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# CSU33031 Computer Networks

## Programming Concepts

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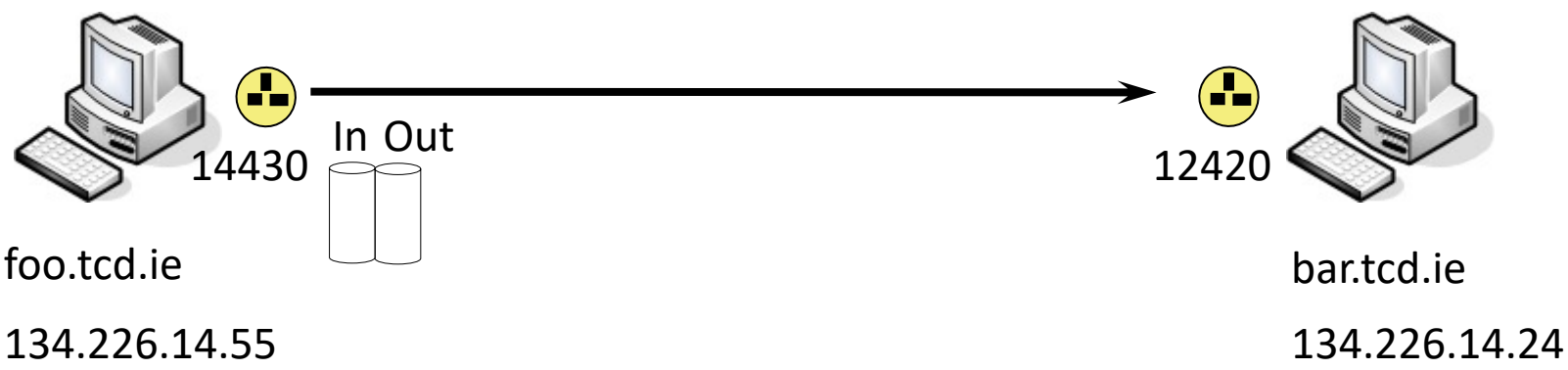
# Programming Concepts

- Sockets
- Multi-threading
- Event-based Programming
  - Callbacks

# Sockets & Ports




socket= new DatagramSocket();

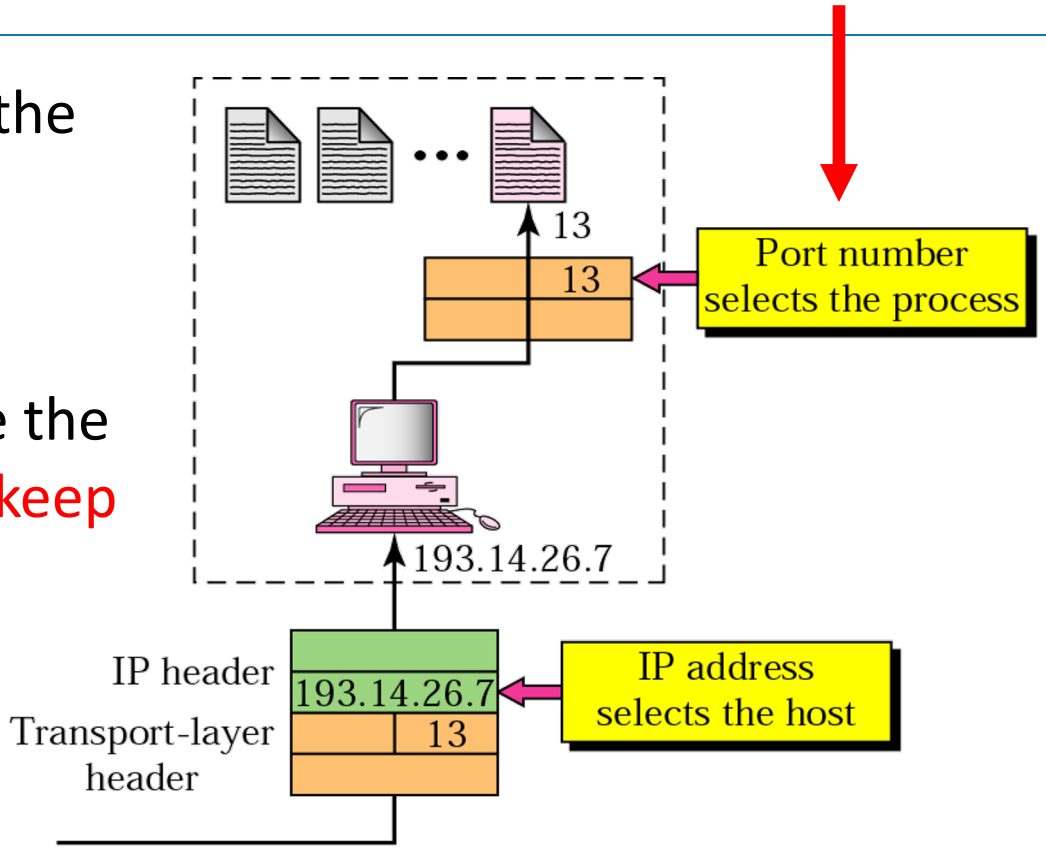
"OS, give me a UDP socket with the next available port number"

```
dstAddress= new InetSocketAddress("bar.tcd.ie", 12420);
packet= new DatagramPacket(data, data.length, dstAddress);
socket.send(packet);
```

# IP Addresses & Port Numbers

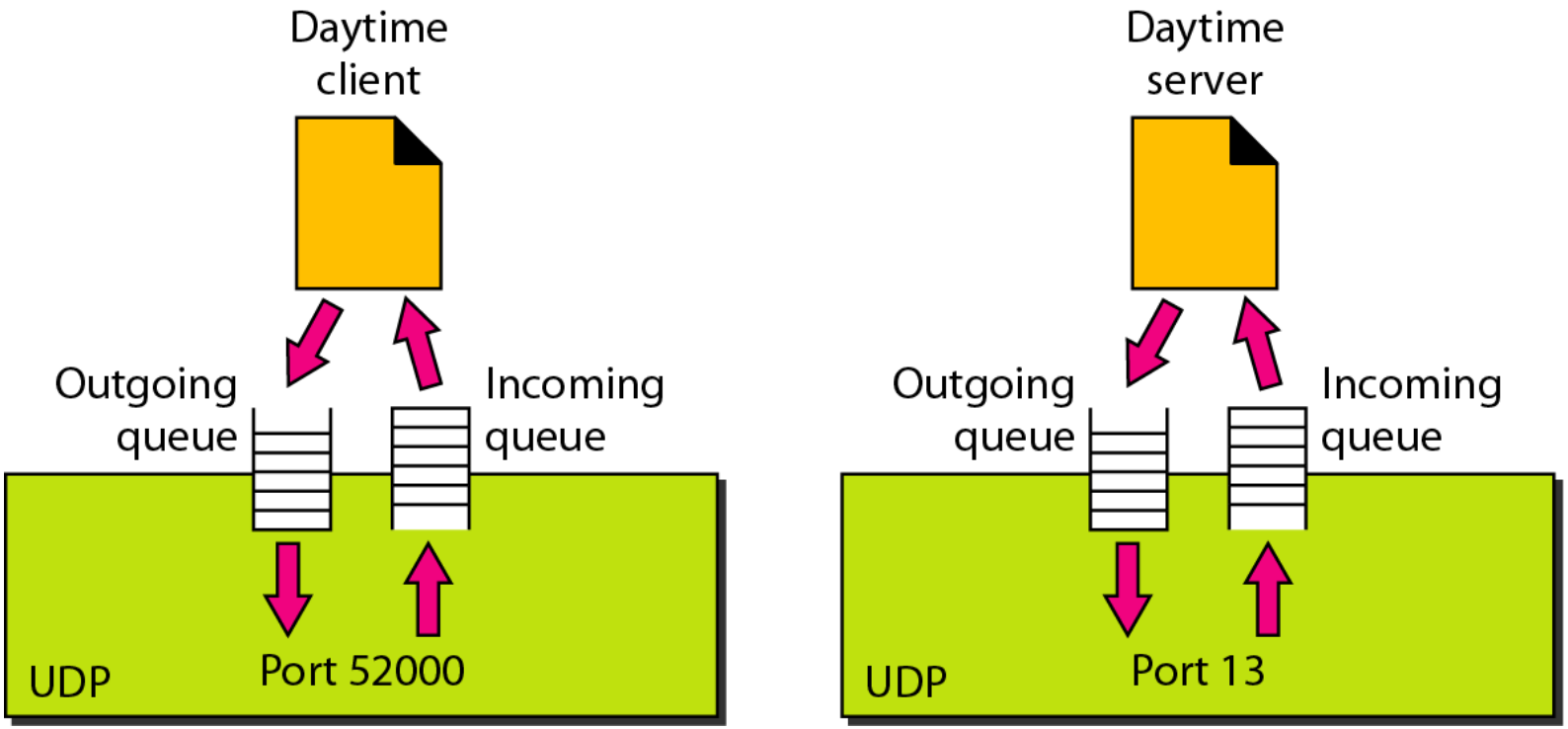
No it does not!!!

