# Lecture 19: Mandelbrot and Sequential Consistency

COSC 273: Parallel and Distributed Computing

Spring 2023

# Announcements

1. Lab 03 Due ~~Friday~~ MONDAY!!
   - Mandelbrot computations using `Vector` operations
   - Make sure your machine supports `Vector` ops **today**:

     ```
     > javac --add-modules jdk.incubator.vector SomeFile.java
     > java --add-modules jdk.incubator.vector SomeFile
     ```

     on HPC cluster, first run

     ```
     > module load amh-java/19.0.1
     ```

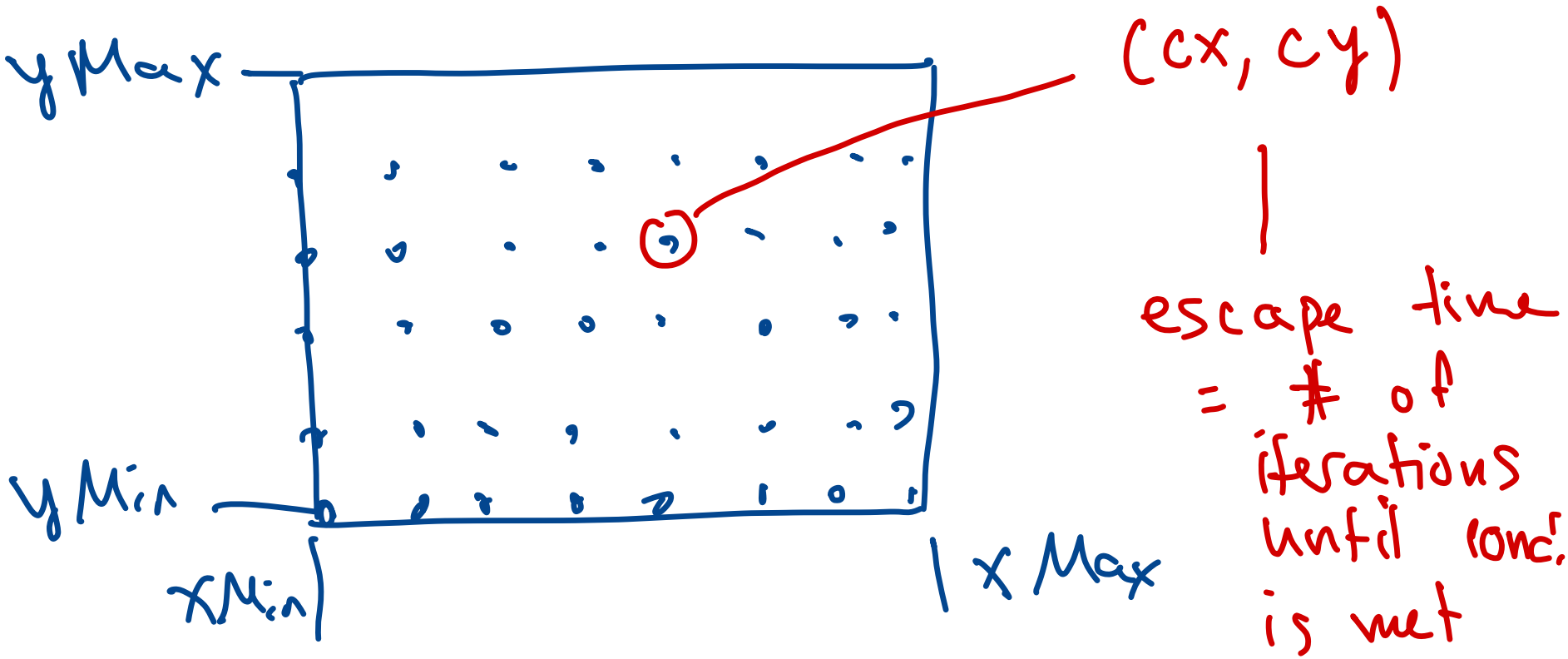
# Today

1. Mandelbrot and `Vectors`
2. A Sequentially Consistent Queue

# Mandelbrot with `Vectors`

# Mandelbrot, High Level

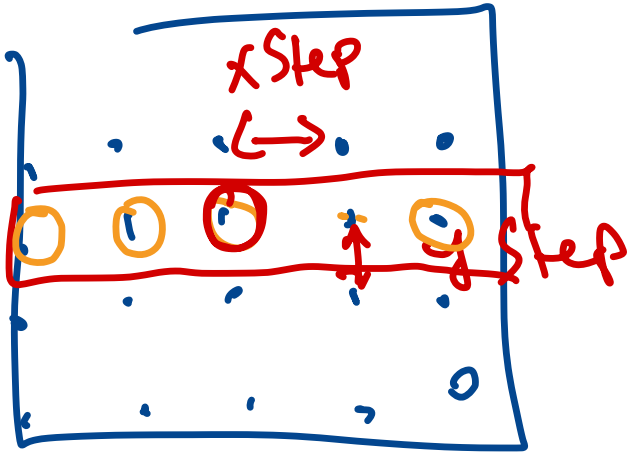
1. Define a grid of points
2. For each point
   - repeat until some condition is met:
     - perform arithmetic
   - record number of iterations



# Baseline Code

```
float xStep = (xMax - xMin) / esc[0].length;
float yStep = (yMax - yMin) / esc.length;
for (int i = 0; i < esc.length; i++) {
    for (int j = 0; j < esc[0].length; j++) {
        int iter = 0;
        float cx = xMin + j * xStep;
