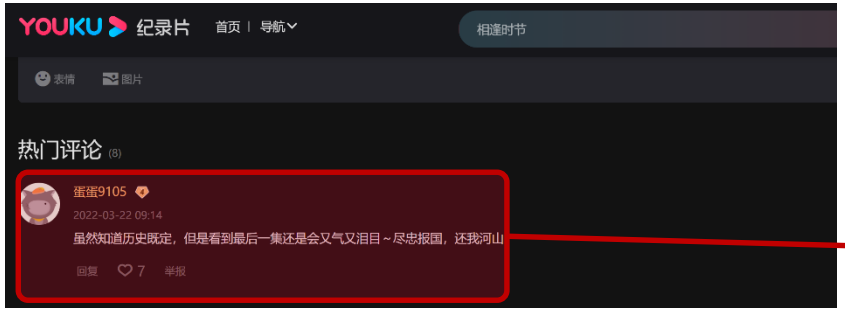
- Modern Applications
  - Example: Multithreaded Web Server



# Threaded Applications

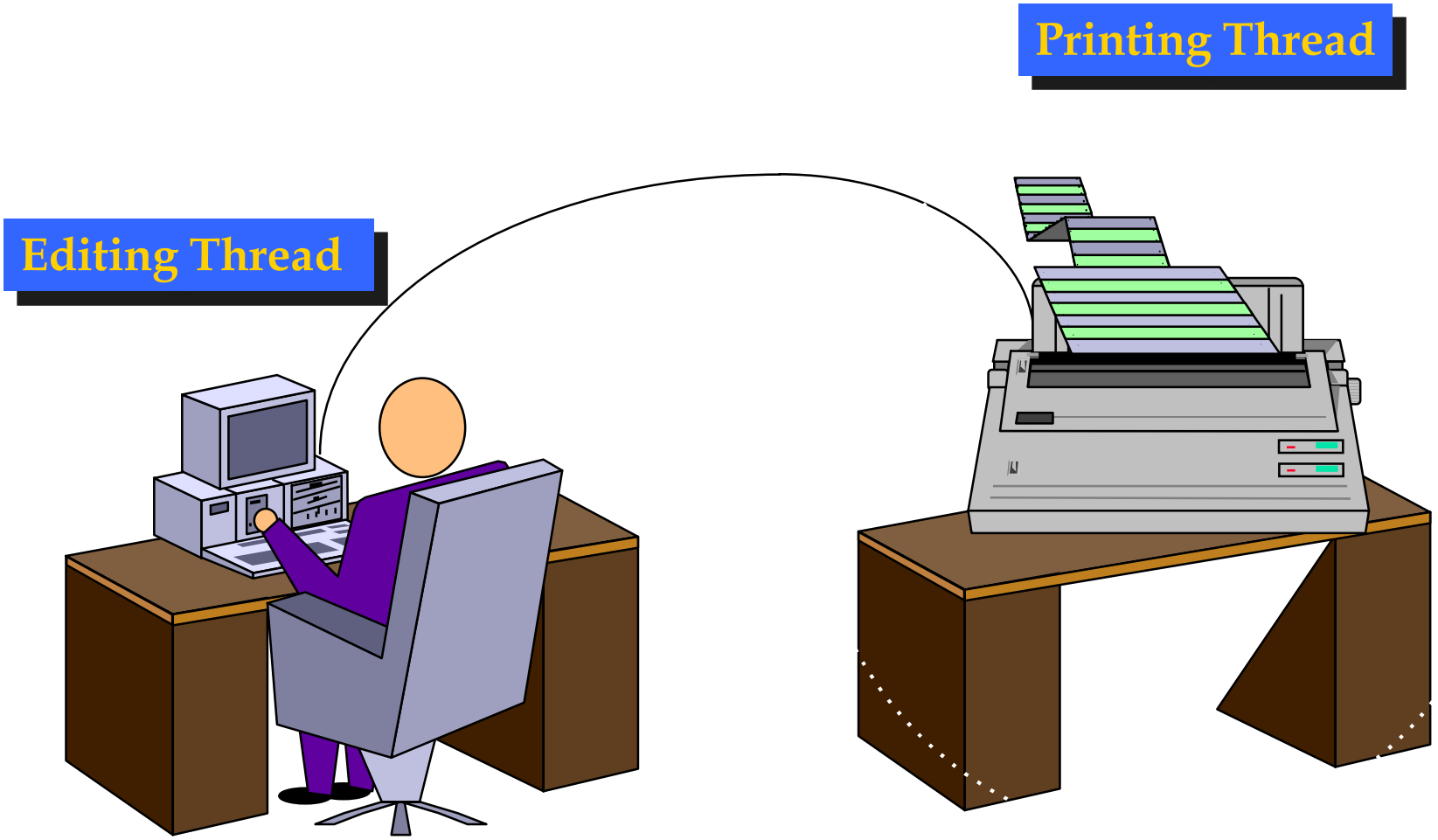
- Modern Applications
  - Example: Internet Browser + YouKu