- IP Addresses determine the host
- Port Numbers determine the storage where UDP/TCP keep datagrams/data



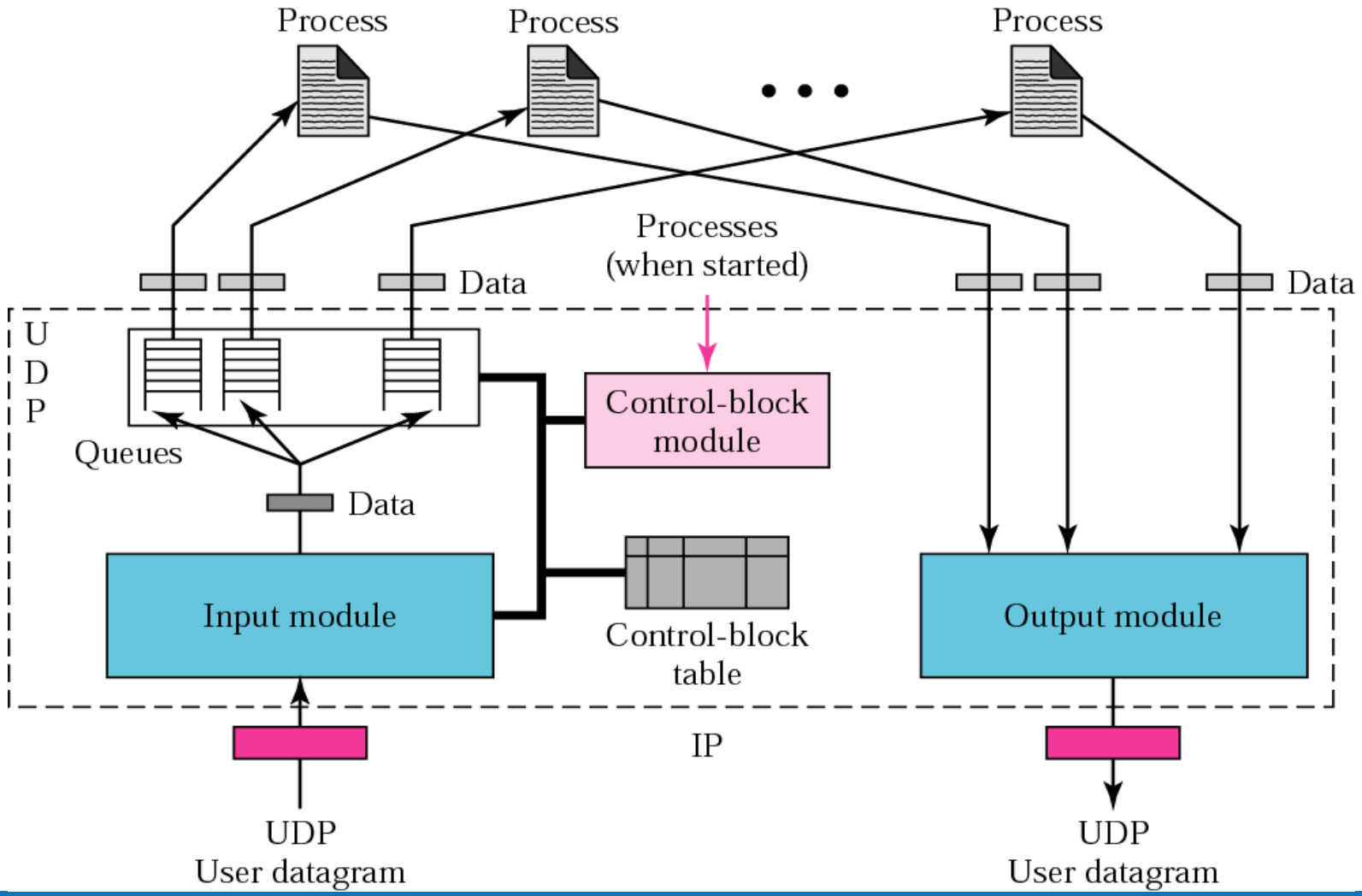

* Figure is courtesy of B. Forouzan

# Queuing in UDP



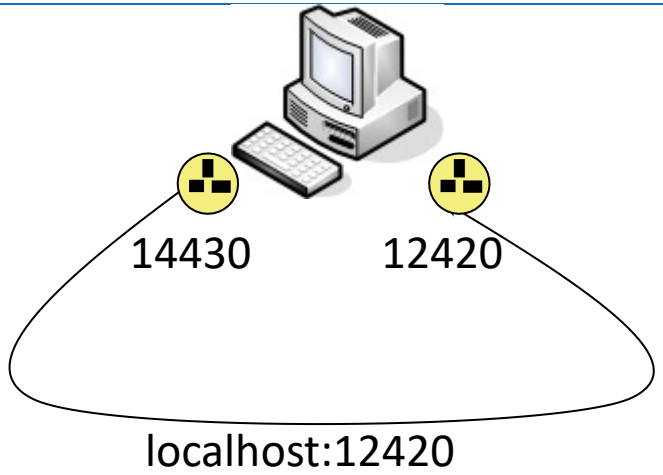

* Figure is courtesy of B. Forouzan

# Processes and UDP Queues



# Sockets & Ports

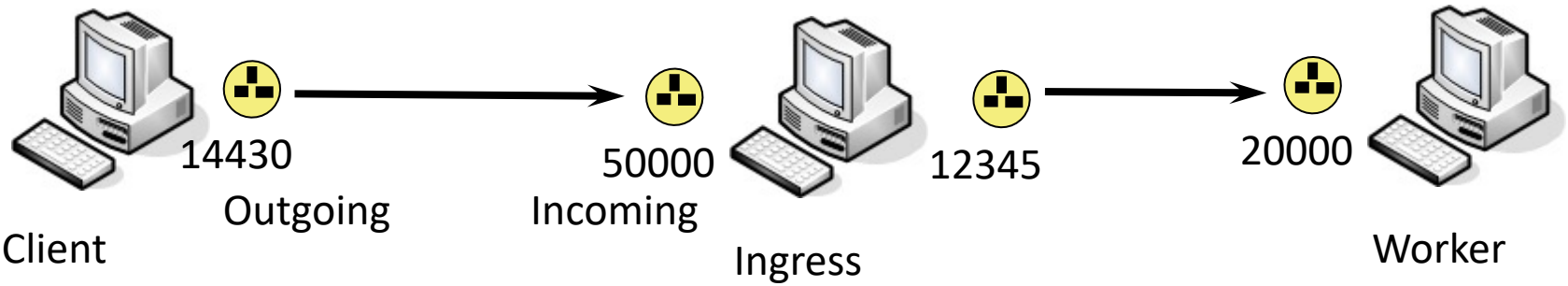
(localhost = 127.0.0.1 – lo interface)




```
socket= new DatagramSocket(14430);

dstAddress= new InetSocketAddress("localhost", 12420);
packet= new DatagramPacket(data, data.length, dstAddress);
socket.send(packet);
```

# Sockets & Ports

(Assignment setup on a local machine)




Setup on localhost:

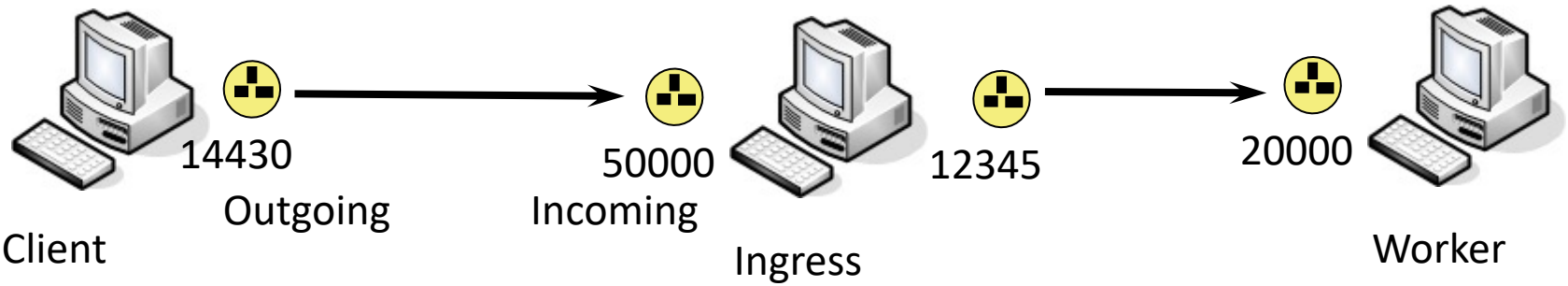
127.0.0.1

127.0.0.1

127.0.0.1

# Sockets & Ports

(Using docker and multiple networks – see walkthrough)

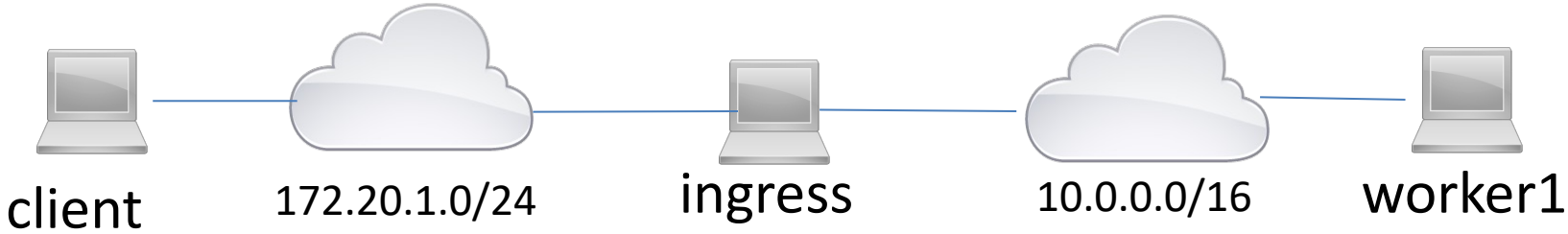



Setup on localhost:

127.0.0.1 127.0.0.1 127.0.0.1

Setup on docker:

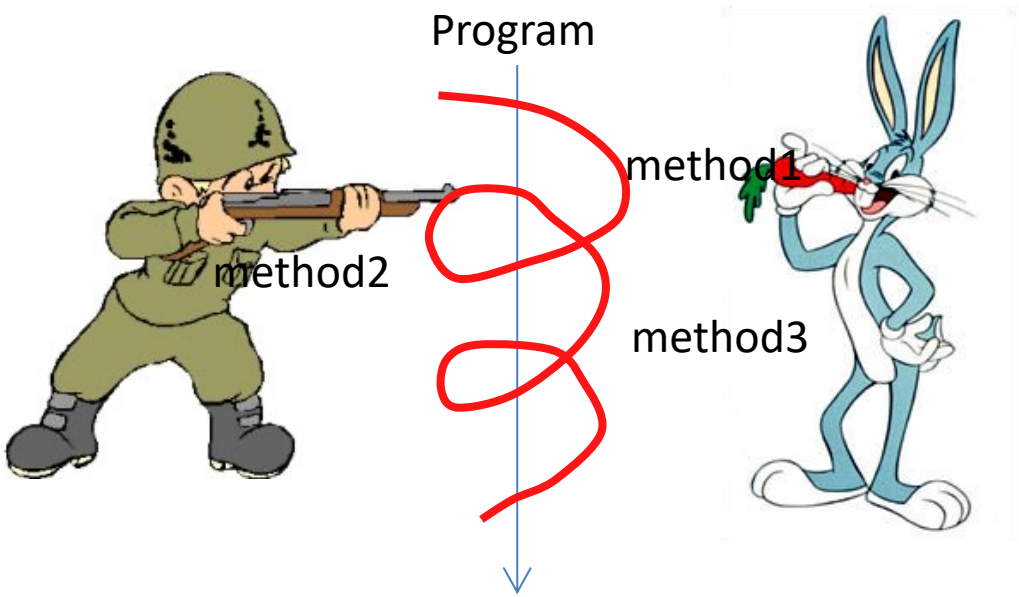
eth1 172.20.1.2 | eth1 172.20.1.3 | eth2 10.0.0.2 | eth1 10.0.0.3



# Threads

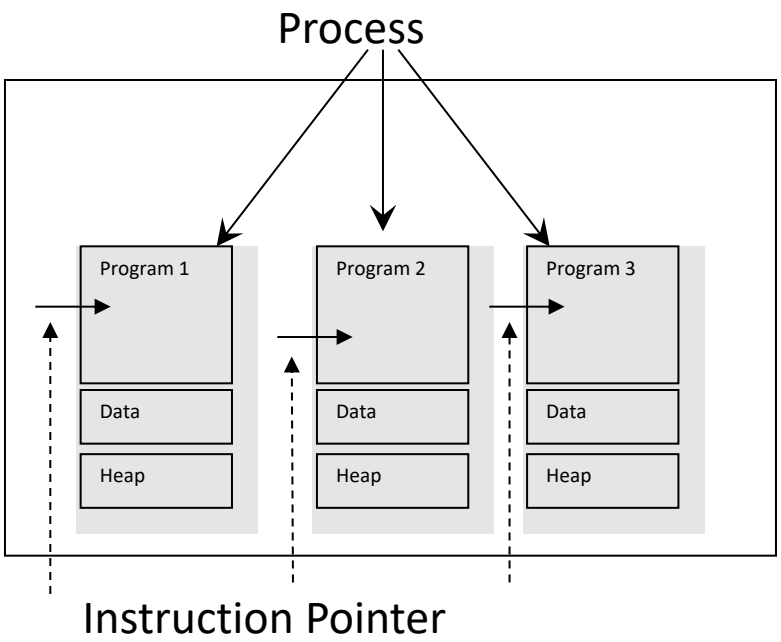
(How to handle traffic w/ sockets)

- Threads of Execution
  - Lightweight Processes



# Processes

- Separate address spaces
- Registers per process




- Problem:
  - Switching between processes

Processor

Register 1 Register 2 Register 3 Register 4 Register 5 Register 6 Register 7 Register 8 Register 9 Register 10 Register 11 Register 12 Register 13 Register 14 Register 15 Register 16 Register 17 Register 18 Register 19 Register 20 Register 21 Register 22 Register 23 Register 24

# Per-Process Details

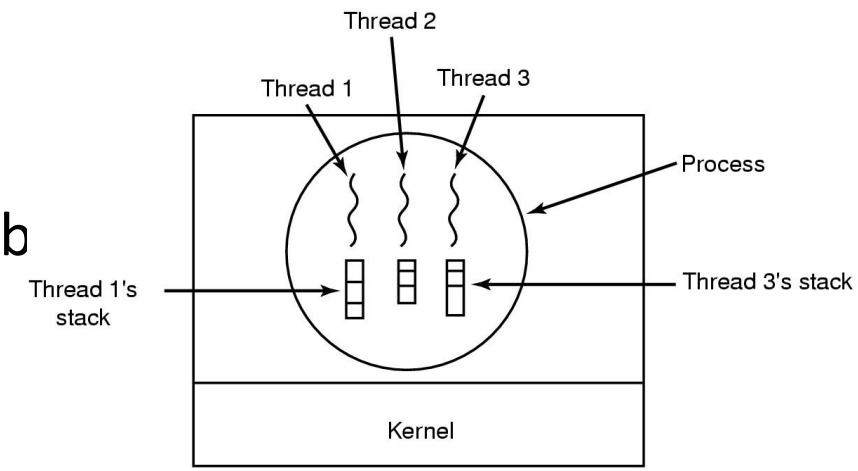
(That need to be saved at context switch)

| Process management | Memory management | File management |
|---|---|---|
| Registers | Pointer to text segment | UMASK mask |
| Program counter | Pointer to data segment | Root directory |
| Program status word | Pointer to bss segment | Working directory |
| Stack pointer | Exit status | File descriptors |
| Process state | Signal status | Effective uid |
| Time when process started | Process id | Effective gid |
| CPU time used | Parent process | System call parameters |
| Children's CPU time | Process group | Various flag bits |
| Time of next alarm | Real uid | |
| Message queue pointers | Effective uid | |
| Pending signal bits | Real gid | |
| Process id | Effective gid | |
| Various flag bits | Bit maps for signals | |
| | Various flag bits | |

