Smith College

Computer Science

CSC352

Week #6 — Spring 2017

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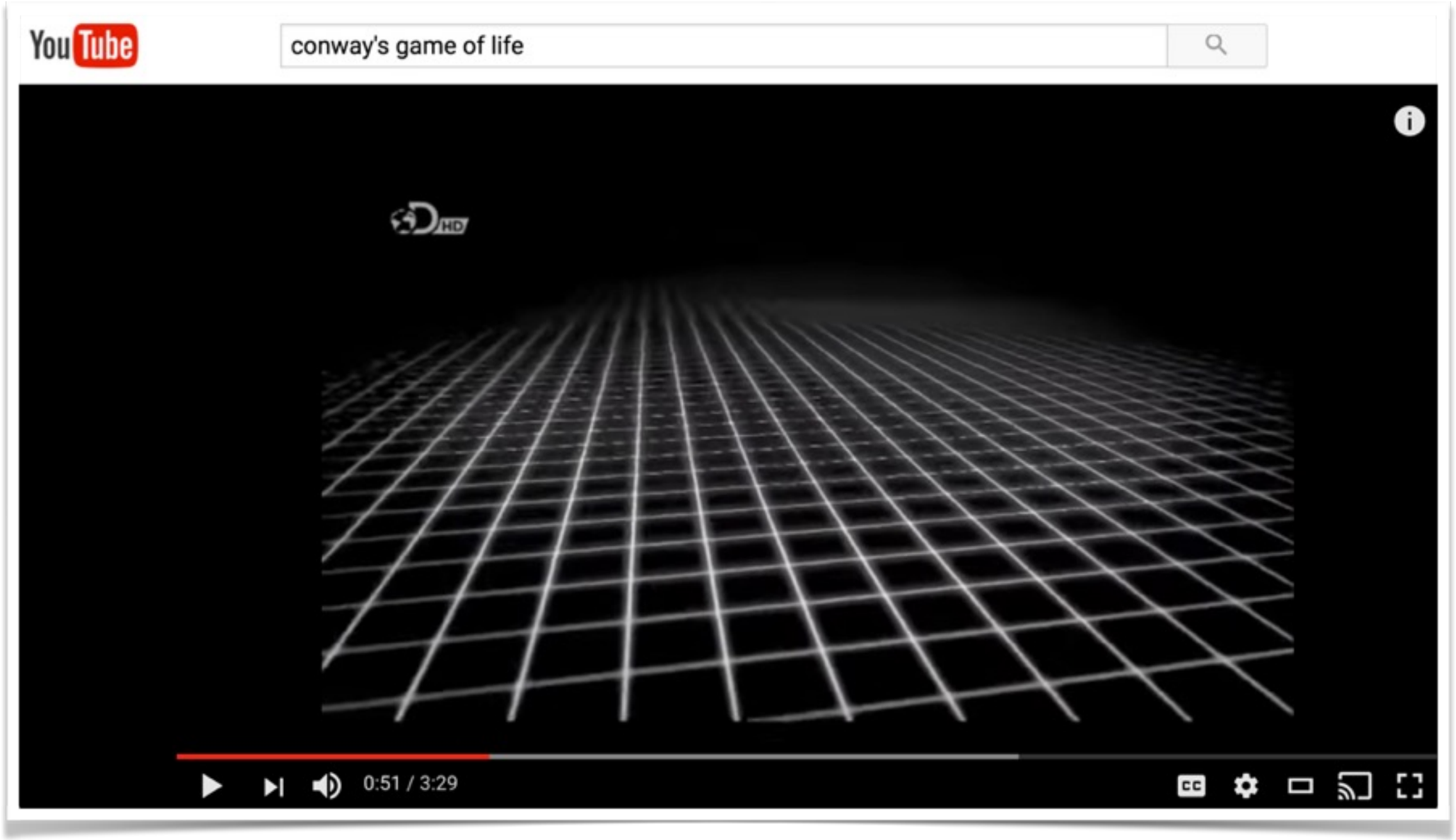
Programming Lab

Making the Game of Life Parallel



https://www.youtube.com/watch?v=CgOcEZinQ2I

Serial Version

- Study it

login to your **352b** account

```
getCopy GameOfLife.java
 javac GameOfLife.java
  java GameOfLife
```

- Run it on your laptop

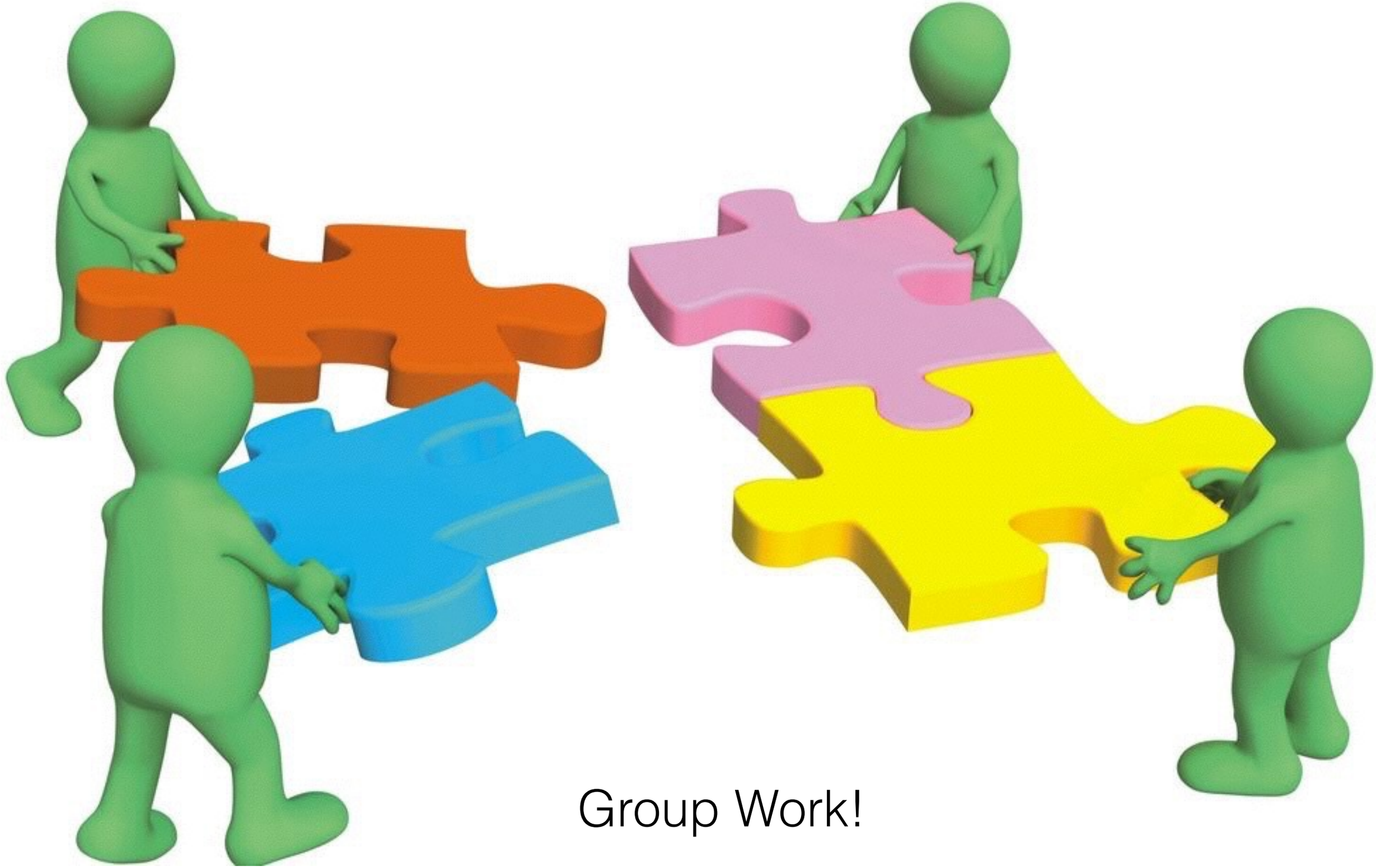
- Use both dish and dish2 as the array of live cells, and see how they evolve

Other option:

http://cs.smith.edu/dftwiki/index.php/CSC352_Game_of_Life_Lab_2017

2-Thread Version

- As a group, discuss the different tissues associated with parallelizing the Game of Life and running it with two threads.
- List all the issues that must be addressed on the whiteboard
- How will you verify the correctness of the parallel version?
- Play-out (human play) the execution of the 2-thread program: two people or two groups play the roles of the two threads.



Group Work!

Image taken from: http://www.brocku.ca/blogs/futurestudents/files/2014/10/puzzle-work.jpg

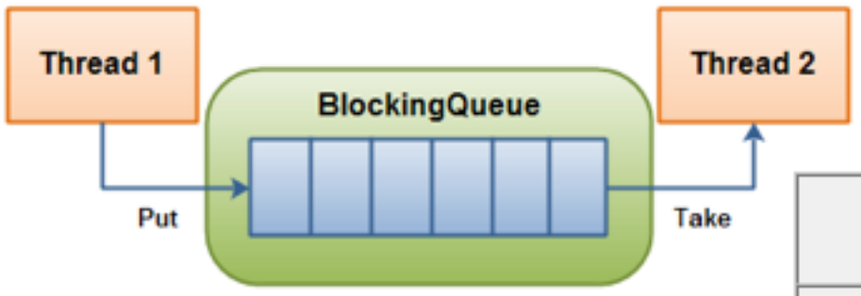
Could be Usefull…

- **What is a BlockingQueue?**
  BlockingQueue is a queue which is **thread safe** to insert or retrieve elements from it. Also, it provides a mechanism which blocks requests for inserting new elements when the queue is full or requests for removing elements when the queue is empty, with the additional option to stop waiting when a specific timeout passes. This functionality makes *BlockingQueue* a nice way of implementing the Producer-Consumer pattern, as the producing thread can insert elements until the upper limit of *BlockingQueue* while the consuming thread can retrieve elements until the lower limit is reached and of course with the support of the aforementioned blocking functionality.

https://examples.javacodegeeks.com/core-java/util/concurrent/java-blockingqueue-example/

Thread safe: Implementation is guaranteed to be free of race conditions when accessed by multiple threads simultaneously.

