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CS 561: Data Systems Architectures

class 2

Data Systems 101

Prof. Manos Athanassoulis

https://midas.bu.edu/classes/CS591A1/

If you are at home, make it full screen and focus on our discussion

some reminders

no smartphones

no laptop

class summary

2 classes per week / OH 5 days per week

each student

1 presentation/discussion lead + 1 review/question per week

project 0 + systems or research project

proposal + mid-semester report + final report/presentation

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systems project

implementation-heavy C/C++ project

groups of 2

research project

groups of 3

pick a subject (list will be available)

design & analysis

experimentation

Project 0:
A small implementation project to sharpen dev skills

<u>independent project</u>

more details this week

class timeline

now

Week 2
register for presentations by 2/4
(first presentation on 2/11)

Week 3
project 0 by 2/11
form groups by 2/12

Week 4
find project by 2/19

discussions
interaction in OH & Lab
questions

Week 5
submit project proposal on 2/28

Week 8
submit mid-semester
project report on 3/21

discussions
interaction in OH & Lab
questions

discussions
interaction in OH & Lab
questions

Week 14: Project presentations
submit all material by 4/26

Piazza

all discussions & announcements

http://piazza.com/bu/spring2021/cs561/

also available on class website

I have added everyone who already registered!

Please double-check!

size (volume)

rate (velocity)

sources (variety)

big data

(it's not only about size)

The 3 V's

+ our ability to collect ***machine-generated*** data

scientific experiments

sensors

social

Internet-of-Things

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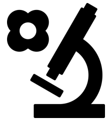
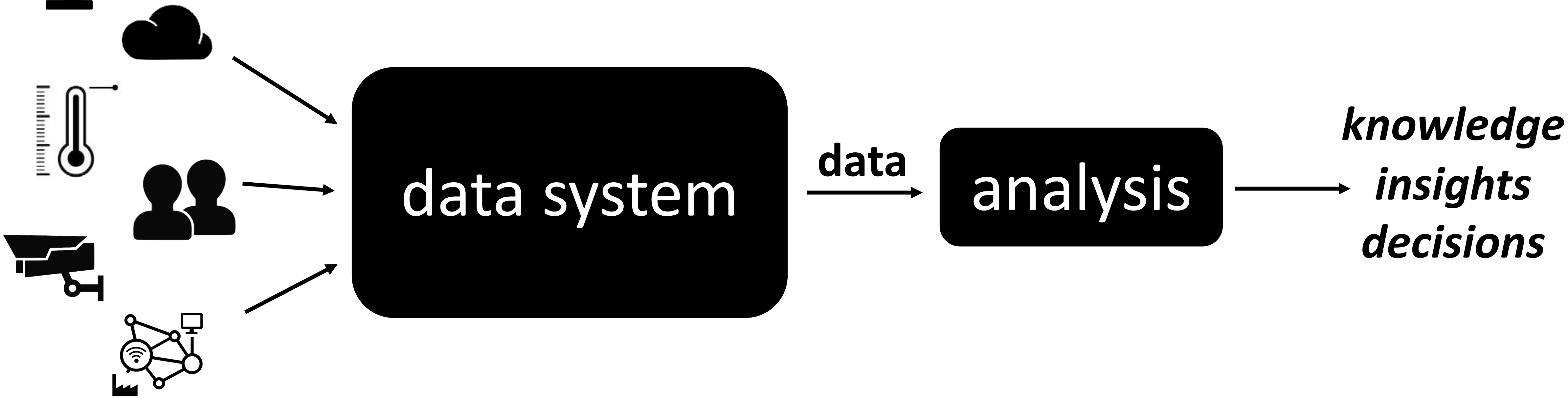
a **data system** is a large software system
that **stores data**, and provides the **interface** to
update and **access** them **efficiently**