* Figure is courtesy of A. Tanenbaum

# Threads

- Lightweight processes
- Share same address space
- Less overhead for switching b
  between processes

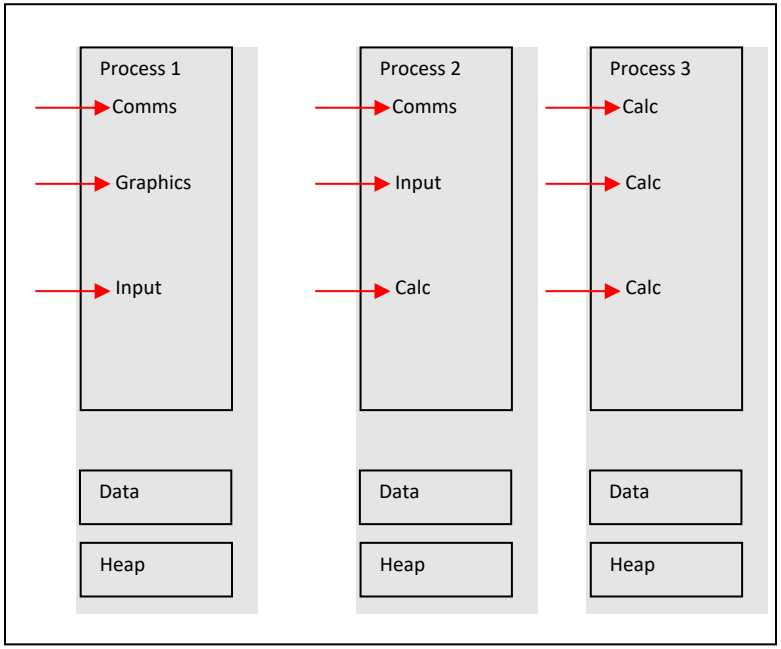



| **Per process items** | **Per thread items** |
|---|---|
| Address space | Program counter |
| Global variables | Registers |
| Open files | Stack |
| Child processes | State |
| Pending alarms | |
| Signals and signal handlers | |
| Accounting information | |

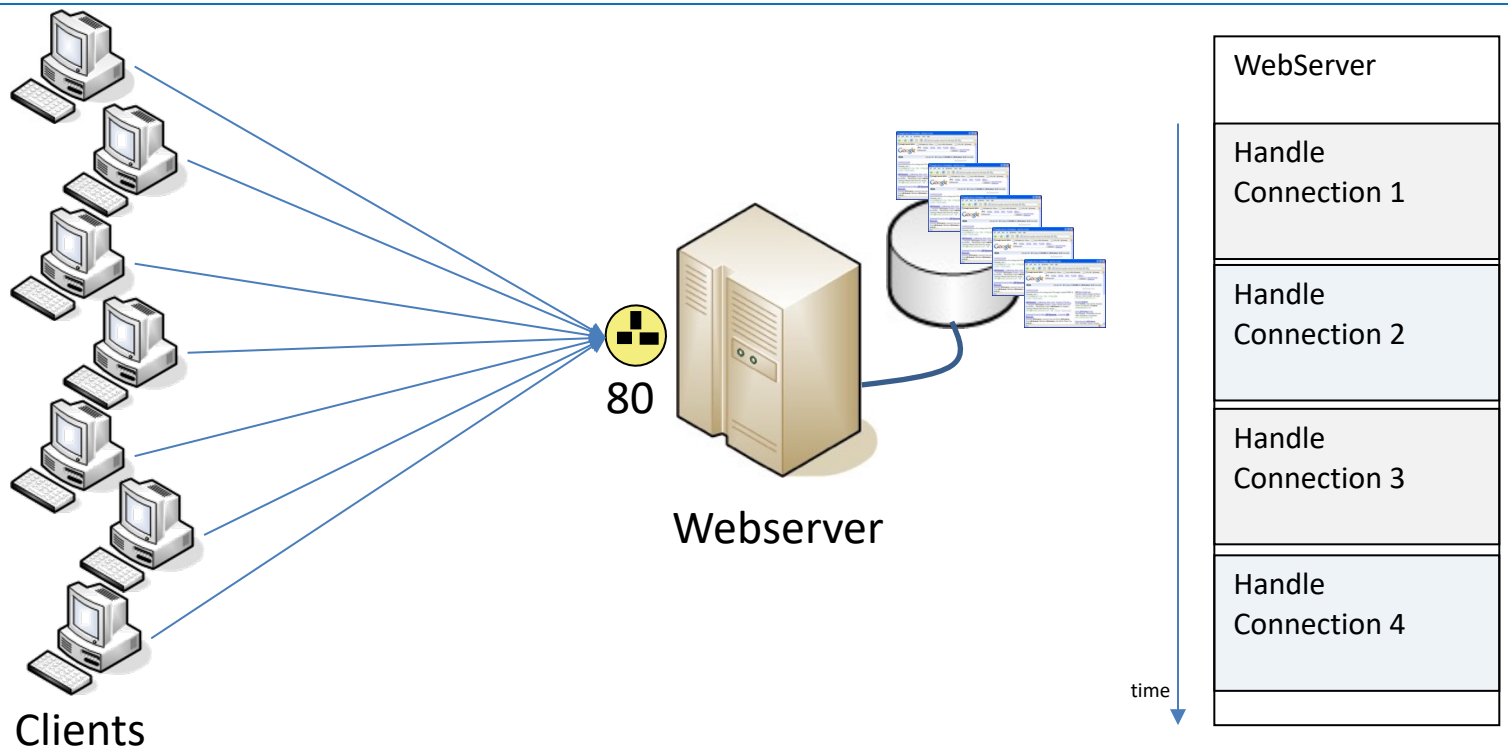
* Figure is courtesy of A. Tanenbaum

# Multi-Threaded

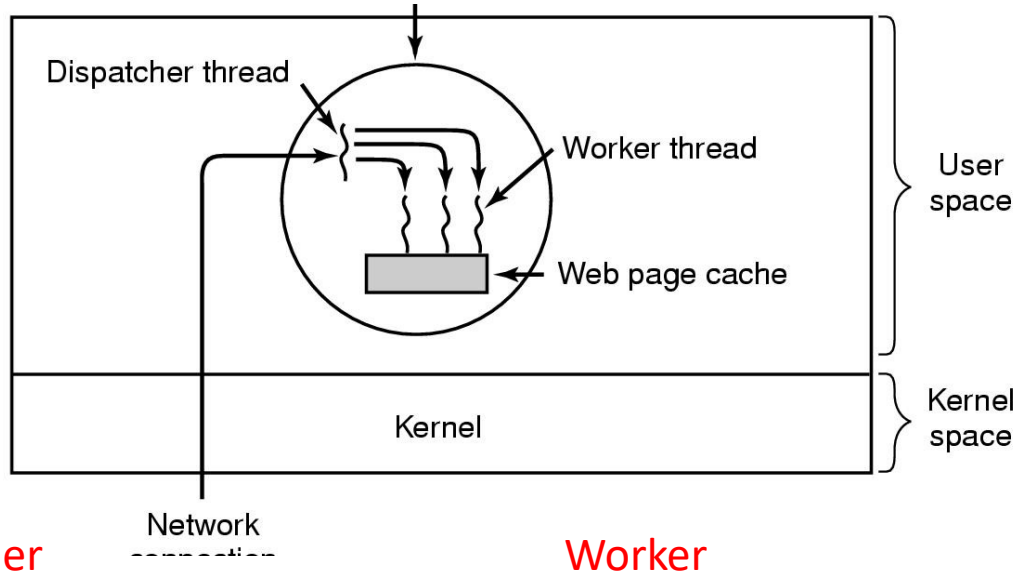
**Per thread items**
Program counter
Registers
Stack
State