–Johnny Appleseed



	Throws Exception	Special Value	Blocks	Times Out
Insert	`add(o)`	`offer(o)`	`put(o)`	`offer(o, timeout, timeunit)`
Remove	`remove(o)`	`poll()`	`take()`	`poll(timeout, timeunit)`
Examine	`element()`	`peek()`		

- BlockingQueue

- Need to use an implementation of it:
  - **ArrayBlockingQueue**
  - DelayQueue
  - LinkedBlockingQueue
  - PriorityBlockingQueue
  - SynchronousQueue

"A Queue that additionally supports operations that ***wait*** for the queue to become non-empty when retrieving an element, and ***wait*** for space to become available in the queue when storing an element"

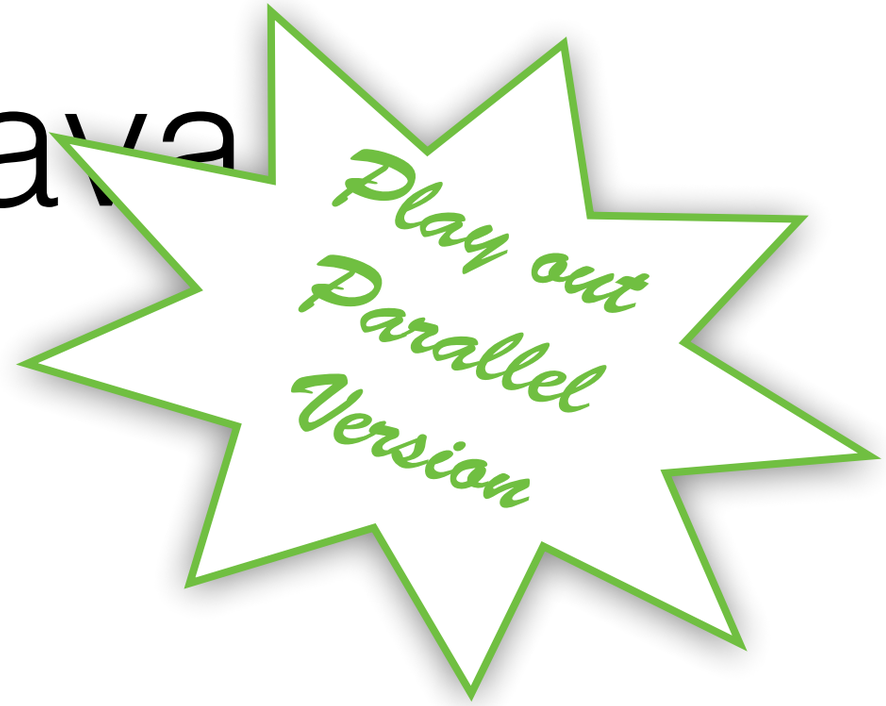
Image & table from: http://tutorials.jenkov.com/java-util-concurrent/blockingqueue.html

```java
import java.util.concurrent.ArrayBlockingQueue;
import java.util.concurrent.BlockingQueue;


public class UsingQueues {

        public static void main(String[] args) throws InterruptedException {
                BlockingQueue<Integer> toWorkerQ = new ArrayBlockingQueue<Integer>(2);
        BlockingQueue<Integer> fromWorkerQ = new ArrayBlockingQueue<Integer>(2);

        // create a worker and give it the two queues
        DemoThread t=new DemoThread( fromWorkerQ, toWorkerQ );

        // start thread
        t.start();

        // wait 1/2 second
        try {
                Thread.sleep( 500 );
            } catch (InterruptedException e) {
                e.printStackTrace();
            }

        // send work to worker
        toWorkerQ.put( 100 );

        // wait for answer back from worker
        int x = fromWorkerQ.take();

        // display the result
        System.out.println( "x = " + x );

        }

}
```

Code available here: http://cs.smith.edu/dftwiki/index.php/CSC352:_Using_BlockingQueues

```java
/**
 * DemoThread
 */
class DemoThread extends Thread {
        BlockingQueue<Integer> sendQ;
        BlockingQueue<Integer> receiveQ;

        DemoThread( BlockingQueue<Integer> sendQ,
                                BlockingQueue<Integer> receiveQ ) {
                this.sendQ = sendQ;
                this.receiveQ = receiveQ;
        }

        public void run(){
                int x=0;

                // block until there's something in the queue
                try {
                        x = receiveQ.take( );
                } catch (InterruptedException e1) {
                        e1.printStackTrace();
                }

                // do some computation
                x = x*2;

                // send results back
                try {
                        sendQ.put( x );
                } catch (InterruptedException e) {
                        e.printStackTrace();
                }
        }
}
```

Implement the 2-Thread Game of Life in Java




We Stopped
Here
Last Time

*The following slides present an **approach** for*

1) Running experiments
2) Evaluating performance
3) Displaying a meaningful graph

The Next Slides present…

- An **approach** for
- ***Running*** experiments ***automatically***
- ***Measuring*** and ***recording*** performance measures
- ***Filtering*** and ***graphing*** the results

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- An **approach** for
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  - ***Measuring*** and ***recording*** performance measures
  - ***Filtering*** and ***graphing*** the results

bash scripts

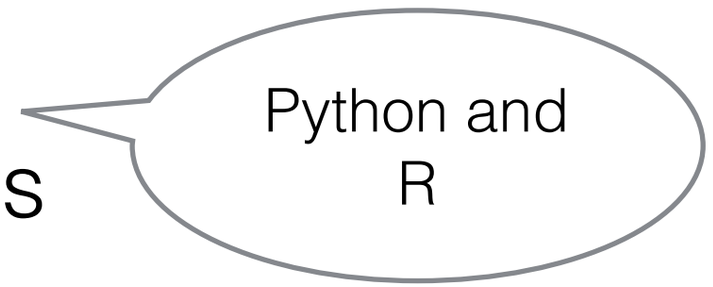
The Next Slides present…

- An **approach** for
- ***Running*** experiments ***automatically***
- ***Measuring*** and ***recording*** performance measures
- ***Filtering*** and ***graphing*** the results

time, redirection

The Next Slides present…

- An **approach** for
  - ***Running*** experiments ***automatically***
  - ***Measuring*** and ***recording*** performance measures
  - ***Filtering*** and ***graphing*** the results



Defining the Number of Threads at Execution Time

UsingQueuesN.java

```java
public class UsingQueuesN {

    public static void main(String[] args) throws InterruptedException {

        if ( args.length < 1 ) {
            System.out.println( "Syntax: java UsingQueuesN n" );
            System.out.println( " where n = # of threads" );
            return;
        }

        int N = Integer.parseInt( args[0] );

        BlockingQueue<Integer> toWorkersQ = new ArrayBlockingQueue<Integer>(2*N);
        BlockingQueue<Integer> fromWorkersQ = new ArrayBlockingQueue<Integer>(2*N);

        // create a worker and give it the two queues
        DemoThreadN[] threads = new DemoThreadN[N];

        for ( int i=0; i<N; i++ ) {
            DemoThreadN t=new DemoThreadN( i, fromWorkersQ, toWorkersQ );
            t.start();
            threads[i] = t;
        }

        // wait 1/2 second
        try {
            Thread.sleep( 500 );
        } catch (InterruptedException e) {
            e.printStackTrace();
        }

        // send same amount of work to each worker
        for ( int i=0; i<N; i++ )
            toWorkersQ.put( 100 );

        // wait for answer back from worker
        for (int i=0; i<N; i++ ) {
            int x = fromWorkersQ.take();

            // display the result
            System.out.println( "x = " + x );
        }
    }
}
```

getCopy UsingQueuesN.java
`javac UsingQueuesN.java`
`java UsingQueuesN 8`

Code available from: http://cs.smith.edu/dftwiki/index.php/CSC352:_Defining_Number_of_Threads_at_Execution_Time#Source

UsingQueuesN.java

```
class DemoThreadN extends Thread {
    private BlockingQueue<Integer> sendQ;
    private BlockingQueue<Integer> receiveQ;
    private int Id;

    DemoThreadN( int Id,
                 BlockingQueue<Integer> sendQ,
                 BlockingQueue<Integer> receiveQ ) {
        this.Id = Id;
        this.sendQ = sendQ;
        this.receiveQ = receiveQ;
    }

    public void run(){
        int x=0;

        // block until there's something in the queue
        try {
            x = receiveQ.take( );
        } catch (InterruptedException e1) {
            e1.printStackTrace();
        }

        // do some computation
        x = x*( Id + 1 );

        // send results back
        try {
            sendQ.put( x );
        } catch (InterruptedException e) {
            e.printStackTrace();
        }
    }
}
```

Code available from: http://cs.smith.edu/dftwiki/index.php/CSC352:_Defining_Number_of_Threads_at_Execution_Time#Source

Measuring Performance

Pick the Performance Measure that is Right for Your Application

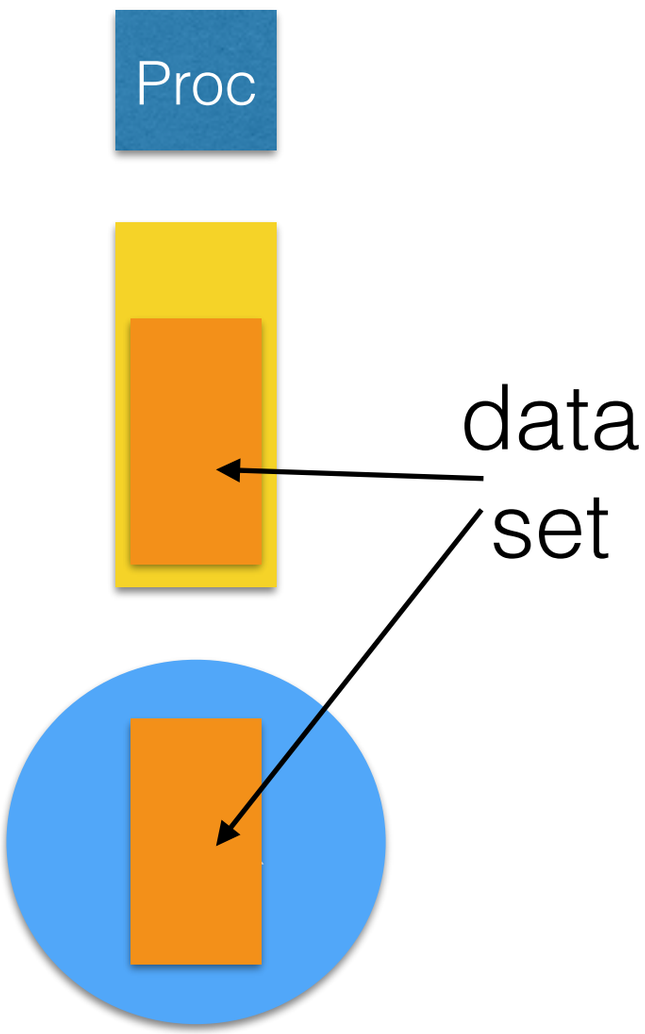
- **Speedup** = T(1) / T(***N***) as a function of ***N***
- Pick the ***best serial algorithm***!
- Define ***N*** (# of cores, # of threads, # of processors)
- Pick the right size problem and keep it constant (size of life grid, for example)
- Make sure data size is large enough, but fits in memory (avoid *disk thrashing*)

(side note)

- How can Amdahl's Law be circumvented:

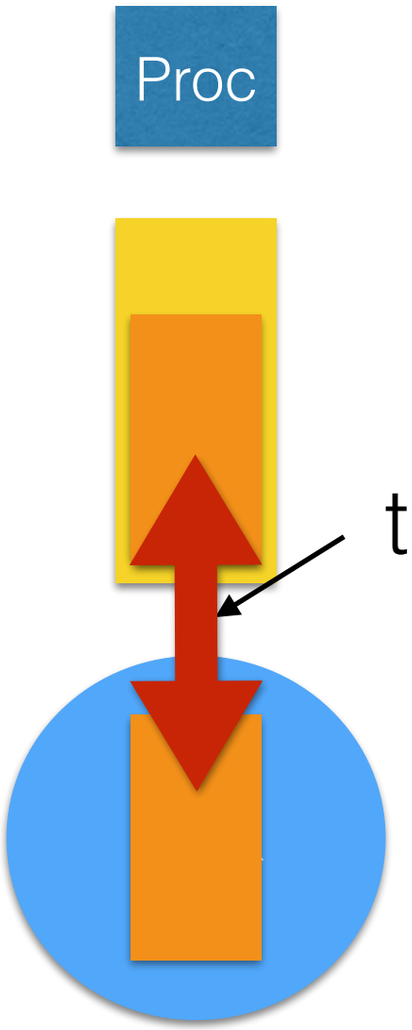
(side note)

- How can Amdahl's Law be circumvented:
- Pick a very large data set

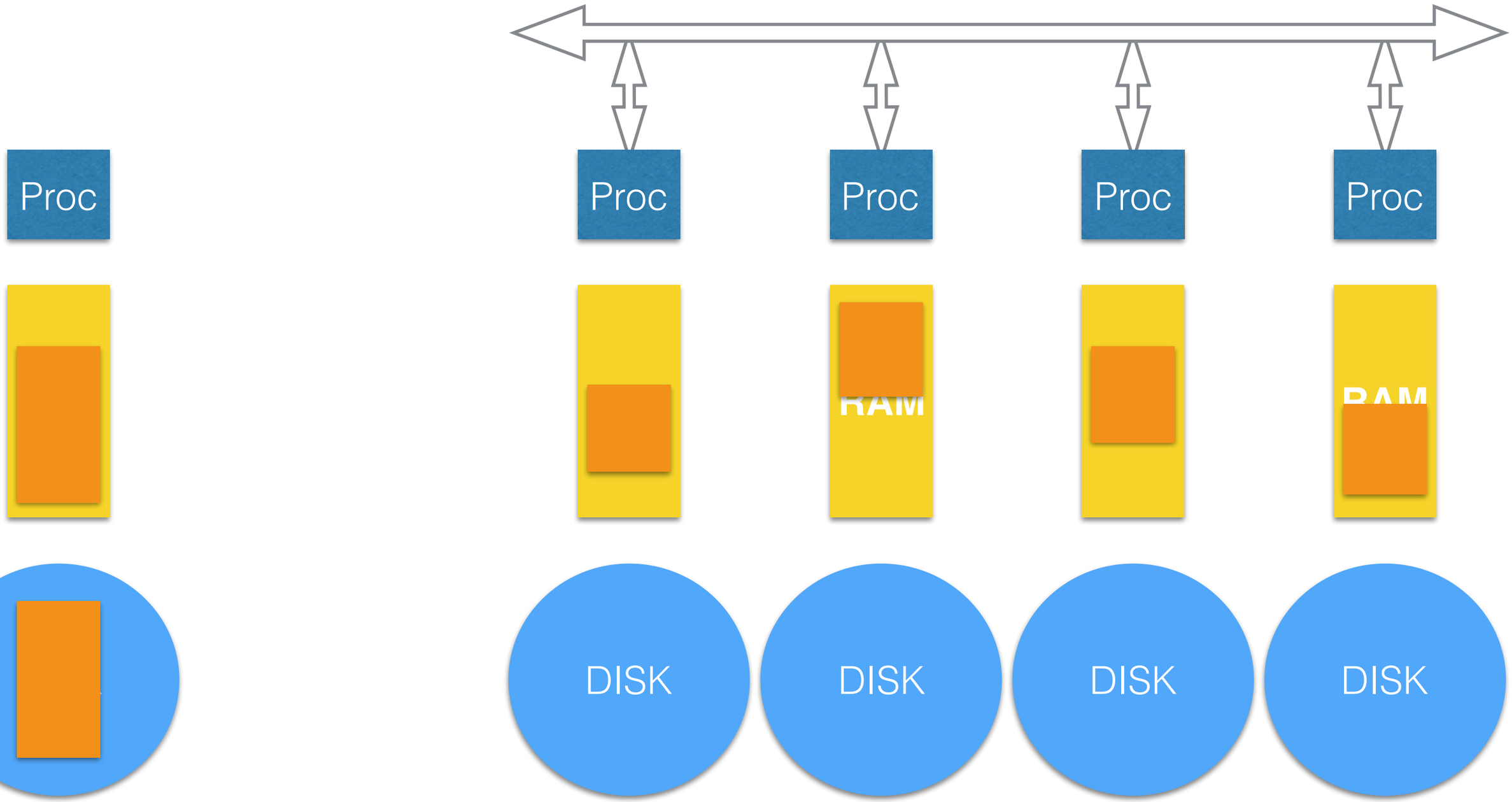


(side note)

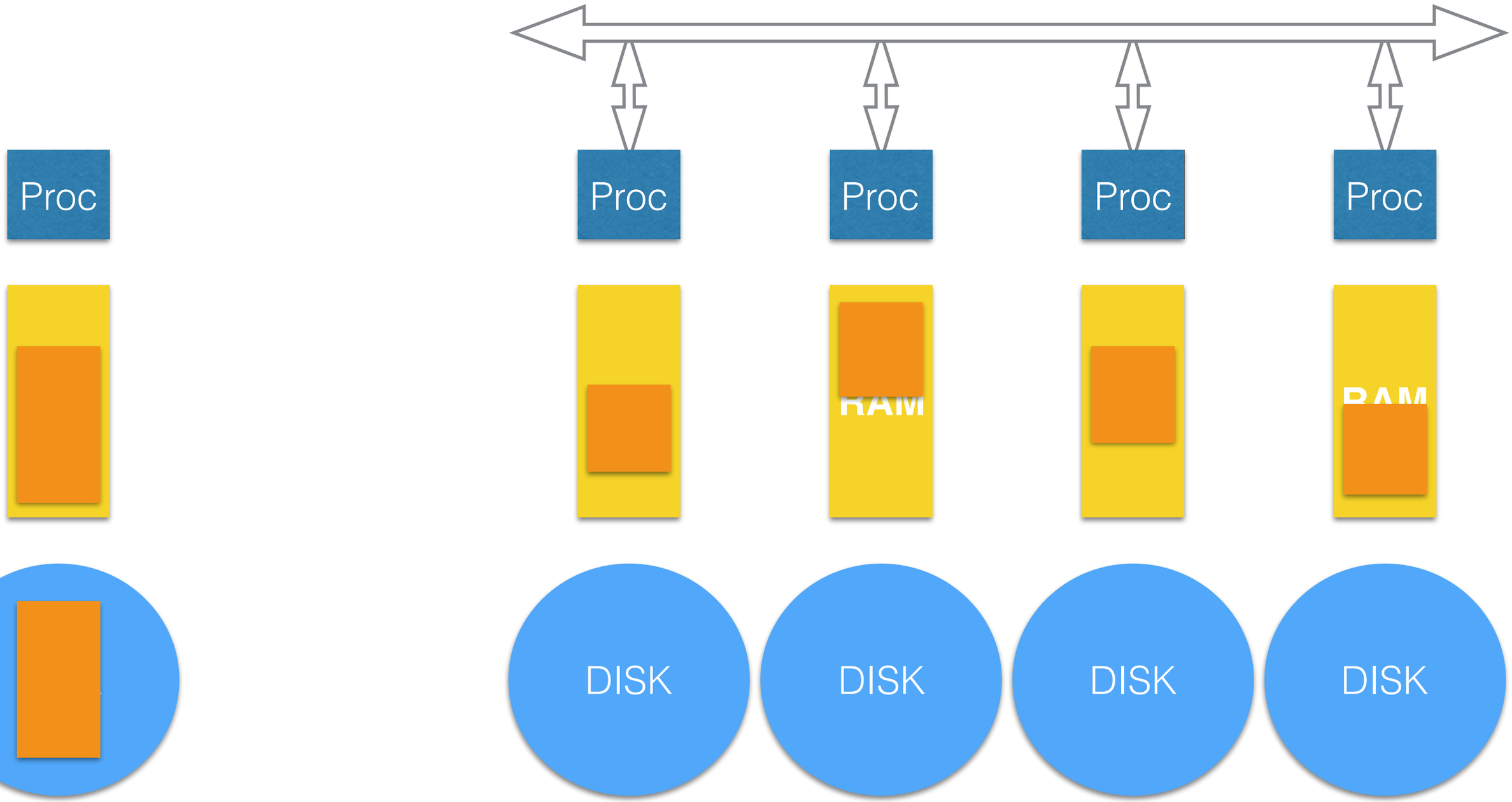
- How can Amdahl's Law be circumvented:
- Pick a very large data set