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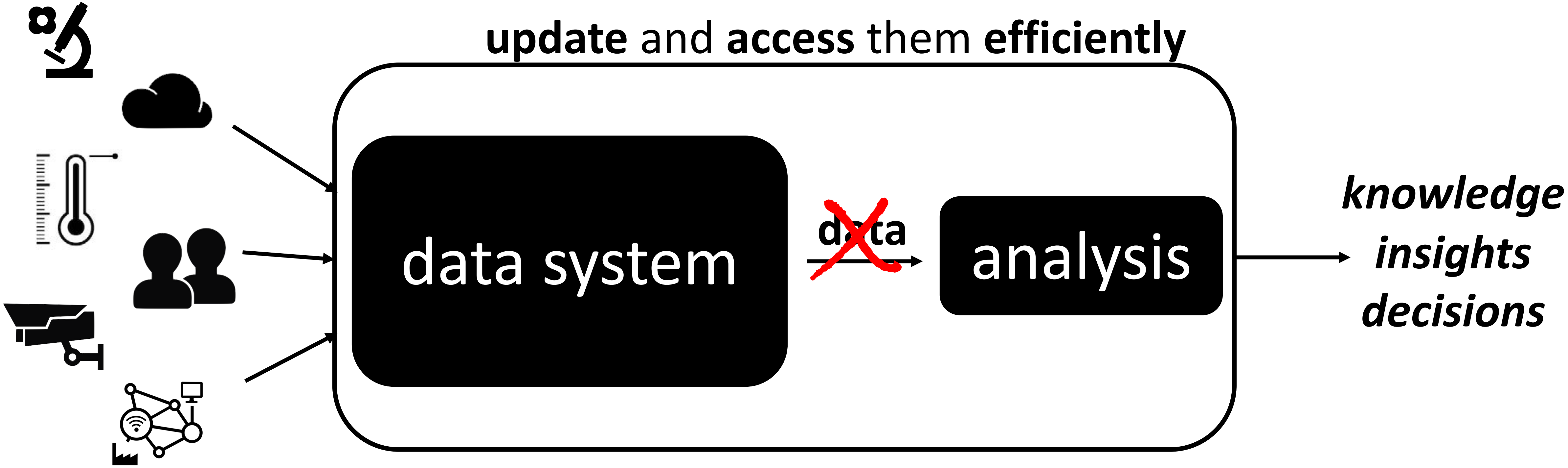

