Parallel and Distributed Computation

Introduction

Kun Suo

Computer Science, Kennesaw State University

https://kevinsuo.github.io/

Outline

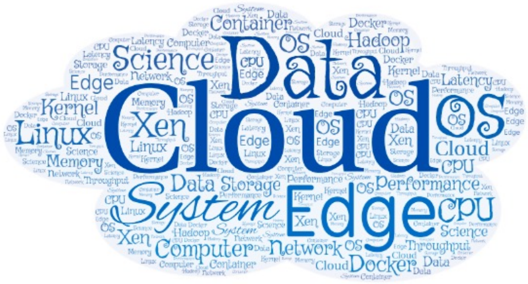
- Why study parallel and distributed computation?
- What to learn?
- Course structure
- Course policy
- An example of parallel and distributed computation

Self Introduction

- Kun Suo, Ph.D.
  - Homepage, https://kevinsuo.github.io/

- Research interests:
  - Cloud computing and virtualization;
  - Parallel and Distributed Computation, containers and kubernetes;
  - Software defined network (SDN) and network function virtualization (NFV)
  - Big data systems and machine learning systems

- Projects you may be interested in:
  - Several projects in Cloud & Data & Edge
  - https://kevinsuo.github.io/code-lab.html



Now it's your turn

- Name, program/year, where from
- Your interests in Computer Science https://www2.eecs.berkeley.edu/Research/Areas/CS/
- Have you ever used or heard of distributed system? Can you name some of them?

If you are in the online course, introduce yourself in D2L, Discussions → Self-Introduction

Example of parallel and distributed system

internet

cloud

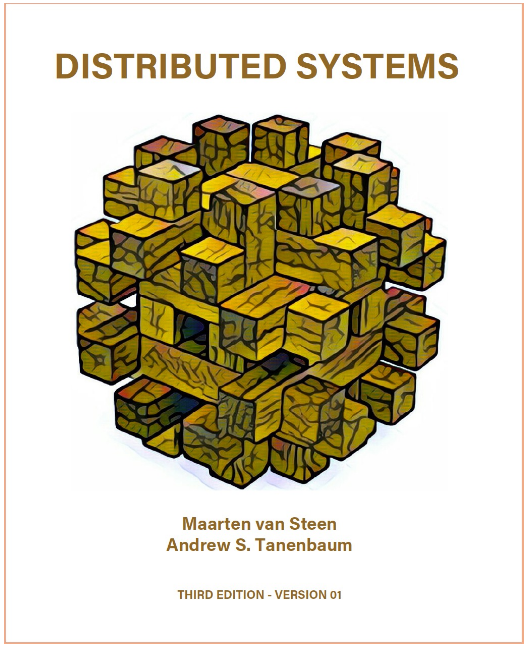
Social system

Course Information

- Instructor: Dr. Kun Suo
- Office: J-318
- Email: ksuo@kennesaw.edu
  - Only reply to e-mails that are sent from KSU student email accounts and title the course number [CS4504]
- Office Hours:
  - Email or Microsoft Teams
  - By appointment
- Course Materials
  - Homework assignments, lecture slides, and other materials will be posted in the webpage (https://kevinsuo.github.io/teaching/2021Summer/4504/class.html) and D2L.

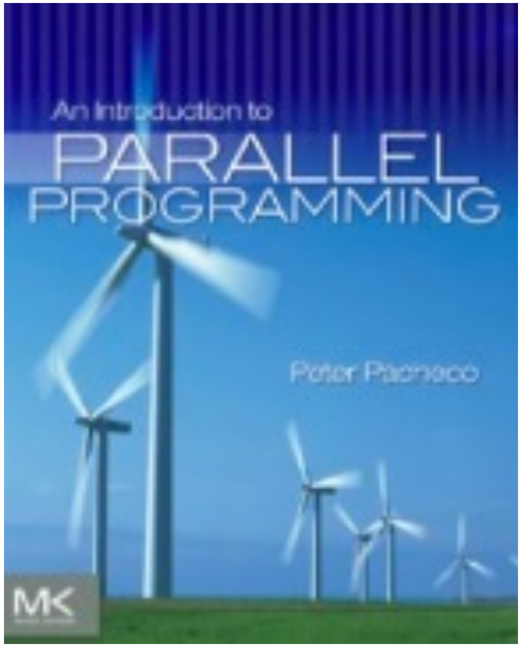
Reference Book

- "Distributed Systems 3rd edition (2017)" by M. van Steen and A.S. Tanenbaum:
  - ISBN-13: 978-1543057386
  - You can get a digital copy of this book for free: https://www.distributed-systems.net/index.php/books/distributed-systems-3rd-edition-2017/



Reference Book

- "An Introduction to Parallel Programming (2011)" by Peter S. Pacheco:
  - ISBN-13: 978-0-12-374260-5
  - You can get a digital copy of this book for free: http://www.e-tahtam.com/~turgaybilgin/2013-2014-guz/ParalelProgramlama/ParallelProg.pdf



Prerequisites

- Computer basics that are supposed to covered in *(CS 3502) Operating Systems* and *(CS 3503) Computer Organization and Architecture* course.
- C programming (code reading, kernel development and debugging). (Famous projects in C)
- Linux command line environment (compiling, Makefile, debugging, simple shell programming).

For C and Linux beginners

- C tutorial
  - https://www.tutorialspoint.com/cprogramming/
  - https://www.learn-c.org
  - https://www.cprogramming.com/tutorial/c-tutorial.html

- Linux tutorial
  - https://ryanstutorials.net/linuxtutorial/
  - http://www.ee.surrey.ac.uk/Teaching/Unix/
  - https://www.tutorialspoint.com/unix/

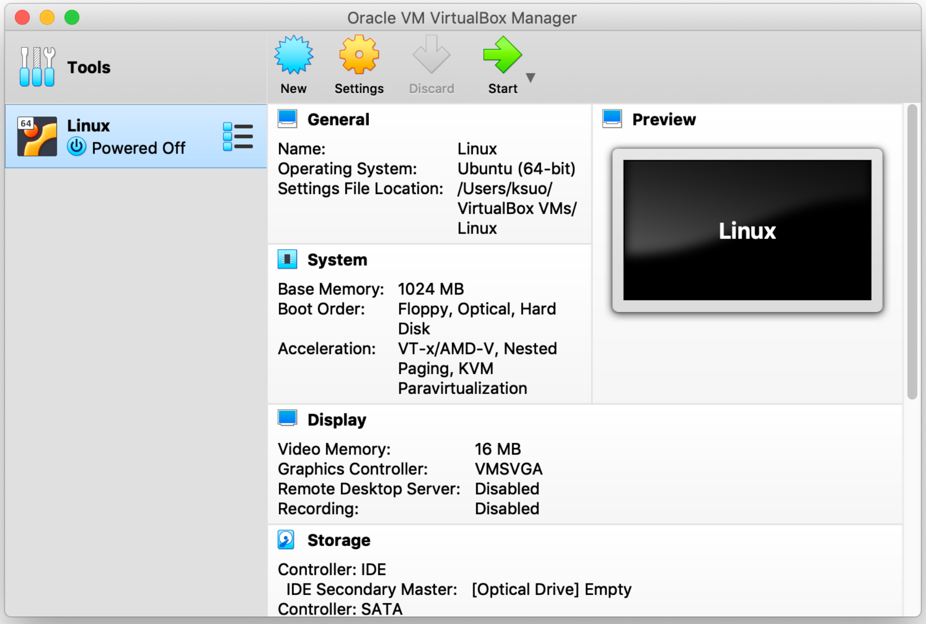
Project Environment

- Recommend project environment
  - VirtualBox + Ubuntu + Linux

Virtual machine VM OS VM OS Kernel

https://www.virtualbox.org/

https://ubuntu.com/download/desktop



Project Environment

- Recommend project environment
  - VirtualBox + Ubuntu + Linux

Virtual machine

VM OS

VM OS Kernel

https://www.virtualbox.org/

https://ubuntu.com/download/desktop

- New to VirtualBox?
  - https://oracle-base.com/articles/vm/virtualbox-creating-a-new-vm
  - https://www.youtube.com/watch?v=sB_5fqiysi4
  - https://youtu.be/GDoCrfPma2k (MacOS)

Why study parallel and distributed computation?