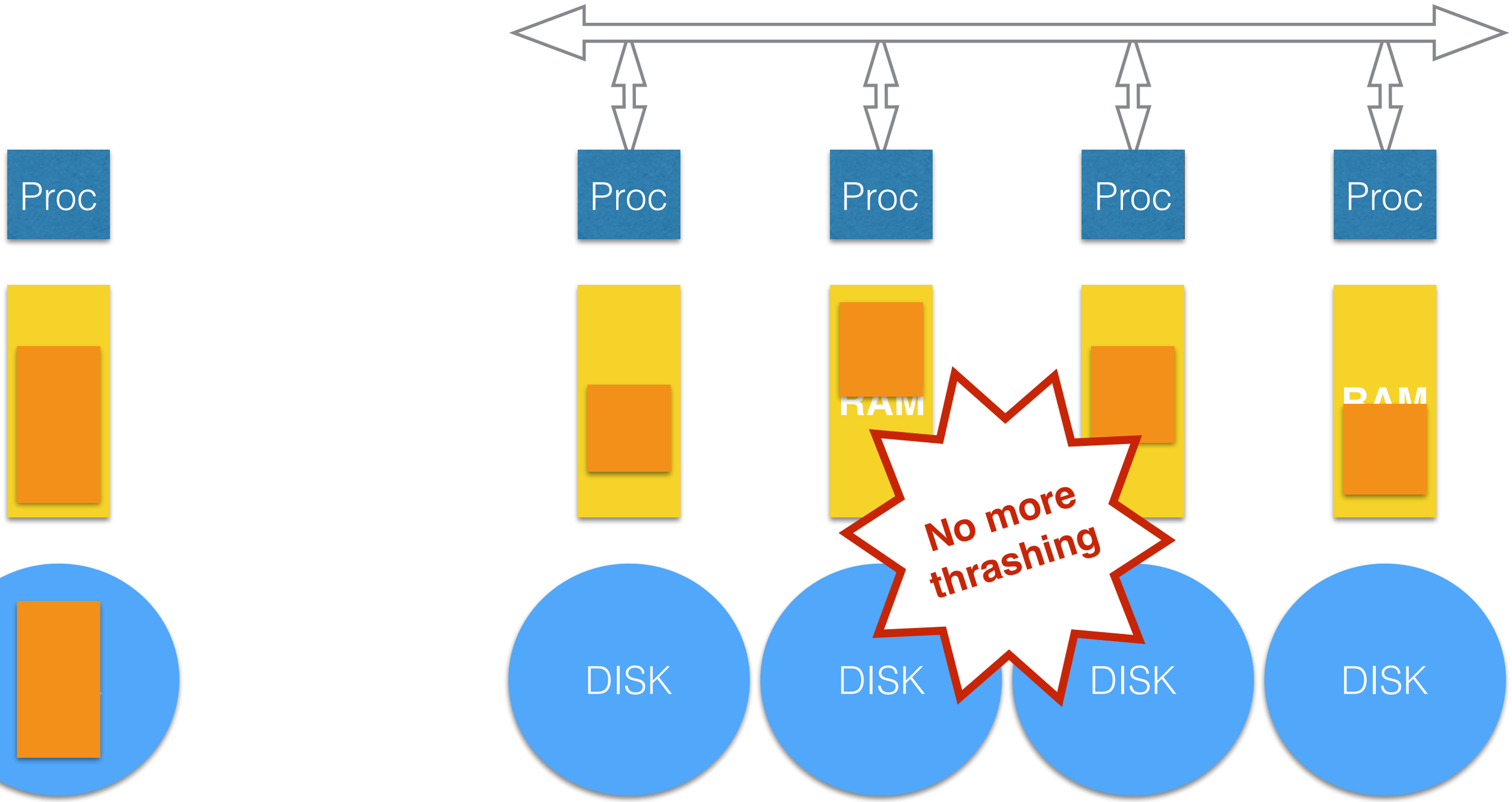
(side note)



(side note)



(side note)


Proc
Proc
Proc
Proc
Proc
RAM
RAM
No more thrashing
DISK
DISK
DISK
DISK

Measuring Performance

- Measure the **average** execution time of several runs for each case, or the **average** quantity of interest per unit of time.

- Use shell **scripts** and programming tools (See next slides)

Using Shell Scripts

http://www.science.smith.edu/dftwiki/index.php/CSC352:_Using_Bash,_an_example

```
# from 352b-xx account on aurora…
getcopy PrintN.java
getcopy processTimingData.py
getcopy runPrintN.sh
```

The target program

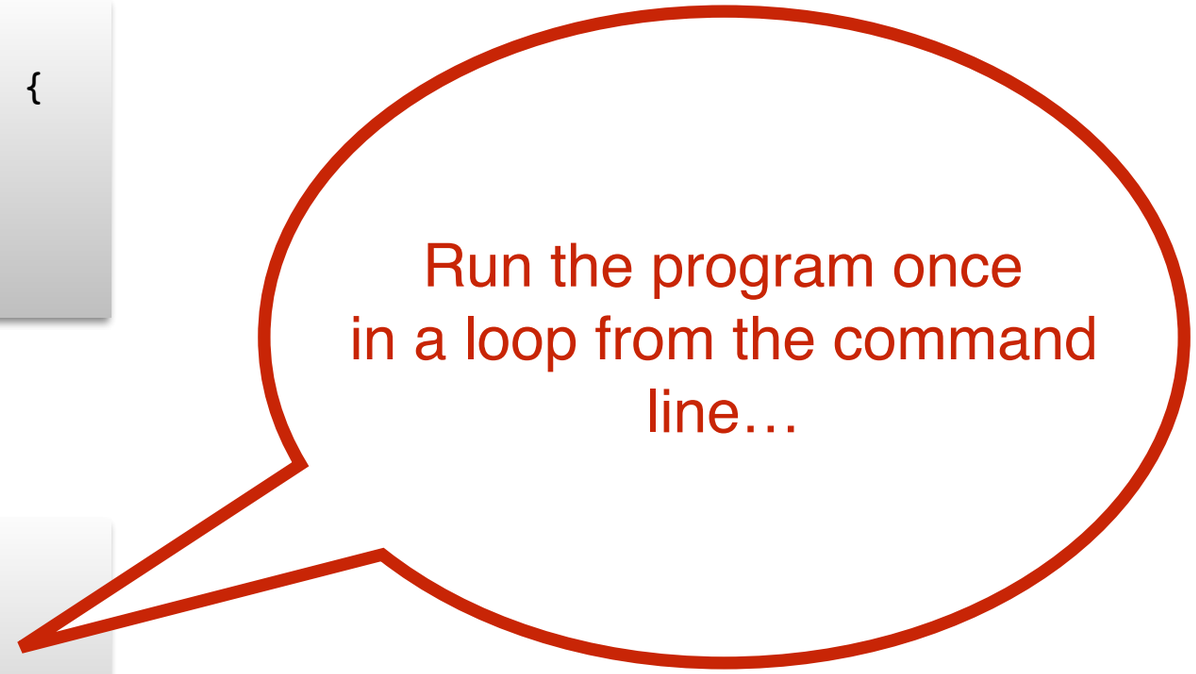
```
class PrintN {
     public static void main( String[] args ) {
         int N = Integer.parseInt( args[0] );
         System.out.println( "I got " + N );
     }
 }
```

Create a program that gets its (fake) degree of parallelism from the command line

Code available at: http://www.science.smith.edu/dftwiki/index.php/CSC352:_Using_Bash_Scripts_to_Measure_Program_Execution_Time

```
class PrintN {
     public static void main( String[] args ) {
         int N = Integer.parseInt( args[0] );
         System.out.println( "I got " + N );
     }
 }
```

```
# at the Linux prompt:
bash
javac PrintN.java
for i in 1 2 3 4 5 6 7 8 9 10 ; do
    java PrintN $i
done
```



```
class PrintN {
     public static void main( String[] args ) {
         int N = Integer.parseInt( args[0] );
         System.out.println( "I got " + N );
     }
 }
```

```
# at the Linux prompt:
bash
javac PrintN.java
for i in 1 2 3 4 5 6 7 8 9 10 ; do
    java PrintN $i
done
```

```
#! /bin/bash
# runPrintN.sh
#

javac PrintN.java
for i in 1 2 3 4 5 6 7 8 9 10 ; do
    java PrintN $i
done
```

Embed the commands just typed at the prompt into a Bash shell script

```
class PrintN {
     public static void main( String[] args ) {
         int N = Integer.parseInt( args[0] );
         System.out.println( "I got " + N );
     }
 }
```

```
# at the Linux prompt:
bash
javac PrintN.java
for i in 1 2 3 4 5 6 7 8 9 10 ; do
    java PrintN $i
done
```

```
#! /bin/bash
# runPrintN.sh
#

javac PrintN.java
for i in 1 2 3 4 5 6 7 8 9 10 ; do
    java PrintN $i
done
```

Run each program a few times for the same level of parallelism, and measure execution time for each run…

```
#! /bin/bash
# runPrintN.sh
#

javac PrintN.java
for i in 1 2 3 4 5 6 7 8 9 10 ; do
    for j in 1 2 3 ; do
        /usr/bin/time java PrintN $i
    done
done
```

```
./runPrintN.sh


1
I got 1

real  0m0.080s
user  0m0.067s
sys   0m0.011s
1
I got 1

real  0m0.082s
user  0m0.067s
sys   0m0.011s


…

I got 10

real  0m0.079s
user  0m0.066s
sys   0m0.011s
```

Note, the time command outputs its timing information to **stderr**, while the other command and java program outputs to **stdout**…

```
./runPrintN.sh  2>&1 | grep "got\|real" > timing.data
```

Redirect stderr to stdout, and capture lines with "got" or "real" to a text file.

```
./runPrintN.sh  2>&1 | grep "got\|real" > timing.data

cat timing.data

I got 1
real 0m0.085s
I got 1
real 0m0.086s
I got 1
real 0m0.085s
I got 2
real 0m0.093s
I got 2
real 0m0.096s

…

real 0m0.079s
I got 10
real 0m0.079s
I got 10
real 0m0.079s
I got 10
real 0m0.079s
```

Contents of timing.data (with middle lines removed for conciseness)

```
# processTimingData.py
# D. Thiebaut

from __future__ import print_function

file = open( "timing.data", "r" )
lines = file.readlines()
file.close()


# create array of time averages
times = [0]*11   # 0-10, hence 11

# parse lines of text
for line in text.split( "\n" ):
    if len(line) < 2:
        continue
    if line.find( "got" ) != -1:
        n = int( line.split()[-1] )
    else:
        time = line.replace( 'm', ' ' ).replace( 's', '' ).split()[-1]
        time = float( time )
        times[n] += time

# compute averages and print them
for i in range( len( times ) ):
    if times[i] != 0:
        print( i, times[i]/3.0 )
```

Write a Python program to filter timing.data and print a simple output of x and y values.

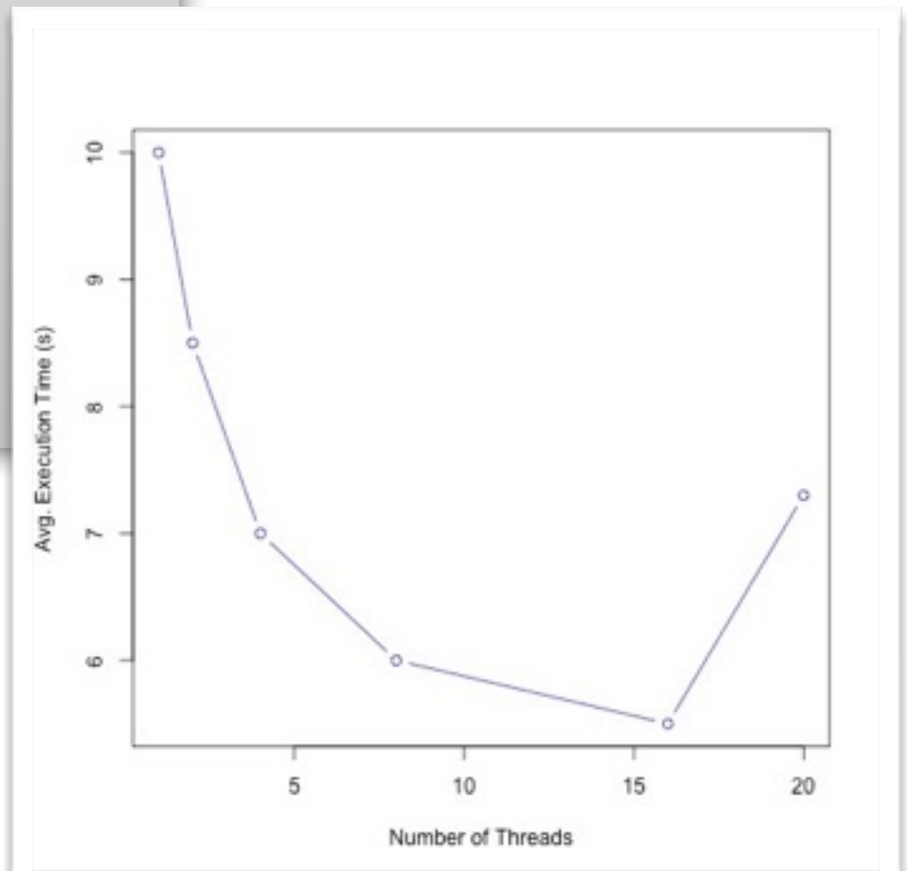
```
# processTimingData.py
# D. Thiebaut

from __future__ import print_function

file = open( "timing.data", "r" )
lines = file.readlines()
file.close()


# create array of time averages
times = [0]*11   # 0-10, hence 11

# parse lines of text
for line in text.split( "\n" ):
    if len(line) < 2:
        continue
    if line.find( "got" ) != -1:
        n = int( line.split()[-1] )
    else:
        time = line.replace( 'm', ' ' ).replace( 's', ''
        time = float( time )
        times[n] += time

# compute averages and print them
for i in range( len( times ) ):
    if times[i] != 0:
        print( i, times[i]/3.0 )
```

