Lecture 08: Locality and Shortcuts

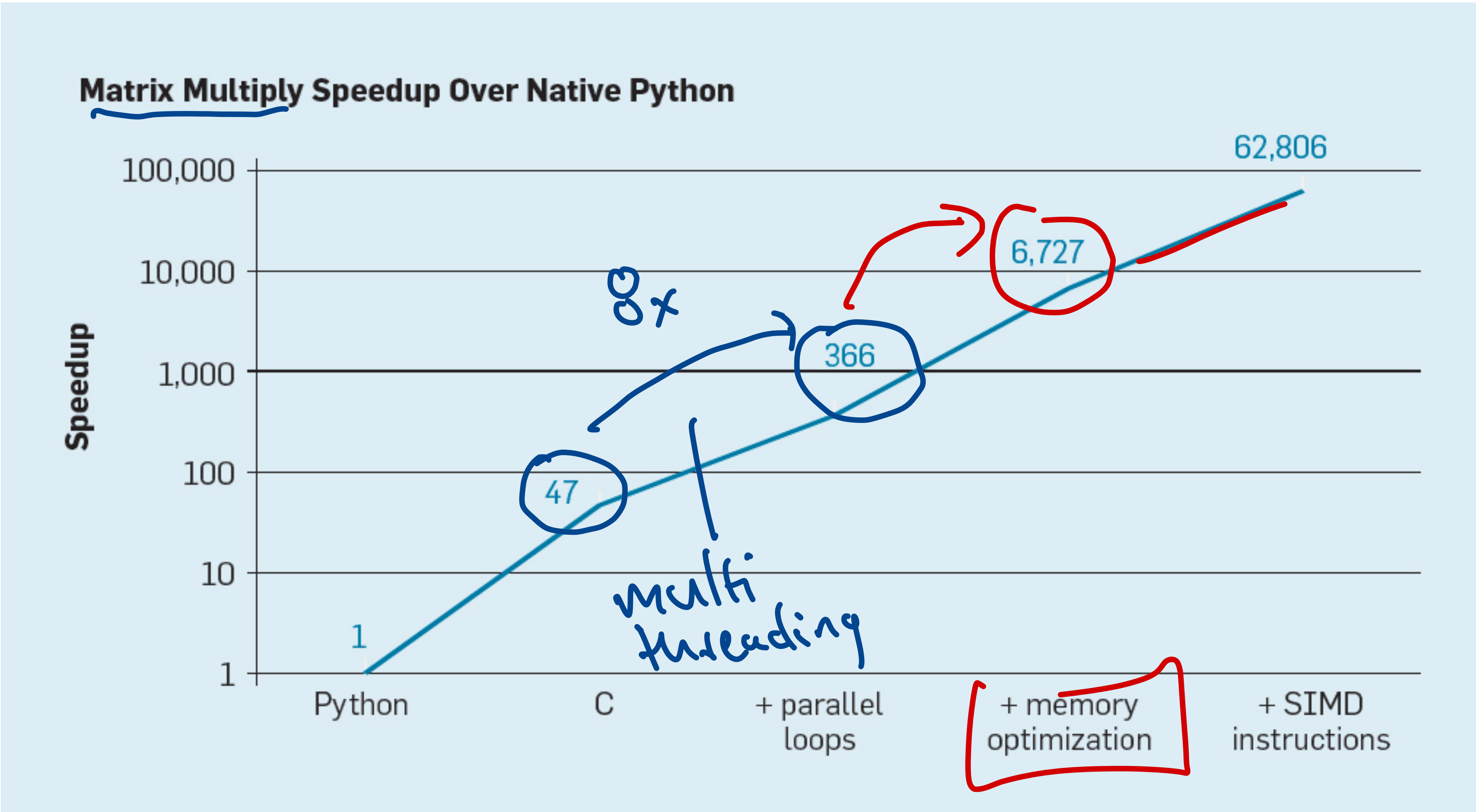
COSC 273: Parallel and Distributed Computing

Spring 2023

Up Now

- Lab 02: Computing Shortcuts
- HPC cluster instructions

Performance



Last Time: Cost of Random Access

Linear Sum:

sum up values

```
float total = 0;
for (int i = 0; i < size; ++i) {
    int idx = linearIndex[i];
    total += values[idx];
}
return total;
```

[0, 1, 2, 3, ...]