Video Streaming

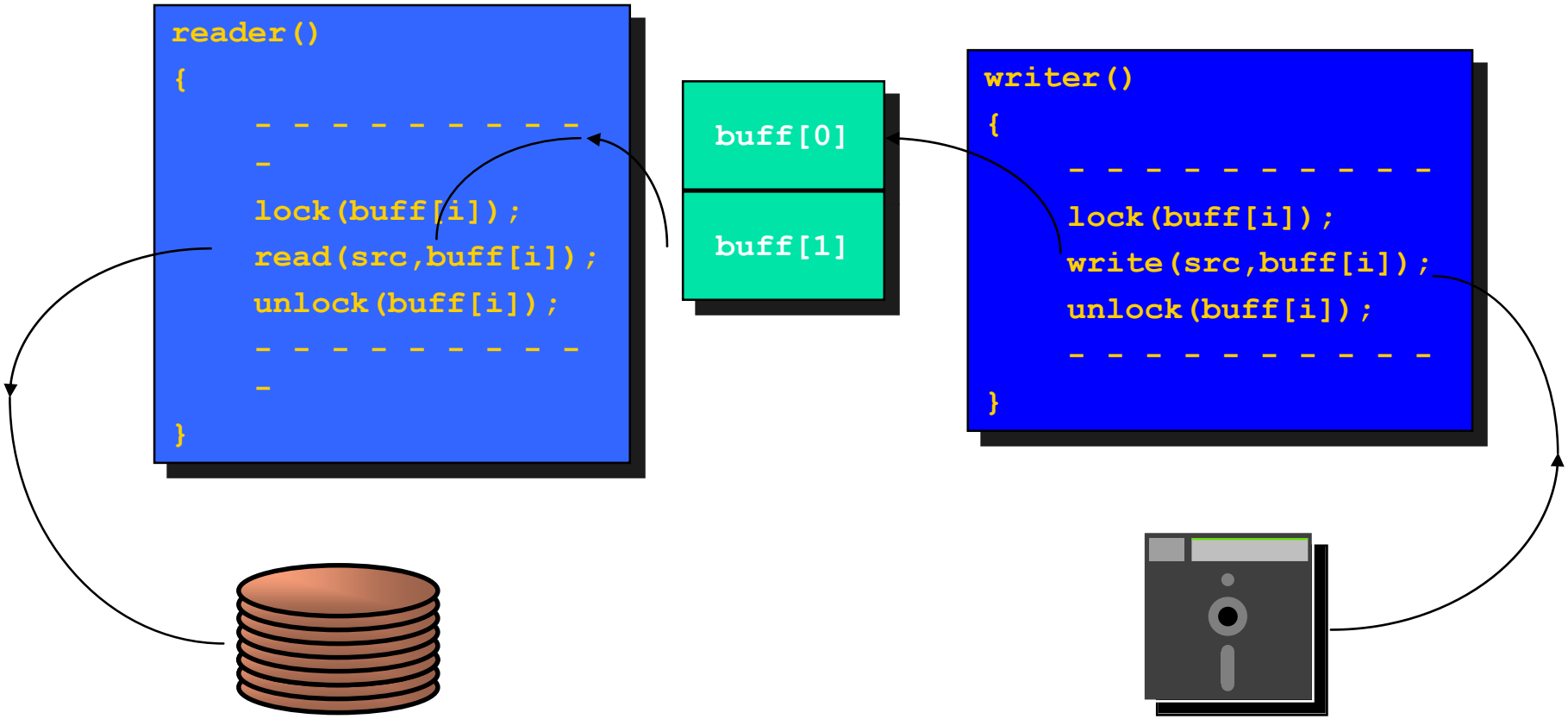



Favorities, Share, Comments Posting

# Modern Applications need Threads (ex1): Editing and Printing documents in background.



# Multithreaded/Parallel File Copy



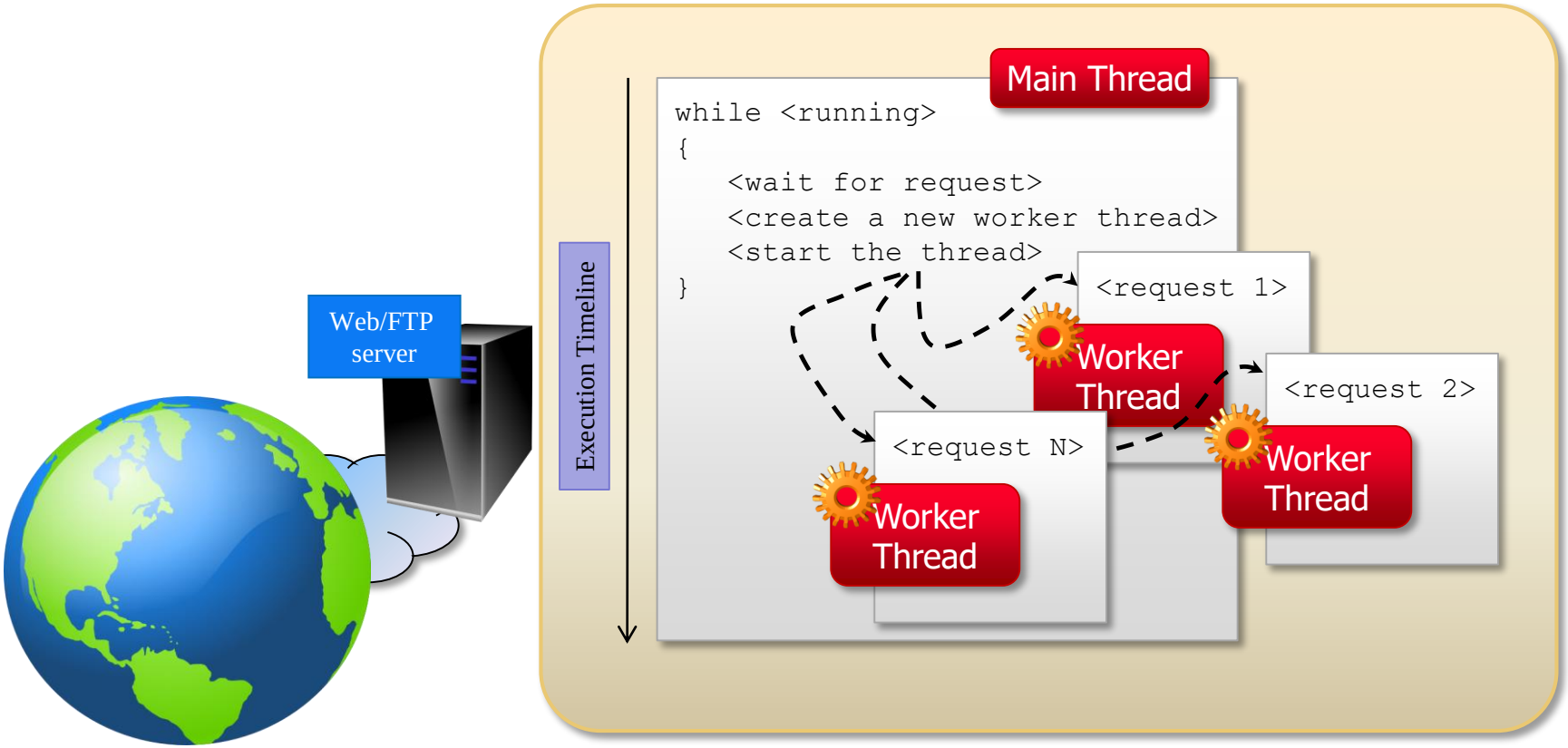

**Cooperative Parallel Synchronized Threads**

# Defining Threads


- Applications – Threads are used to perform:
  - Parallelism and concurrent execution of independent tasks / operations.
  - Implementation of reactive user interfaces.
  - Non blocking I/O operations.
  - Asynchronous behavior.
  - Timer and alarms implementation.