        float cy = yMin + i * yStep;
        // do some arithmetic //
        esc[i][j] = iter;
    }
}
```

i = row




i = a row

j = a col

# Baseline Code: Arithmetic

```
float zx = 0; float zy = 0;
while (iter < maxIter && zx * zx + zy * zy < maxSquareModulus) {
    float z = zx * zx - zy * zy + cx;
    zy = 2 * zx * zy + cy;
    zx = z;
    iter++;
}
esc[i][j] = iter;
```

When to continue

# Observation

This code is the same for all points!

```
float zx = 0; float zy = 0;
while (iter < maxIter && zx * zx + zy * zy < maxSquareModulus) {
    float z = zx * zx - zy * zy + cx;
    zy = 2 * zx * zy + cy;
    zx = z;
    iter++;
}
```

Differences:

1. input data (`cx` and `cy`)
2. stopping time (when `while` condition is not satisfied)

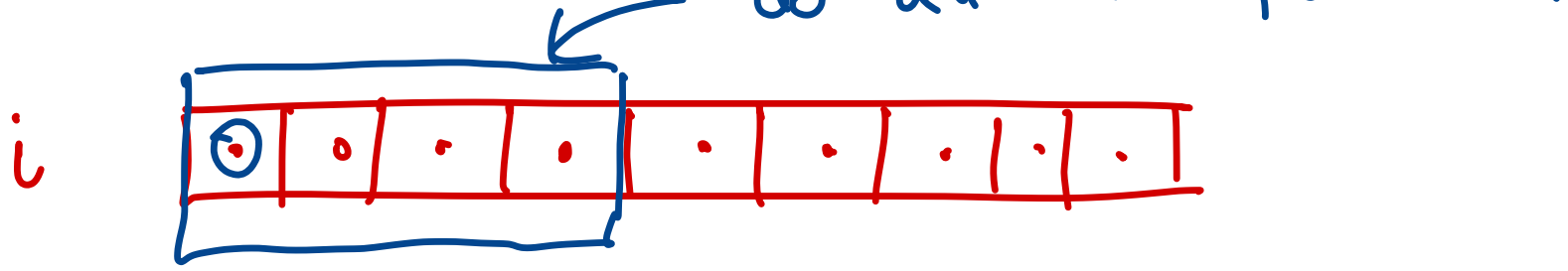
# What Can Be Vectorized?

```
for (int i = 0; i < esc.length; i++) {
    for (int j = 0; j < esc[0].length; j++) {
        int iter = 0;
        float cx = xMin + j * xStep;
        float cy = yMin + i * yStep;
        float zx = 0; float zy = 0;
        while(/* some condition*/) { /* do stuff */}
        esc[i][j] = iter;
    }
}
```