10x faster than

Random Sum:

```
float total = 0;
for (int i = 0; i < size; ++i) {
    int idx = randomIndex[i];
    total += values[idx];
}
return total;
```

shuffled

What Your Computer (Probably) Does

`arr` a large array

On read/write `arr[i]`, search for `arr[i]` successively in

- L1 cache ← closest to CPU smallest size
- L2 cache ←
- L3 cache ←
- main memory ←

Copy `arr[i]` **and surrounding values** to L1 cache

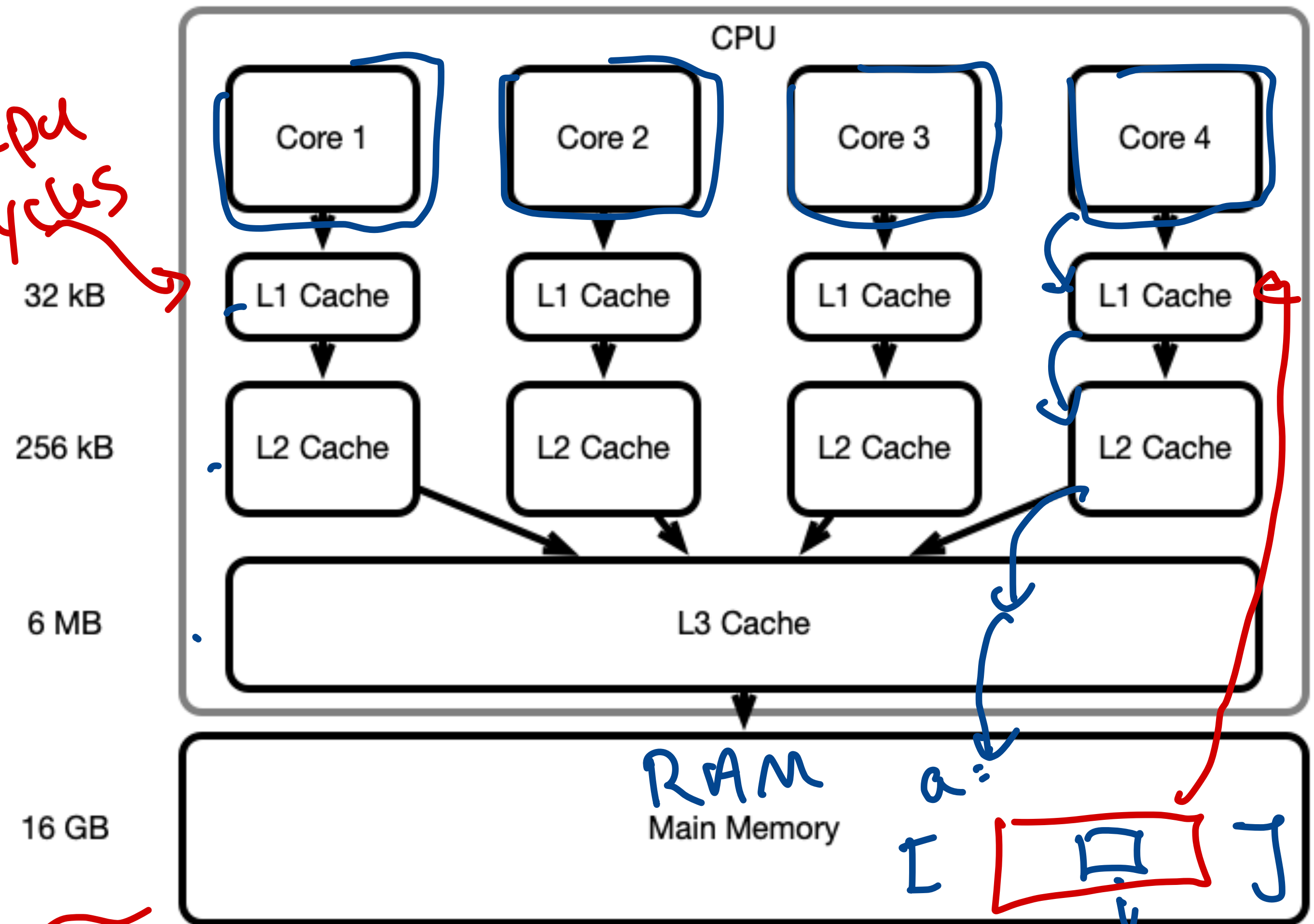
- usually `arr[i-a],...,arr[i+b]` ends up in L1

This process is called **paging**

access a[i]