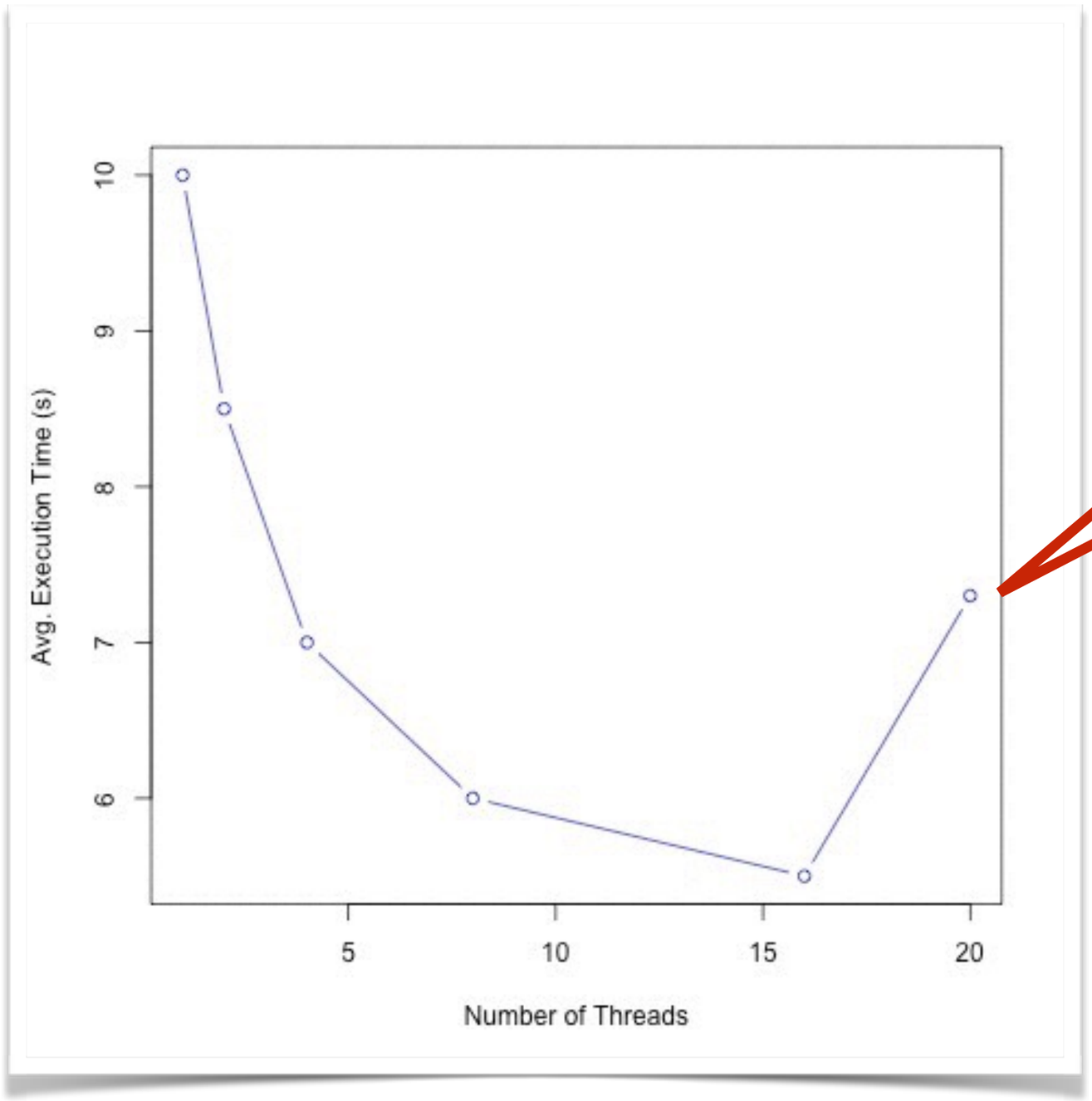
Output.
Ready for plotting!

```
python processTimingData.py
1 0.0853333333333
2 0.0923333333333
3 0.0843333333333
4 0.0816666666667
5 0.079
6 0.0866666666667
7 0.0843333333333
8 0.0796666666667
9 0.0806666666667
10 0.079
```

Plotting the Resulting Timing Information With **R**

````
---
title: "Plotting Execution Times"
author: "D. Thiebaut"
date: "2/21/2017"
output: html_document
---

This R-Markdown illustrates how to quickly display a graph of the
average execution times of an application running on 1 to 20 threads.

```{r}
noThreads <- c( 1,  2,   4,   8,   16,  20 )
execTimes <- c( 10, 8.5, 7.0, 6.0, 5.5, 7.3 )

jpeg( '/Users/thiebaut/Desktop/executionTimes.jpg' )
plot( noThreads, execTimes, type="b", col="blue",
      xlab="Number of Threads", ylab="Avg. Execution Time (s)")
dev.off()


plot( noThreads, execTimes, type="b", col="blue",
      xlab="Number of Threads", ylab="Avg. Execution Time (s)")
```
````





Make sure that the graph clearly shows **POINTS** and that the lines are understood to show the trend.


We Stopped
Here
Last Time

Some Comments On Papers

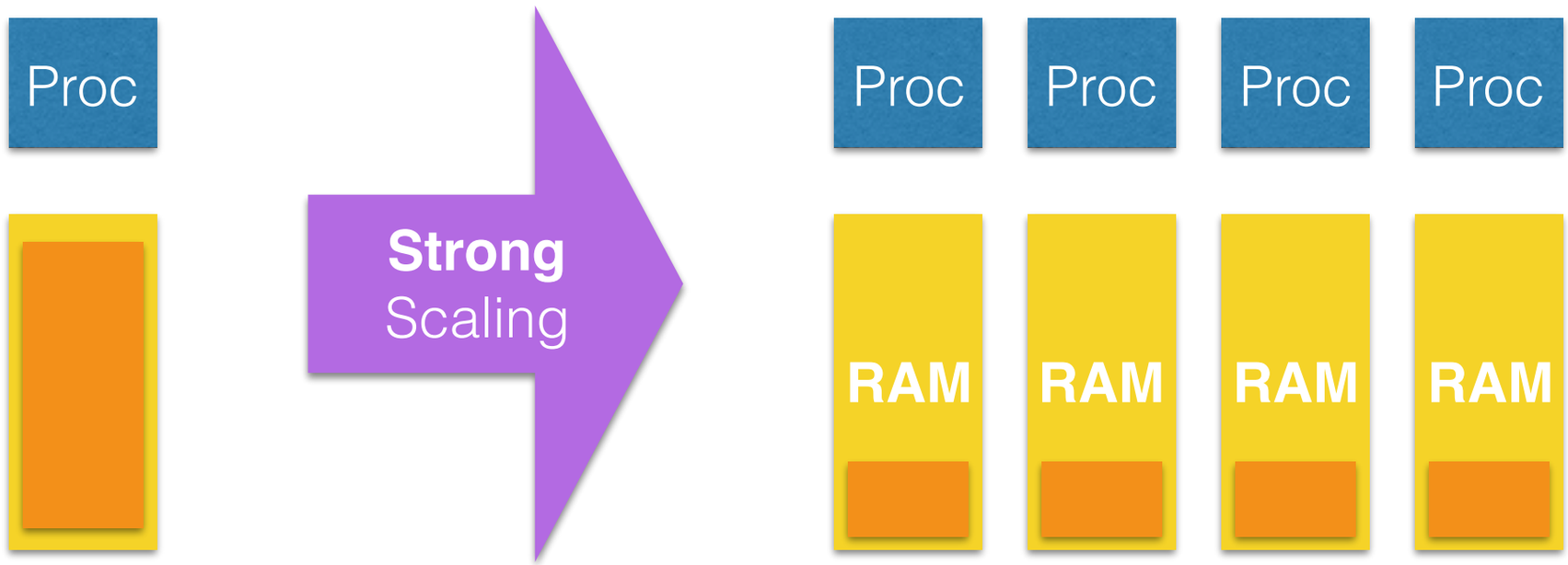
What *Is* Scalability?