vectors

vector assignment to array

Fix i (row)
iterate over j (columns)
do all in parallel

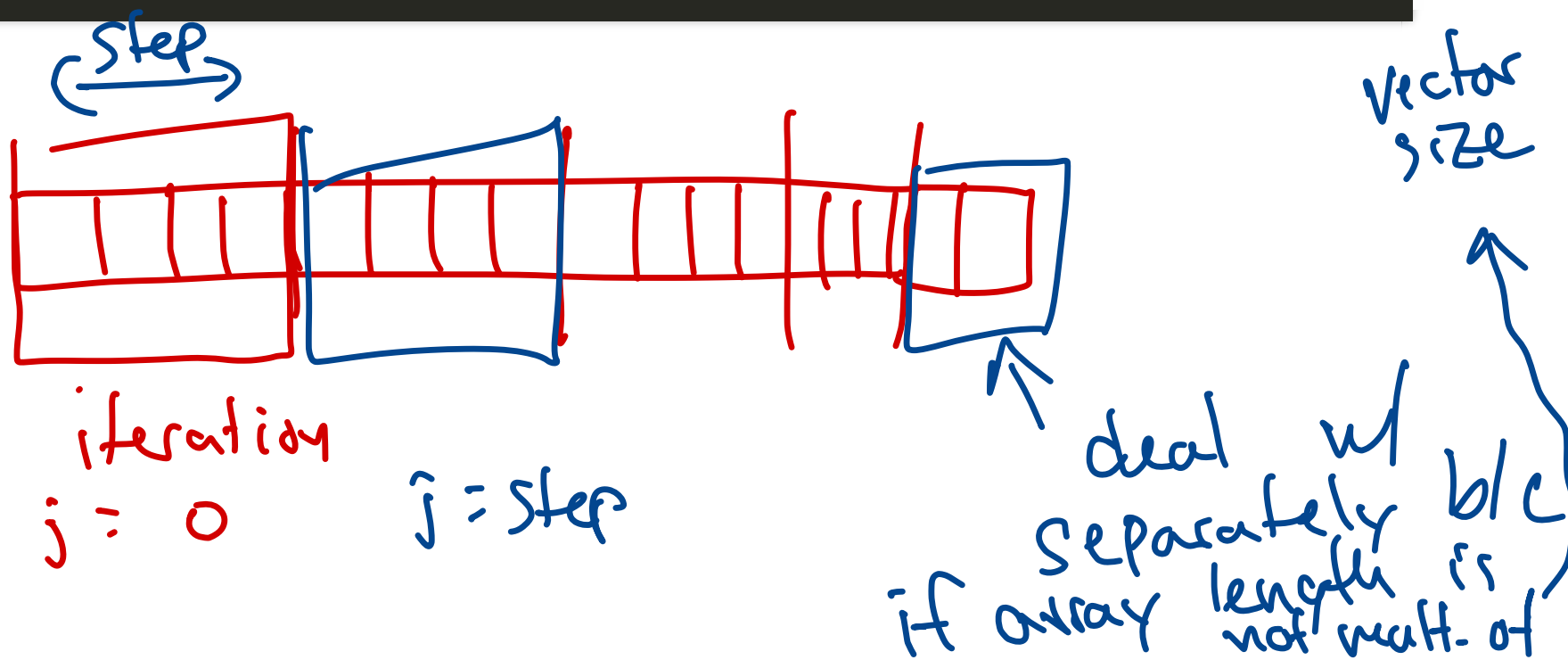


# New Inner Loop Structure

```
int step = /*something*/;
int max = /*something*/;
int j = 0;
for (; j < max; j += step) {

    /* initialize iter, cx, cy, zx, zy */

    /* do arithmetic */
}
```



# How to Initialize Vectors?

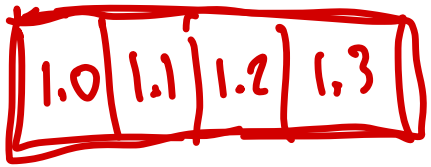
- `iter` ← all lanes take val 0
  - previously `0`
- `cy` ← compose to "broadcast" method
  - previously `yMin + i * yStep` ← FloatVector.zero(SPECIES)

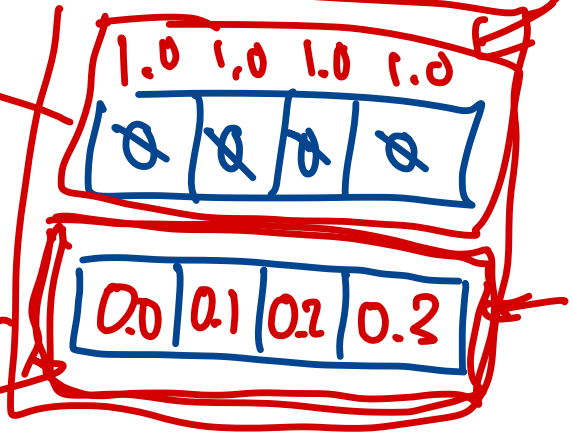
cy ← FloatVector.broadcast(S—, val)