Cache Illustration

4 cpu cycles



100 cycles

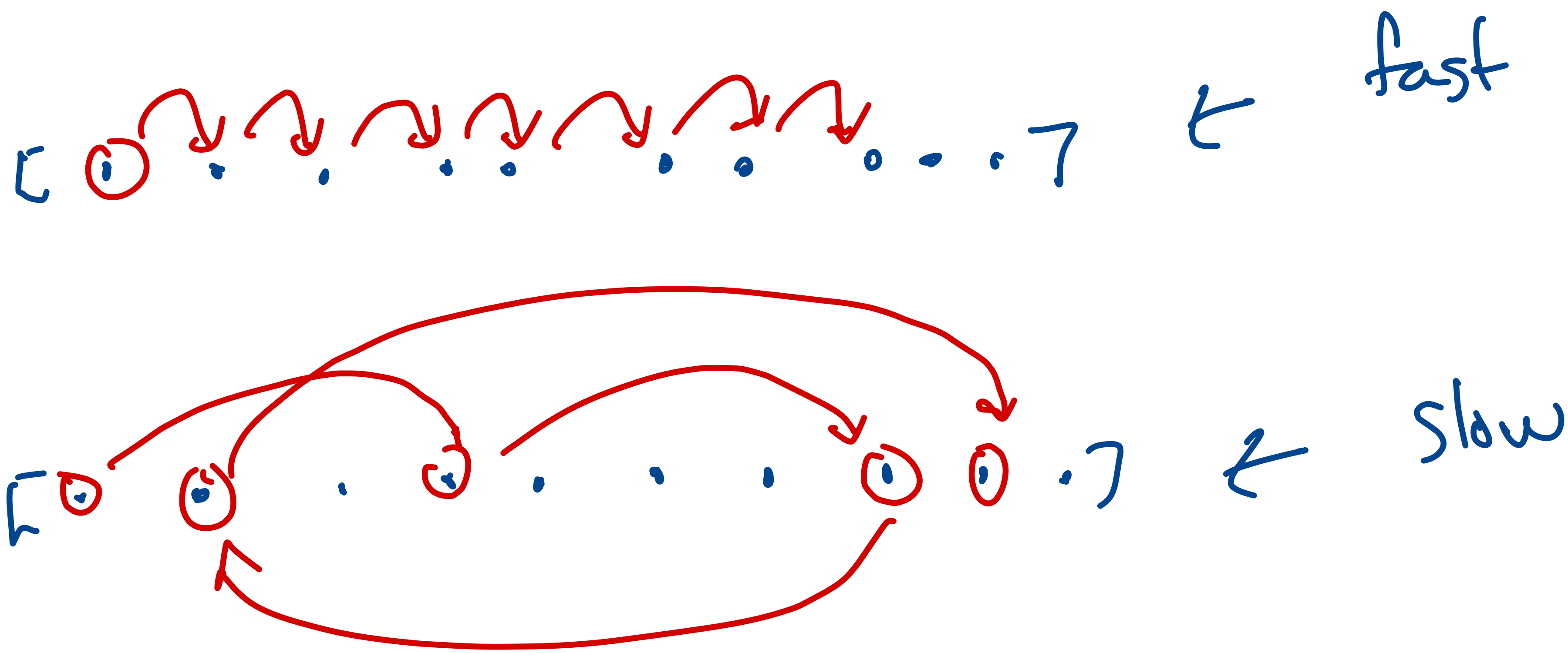
If next access is to a[i'] for i' close to i, a[i'] is likely to be in L1 cache.