- Ideal is to get *N* times more work done on *N* processors

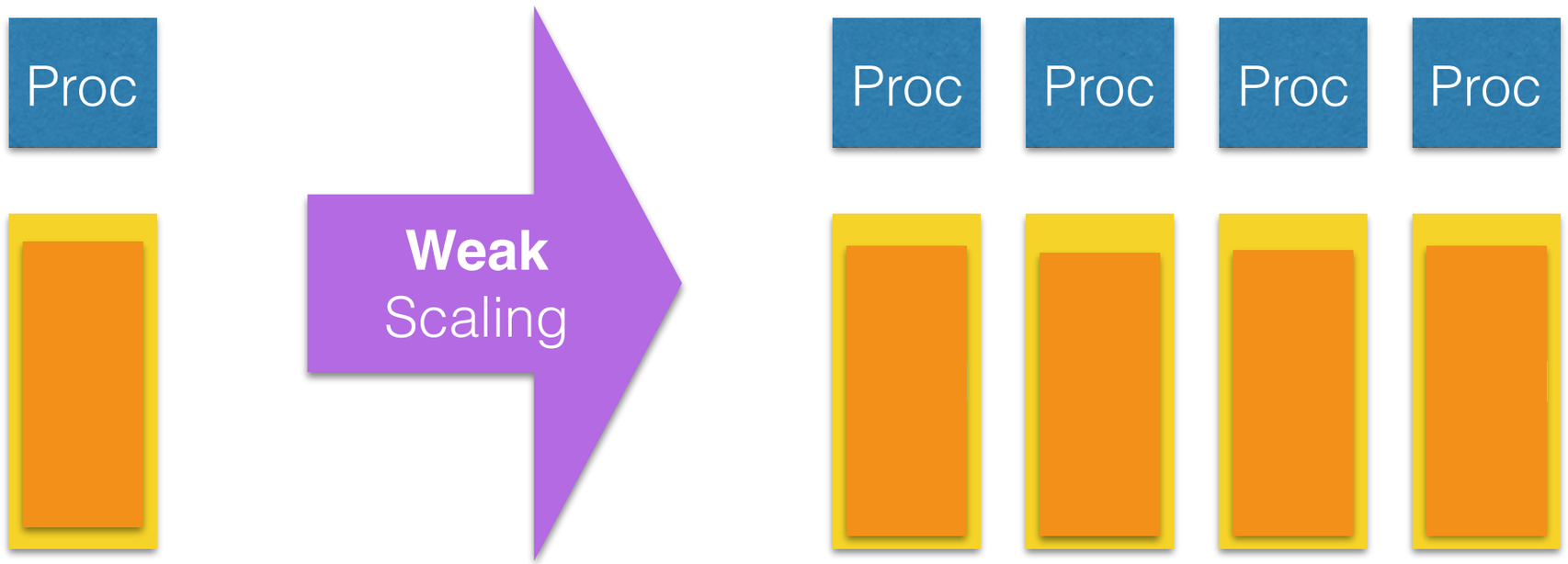
- Strong scaling: compute a fixed-size problem *N* times faster
  - Speedup $S = T_1 / T_N$; linear speedup occurs when $S = N$
  - Can't achieve it due to Amdahl's Law (no speedup for serial parts)

- Weak scaling: compute a problem *N* times bigger in the same amount of time
  - Speedup depends on the amount of serial work remaining constant or increasing slowly as the size of the problem grows
  - Assumes amount of communication among processors also remains constant or grows slowly

Strong vs Weak Scaling



Strong vs Weak Scaling



Top500 List

https://www.top500.org/lists/2016/11/

#1 National Supercomputing Center in Wuxi China
10,649,600 cores

93,014.6 TFlops

Name	The Number	Prefix
quadrillion	10^15	peta
trillion	1,000,000,000,000	tera
billion	1,000,000,000	giga
million	1,000,000	mega
thousand	1,000	kilo

Top500 List

https://www.top500.org/lists/2016/11/

CPU	MHz	MFlops	MFlops (no opt)
Core i5 2467M	@@@@	1064.70	315.46
Celeron C2 M	2000	1092.56	121.25
Core 2 Duo 1 CP	2400	1315.42	195.13
Phenom II	3000	1412.83	244.43
Core i7 930	****	1764.75	428.00
Core i7 860	####	2004.31	381.97
Core i7 3930K	&&&&	2529.73	746.01
Core i7 4820K	$$$1	2671.15	892.04
Core i7 4820K	$$$2	2684.05	895.54
Core i7 3930K	OC	3112.94	926.92

Rated as 2800 MHz but running at up to 3460 MHz using Turbo Boost

**** Rated as 2800 MHz but running at up to 3066 MHz using Turbo Boost

@@@@ Rated as 1600 MHz running at up to 2300 MHz using Turbo Boost

&&&& Rated as 3200 MHz but running at up to 3800 MHz OC OverClocked ~4720 MHz

$$$1 Rated as 3700 MHz but running at up to 3900 MHz using Turbo Boost

$$$2 Performance not Balanced Power Setting for 3900 MHz

M = Mobile CPU

10^7 cores
93 10^15 Flops

4 cores
3 10^9 Flops

2.5 10^6 more cores
30 10^6 more computing power

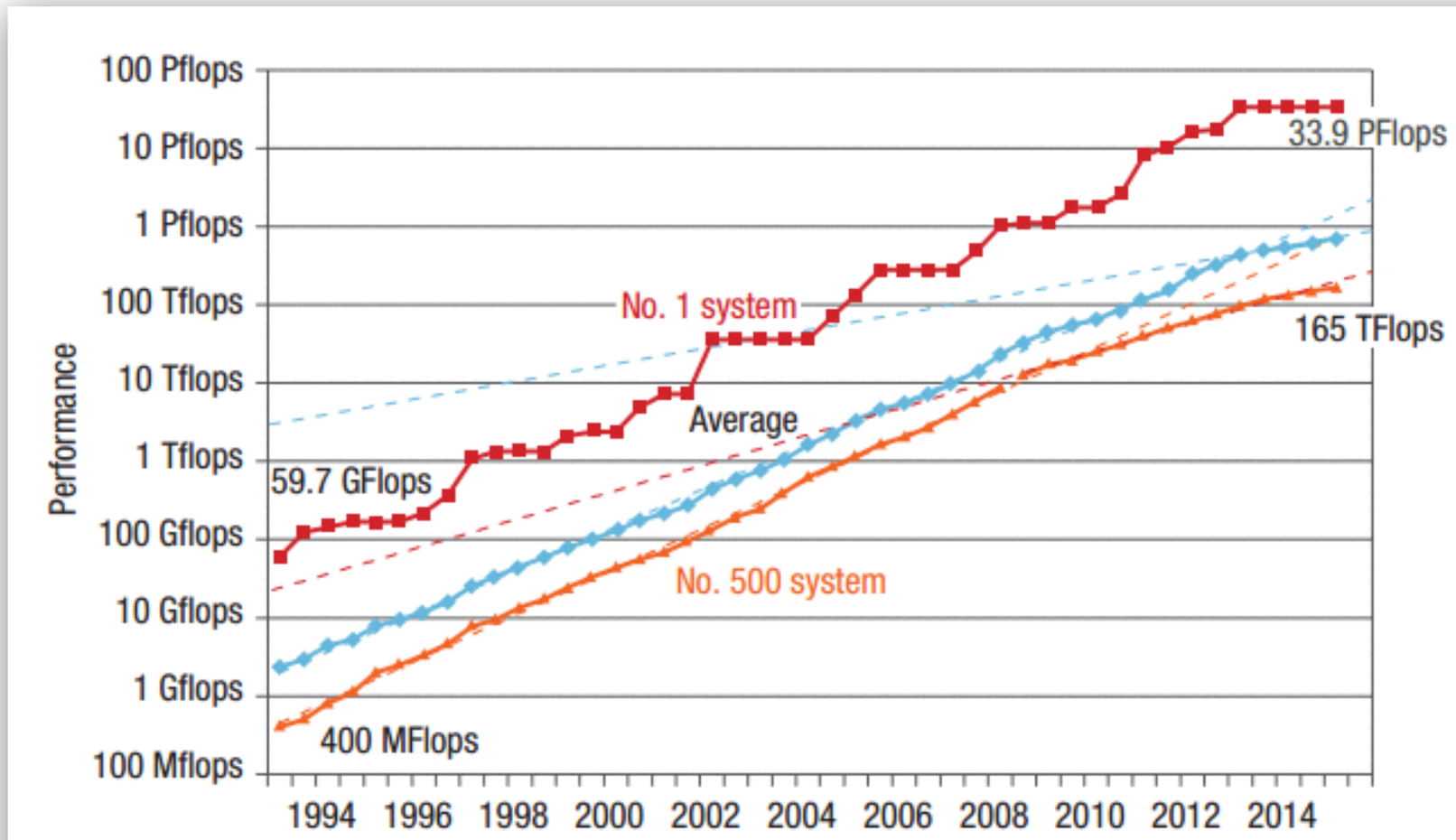


FIGURE 1. Supercomputer performance over time as tracked by the TOP500 list. The red and orange lines show performance of the first (number 1) and last (number 500) systems, respectively, and the blue line shows average performance of all systems. Dashed lines are fitted exponential growth curves before and after 2008 for the orange line and before and after 2013 for the blue line.

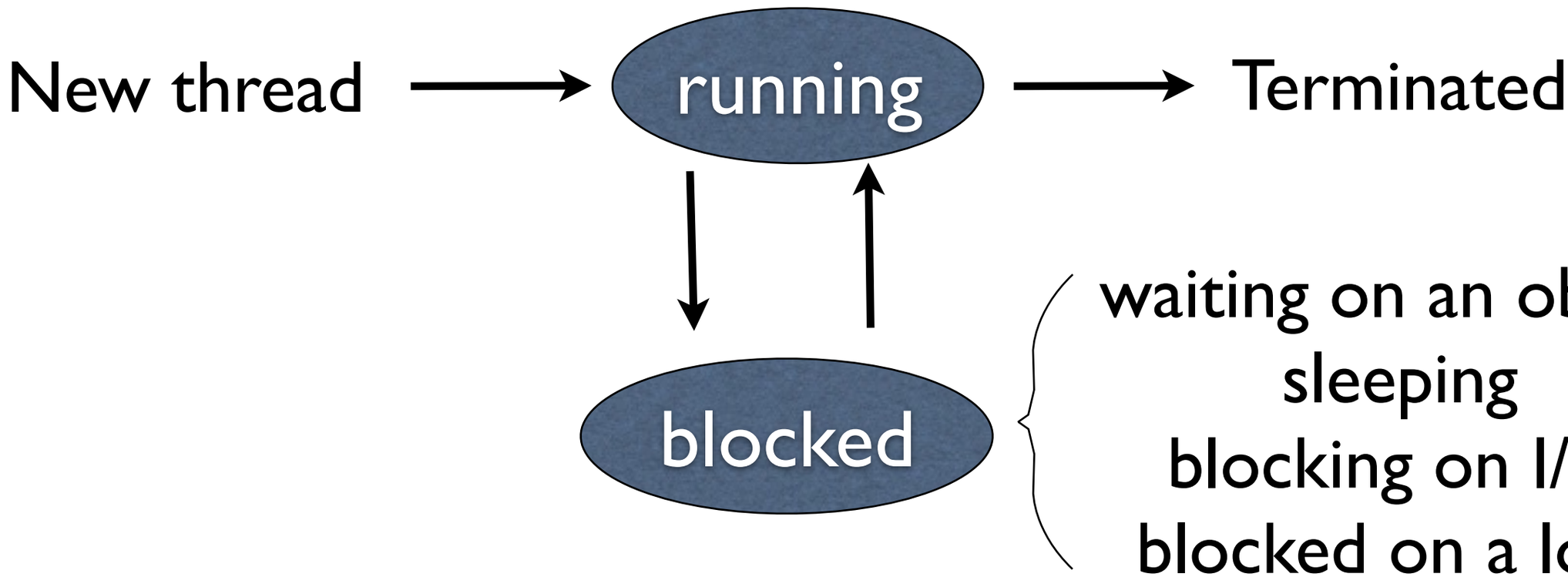
From: https://www.nextplatform.com/2015/11/25/2241/

Advanced Concepts on Threads

The Basics

- **Threads Operation**
  - `run()`/`start()`
  - `yield()`
  - `sleep()`
  - `join()`
  - `wait()`, `notify()`, and also `notifyAll()`

States of a Thread



How does one get the state?