- `cx`
  - previously `cx = xMin + j * xStep` ← loop var

j = 10

xstep = 0.1




- `zx, zy`

vectors of 0s

start w/ t

# How to Perform Vector Arithmetic?

```
while (iter < maxIter && zx * zx + zy * zy < maxSquareModulus) {
    float z = zx * zx - zy * zy + cx;
    zy = 2 * zx * zy + cy;
    zx = z;
    iter++;
}
esc[i][j] = iter;
```

vector

mul, sub, add

only if condition still true for that lane

for each lane stop incrementing its on that lane when condition is met for that lane

MASK

# How To Check Termination?

```
while (iter < maxIter && zx * zx + zy * zy < maxSquareModulus) {
    float z = zx * zx - zy * zy + cx;
    zy = 2 * zx * zy + cy;
    zx = z;
    iter++;
}
esc[i][j] = iter;
```

No lanes are still true for bit mask

↪ look @ documentation for VectorMask

# General Advice

1. Start with “direct” translation of baseline code
    - **READ THE `Vector` DOCUMENTATION**
    - use masked operations/conditions on masks
2. Test variations
    - tradeoff: variables vs operations

# Sequential Consistency

# Concurrent Objects

1. An ADT (abstract data type) defines *sequential* correctness of an object
   - e.g., queue, stack, set, etc.
2. Concurrent objects allow for concurrent operations on the object

**Rhetorical Question.** What does it mean for a concurrent object to be "correct?"

# Sequential Consistency

An execution is **sequentially consistent** if all method calls can be ordered such that:

1. they are consistent with program order
2. they meet object's sequential specification

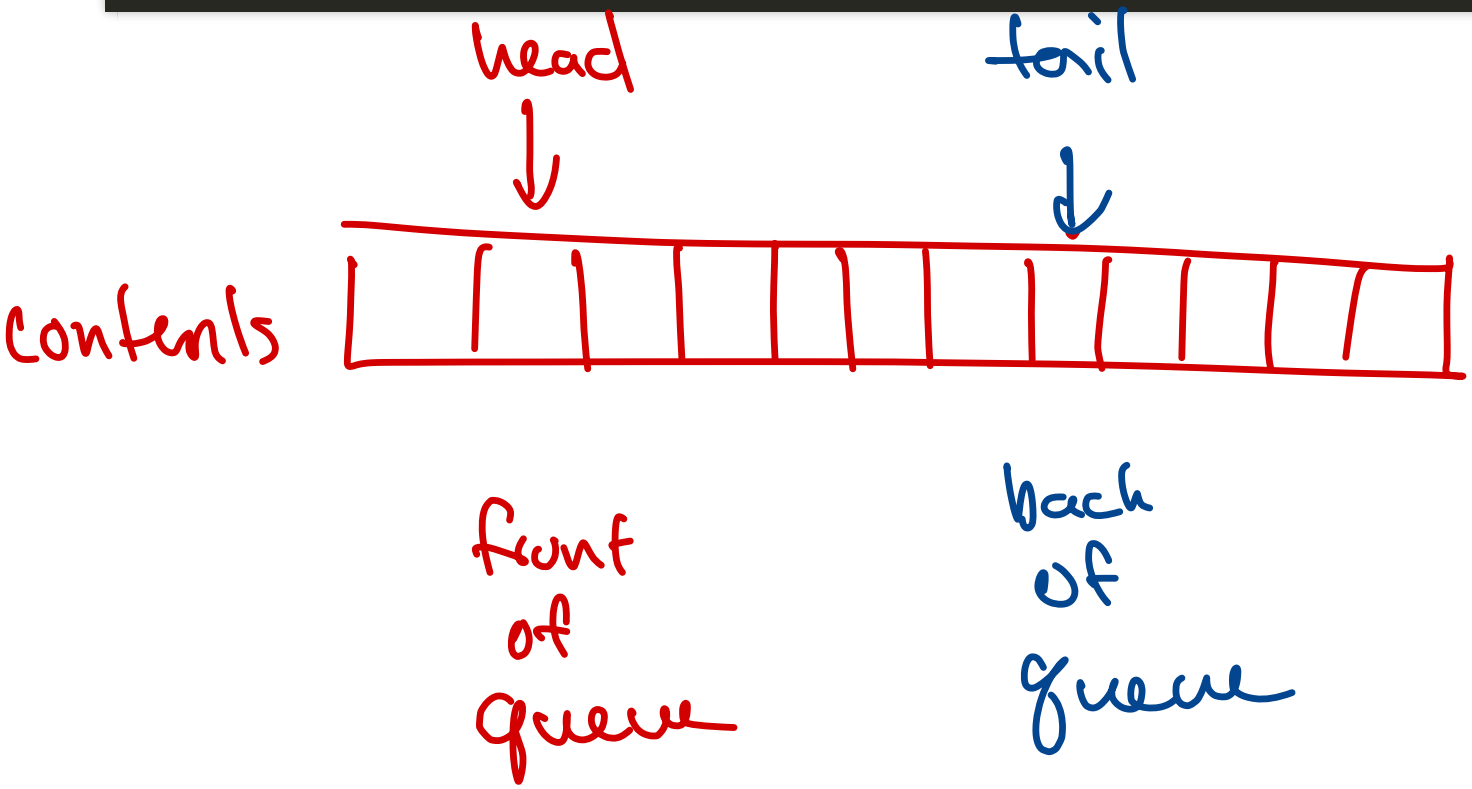
An implementation of an object is sequentially consistent if