# Threads & Webserver



# Application of Threads




Dispatcher

```
while (TRUE) {
    get_next_request(&buf);
    handoff_work(&buf);
}
```

(a)

Worker

```
while (TRUE) {
    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);
}
```

(b)

* Figure is courtesy of A. Tanenbaum

# Java Threads

```
class Thread {
    public Thread (String name);
    public Thread (Runnable target)
    …
    public void start ();
    static void sleep (long millis)
}
```

Selection of methods of class “Thread”

# Inheriting from Threads + Overload run()

```
class Thread {
    public Thread (String name);
    …
    public void start ();
    public void run();
}
```

Selection of methods of class "Thread"

```
class XYZ extends Thread {
    public void run() {
    }
}
```

Class that extends "Thread" needs to implement the **`run`** method

# Java Thread – Socket Example I

```
class SocketThread extends Thread {
    DatagramSocket socket;

    SocketThread (String name, int port) {
        super (name);
        socket= new DatagramSocket(port);
    }
}
```

```
t1 = new SocketThread (“Socket1”, 50000);
```

# Java Thread – Socket  Example II

```
class SocketThread extends Thread {

    DatagramSocket socket;

    SocketThread (String name, int port) {
        super (name);
        socket= new DatagramSocket(port);
    }

    public void run() {
        while(TRUE) {
            packet= socket.receive();
            System.out.println (name + ": " + packet.getData());
        }
    }
}
```

# Creating & Starting Threads I

```
SocketThread t1, t2, t3;

t1 = new SocketThread (“Socket1”, 50000);
t2 = new SocketThread (“Socket2”, 50200);
t3 = new SocketThread (“Socket3”, 55000);
```

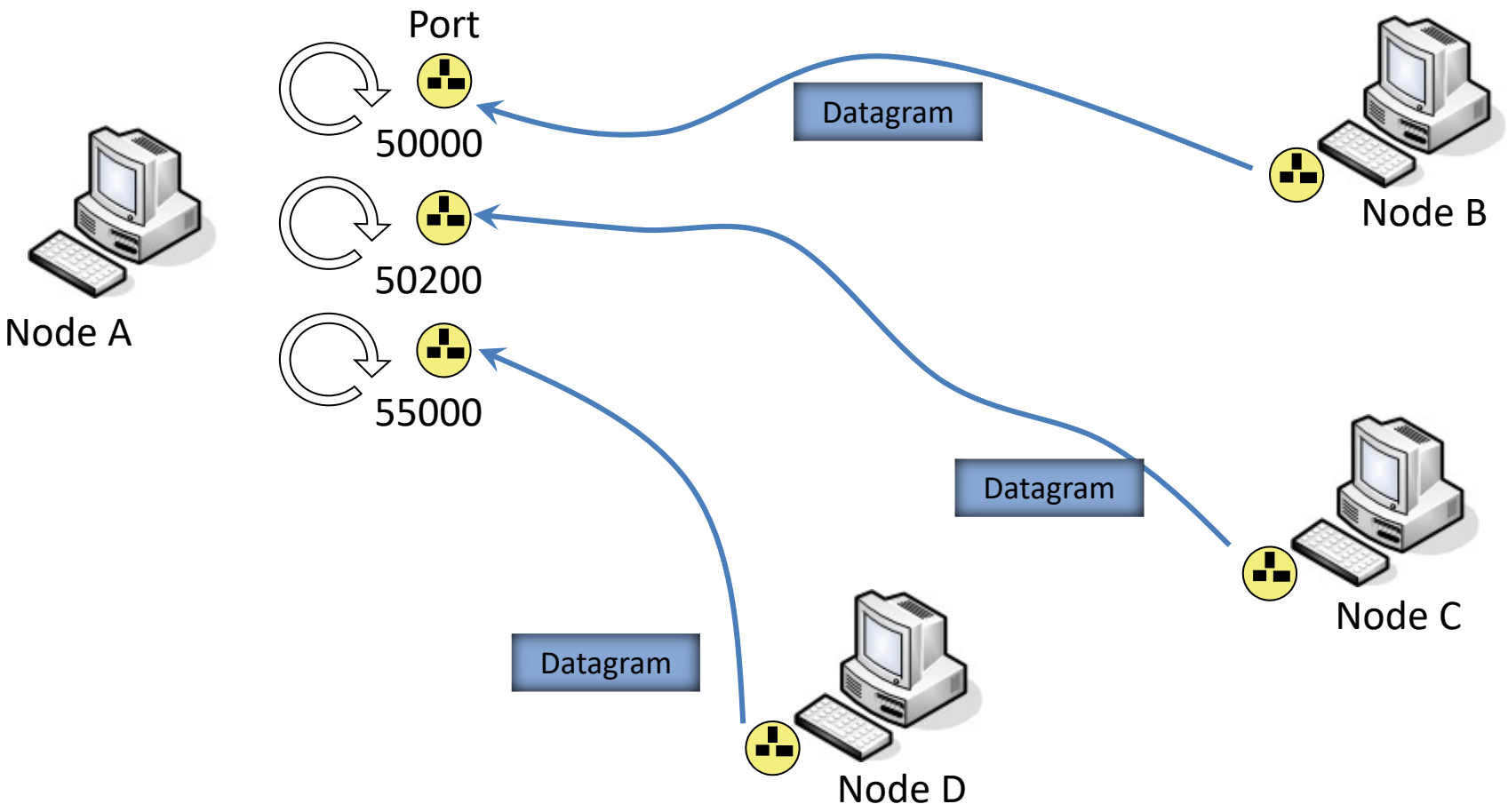
# Creating & Starting Threads II

```
SocketThread t1, t2, t3;

t1 = new SocketThread ("Socket1", 50000);
t2 = new SocketThread ("Socket2", 50200);
t3 = new SocketThread ("Socket3", 55000);

t1.start();
t2.start();
t3.start();
```