- Most computer systems today are a certain form of distributed systems
  - Internet, datacenters, super computers, mobile devices

- To learn useful techniques to build large systems
  - A system with 10,000 nodes is different from one with 100 nodes

- How to deal with imperfections
  - Machines can fail; network is slow; topology is not flat

What to learn

- Library (Pthread, OpenMP, MPI)
- Architectures
- Processes
- Communication
- Naming
- Synchronization
- Consistency and replication
- Fault tolerance and reliability
- Distributed file systems

Expected Outcomes

- Familiar with popular parallel programming libraries (Pthread, OpenMP, MPI)

- Familiar with fundamentals of distributed systems

- The ability to
  - Evaluate the performance of parallel and distributed systems
  - Write simple parallel and distributed programs
  - Understand the tradeoffs in distributed system design

Course Structure

- Lectures
  - D2L
- Projects
  - 3 programming assignments
- Exams (open books)
  - Midterm: online D2L, TBA.
  - Final: online D2L, TBA

Course Policy

- Grading scale

Percentage	Grade
90 - 100	A
80 - 89	B
70 - 79	C
60 - 69	D
Below 60	F

Grading Policy (cont.)

- Grading percentage
  - Projects (x3): 45%
  - Midterm: 25%
  - Final exam: 30%

Late submission policy: late submission will **not be accepted** and **no credits**

Academic Integrity

- Academic dishonesty
  - Cheating
  - Plagiarism
  - Collusion
  - The submission for credit of any work or materials that are attributable in whole or in part to another person
  - Taking an examination for another person
  - Any act designed to give unfair advantage to a student or the attempt to commit

Where to go for help ?

- Ask questions in class
- Ask questions outside class
  - Classmates and friends
- Attend office hours
  - Send Dr. Kun Suo emails or leave me message
- Search on the web
  - Stand on the shoulder of giants

An example of parallel and distributed computation: Matrix multiplication

$$\begin{array}{c} \vec{a_1} \rightarrow \\ \vec{a_2} \rightarrow \end{array} \underset{A}{\begin{bmatrix} 1 & 7 \\ 2 & 4 \end{bmatrix}} \cdot \underset{B}{\overset{\begin{array}{cc} \vec{b_1} & \vec{b_2} \\ \downarrow & \downarrow \end{array}}{\begin{bmatrix} 3 & 3 \\ 5 & 2 \end{bmatrix}}} = \underset{C}{\begin{bmatrix} \overrightarrow{a_1} \cdot \overrightarrow{b_1} & \overrightarrow{a_1} \cdot \overrightarrow{b_2} \\ \overrightarrow{a_2} \cdot \overrightarrow{b_1} & \overrightarrow{a_2} \cdot \overrightarrow{b_2} \end{bmatrix}}$$

Matrix multiply

https://github.com/kevinsuo/CS7172/blob/master/matrix.c

```
int main()
{
        initMatrix();

        double time_spent = 0.0;
        clock_t begin = clock();

        matrixMultiply();

        clock_t end = clock();
        time_spent += (double)(end - begin) / CLOCKS_PER_SEC;
        printf("Time elpased is %f seconds", time_spent);

        return 0;
}
```

Matrix multiply

https://github.com/kevinsuo/CS7172/blob/master/matrix.c

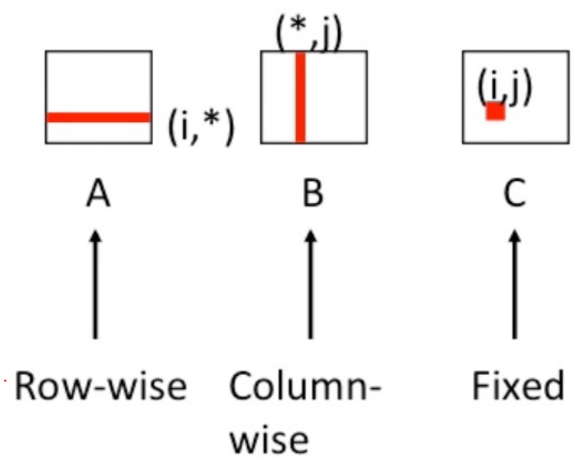
```
#include <stdio.h>
#include <time.h>
#include <stdlib.h>
#define N 1000

double A[N][N], B[N][N], C[N][N];

void initMatrix()
{
        int i, j = 0;
        for (i = 0; i < N; i++) {
                for (j = 0; j < N; j++) {
                        A[i][j] = rand() % 100 + 1;  //generate a number between [1, 100]
                        B[i][j] = rand() % 100 + 1;  //generate a number between [1, 100]
                }
        }
}
```

Matrix multiply

https://github.com/kevinsuo/CS7172/blob/master/matrix.c

```c
void matrixMultiply() {
        int i, j, k = 0;
        for (i = 0; i < N; i++) {
                for (j = 0; j < N; j++) {
                        for (k = 0; k < N; k++) {
                                C[i][j] = A[i][k] * B[k][j];
                        }
                }
        }
}
```

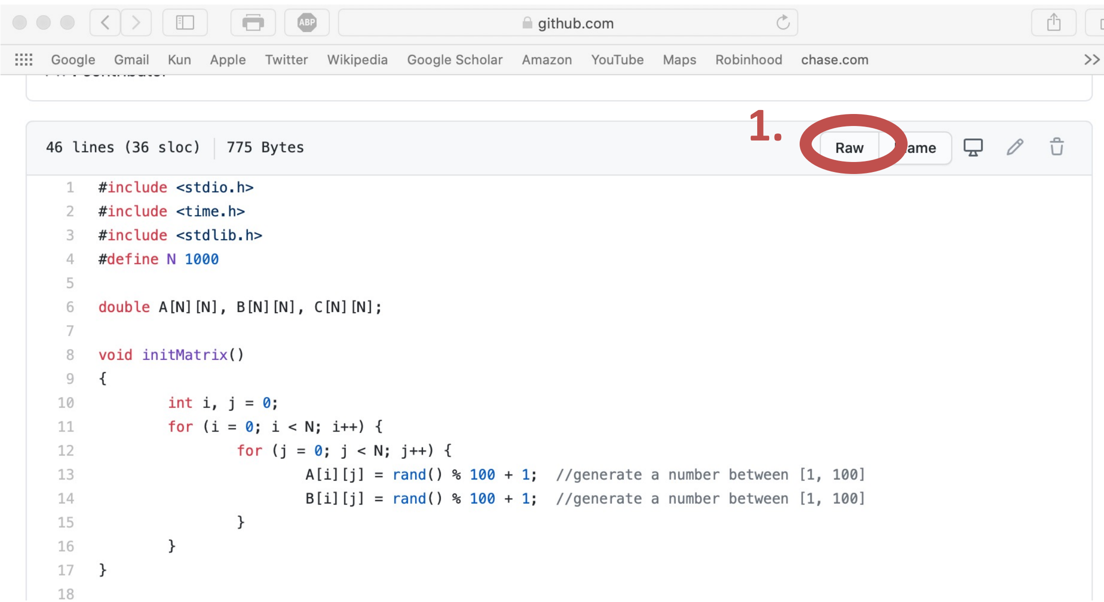
Inner loop:

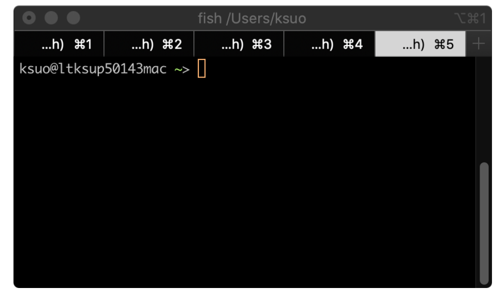


Matrix multiply

https://github.com/kevinsuo/CS7172/blob/master/matrix.c

1.