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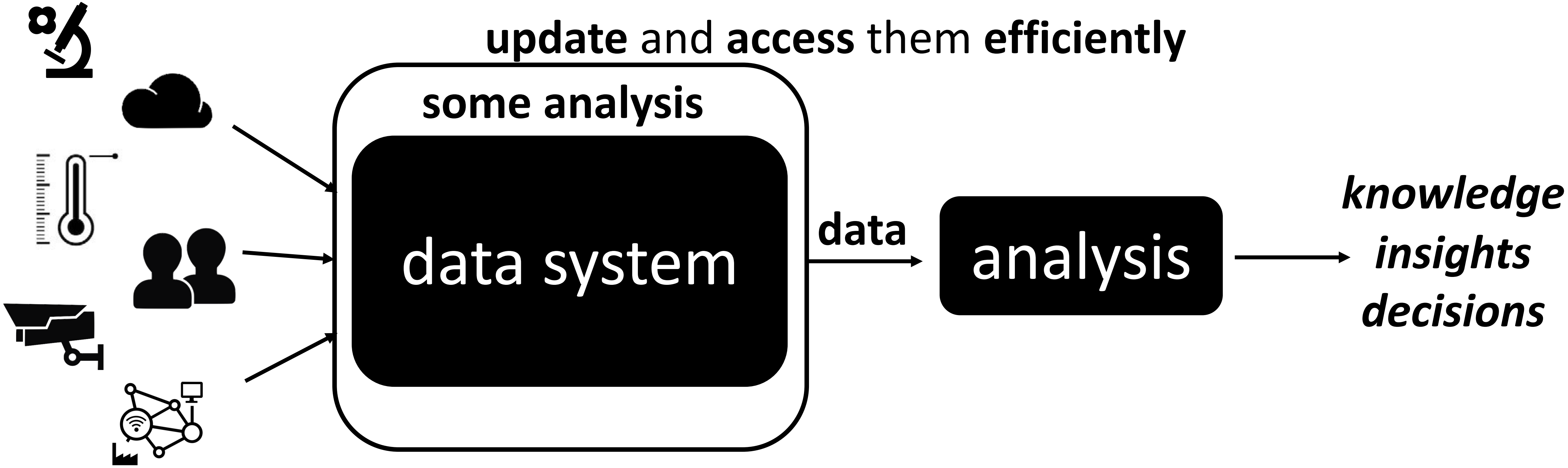
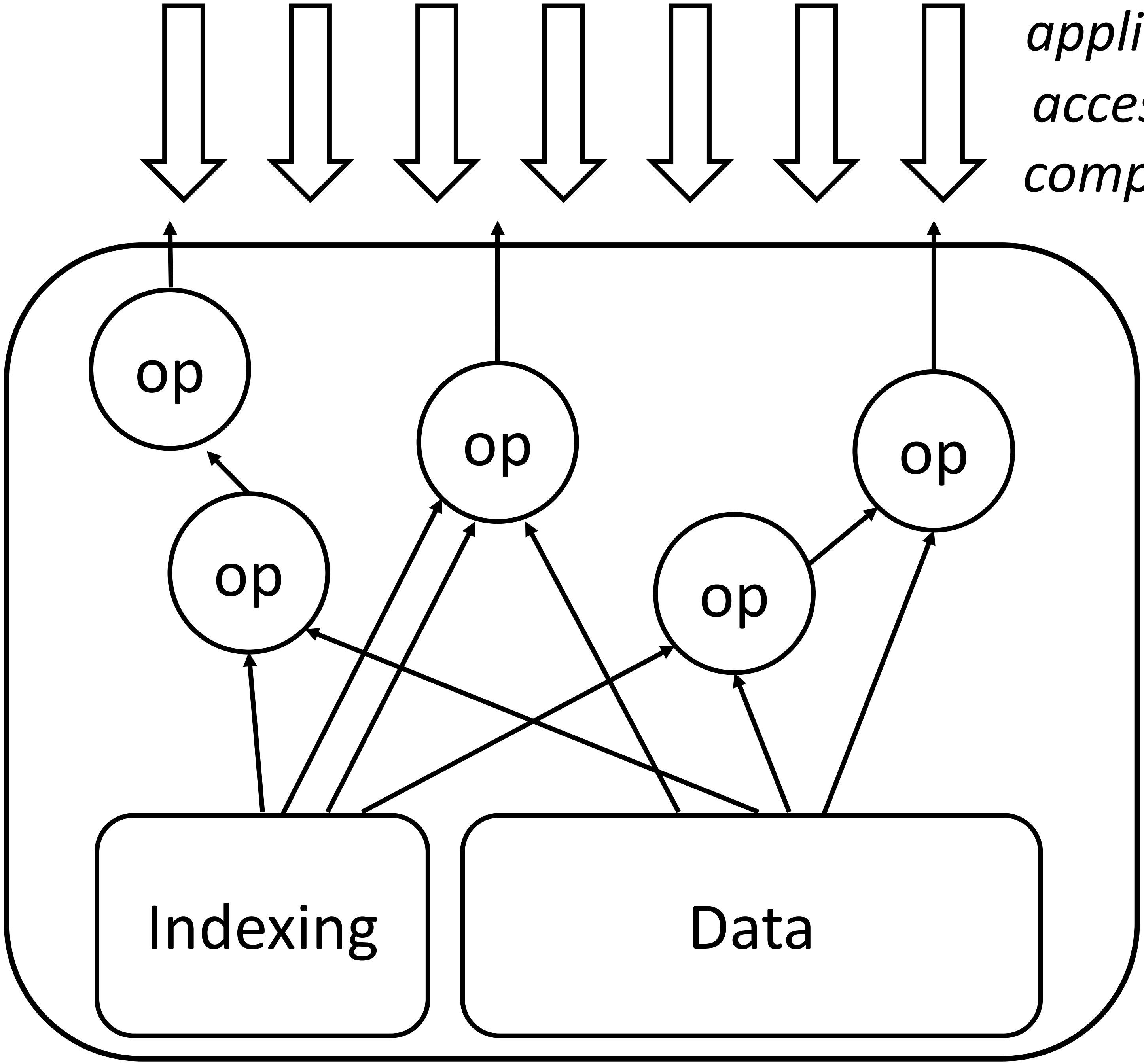


data system, what’s inside?