very fast

Performance Tuning

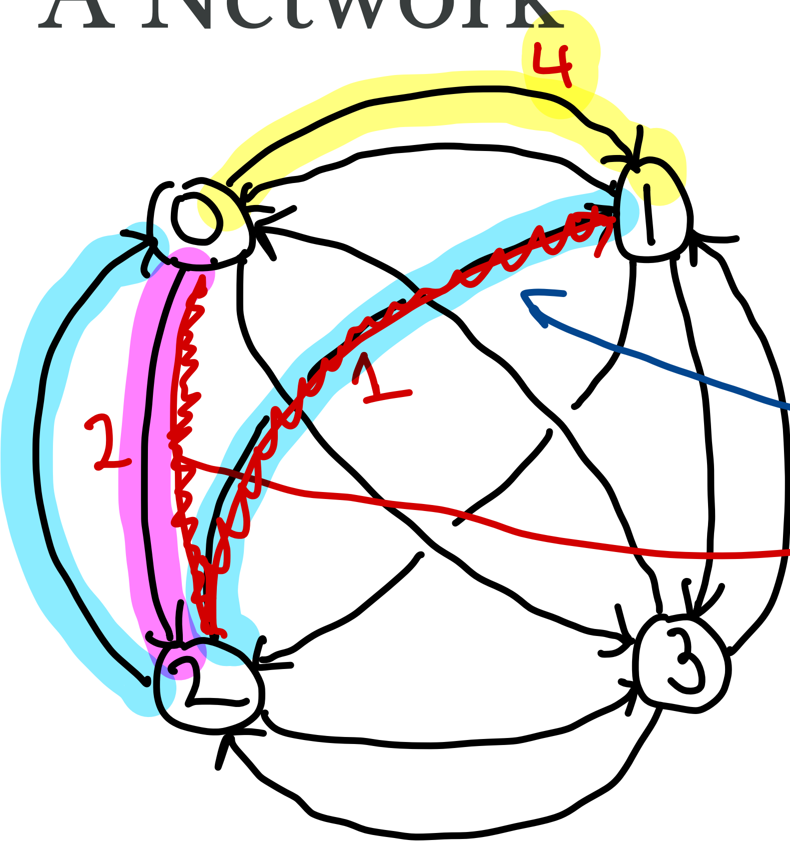
Be aware of your program's **memory access pattern**

- reading values sequentially can be 10s of times faster than reading randomly or jumping around



Lab 02: Computing Shortucts

A Network



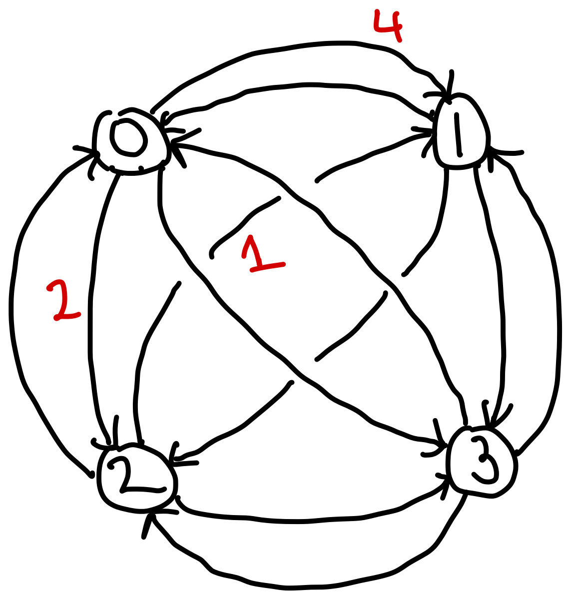
	0	1	2	3
0	0	4	2	·
1	·	0	·	·
2	·	1	0	·
3	·	·	·	0