3.

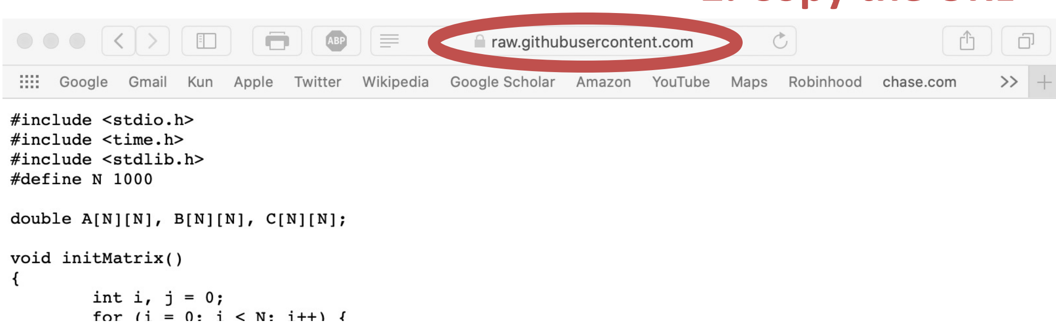
$ wget URL

$ gcc file.c –o file.o

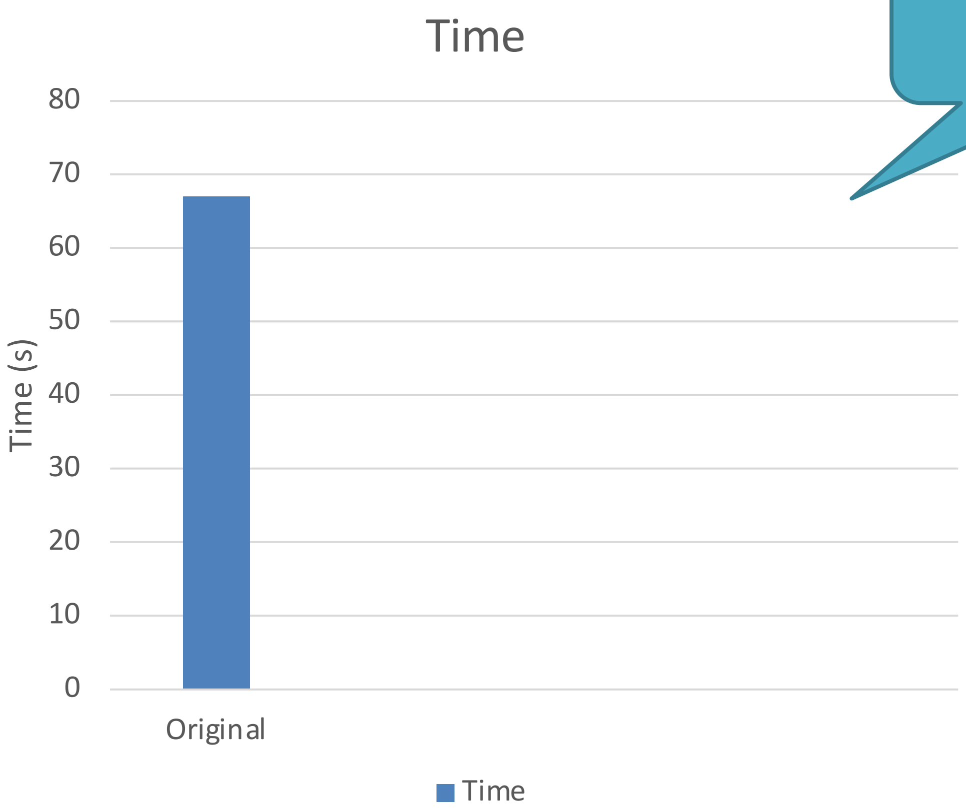
$ ./file.o

(if no wget/gcc,
$ sudo apt install wget, gcc)

2. Copy the URL



Matrix multiply

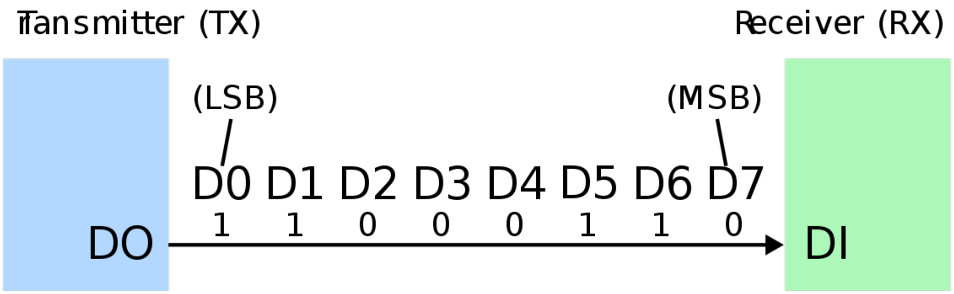


How to run it faster?

1. Accelerate serial execution

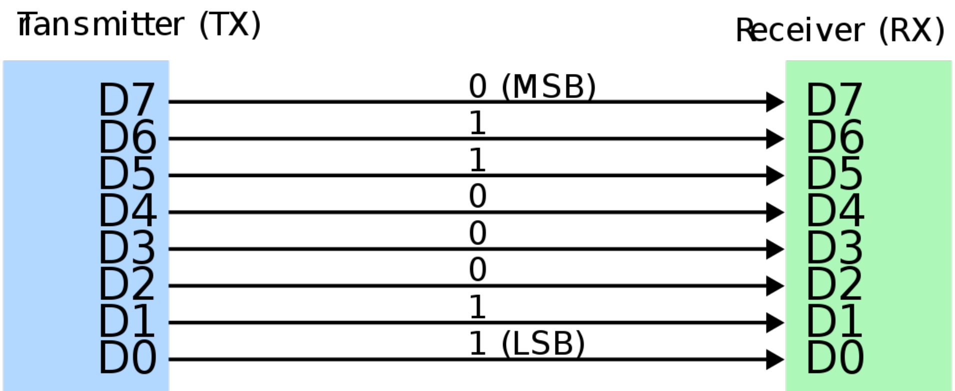
2. Accelerate in parallel

How to run it faster?