application/SQL
access patterns
complex queries

algorithms
and
operators



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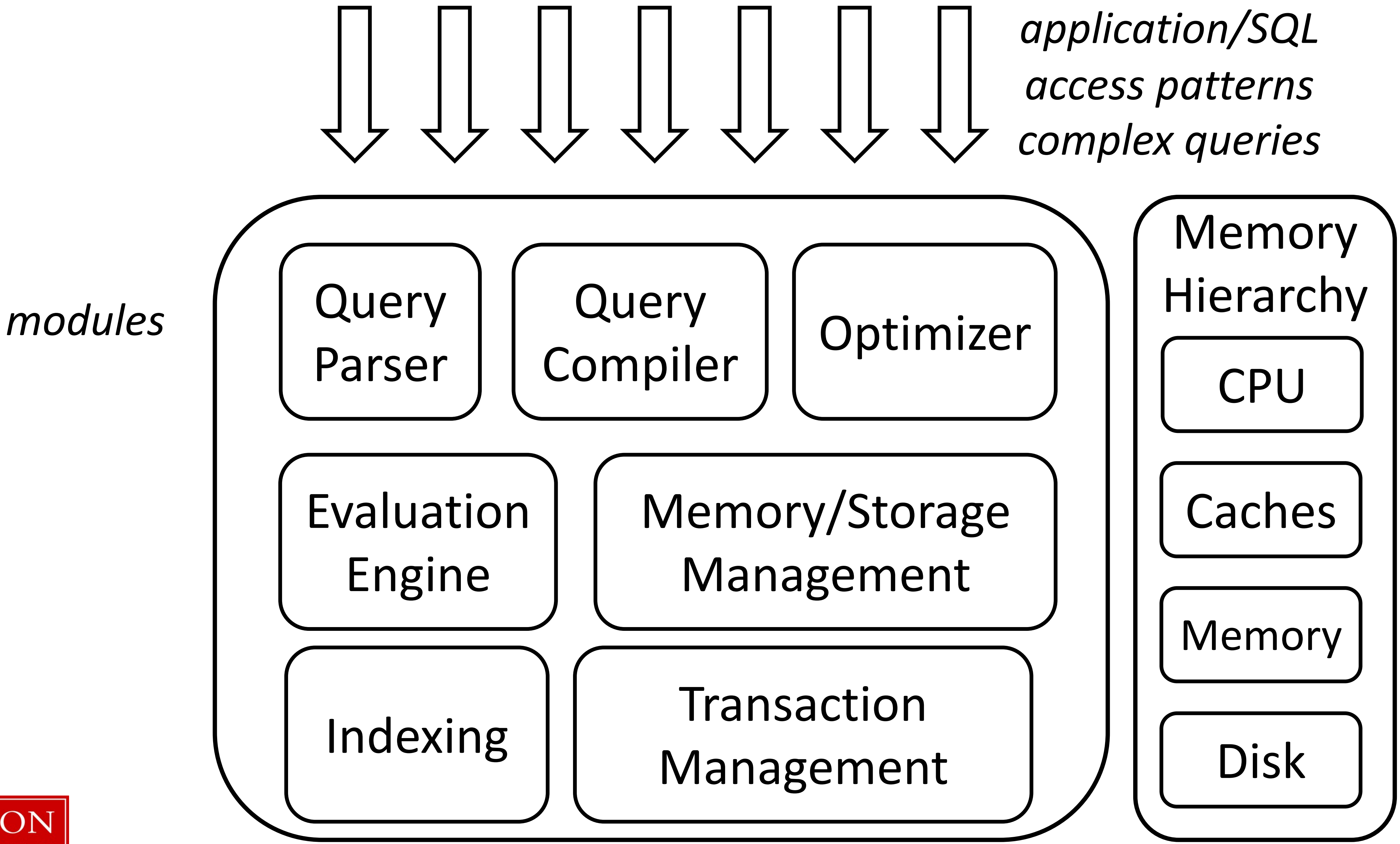

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growing environment

db

large systems
complex
lots of tuning
legacy

noSQL

simple, clean
"just enough"

more **complex** applications

need for **scalability**

newSQL

>$200B by 2020, growing at 11.7% every year

[The Forbes, 2016]

[noSQL]

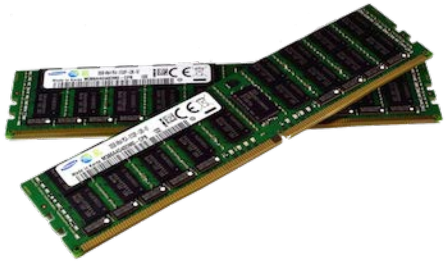
$3B by 2020, growing at 20% every year

[Forrester, 2016]

growing need for tailored systems

new applications

new hardware



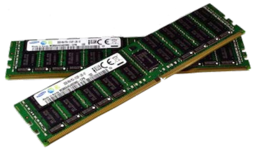
more data

data system, what’s underneath?