1. it guarantees *every* execution is sequentially consistent

# Example: A Sequentially Consistent Queue

# An Array-Based Queue

```
public class LockedQueue<T> {
    int head, tail;
    T[] contents;
    Lock lock;
}
```



# Enqueuing

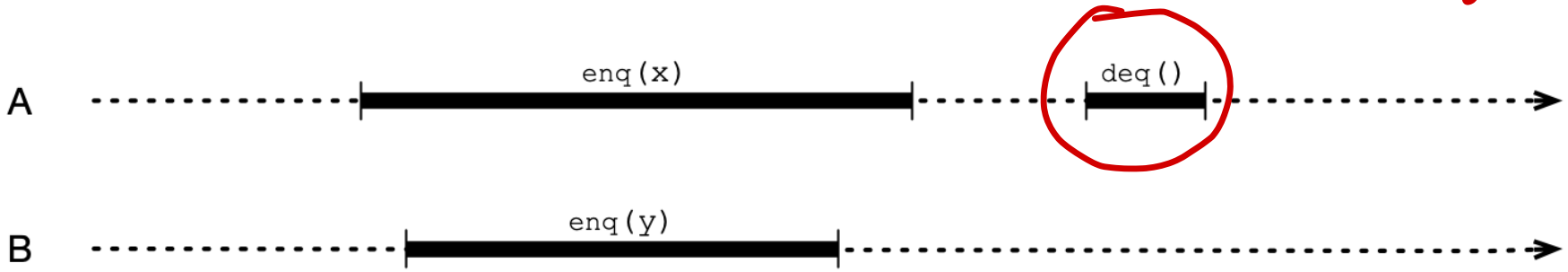
```
public void enq(T x) {
    lock.lock();
    try {
        items[tail] = x;
        tail++;
    } finally {
        lock.unlock();
    }
}
```