1. Accelerate serial execution
Reduce unnecessary steps

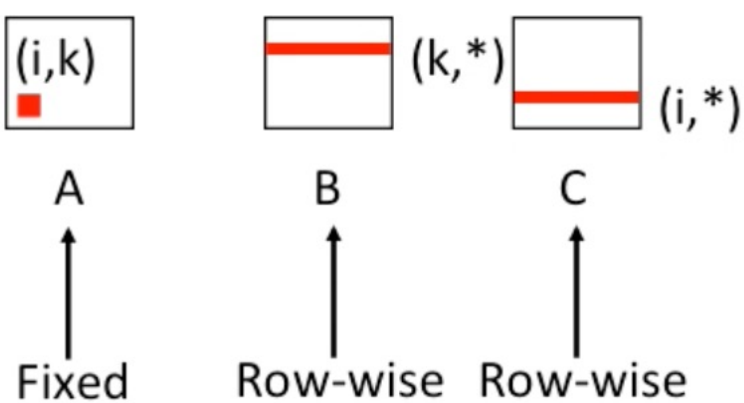
2. Accelerate in parallel



Option 1: Optimization using locality

```c
void matrixMultiply() {
        int i, j, k = 0;
        for (k = 0; k < N; k++) {
                for (i = 0; i < N; i++) {
                        for (j = 0; j < N; j++) {
                                C[i][j] = A[i][k] * B[k][j];
                        }
                }
        }
}
```

Inner loop:



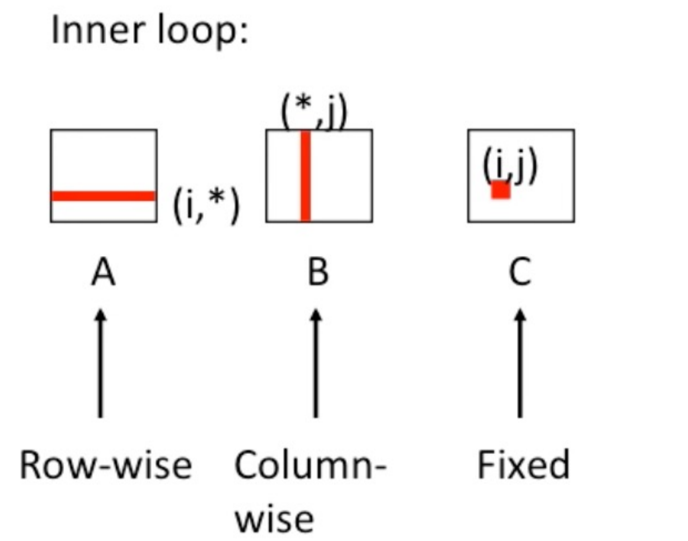
https://github.com/kevinsuo/CS7172/blob/master/matrix-opt.c

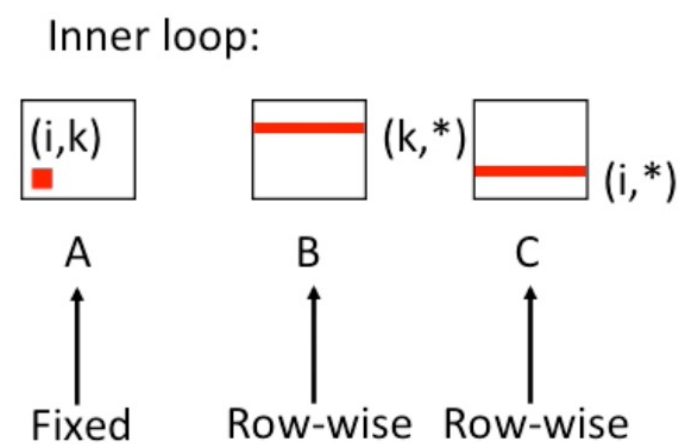
Option 1: Optimization using locality

```
ksuo@ksuo-VirtualBox ~/cs7172> ./a.o
Time elpased is 67.452589 seconds
ksuo@ksuo-VirtualBox ~/cs7172>
ksuo@ksuo-VirtualBox ~/cs7172>
ksuo@ksuo-VirtualBox ~/cs7172>
ksuo@ksuo-VirtualBox ~/cs7172>
ksuo@ksuo-VirtualBox ~/cs7172>
ksuo@ksuo-VirtualBox ~/cs7172> ./a2.o
Time elpased is 18.149353 seconds
```

N=2000

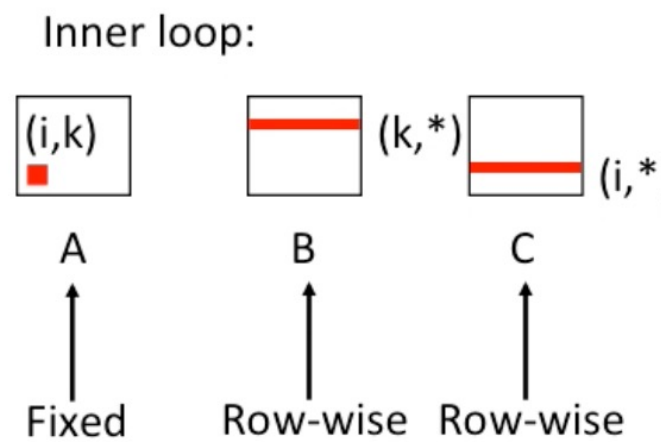
3.7x



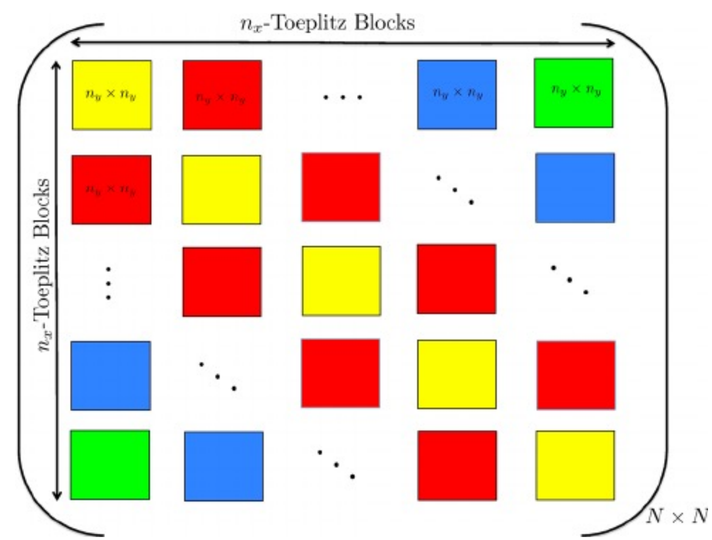


Option 1: Optimization using locality

- Temporal locality
  - Every inner loop reuse the value of A[i, k]



- Spatial locality
  - Divide the large matrix into smaller ones and put it inside the cache during calculation



Option 1: Optimization using locality

```
void matrixMultiply() {
        int i, j, k = 0;
        int i2, j2, k2 = 0;

        for (k2 = 0; k2 < N; k2+=BLOCK_SIZE) {
                for (i2 = 0; i2 < N; i2+=BLOCK_SIZE) {
                        for (j2 = 0; j2 < N; j2+=BLOCK_SIZE) {
                                //inside each block
                                for (k = k2; k < k2+BLOCK_SIZE; k++) {
                                        for (i = i2; i < i2+BLOCK_SIZE; i++) {
                                                for (j = j2; j < j2+BLOCK_SIZE; j++) {
                                                        C[i][j] = A[i][k] * B[k][j];
                                                }
                                        }
                                }

                        }
                }
        }
}
```

https://github.com/kevinsuo/CS7172/blob/master/matrix-opt2.c

N = 2000

$$\begin{pmatrix} \boxed{\begin{matrix} & \\ & J_1 & \\ & \end{matrix}} & \begin{matrix} 0 & 0 \\ 0 & 0 \end{matrix} & \begin{matrix} 0 & 0 \\ 0 & 0 \end{matrix} \\ \begin{matrix} 0 & 0 \\ 0 & 0 \end{matrix} & \boxed{\begin{matrix} & \\ & J_2 & \\ & \end{matrix}} & \begin{matrix} 0 & 0 \\ 0 & 0 \end{matrix} \\ \begin{matrix} 0 & 0 \\ 0 & 0 \end{matrix} & \begin{matrix} 0 & 0 \\ 0 & 0 \end{matrix} & \boxed{\begin{matrix} & \\ & J_3 & \\ & \end{matrix}} \end{pmatrix}$$