Insert thread into list of running threads and execute "run" method

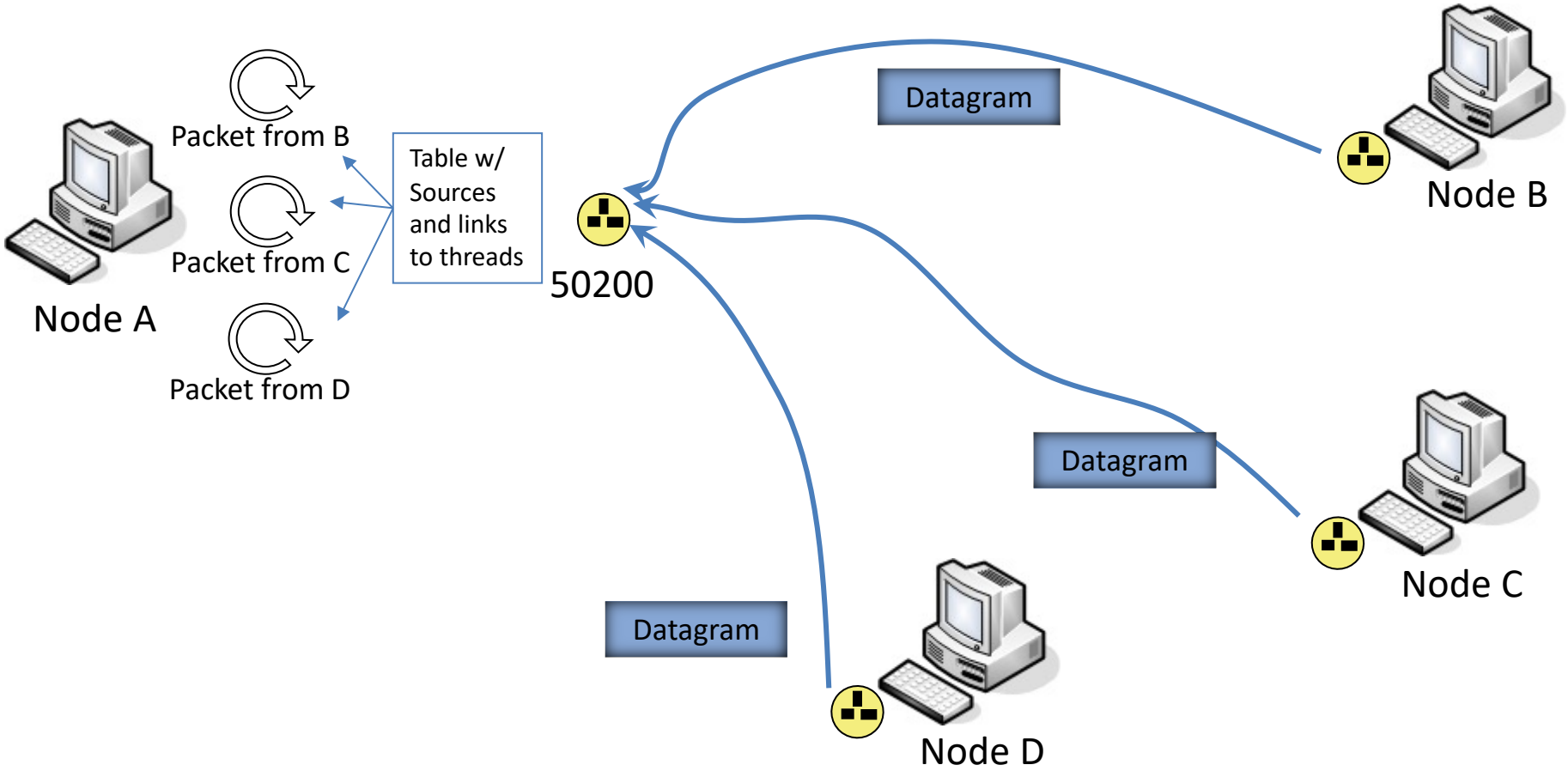
# Concurrent Communication

(Example is wasteful on number of ports used!!!)



# Concurrent Communication

(Multiplexing over one socket is more efficient & common)



# Thread Execution Example I

```
class CounterThread extends Thread {
    long counter;

    CounterThread (String name, long counter) {
        super (name);
        this.counter = counter;
    }
}
```

```
t1 = new CounterThread (“T1”, 10);
```

# Thread Execution Example II

```
class CounterThread extends Thread {
    long counter;

    CounterThread (String name, long counter) {
        super (name);
        this.counter = counter;
    }
    public void run() {
        while(TRUE) {
            counter++;
            System.out.println (name + ": " + counter);
            Thread.sleep (Math.random() * 5000);
        }
```

# Thread Execution Example III

```
CounterThread t1, t2, t3;

t1 = new CounterThread ("T1", 10);
t2 = new CounterThread ("T2", 10);
t3 = new CounterThread ("T3", 10);

t1.start();
t2.start();
t3.start();
```

Insert thread into list of running threads and execute "run" method

# Possible Output

time

T1: 11
T2: 11
T3: 11
T1: 12
T2: 12
T3: 12
...

or

time

T1: 11
T1: 12
T3: 11
T3: 12
T2: 11
T3: 13
...

or

time

T1: 11
T3: 11
T3: 12
T2: 11
T1: 12
T3: 13
...

Execution is **non-deterministic**!

# Interface: java.lang.Runnable

**Java doesn't support Multiple Inheritance:**

```
class AccountThread extends Thread, Account {...
```

**ERROR**

**Java doesn't support multiple inheritance**

# Interface: java.lang.Runnable

**Java doesn't support Multiple Inheritance:**

```
class AccountThread extends Thread, Account {...
```

**ERROR**

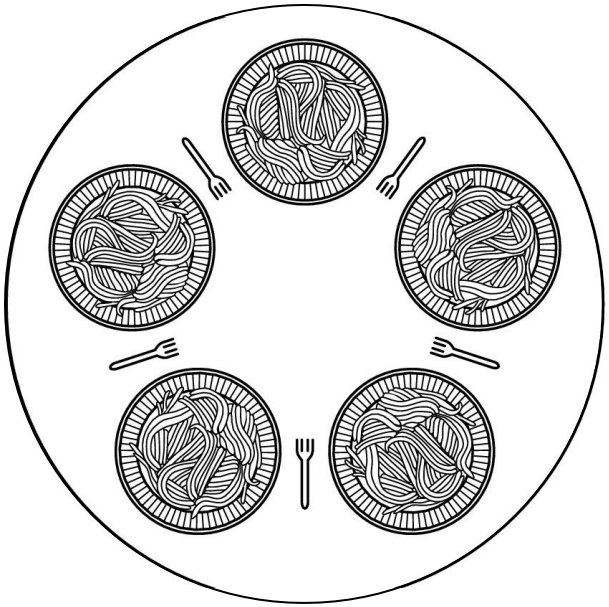
**Java doesn't support multiple inheritance**

```
class CounterThread implements Runnable {
        ...
    public void run() {
}

new Thread (new CounterThread("T1", 10)).start;
```

# Problems with Concurrency

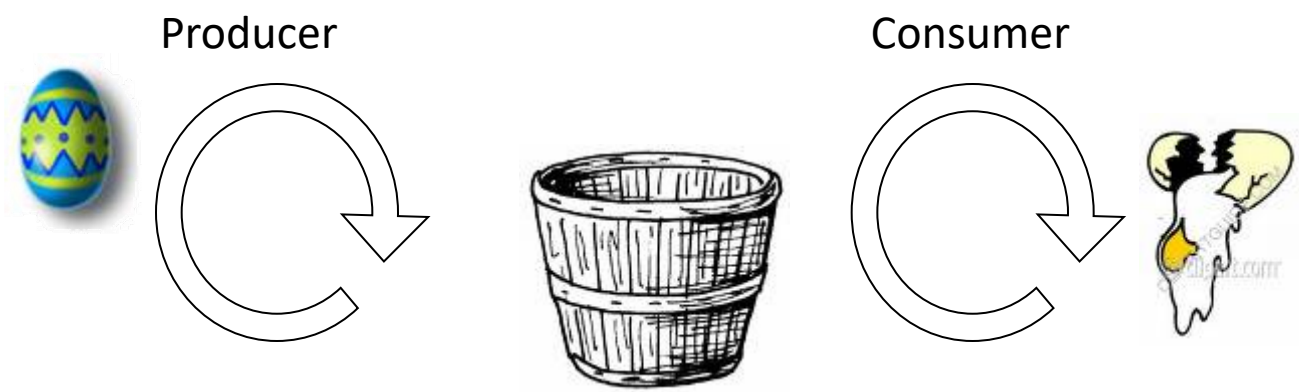
- Concurrent access to global variables, etc
- Requires synchronization
- Approaches
  - Monitors
  - Semaphores
  - Barriers

(see Principles of Concurrent Programming, M. Ben-Ari)



Dining Philosophers

# Producer-Consumer Problem




- Producer delivers 1 egg at a time
- Basket can hold exactly 1 egg
- Consumer can only consume an egg if an egg is in the basket

# Producer-Consumer in Java I

```
class TestSystem {
	Basket basket;

	TestSystem() {
		basket= new Basket(0);
	}

	class Basket {
		int content;

		public Basket (int content) {
			this.content= content;
		}
	}
}
```

# Producer-Consumer in Java II

```
class TestSystem {
    …
    class Basket {
        int content;
        …

        public void putEgg () {
            content++;
        }

        public void takeEgg() {
            content--;
        }
    }
}
```

# Producer-Consumer in Java III

```
class TestSystem {
    Basket basket;

    class Producer extends Thread {
        public void run() {
            while (true)   basket.putEgg();
        }
    }

    class Consumer extends Thread {
        public void run() {
            while (true) basket.takeEgg();
        }
    }
}
```

# Producer-Consumer in Java IV

```
class TestSystem {

    public static void main (String[] args) {
        Producer producer;
        Consumer consumer;

        producer= new Producer();
        consumer= new Consumer();

        producer.start();
        consumer.start();
    }
}
```

# Problem???

Producer

Execution is non-deterministic!