# Defining Threads

- Example: Web/FTP Server



# Defining Threads

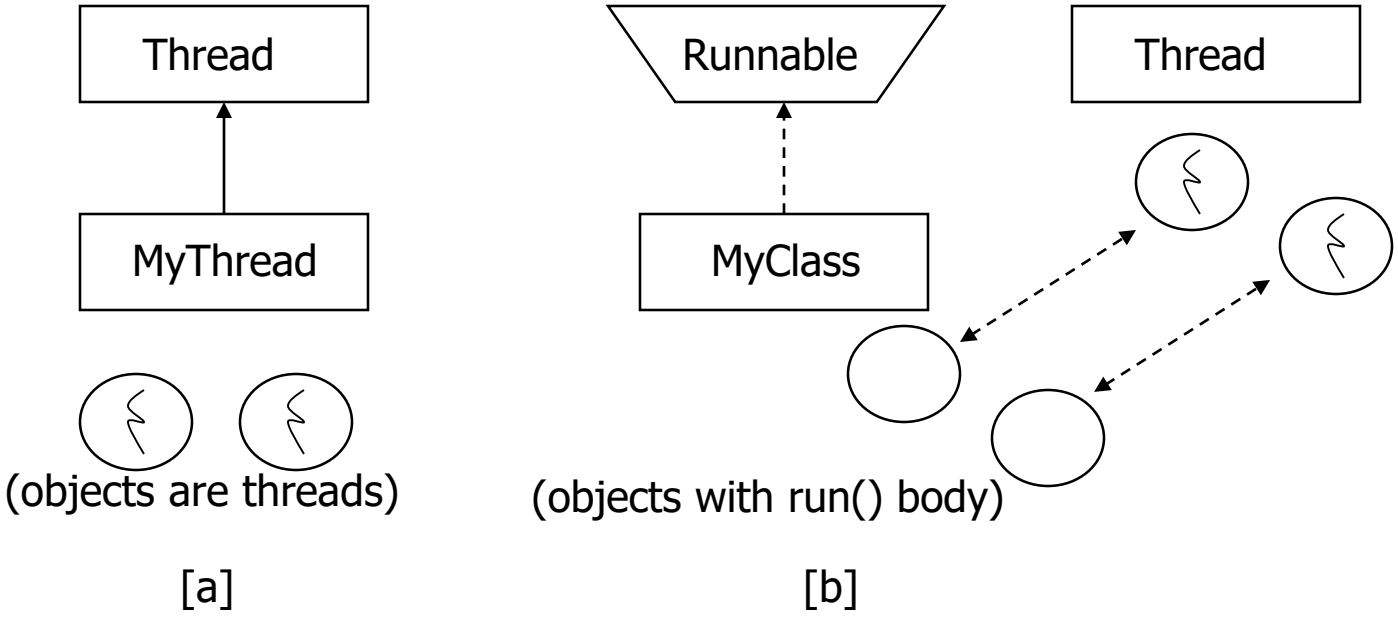

- A Thread is a piece of code that runs in concurrent with other threads.
- Each thread is a statically ordered sequence of instructions.
- Threads are used to express concurrency on both single and multiprocessors machines.
- Programming a task having multiple threads of control – Multithreading or Multithreaded Programming.

# Java Threads


- Java has built in support for Multithreading
- Synchronization
- Thread Scheduling
- Inter-Thread Communication:
  - currentThread
  - yield
  - sleep
  - resume
  - start
  - run
  - stop
  - setPriority
  - getPriority
  - suspend
- Java Garbage Collector is a low-priority thread.

# Threading Mechanisms...

- Create a class that extends the Thread class
- Create a class that implements the Runnable interface



# 1st method: Extending Thread class

- Create a class by extending Thread class and override run() method:

```
class MyThread extends Thread
{
     public void run()
    {
        // thread body of execution
    }
}
```

- Create a thread:

```
MyThread thr1 = new MyThread();
```

- Start Execution of threads:

```
thr1.start();
```

- Create and Execute:

```
new MyThread().start();
```

# An example

```
class MyThread extends Thread {
        public void run() {
                System.out.println(" this thread is running ... ");
        }
}

class ThreadEx1 {
        public static void main(String [] args  ) {
            MyThread t = new MyThread();
             t.start();
       }
}
```

# 2nd method: Threads by implementing Runnable interface


- Create a class that implements the interface Runnable and override run() method:

```
class MyThread implements Runnable
{
   .....
   public void run()
   {
      // thread body of execution
   }
}
```

- Creating Object:

```
MyThread myObject = new MyThread();
```

- Creating Thread Object:

```
Thread thr1 = new Thread( myObject );
```

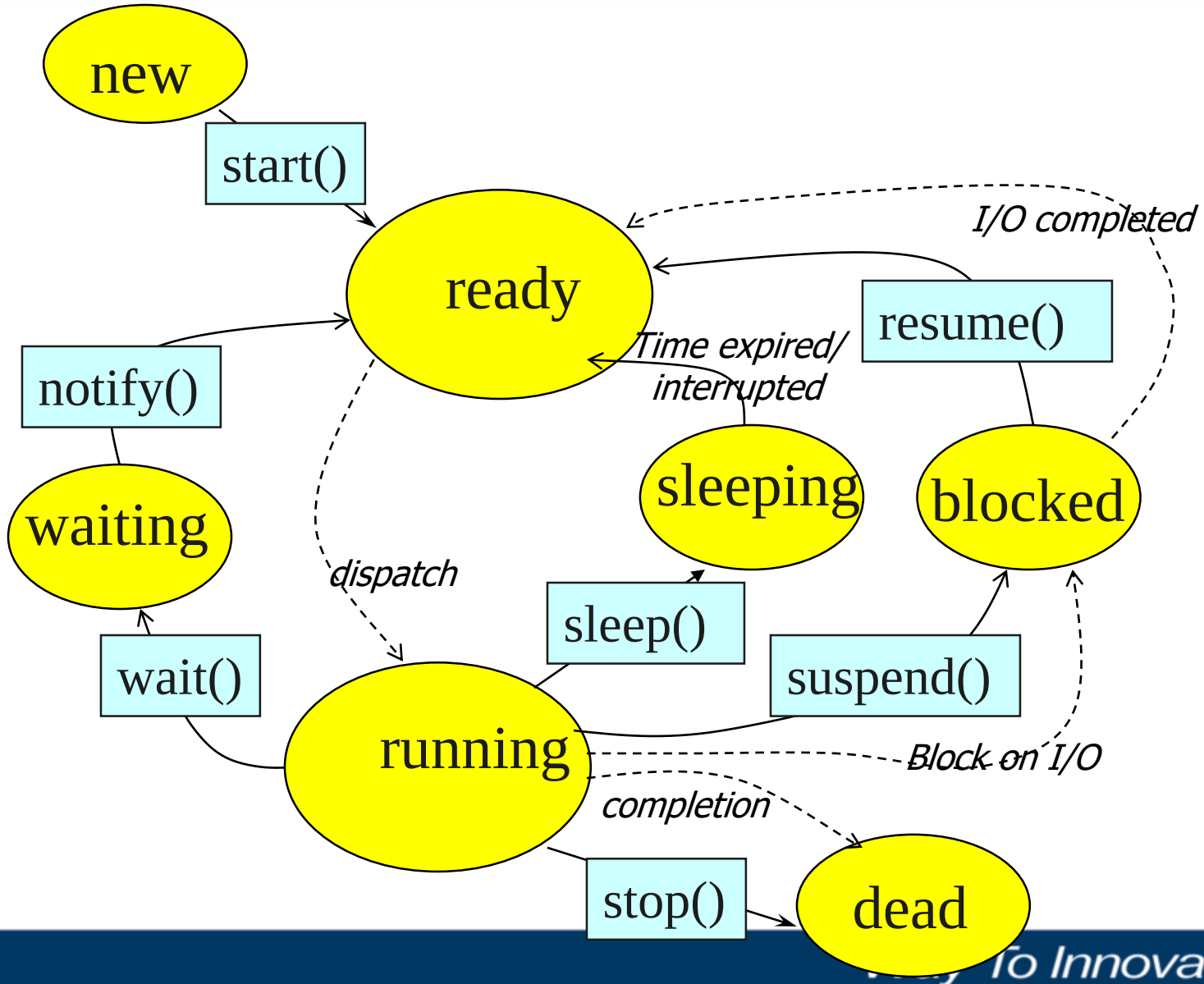
- Start Execution:

```
thr1.start();
```

# An example

```
class MyThread implements Runnable  {
        public void run() {
                System.out.println(" this thread is running ... ");
        }
}

class ThreadEx2 {
        public static void main(String [] args  ) {
                Thread t = new Thread(new MyThread());
                 t.start();
        }
}
```

# Life Cycle of Thread



# A Program with Three Java Threads


- Write a program that creates 3 threads

# Three threads example

```
class A extends Thread
{
    public void run()
    {
        for(int i=1;i<=5;i++)
        {
            System.out.println("\t From ThreadA: i= "+i);
        }
        System.out.println("Exit from A");
    }
}

class B extends Thread
{
    public void run()
    {
        for(int j=1;j<=5;j++)
        {
            System.out.println("\t From ThreadB: j= "+j);
        }
        System.out.println("Exit from B");
    }
}
```