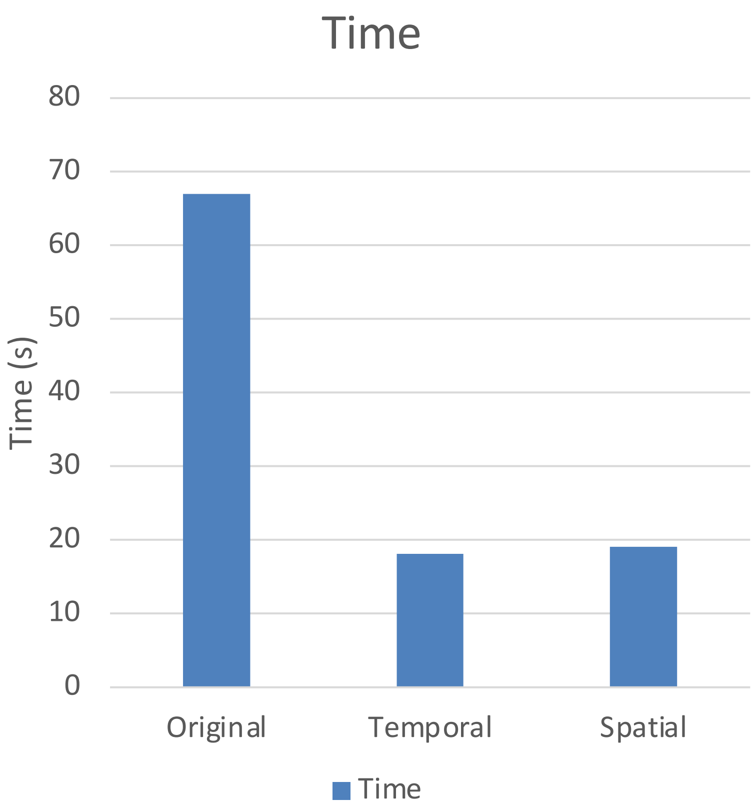
Option 1: Optimization using locality

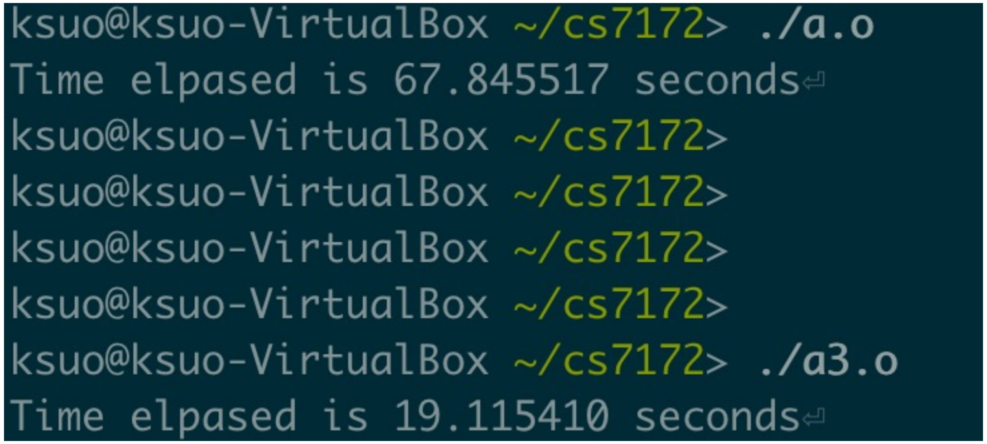
$$A = \left(\begin{array}{cc|cc} a_{11} & a_{12} & a_{13} & a_{1n} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ \hline a_{31} & a_{32} & a_{33} & a_{34} \\ a_{41} & a_{42} & a_{43} & a_{44} \end{array}\right) \Longrightarrow \begin{pmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{pmatrix}$$

$$A_{11} = \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix}, A_{12} = \begin{pmatrix} a_{13} & a_{14} \\ a_{23} & a_{24} \end{pmatrix}$$

$$A_{21} = \begin{pmatrix} a_{31} & a_{32} \\ a_{41} & a_{42} \end{pmatrix}, A_{22} = \begin{pmatrix} a_{33} & a_{34} \\ a_{43} & a_{44} \end{pmatrix}$$

Option 1: Optimization using locality





Optimal 2: Optimization using parallel

$$\begin{pmatrix} A_{1,1} & A_{1,2} \\ A_{2,1} & A_{2,2} \end{pmatrix} \cdot \begin{pmatrix} B_{1,1} & B_{1,2} \\ B_{2,1} & B_{2,2} \end{pmatrix} \rightarrow \begin{pmatrix} C_{1,1} & C_{1,2} \\ C_{2,1} & C_{2,2} \end{pmatrix}$$

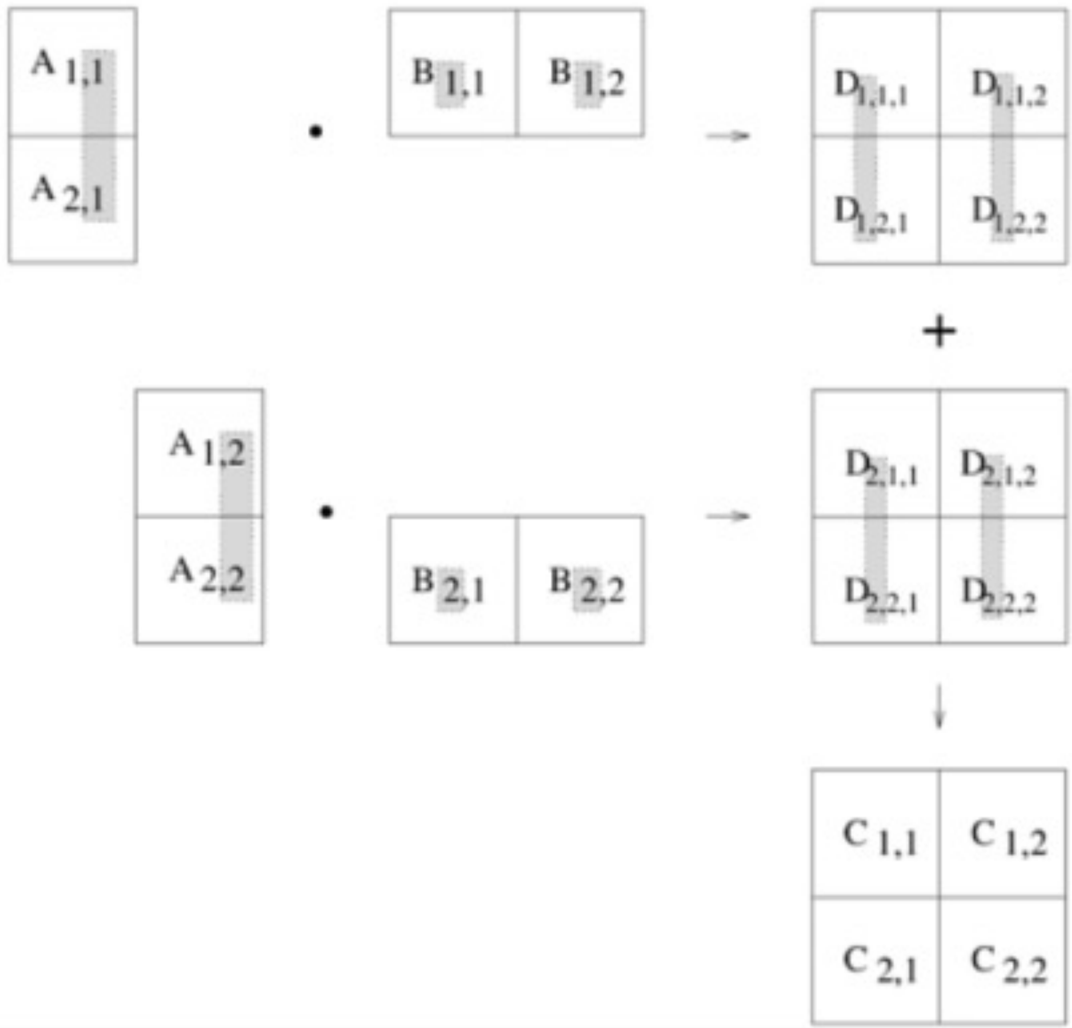
(a)