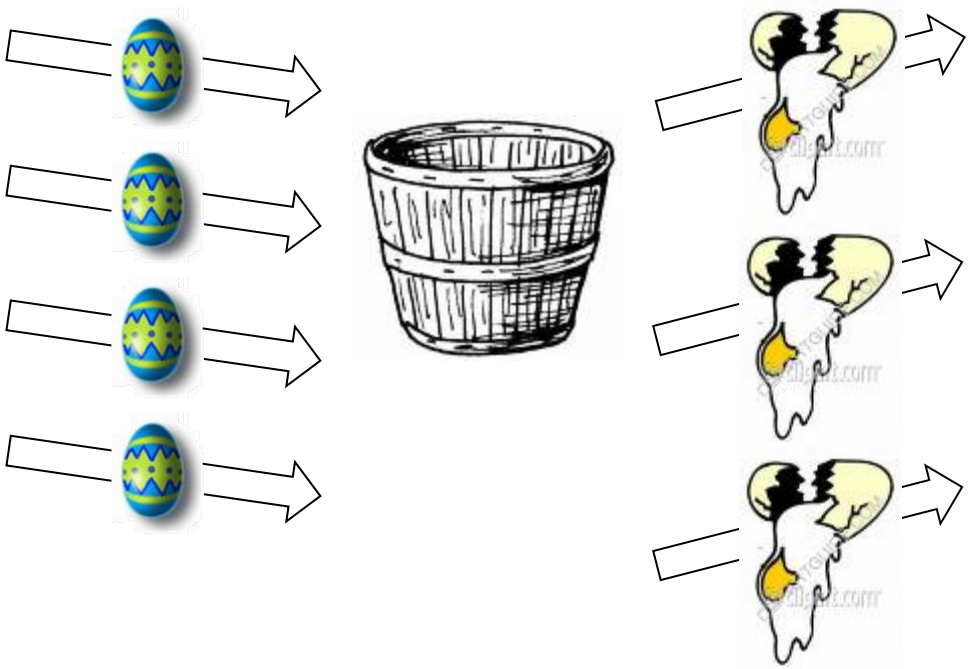
Consumer

putEgg

putEgg

putEgg

putEgg



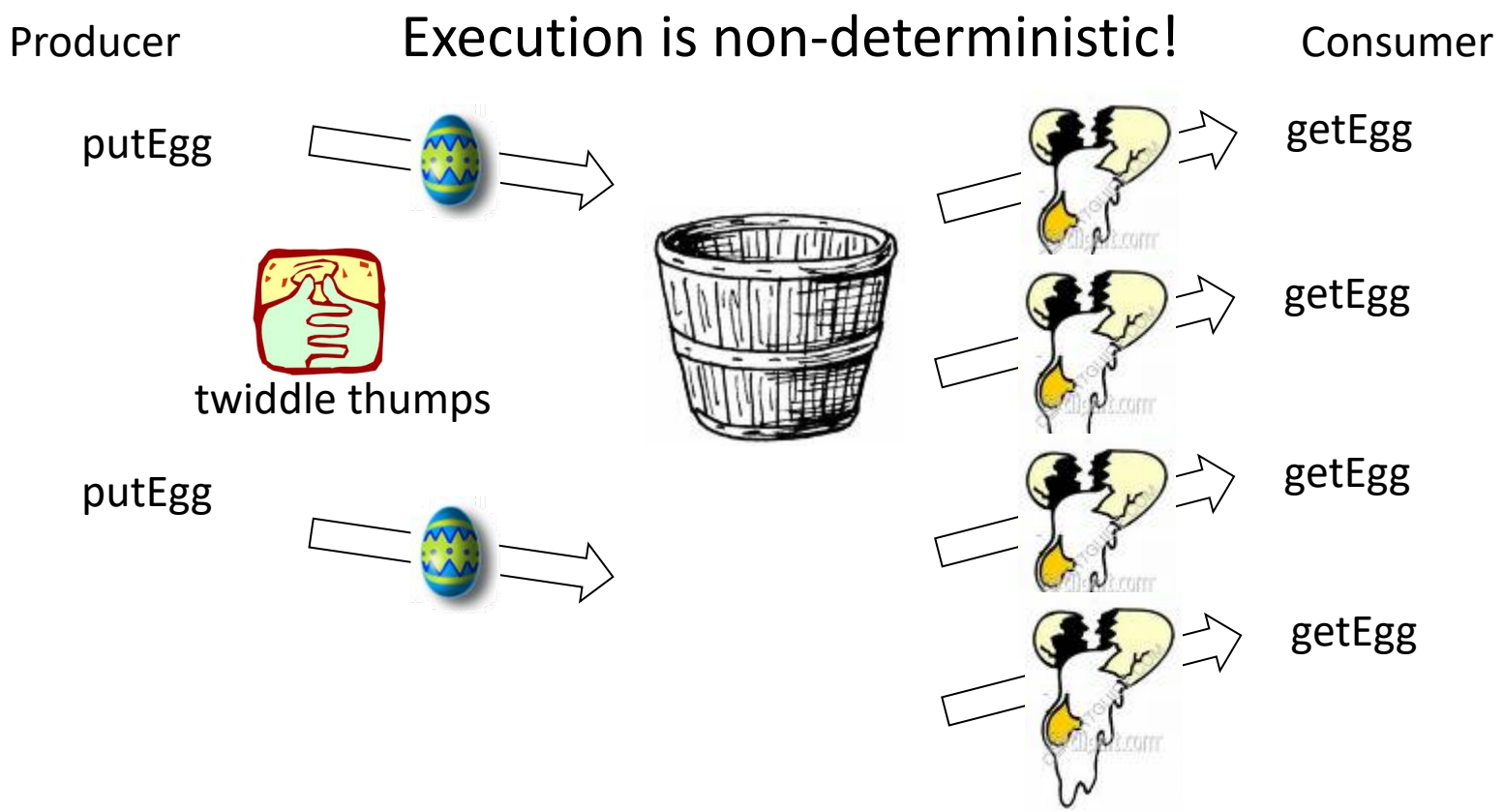
getEgg

getEgg

getEgg

# Problem???

(What if getEgg executes before or more than putEgg???)



# Producer-Consumer in Java V

(synchronized = only one thread can execute method at a time)

```
class TestSystem {
    …
    class Basket {
        int content;
        …
        public synchronized void putEgg () {
            while (content!=0) wait();
            content++;
            notify();
        }
    }
}
```

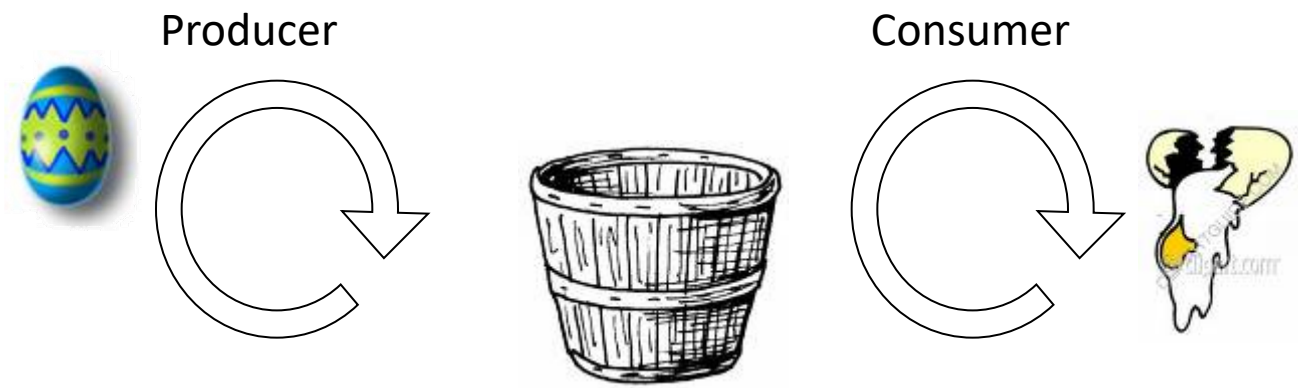
# Producer-Consumer in Java VI

(synchronized = only one thread can execute method at a time)

```
class TestSystem {
    …
    class Basket {
        int content;
        …
        public synchronized void takeEgg () {
            while (content!=1) wait();
            content--;
            notify();
        }
    }
}
```

# Producer-Consumer Problem

(notify = wakes up waiting threads, one will succeed to execute)

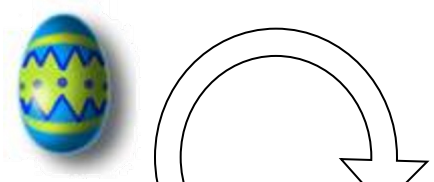



```
public synchronized void putEgg () {
        while (content!=0) wait();
        content++;
        notify();
}
```

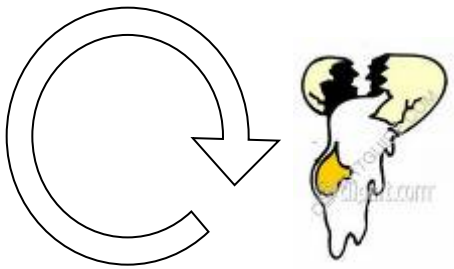
```
public synchronized void takeEgg () {
        while (content!=1) wait();
        content--;
        notify();
}
```

# Producer-Consumer Problem

Producer



Consumer



```
public synchronized void putEgg () {
        while (content!=0) wait();
        content++;
        notify();
}
```

```
public synchronized void takeEgg () {
        while (content!=1) wait();
        content--;
        notify();
}
```

Monitor in Java: One active thread in method per instance!