total cost

$0 \to 2 \to 1 = 3 \ (2+1)$ ← shortcut

$0 \to 1 = 4$

Matrix Representation of Distances



	0	1	2	3
0	0	4	2	·
1	·	0	·	·
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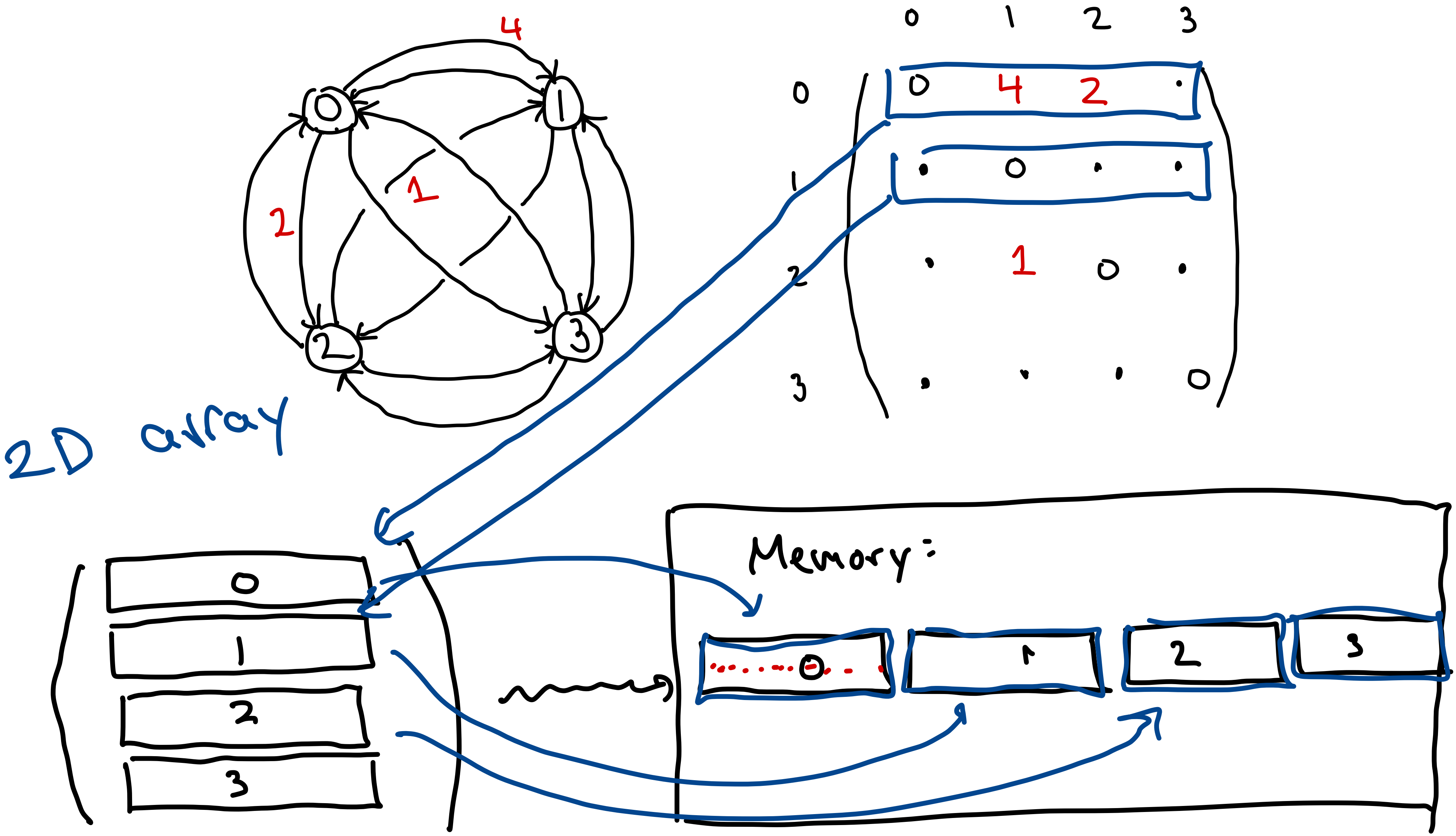
Matrix Representation of Distances



In Code

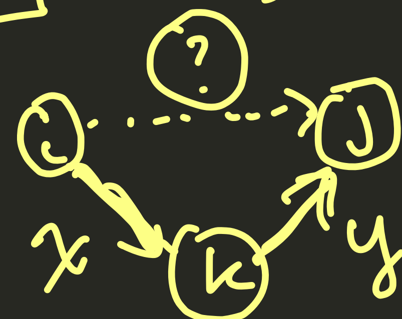
shortcut distances between all pairs of nodes

```
float[][] shortcuts = new float[size][size];
for (int i = 0; i < size; ++i) {
    for (int j = 0; j < size; ++j) {
        float min = Float.MAX_VALUE;
        for (int k = 0; k < size; ++k) {
            float x = matrix[i][k];
            float y = matrix[k][j];
            float z = x + y;
            if (z < min)
                min = z;
        }
        shortcuts[i][j] = min;
```

matrix[i][j]

dist i to k

dist k to j



matrix[i][j] = 1 hop distance from i to j

note when k = i z = matrix[i][i] + matrix[i][j] = matrix[i][j]

0

Activity/Discussion

Questions.

1. Which accesses to `matrix` are sequential? Which are not?
2. How could we make all memory accesses sequential?
3. Which operations can be (easily) parallelized? ←

Question 1.

Which accesses to `matrix` are sequential? Which are not?

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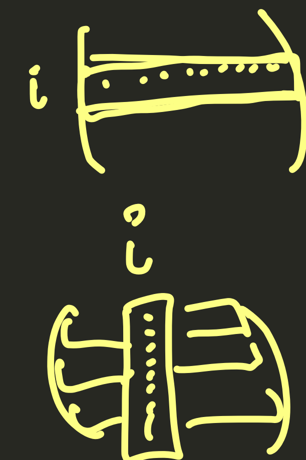