Task 1: $C_{1,1} = A_{1,1}B_{1,1} + A_{1,2}B_{2,1}$
Task 2: $C_{1,2} = A_{1,1}B_{1,2} + A_{1,2}B_{2,2}$
Task 3: $C_{2,1} = A_{2,1}B_{1,1} + A_{2,2}B_{2,1}$
Task 4: $C_{2,2} = A_{2,1}B_{1,2} + A_{2,2}B_{2,2}$

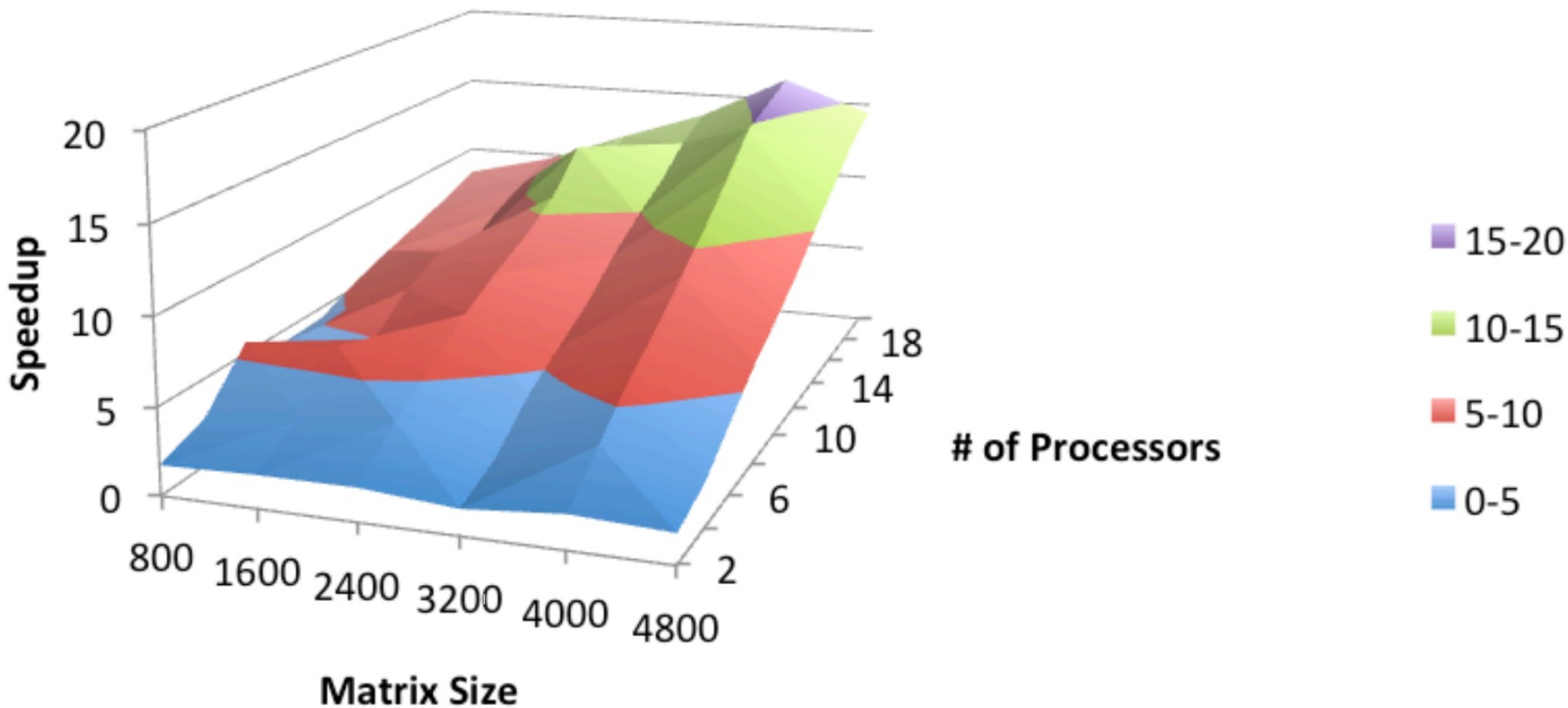
Optimal 2: Optimization using parallel

Thread 1:

Thread 2:



Optimal 2: Optimization using parallel



https://www.cse.unr.edu/~fredh/class/415/Nolan/matrix_multiplication/writeup.pdf

Example of distributed system: sorting

- Sorting on a single machine, e.g., Database

```
select field_a from table_b order by field_a limit 100, 10;
```

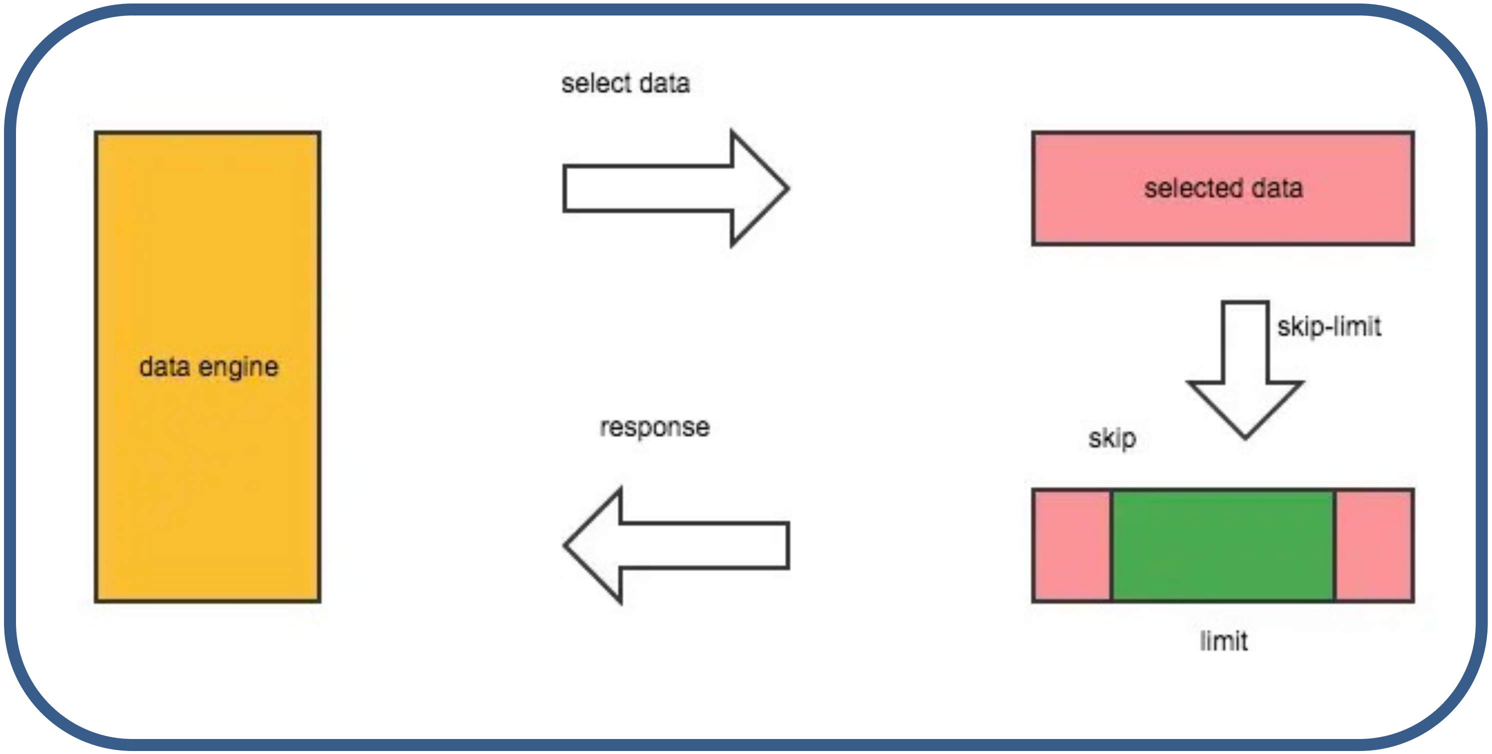
From line 100 to the next 10 lines of data

```
db.collection_b
.find()
.sort({"field_a":1})
.skip(100)
.limit(10);
```