# Summary: Threads

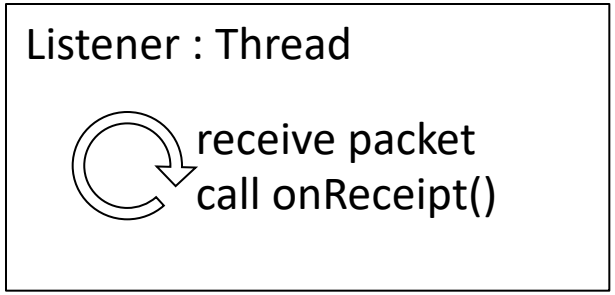
- Concurrent Execution
  - Non-deterministic Execution
- Java
  - Inherit from Thread class
  - Implement Runnable interface
- Synchronization
  - wait() & notifyAll() / notify()

# “Event-based Programming”

```
public void run() {
    DatagramPacket packet;


    try {
        while(true) {
            packet = new DatagramPacket(new byte[PACKETSIZE], PACKETSIZE);
                                socket.receive(packet);
                                onReceipt(packet);
        }
    } catch (Exception e)  {e.printStackTrace();}
}
```

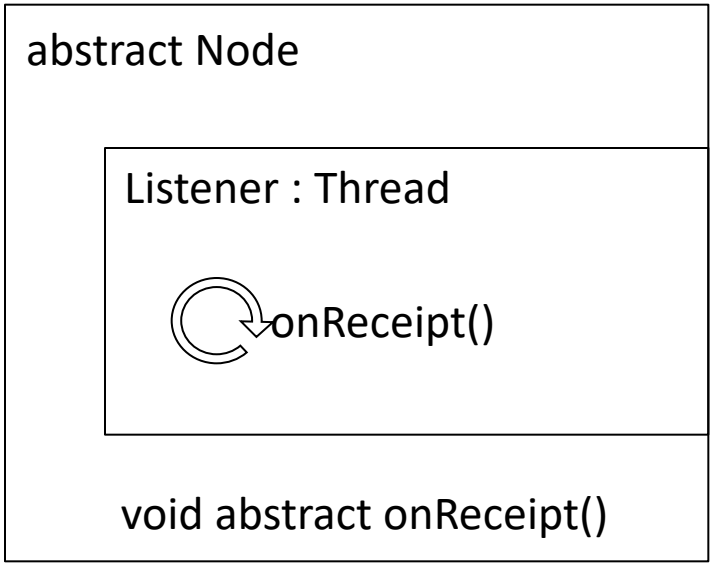
# “Event-based Programming”

(Callback -> onReceipt method – event happens, call onReceipt)

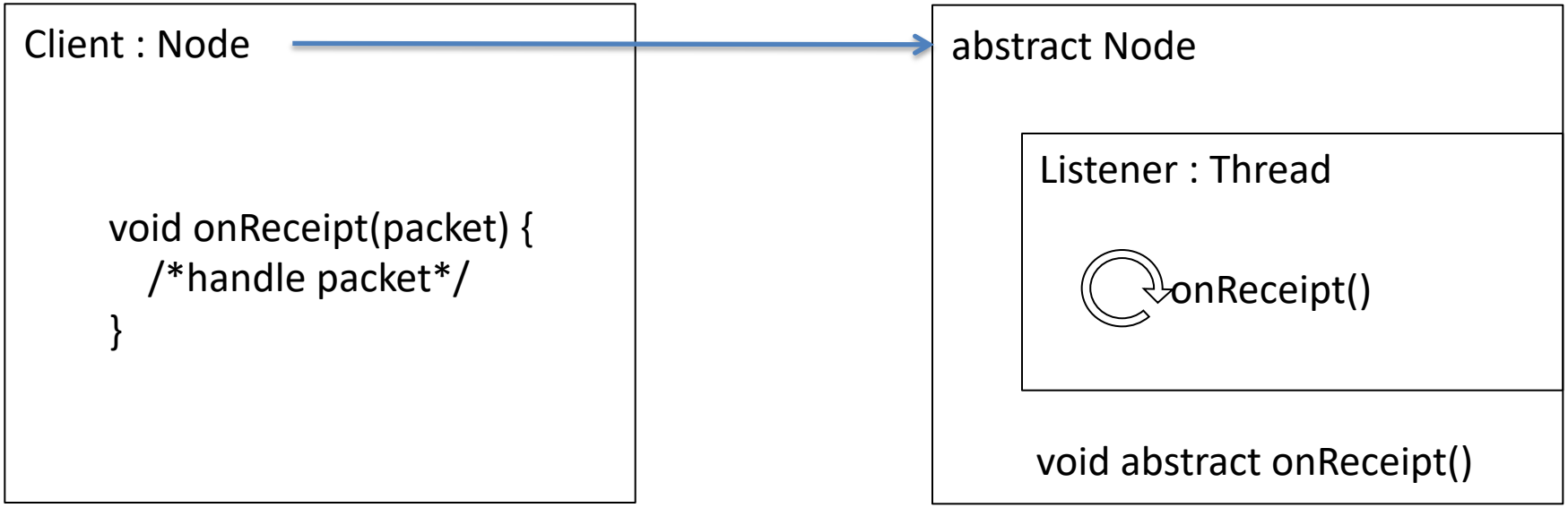


# “Event-based Programming”

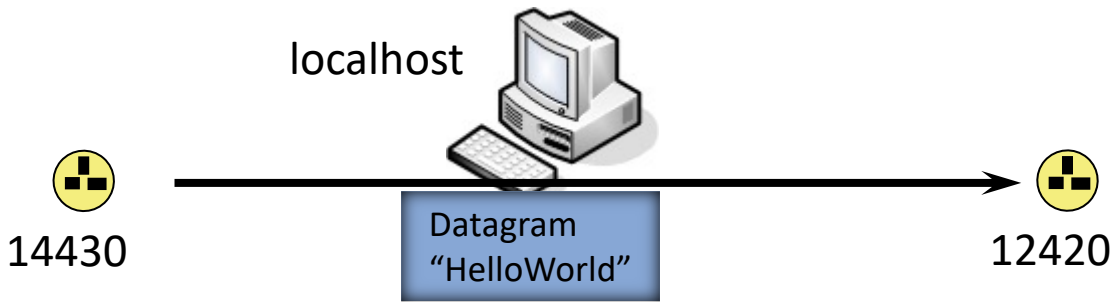
(Abstract class that forces all Node classes to have an onReceipt method)



# “Event-based Programming”



# “Event-based Programming”




Listener

Server

```
void onReceipt(packet) {
}
```

# “Event-based Programming”

(latch as quick-fix to only start receiving packets when receiver is ready)

```
public void go() {latch.countDown();}
public void run() {
    DatagramPacket packet;

    try {
        latch.await();
        while(true) {
            packet = new DatagramPacket(new byte[PACKETSIZE], PACKETSIZE);
                                socket.receive(packet);
                                onReceipt(packet);
    }
    } catch (Exception e)
            {if (!(e instanceof SocketException)) e.printStackTrace();}
}
```

# Summary: Socket Communication

- Sockets
  - Localhost
- Threading
  - Process vs Threads
  - Synchronization
  - Monitors in Java (synchronized keyword)
- Event-based Programming

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