# Three threads example

```
class C extends Thread
{
    public void run()
    {
        for(int k=1;k<=5;k++)
        {
            System.out.println("\t From ThreadC: k= "+k);
        }

        System.out.println("Exit from C");
    }
}

class ThreadTest
{
    public static void main(String args[])
    {
        new A().start();
        new B().start();
        new C().start();
    }
}
```

# Run 1


- [mx@msiat] threads [1:76] java ThreadTest

```
        From ThreadA: i= 1
        From ThreadA: i= 2
        From ThreadA: i= 3
        From ThreadA: i= 4
        From ThreadA: i= 5
Exit from A
        From ThreadC: k= 1
        From ThreadC: k= 2
        From ThreadC: k= 3
        From ThreadC: k= 4
        From ThreadC: k= 5
Exit from C
        From ThreadB: j= 1
        From ThreadB: j= 2
        From ThreadB: j= 3
        From ThreadB: j= 4
        From ThreadB: j= 5
Exit from B
```

# Run 2


- [mx@siat] threads [1:77] java ThreadTest

```
        From ThreadA: i= 1
        From ThreadA: i= 2
        From ThreadA: i= 3
        From ThreadA: i= 4
        From ThreadA: i= 5
        From ThreadC: k= 1
        From ThreadC: k= 2
        From ThreadC: k= 3
        From ThreadC: k= 4
        From ThreadC: k= 5
Exit from C
        From ThreadB: j= 1
        From ThreadB: j= 2
        From ThreadB: j= 3
        From ThreadB: j= 4
        From ThreadB: j= 5
Exit from B
Exit from A
```

# Thread Priority

- In Java, each thread is assigned priority, which affects the order in which it is scheduled for running. The threads so far had same default priority (NORM_PRIORITY) and they are served using FCFS policy.
  - Java allows users to change priority:
    - ThreadName.setPriority(intNumber)
      - MIN_PRIORITY = 1
      - NORM_PRIORITY=5
      - MAX_PRIORITY=10

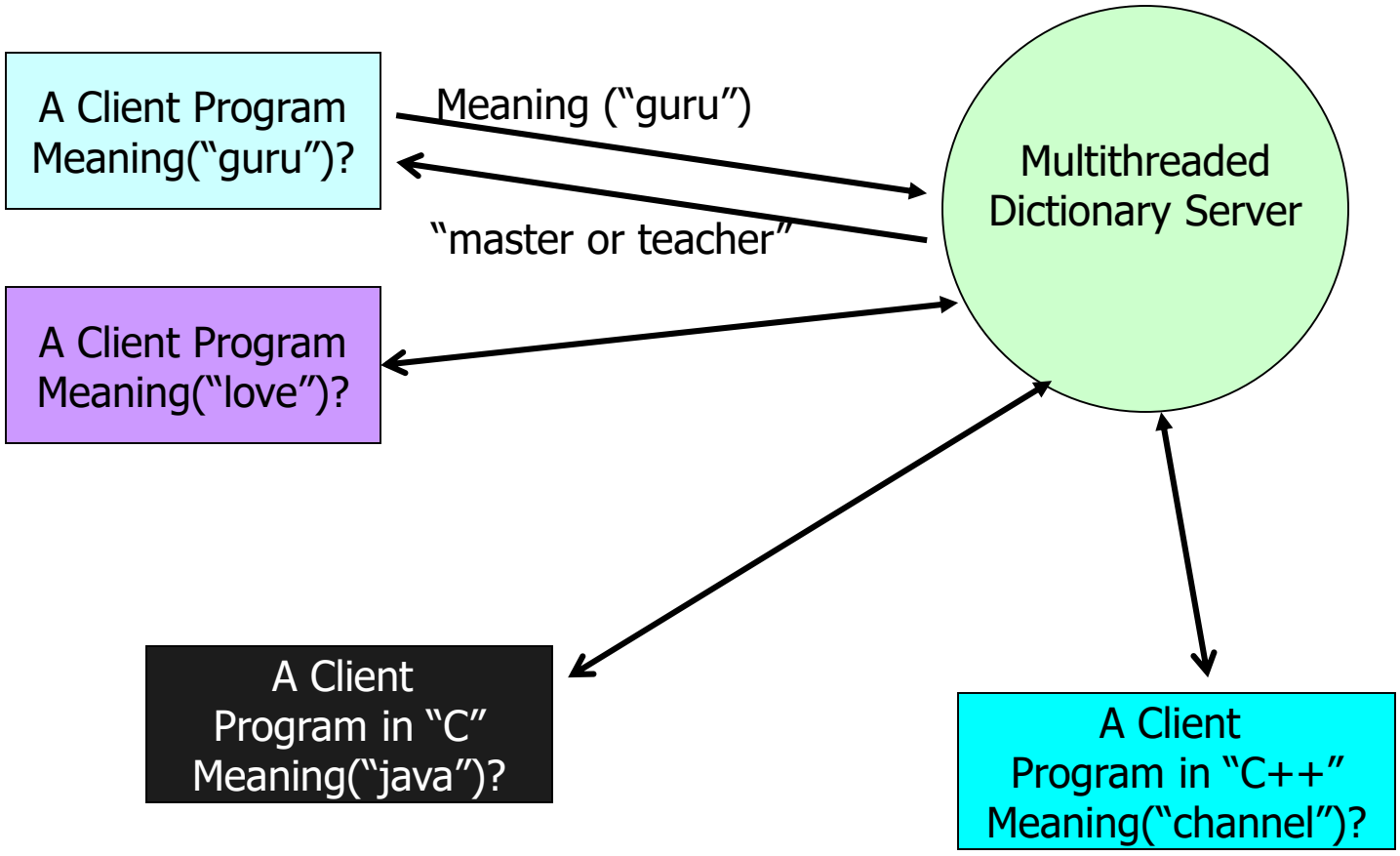
# Thread Priority Example

```
class A extends Thread
{
      public void run()
       {
           System.out.println("Thread A started");
           for(int i=1;i<=4;i++)
            {
                 System.out.println("\t From ThreadA: i= "+i);
            }
             System.out.println("Exit from A");
       }
}
class B extends Thread
{
      public void run()
       {
           System.out.println("Thread B started");
           for(int j=1;j<=4;j++)
            {
                 System.out.println("\t From ThreadB: j= "+j);
            }
             System.out.println("Exit from B");
       }
}
```

# Thread Priority Example

```
class C extends Thread
{
      public void run()
       {
           System.out.println("Thread C started");
           for(int k=1;k<=4;k++)
            {
                 System.out.println("\t From ThreadC: k= "+k);
            }
             System.out.println("Exit from C");
       }
}
class ThreadPriority
{
        public static void main(String args[])
         {
                  A threadA=new A();
                  B threadB=new B();
                  C threadC=new C();
                threadC.setPriority(Thread.MAX_PRIORITY);
                threadB.setPriority(threadA.getPriority()+1);
                threadA.setPriority(Thread.MIN_PRIORITY);
                System.out.println("Started Thread A");
                 threadA.start();
                System.out.println("Started Thread B");
                 threadB.start();
                System.out.println("Started Thread C");
                 threadC.start();
                 System.out.println("End of main thread");
         }
}
```