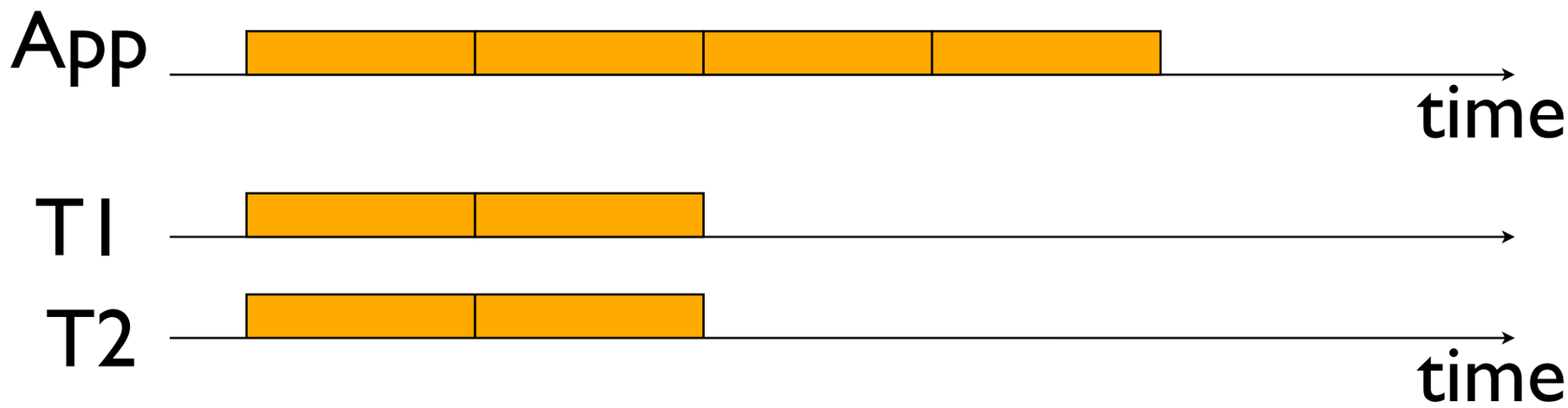
- NEW
- RUNNABLE
- BLOCKED

`getState()`

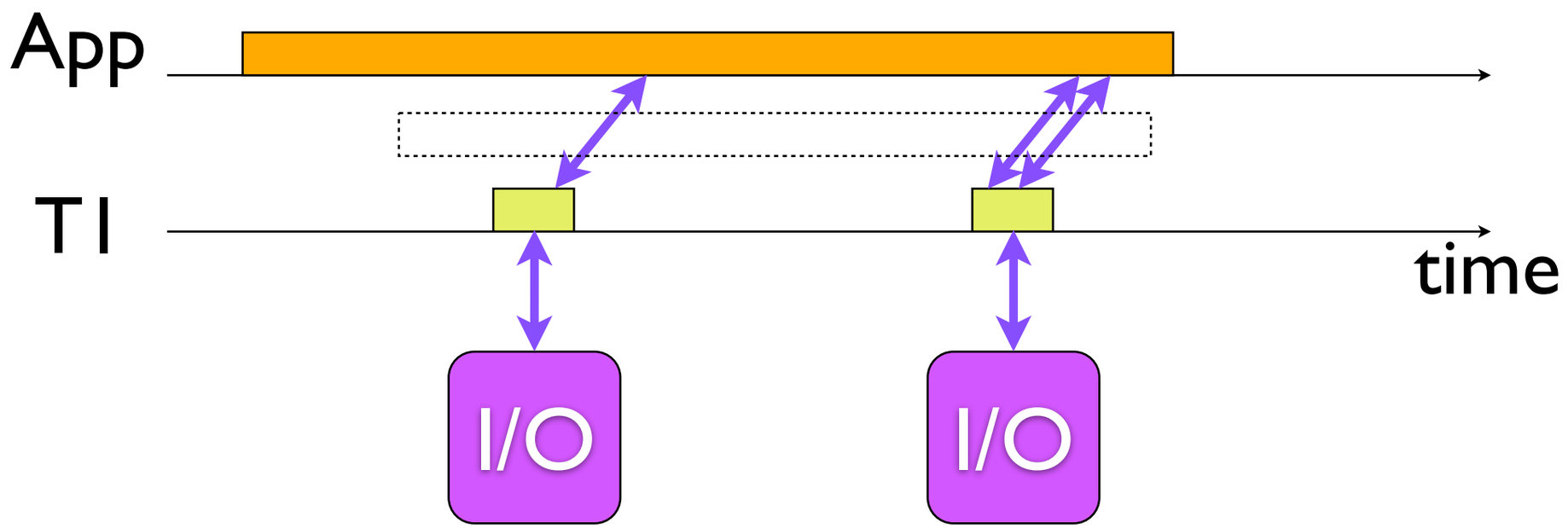
- WAITING
- TIME_WAITING
- TERMINATED

http://docs.oracle.com/javase/1.5.0/docs/api/java/lang/Thread.State.html

Threads good not only for speedup



Threads good not only for speedup



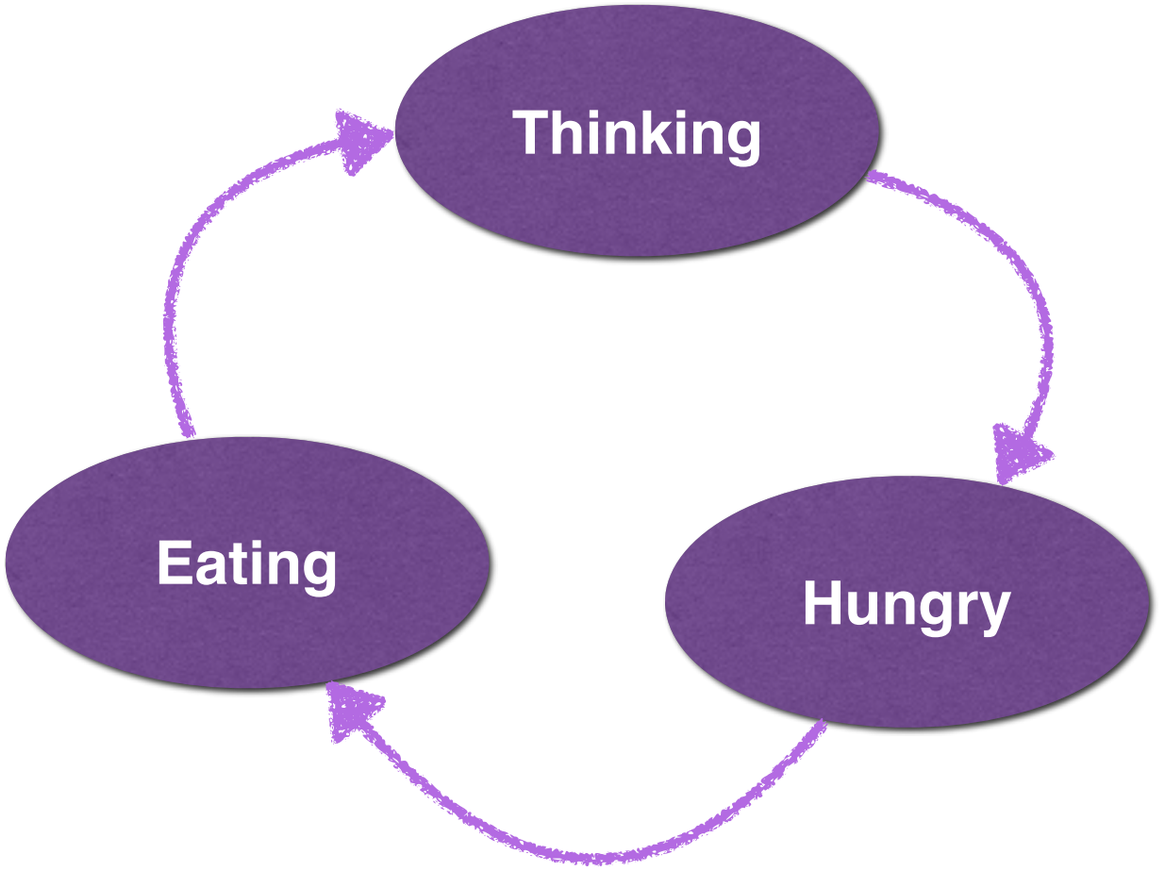
Important Concepts

- CPU Bound Processes/Threads
- I/O Bound Processes/Threads

Time Scale

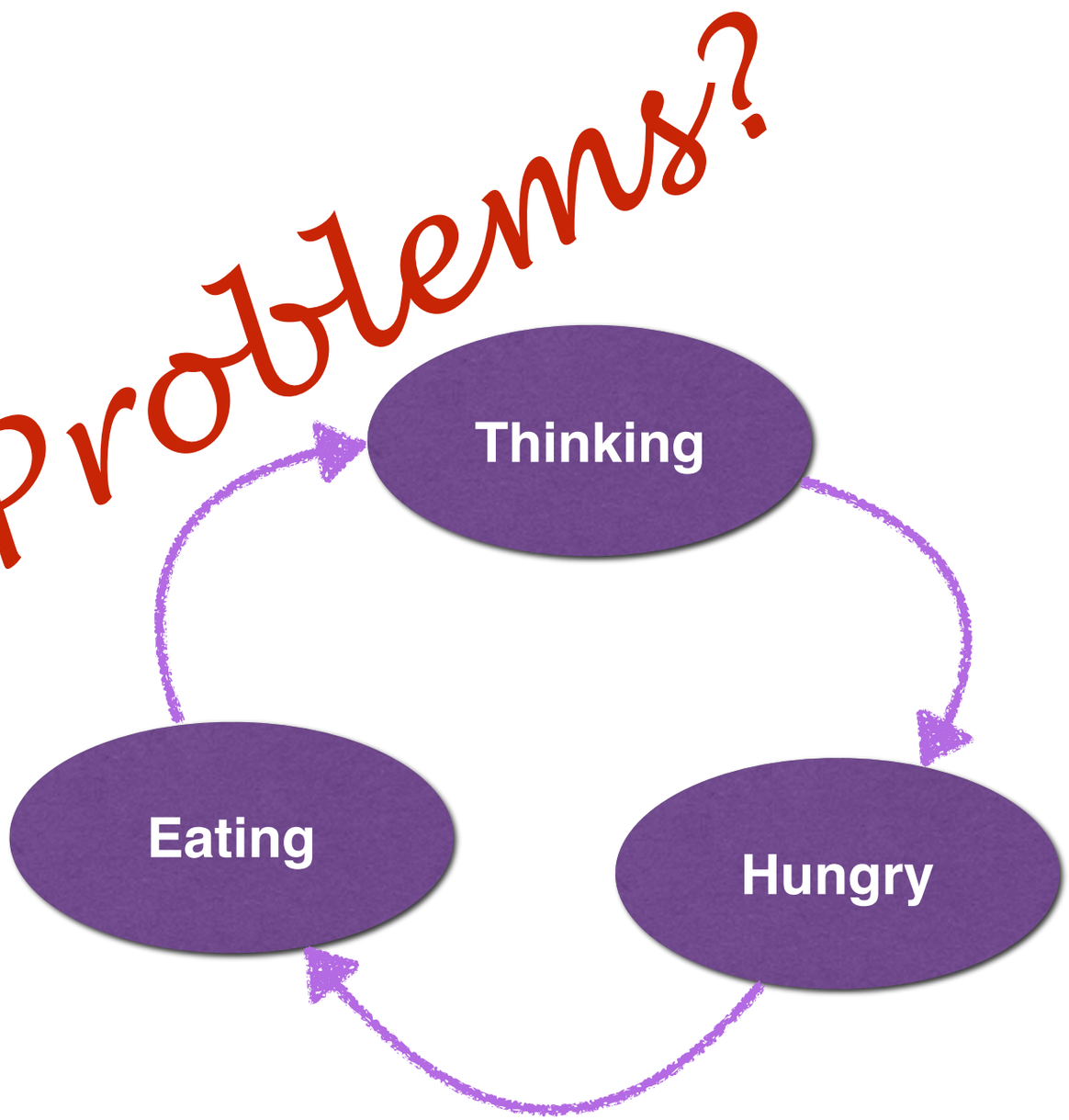
- Why I/O recognizing I/O-bound process is important
  - CPU cycle: 1 ns
  - RAM cycle: 100-500 ns
  - Disk access = seek + latency
    - seek = 1 ms
    - latency = 1/2 rotation, at 10,000 RPM
  - Question: How long does the processor wait for data from disk?