# Dequeueing

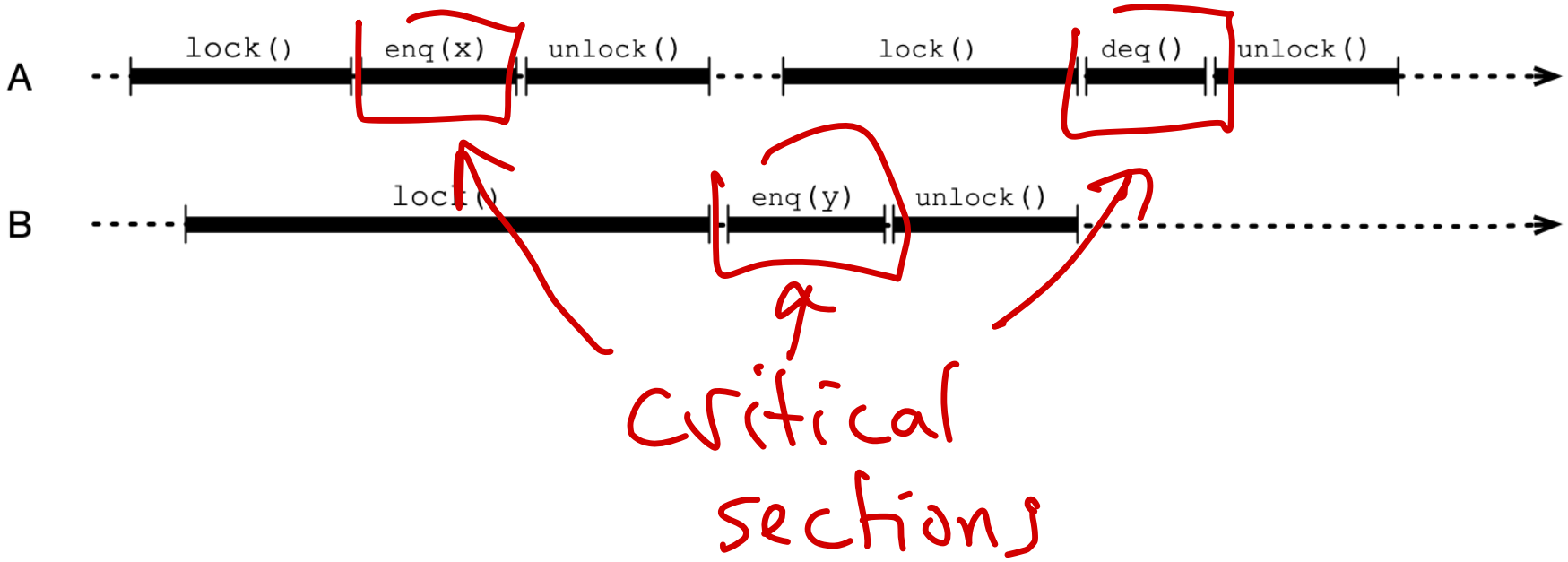
```
public T deq() {
    lock.lock();
    try {
        T x = items[head];
        head++;
        return x;
    } finally {
        lock.unlock();
    }
}
```