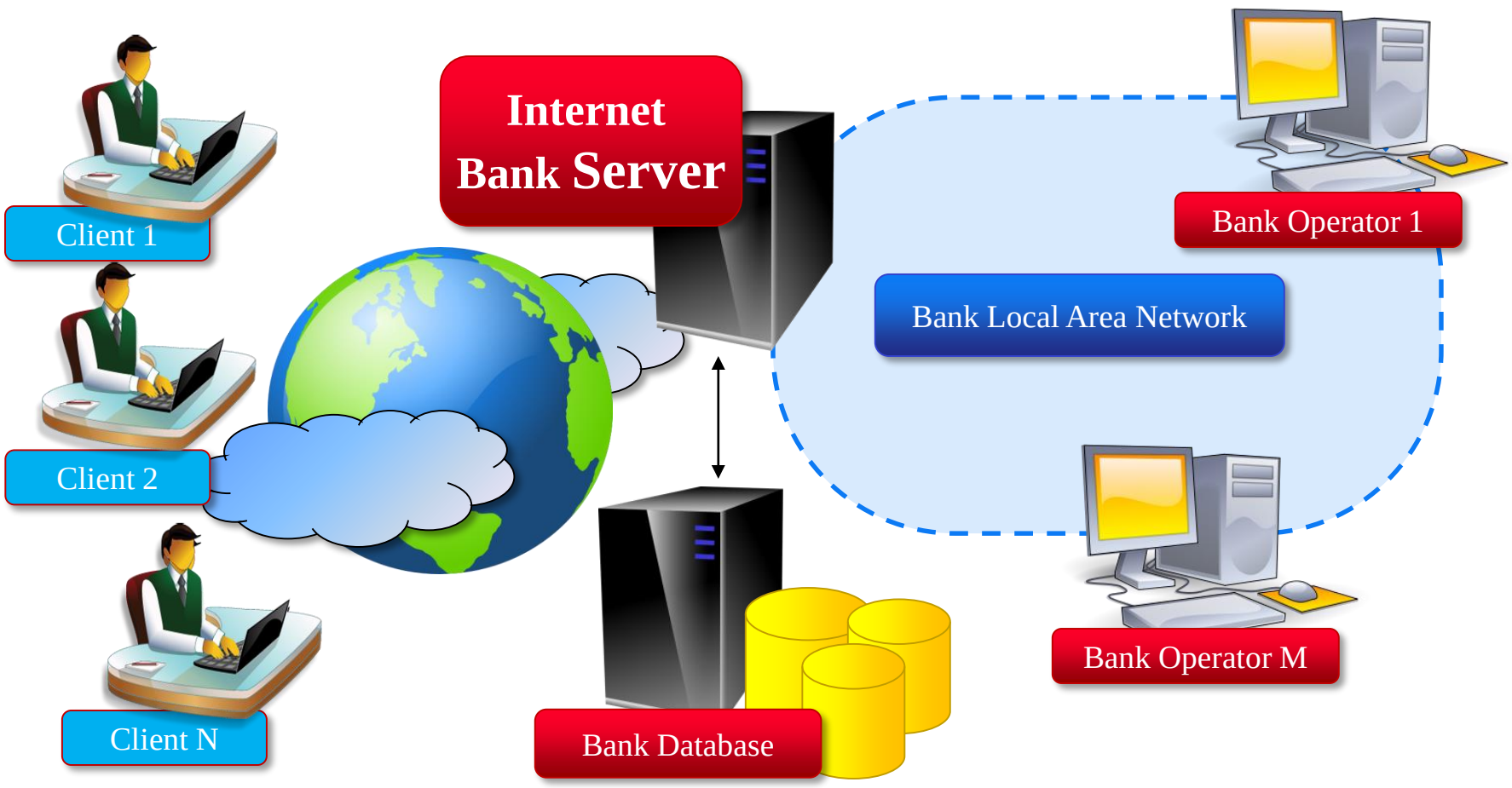
# Assignment 1 at a Glance: Multithreaded Dictionary Server – Using Sockets and Threads



# Accessing Shared Resources


- Applications access to shared resources need to be coordinated.
  - Printer (two person jobs cannot be printed at the same time)
  - Simultaneous operations on your bank account.
  - Can the following operations be done at the same time on the same account?
    - Deposit()
    - Withdraw()
    - Enquire()

# Online Bank: Serving Many Customers and Operations



# Shared Resources

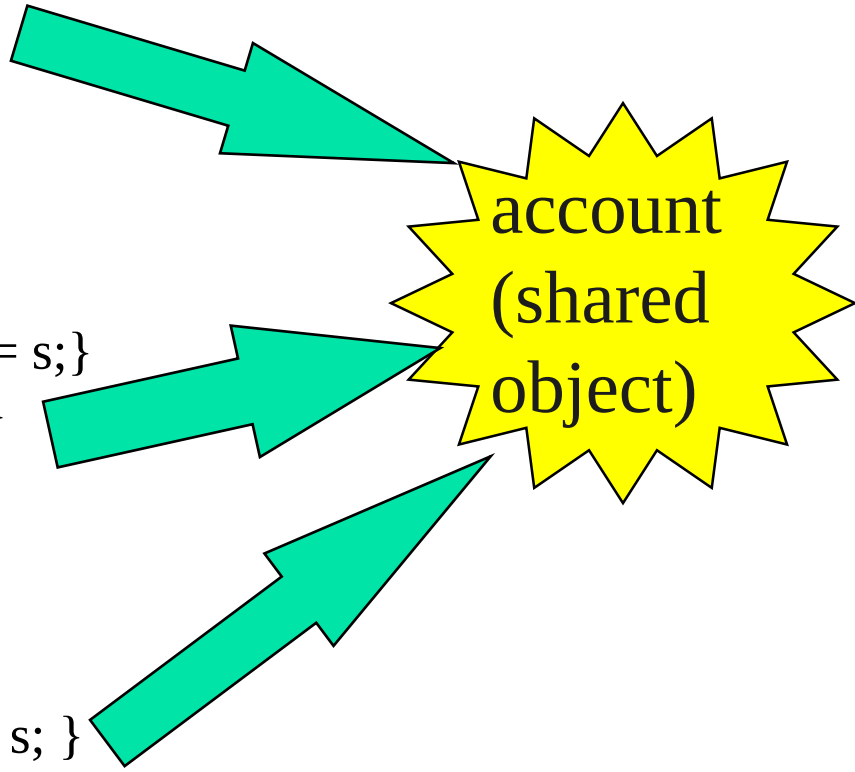
- If one thread tries to read the data and other thread tries to update the same data, it leads to inconsistent state.
- This can be prevented by synchronising access to the data.
- Use "synchronized" method:
  - public synchronized void update()
  - {
    - …
  - }

# the driver: 3 Threads sharing the same object


```
class InternetBankingSystem {
        public static void main(String [] args  ) {
            Account accountObject = new Account ();
            Thread t1 = new Thread(new MyThread(accountObject));
            Thread t2 = new Thread(new YourThread(accountObject));
            Thread t3 = new Thread(new HerThread(accountObject));
            t1.start();
            t2.start();
            t3.start();
          // DO some other operation
       } // end main()
}
```

# Shared account object between 3 threads

```
class MyThread implements Runnable  {
 Account account;
        public MyThread (Account s) {  account = s;}
        public void run() { account.deposit(); }
} // end class MyThread

class YourThread implements Runnable  {
 Account account;
        public YourThread (Account s) { account = s;}
        public void run() { account.withdraw(); }
} // end class YourThread

class HerThread implements Runnable  {
 Account account;
        public HerThread (Account s) { account = s; }
        public void run() {account.enquire(); }
} // end class HerThread
```