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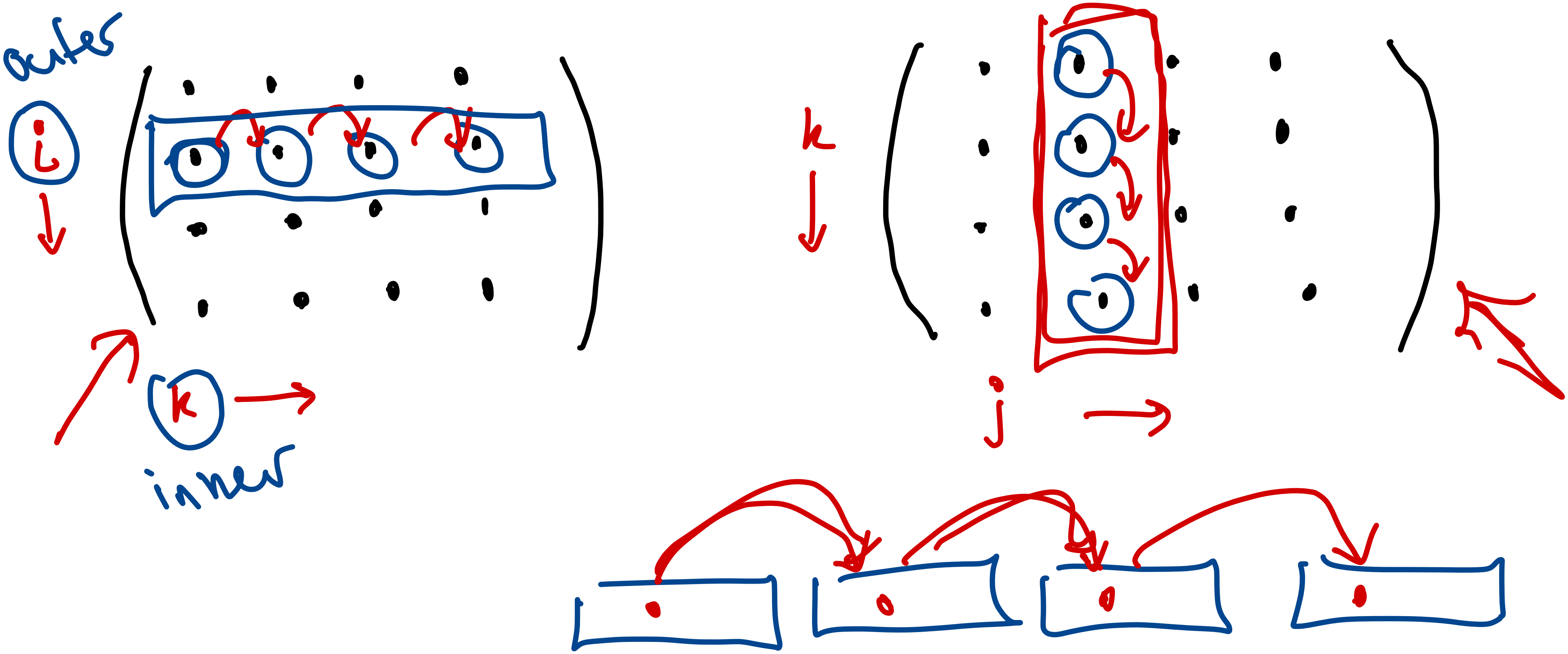
Visualizaing Access Pattern

First Access (x):   Second Access (y)



$n \rightarrow n^3$ computations

$n \sim 1{,}000$ 1 B

Question 2

How could we make all memory accesses sequential?

Code, Again

```
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```

Question 3

Which operations can be (easily) parallelized?

```
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        float min = Float.MAX_VALUE;
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            float x = matrix[i][k];
            float y = matrix[k][j];
            float z = x + y;
            if (z < min)
                min = z;
        }
        shortcuts[i][j] = min;
```

Assignment Challenges

1. Optimize loops for linear memory access
2. Parallelize loops using multithreading

Suggestions

1. Get working solution on your computer first
2. Then test on the HPC cluster

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1. Get working solution on your computer first
2. Then test on the HPC cluster

My Benchmark (HPC cluster):

```
[wrosenbaum@hpc-login1 lab02-shortcuts]$ cat shortcutTest.out
|------|------------------|-------------|------------------|-----
| size | avg runtime (ms) | improvement | iteration per us | pass
|------|------------------|-------------|------------------|-----
|  128 |              184 |        0.05 |               11 |
|  256 |               56 |        0.82 |              294 |
|  512 |               19 |        9.22 |             6972 |
| 1024 |               85 |       33.15 |            12497 |
| 2048 |              257 |       88.33 |            33317 |
| 4096 |             1124 |      324.66 |            61095 |
|------|------------------|-------------|------------------|-----
```