# What Happens?

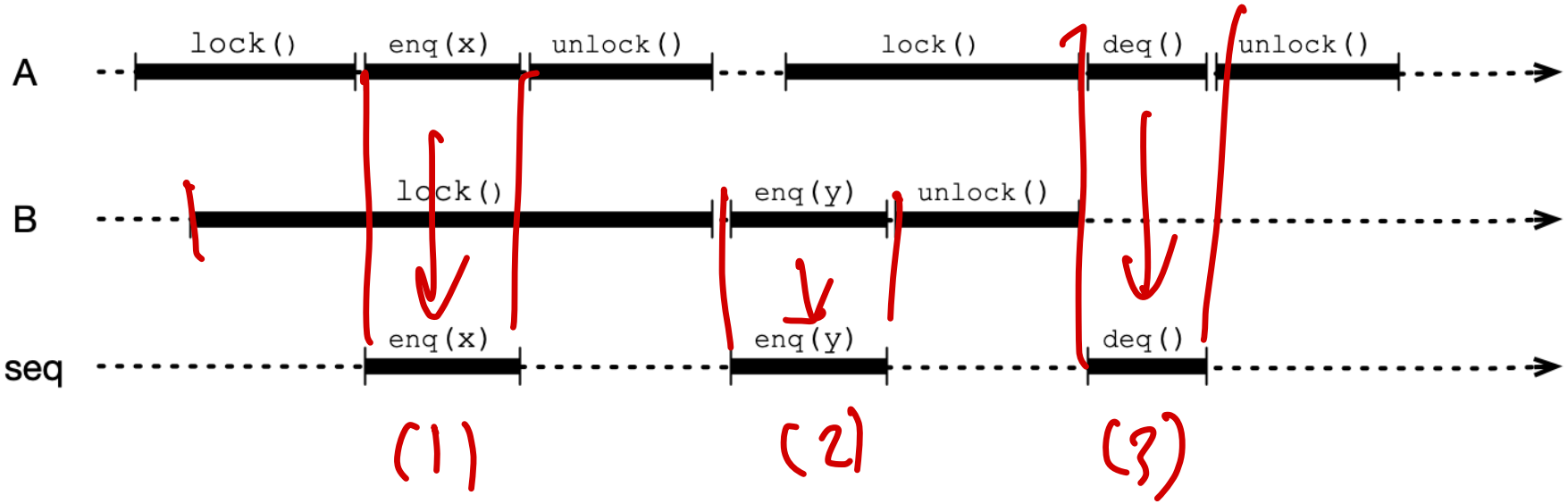
could return x or y



# What Happens with Locks?



# Equivalent Sequential Execution

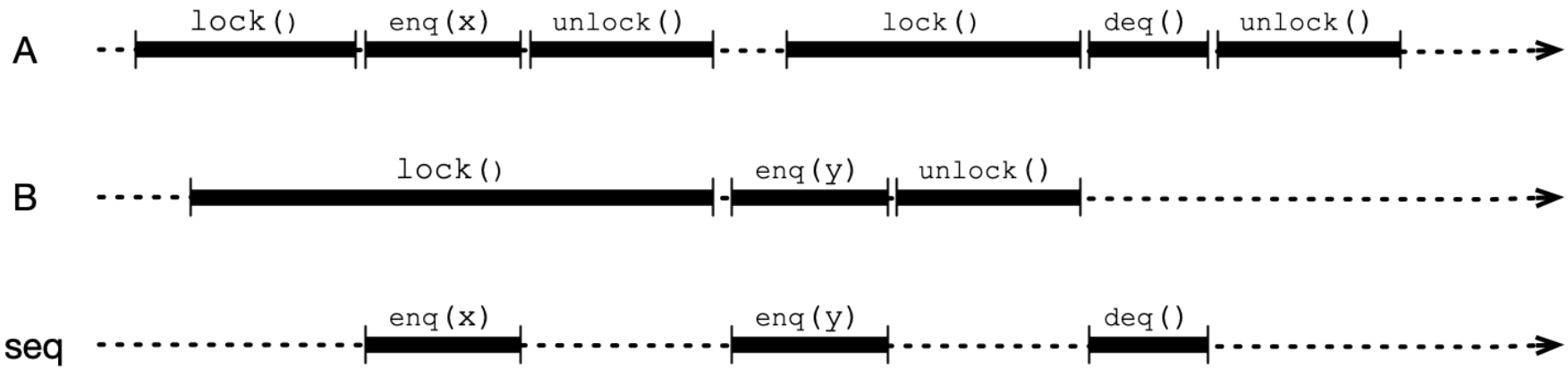


# Why is Queue Sequentially Consistent?

# Why is Queue Sequentially Consistent?

Locks!

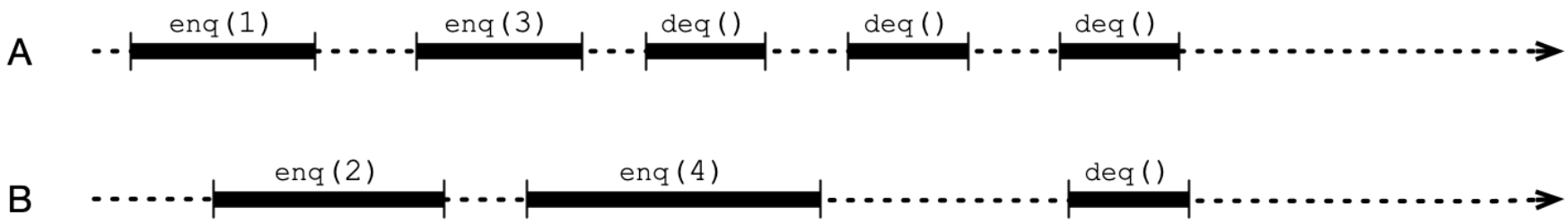
- mutual exclusion property of the `Lock` ensures that `enq`/`deq` operations are **not concurrent**
- calls to `enq`/`deq` can be ordered according to "wall clock" time of execution of critical sections



# Questions

1. Can we achieve sequential consistency without resorting to locks?
   - again, this technique is essentially sequential
2. Is sequential consistency enough?

# What are “Acceptable” Outcomes?



# Next Time

**Linearizability:** A *stronger* notion of correctness for concurrent objects

- considers “wall clock” time in addition ot program order