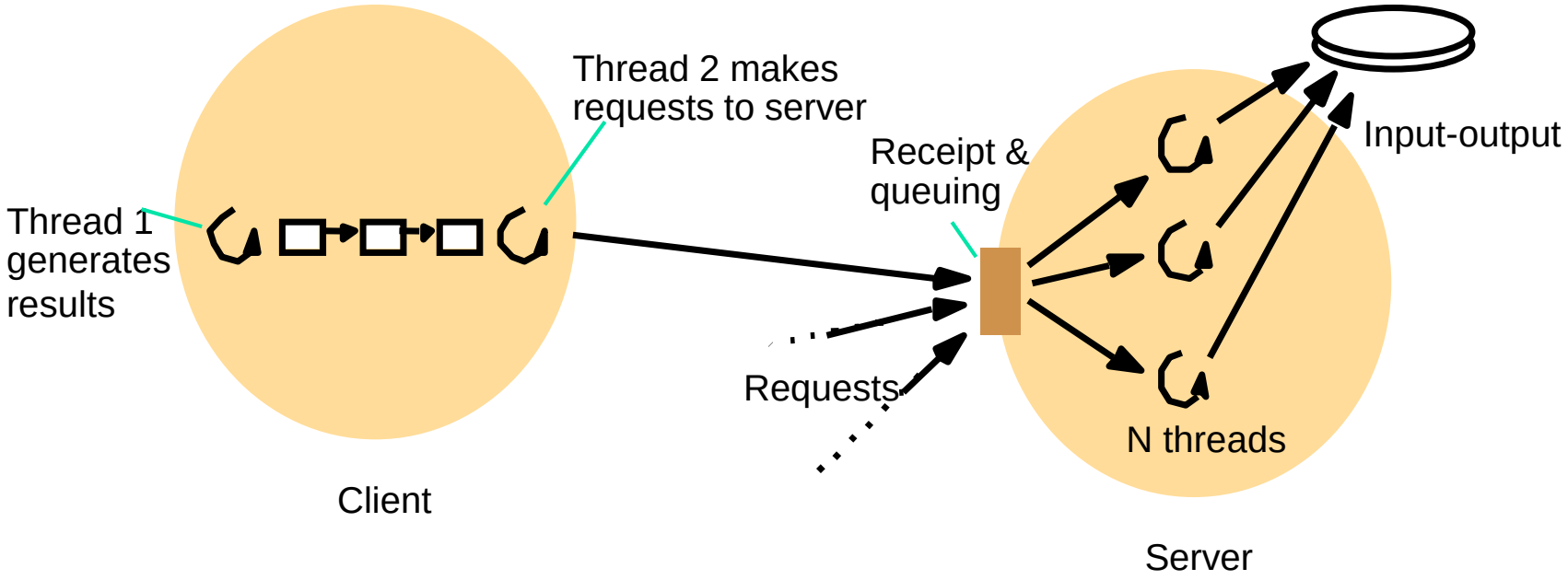
# Monitor (shared object access): serializes operation on shared objects


```
class Account {   // the 'monitor'
   int balance;

      // if 'synchronized' is removed, the outcome is unpredictable
       public synchronized void deposit( ) {
          // METHOD BODY : balance += deposit_amount;
        }

        public synchronized void withdraw( ) {
          // METHOD BODY: balance -= deposit_amount;
        }
        public synchronized void enquire( ) {
          // METHOD BODY: display balance.
        }
}
```

# Architecture for Multithread Servers

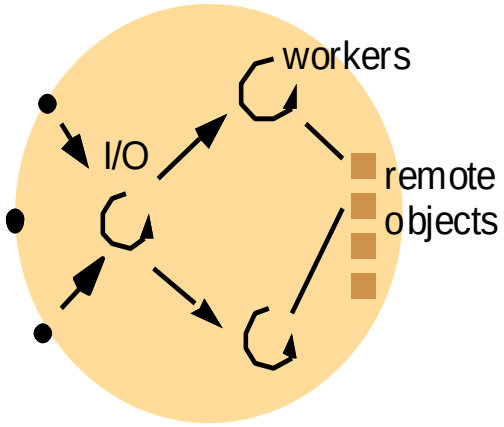

- Multithreading enables servers to maximize their throughput, measured as the number of requests processed per second.
- Threads may need to treat requests with varying priorities:
  - A corporate server could prioritize request processing according to class of customers.
- Architectures:
  - Worker pool
  - Thread-per-request
  - Thread-per-connection
  - Thread-per-object

# Client and server with threads (worker-pool architecture)



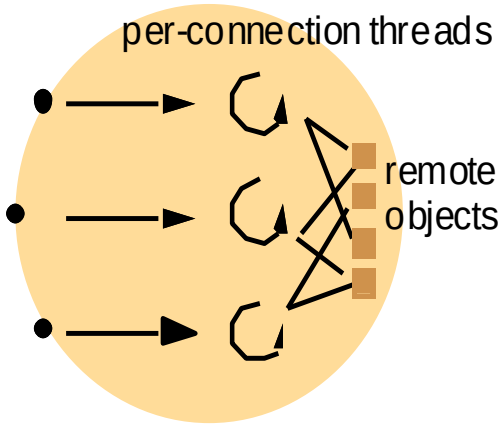

- In worker-pool architectures, the server creates **a fixed pool of worker threads** to process requests.
- The module "receipt and queuing" receives requests from sockets/ports and places them on a shared request queue for retrieval by the workers.

# Alternative server threading architectures



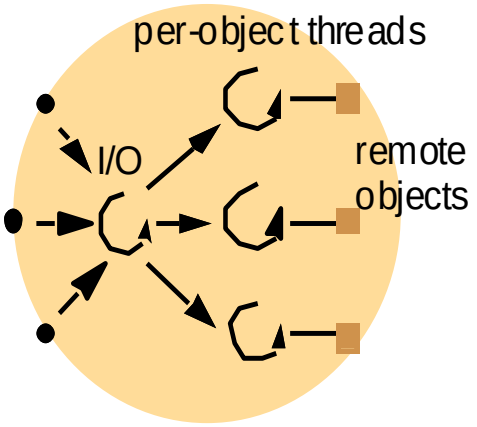

a. Thread-per-request

IO Thread creates a new worker thread for each request and worker thread destroys itself after serving the request.




b. Thread-per-connection

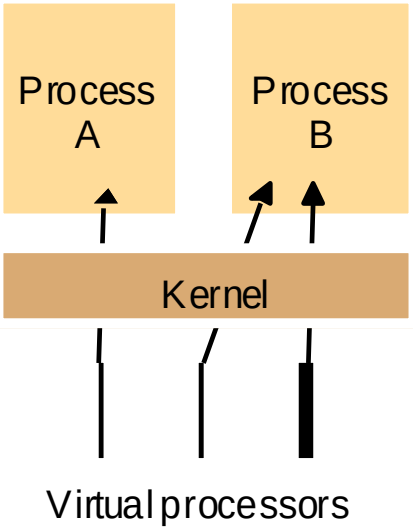
Server associates a Thread with each connection and destroys when client closes the connection.
Client may make many requests over the connection.