	field_a	field_b	field_c
100			
…			
…			
110			

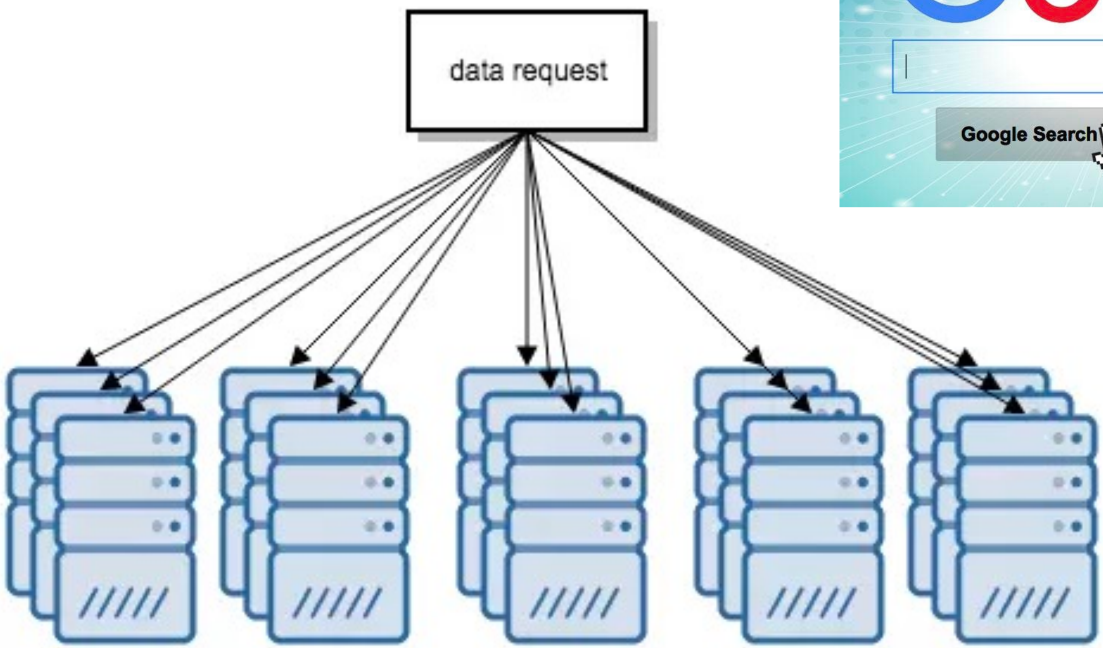
Example of distributed system: sorting

- Workflow on a single node



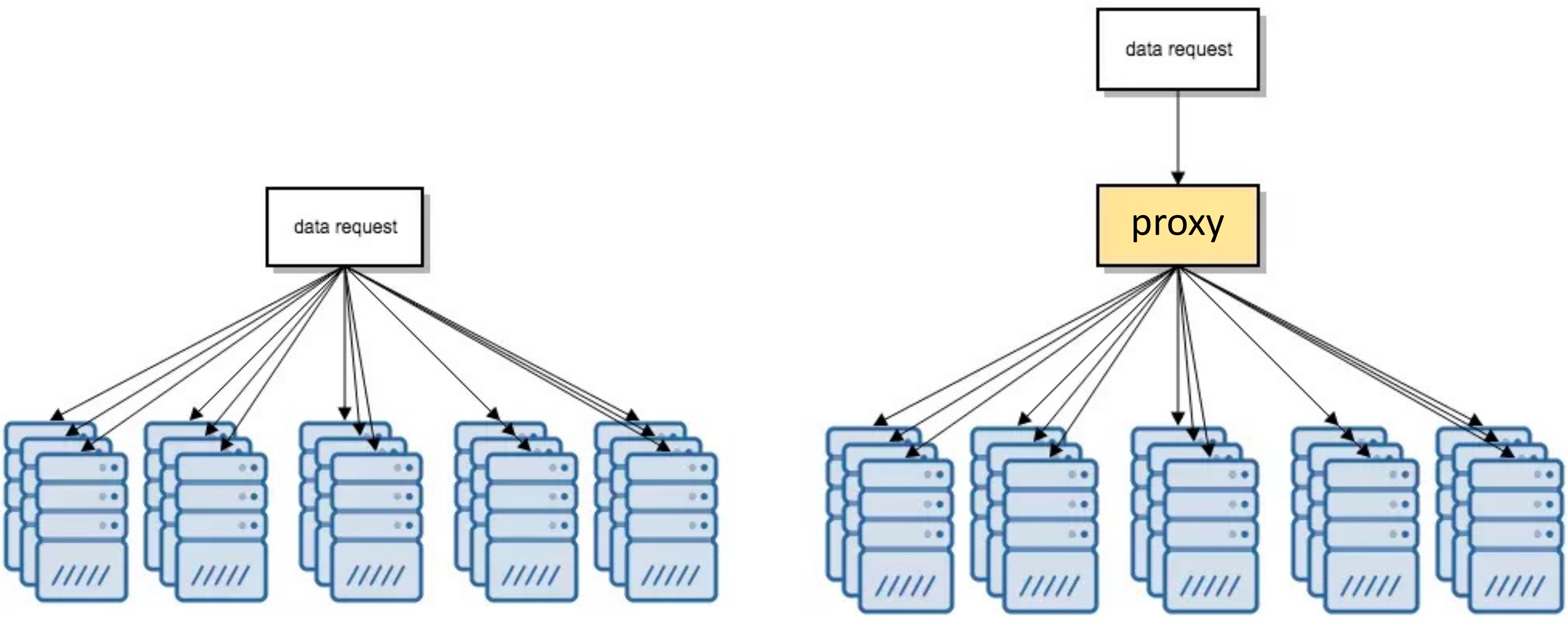
Example of distributed system: sorting

- If the data is too much and single node cannot hold



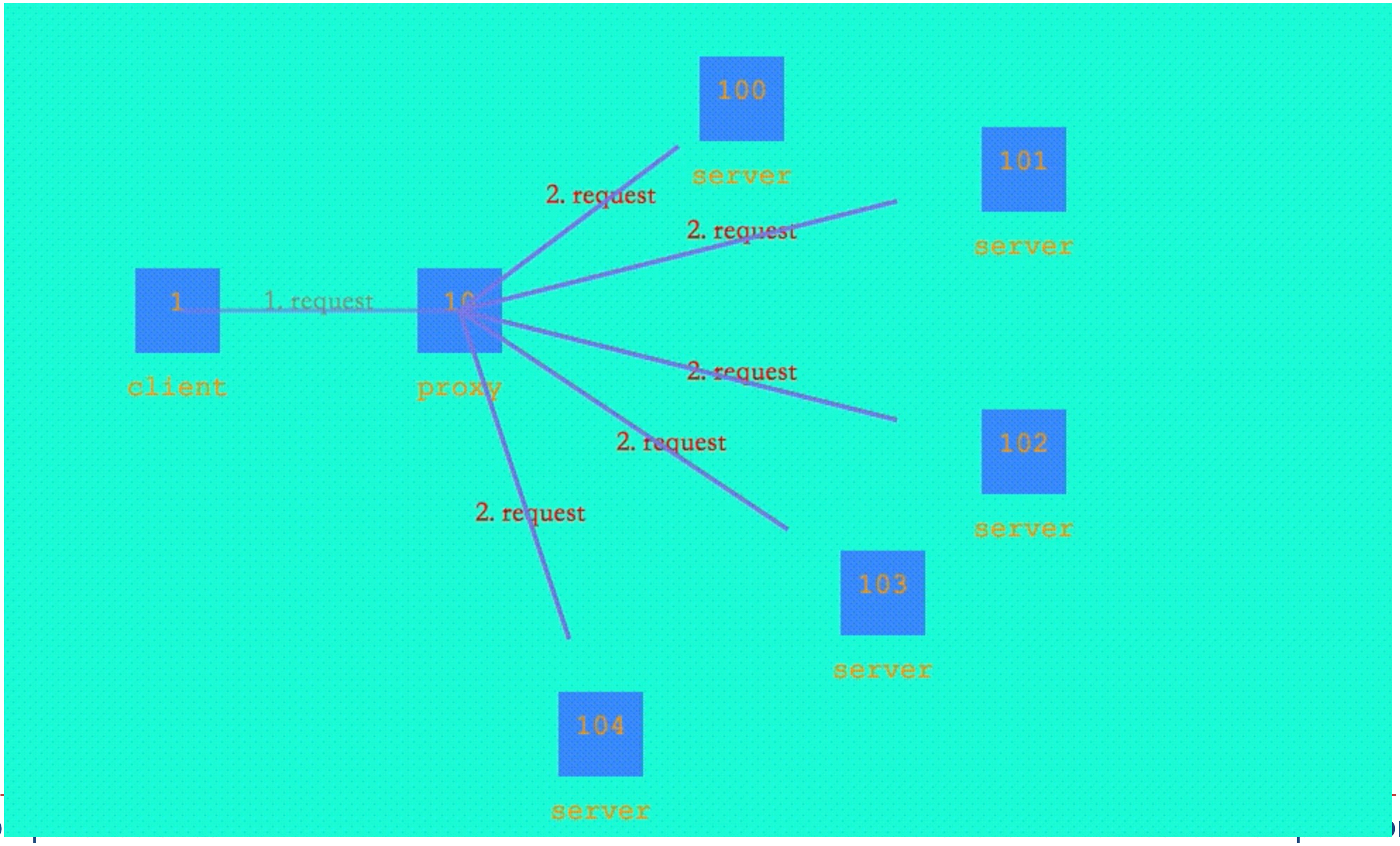
Example of distributed system: sorting

- Choose a node for merge processing



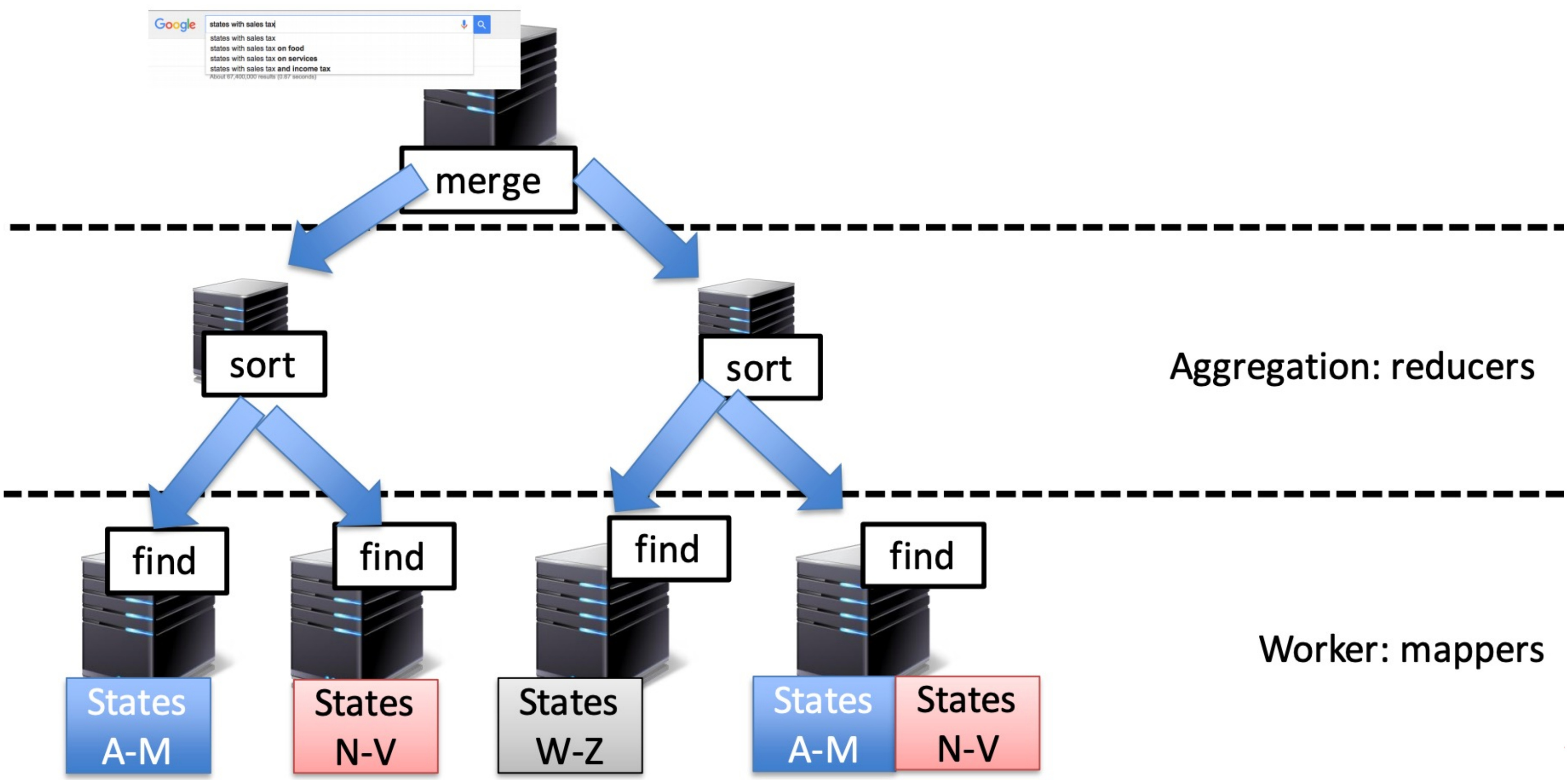
Example of distributed system: sorting

- Workflow



Example of distributed system: sorting

- How Do Request Get Processed in a Data Center



Example of distributed system: sorting

- How Google Search Works
- https://www.youtube.com/watch?v=0eKVizvYSUQ

Conclusion

- Why study parallel and distributed computation?
- What to learn?
- Course structure
- Course policy
- An example of parallel and distributed computation