Problems Associated with Sharing Data



- The Dining-Philosophers Problem
  http://vip.cs.utsa.edu/nsf/pubs/starving/starving.html

Problems Associated with Sharing Data



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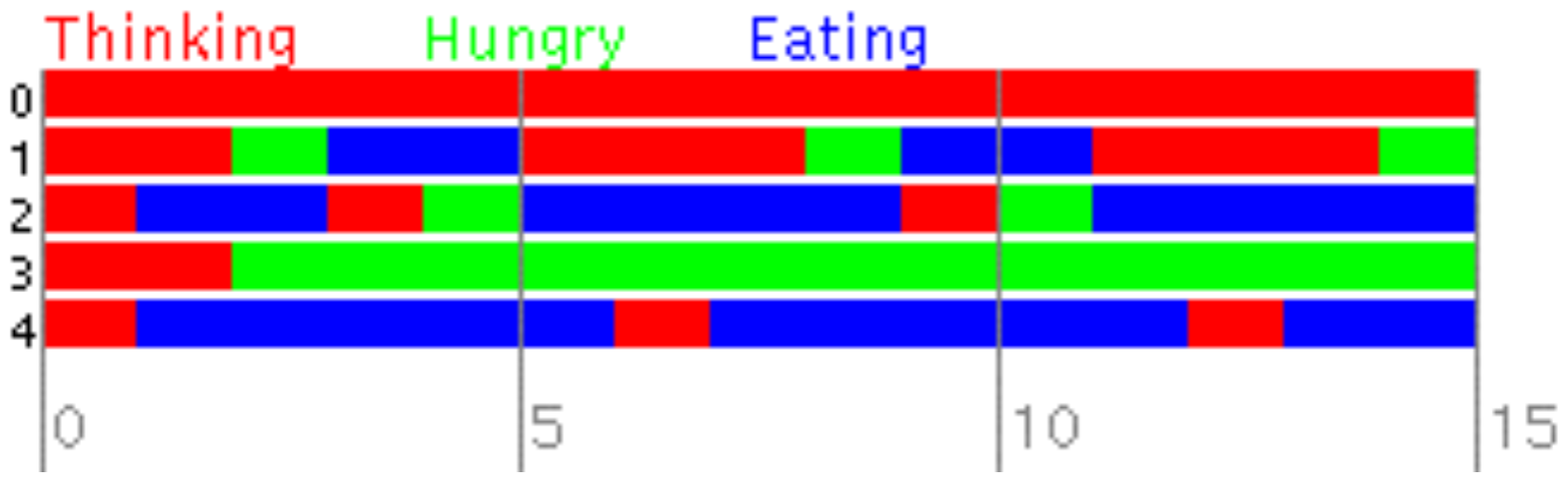
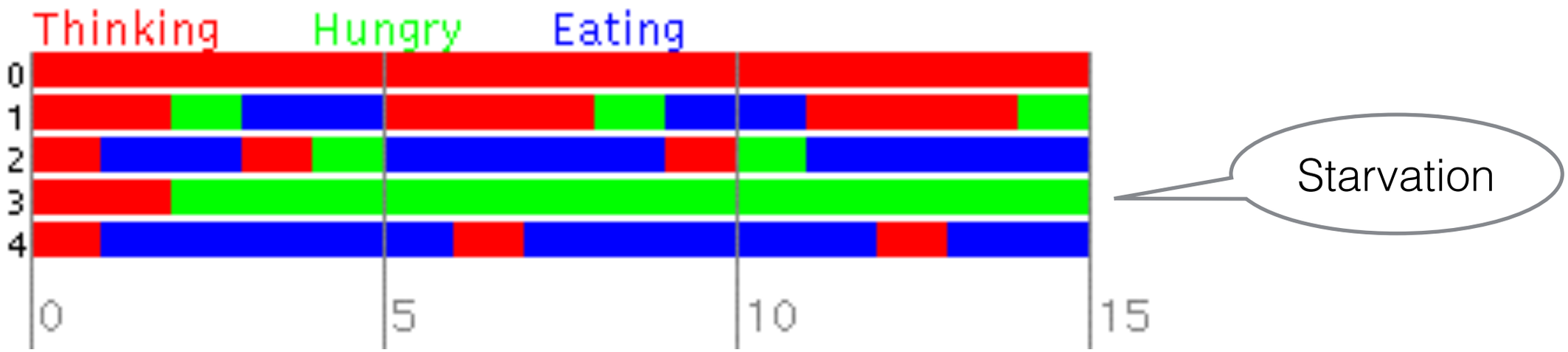

Thinking
Hungry
Eating
0
1
2
3
4
0
5
10
15


Thinking
Hungry
Eating
0
1
2
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4
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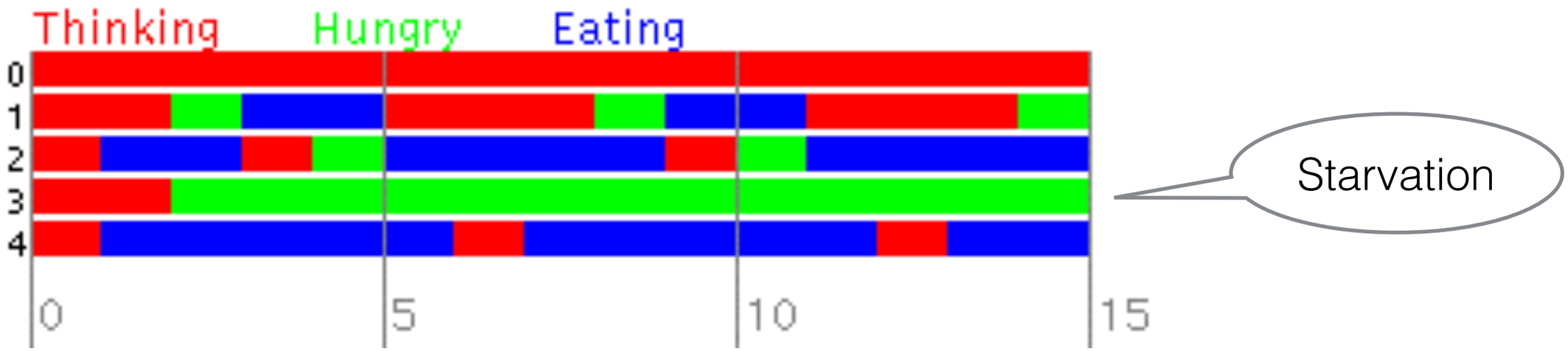
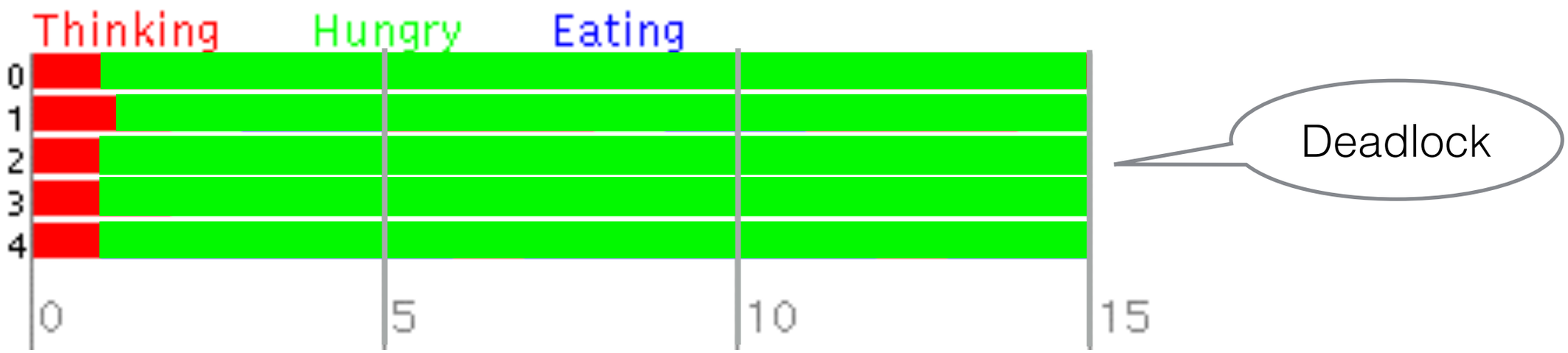
15
Starvation


Thinking
Hungry
Eating
0
1
2
3
4
0
5
10
15
Starvation


Thinking
Hungry
Eating
0
1
2
3
4
0
5
10
15
Deadlock

Thread Scheduling

- What is the policy?
  - Java doc says: *Implemented in the JVM, preemptive, based on priority.* (No mention of time-slices.)
  - 1= low priority, 5 = main, 10 = high priority
  - `getPriority()` & `setPriority()`
  - However, most OS implement time-slices (quanta), roughly 1ms, preemptive, and round-robin ==> JVMs do the same

Rule #1 for Preventing Deadlocks

- **Grab all** the shared data-structures that you need first
- If you can't, **release** them all
- **Wait** a **random amount** of time and try again

Rule #2 for Preventing Starvation

- In Dining Philosophers situation, **do not allow** a philosopher to **eat twice** before one has had a chance to eat once ("polite" algorihm of http://vip.cs.utsa.edu/nsf/pubs/starving/starving.html)

Crash Course on

C

(Switch to Separate Set of Slides)