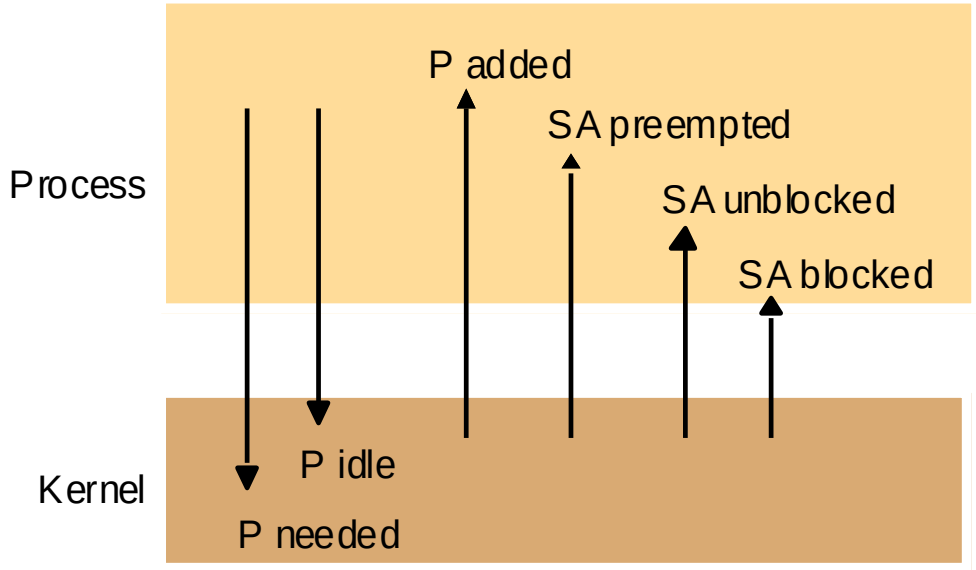

c. Thread-per-object

Associates Thread with each object. An IO thread receives request and queues them for workers, but this time there is a **per-object queue**.