memory hierarchy

- CPU
- on-chip cache

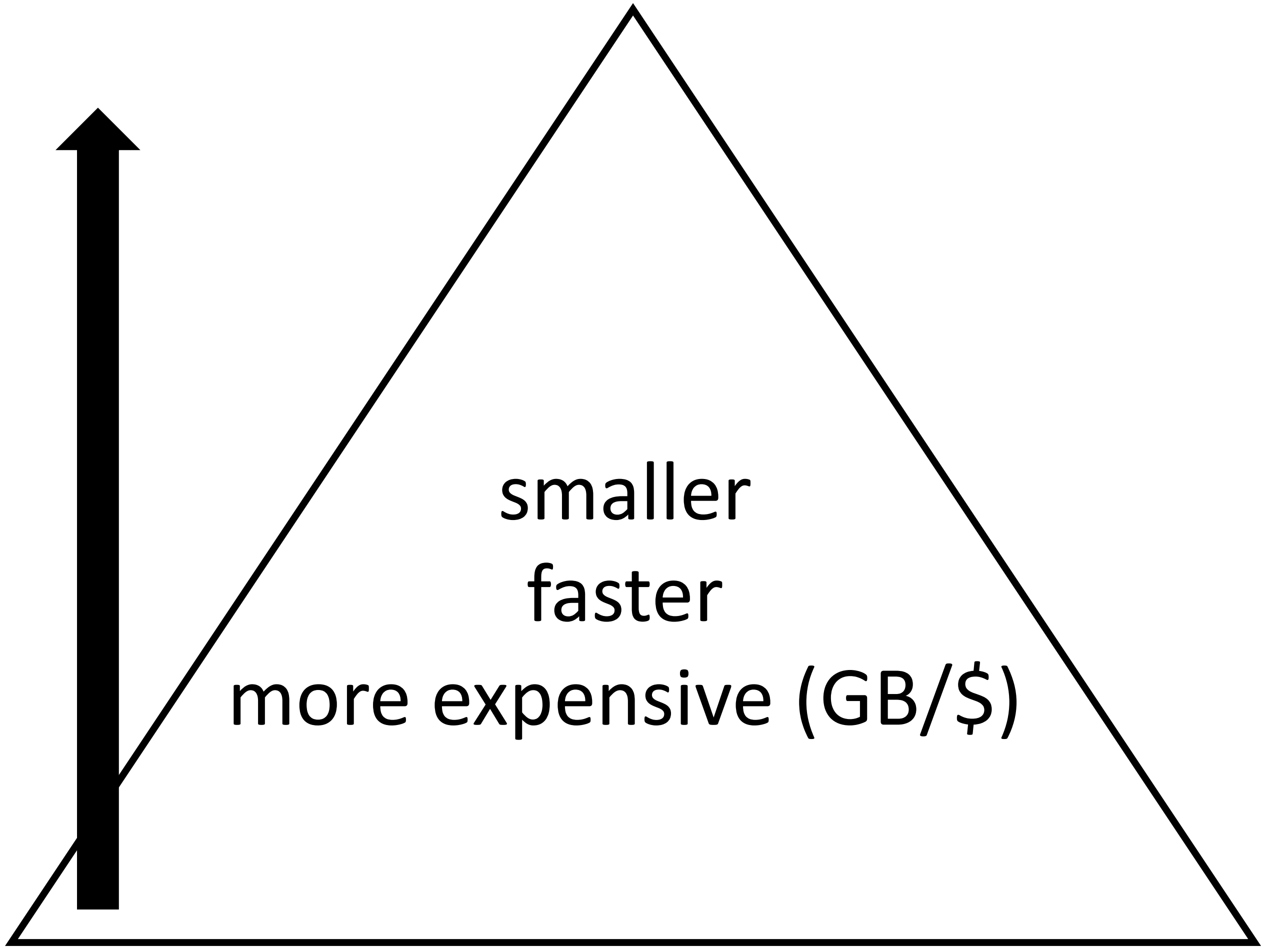
- on-board cache



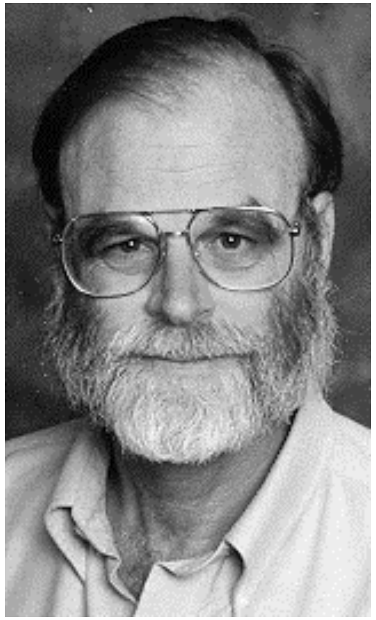
- main memory

- flash storage

- disks
- flash



memory hierarchy (by Jim Gray)



	registers/CPU	my head	~0
2x	**on chip cache**	this room	1min
10x	**on board cache**	this building	10min
100x	**memory**	Washington, DC	5 hours
10^6x	**disk**	Pluto	2 years
10^9x	**tape**	Andromeda	2000 years

Jim Gray, IBM, Tandem, Microsoft, DEC

“The Fourth Paradigm” is based on his vision

ACM Turing Award 1998

ACM SIGMOD Edgar F. Codd Innovations award 1993