# Scheduler activations

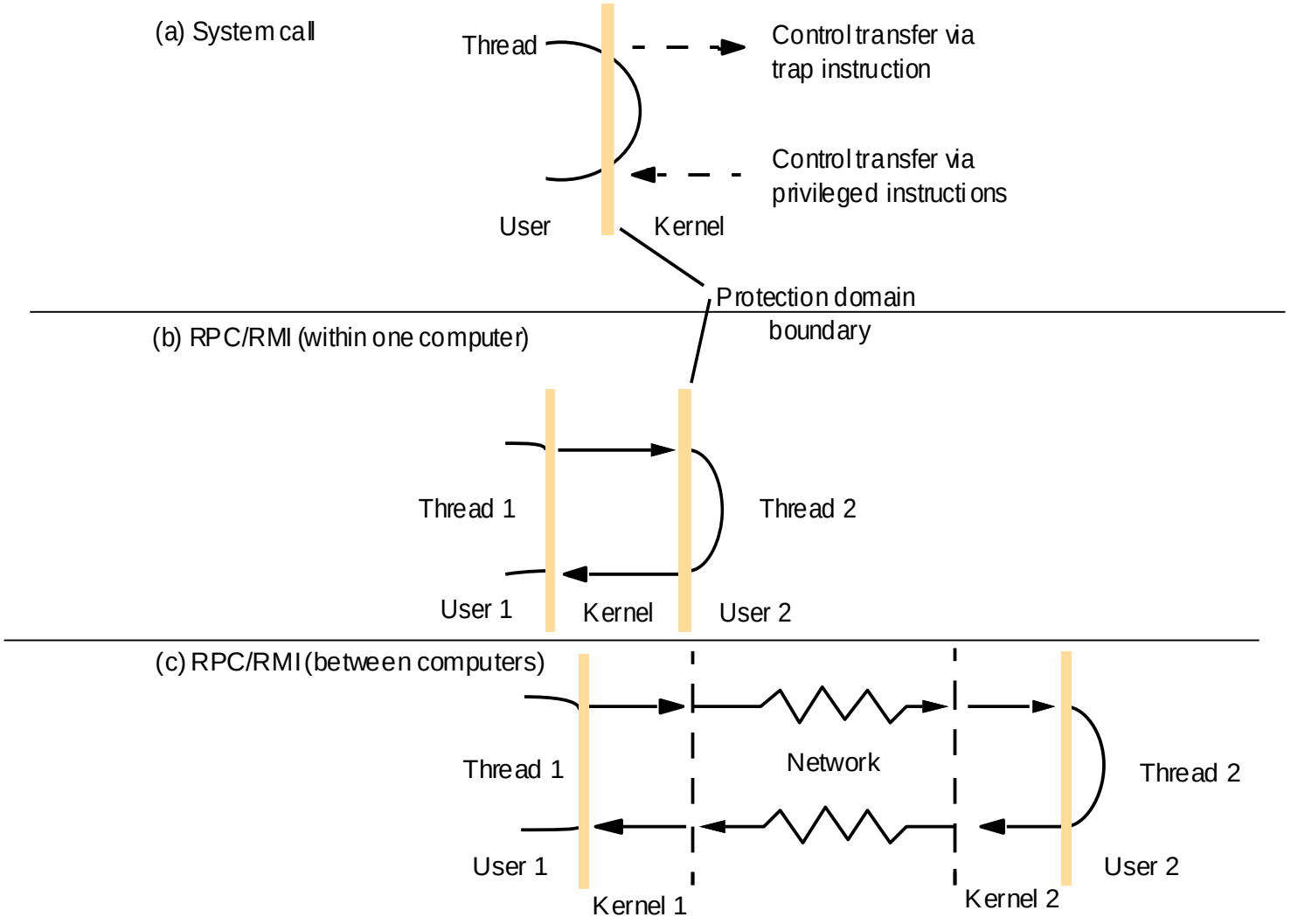



A. Assignment of virtual processors to processes

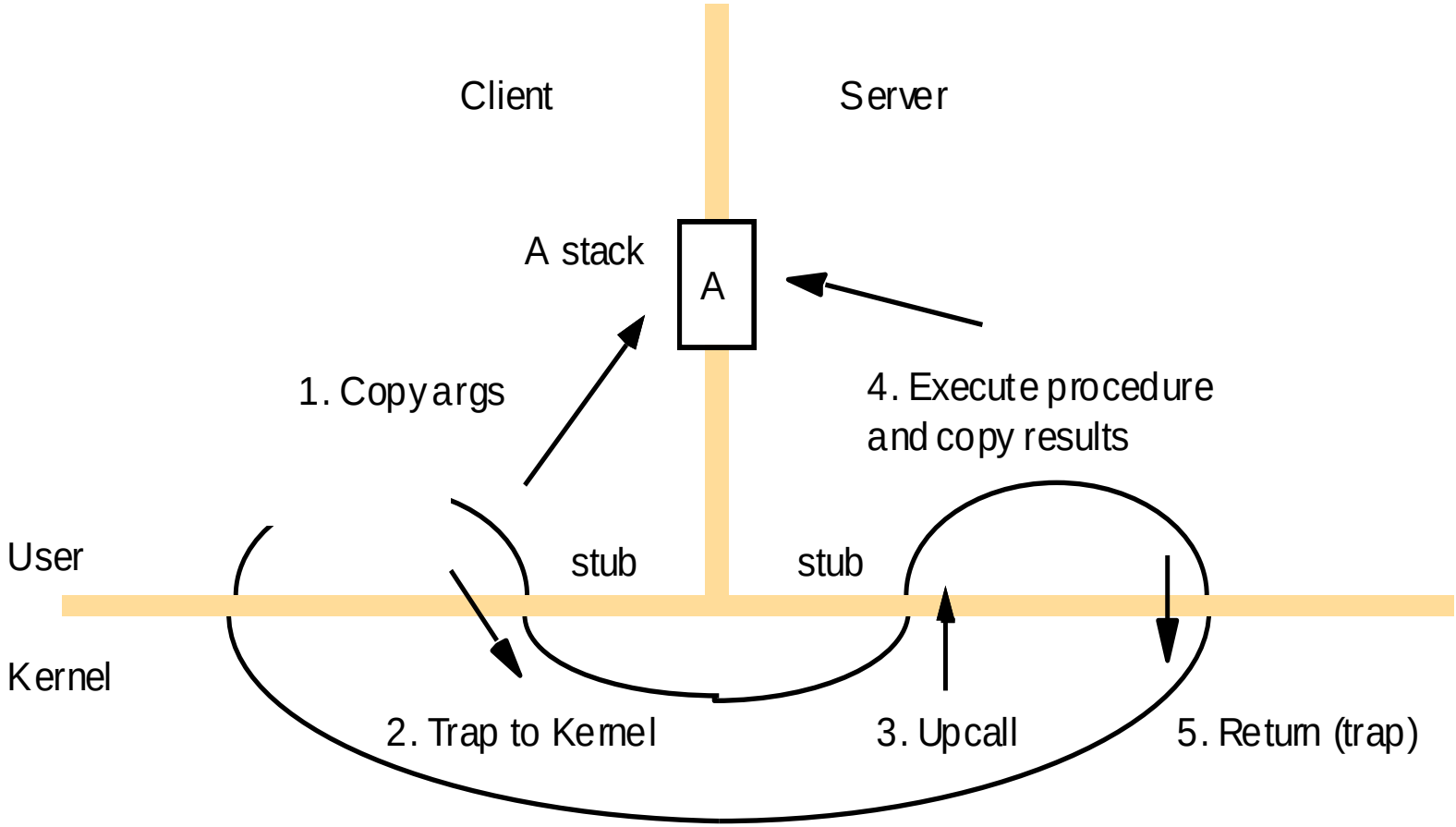



B. Events between user-level scheduler & kernel
Key: P = processor; SA = scheduler activation

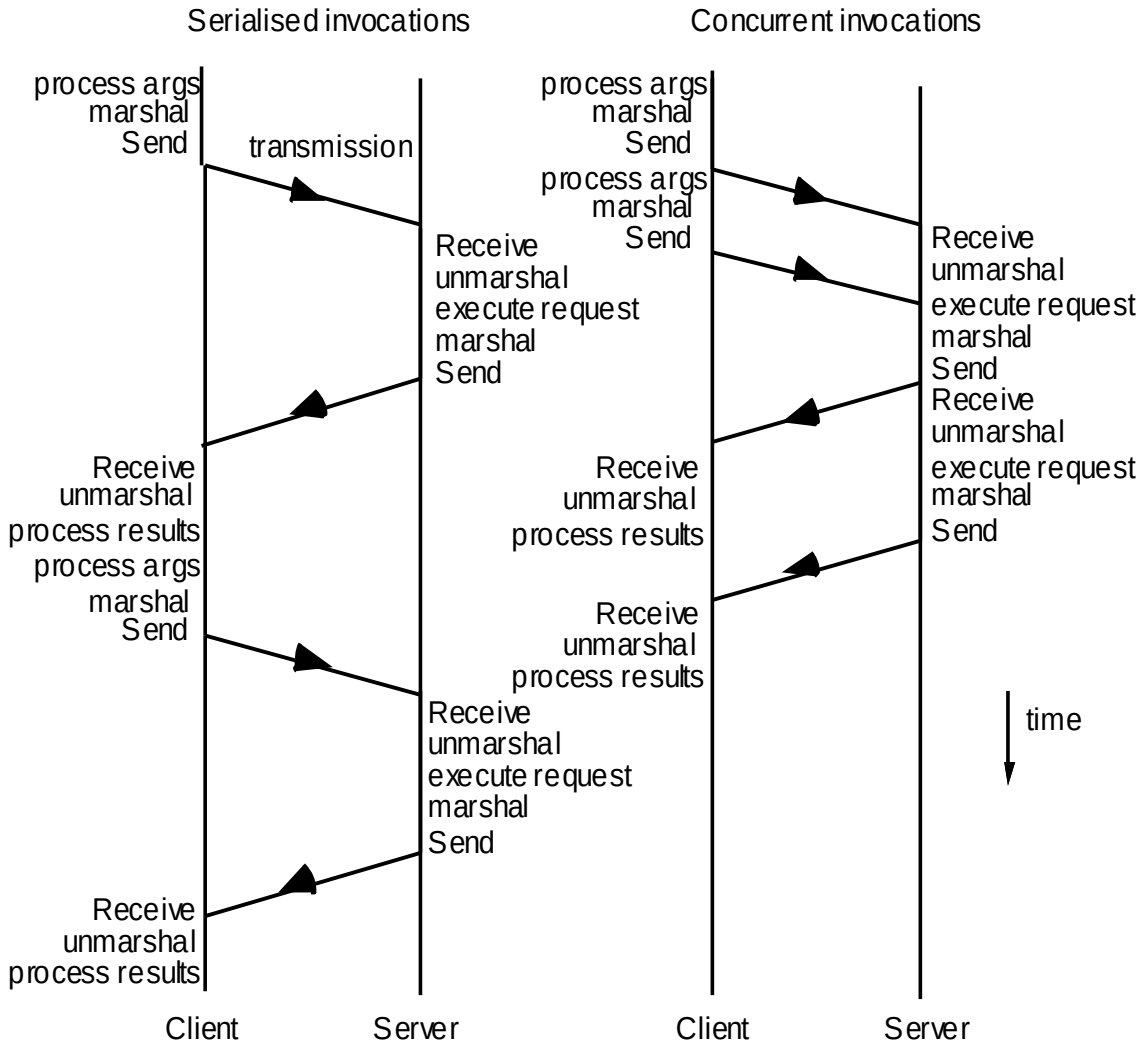
# Invocations between address spaces



# A lightweight remote procedure call



# Times for serialized and concurrent invocations



# Summary


- Operating system provides various types of facilities to support middleware for distributed system:
  - encapsulation, protection, and concurrent access and management of node resources.
- Multithreading enables servers to maximize their throughput, measured as the number of requests processed per second.
- Threads support treating of requests with varying priorities.
- Various types of architectures can be used in concurrent processing:
  - Worker pool
  - Thread-per-request
  - Thread-per-connection
  - Thread-per-object
- Threads need to be synchronized when accessing and manipulating shared resources.
- New OS designs provide flexibility in terms of separating mechanisms from policies.

# References

- CDK Book (Text Book)
  - Chapter 7 – "Operating System Support"
- Chapter 14: Multithread Programming
  - R. Buyya, S. Selvi, X. Chu, **"Object Oriented Programming with Java: Essentials and Applications",** McGraw Hill, New Delhi, India, 2009.

# Demo

## Code Demonstration – Multi-threading in Java

- Sleep
  - Pauses the execution of a thread
- Join
  - Allows one thread to wait for the completion of another
- Synchronized methods
  - Intrinsic ***object locks***
  - When a thread starts executing an object's synchronized method, it obtains the object lock, when it finishes executing the synchronized method, it releases the lock
  - Only one thread at a time can hold the object's lock
  - When one thread is executing a synchronized method for an object, all other threads that invoke synchronized methods for the same object block (suspend execution) until the first thread is done with the object