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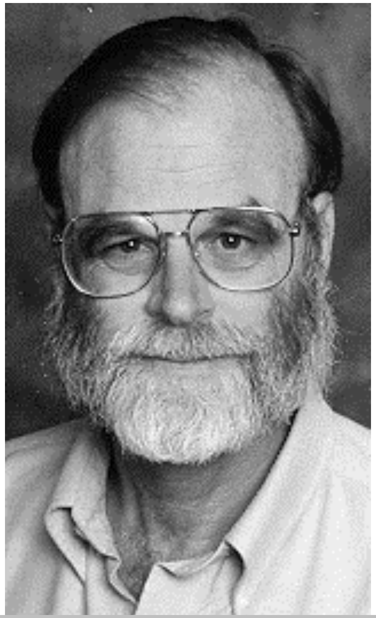
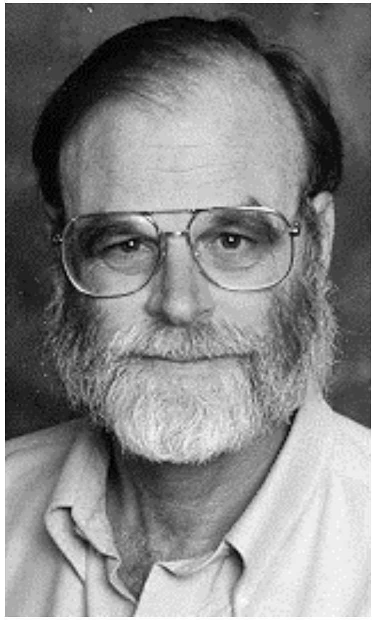
memory hierarchy (by Jim Gray)

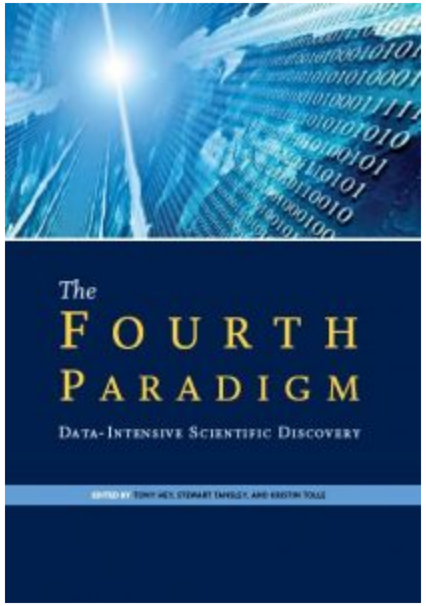


	registers/CPU	my head ~0
2x	**on chip cache**	this room 1min
10x	**on board cache**	this building 10min

tape?
sequential-only magnetic storage
still a multi-billion industry

Jim Gray (a great scientist and engineer)





Jim Gray, IBM, Tandem, Microsoft, DEC
"The Fourth Paradigm" is based on his vision
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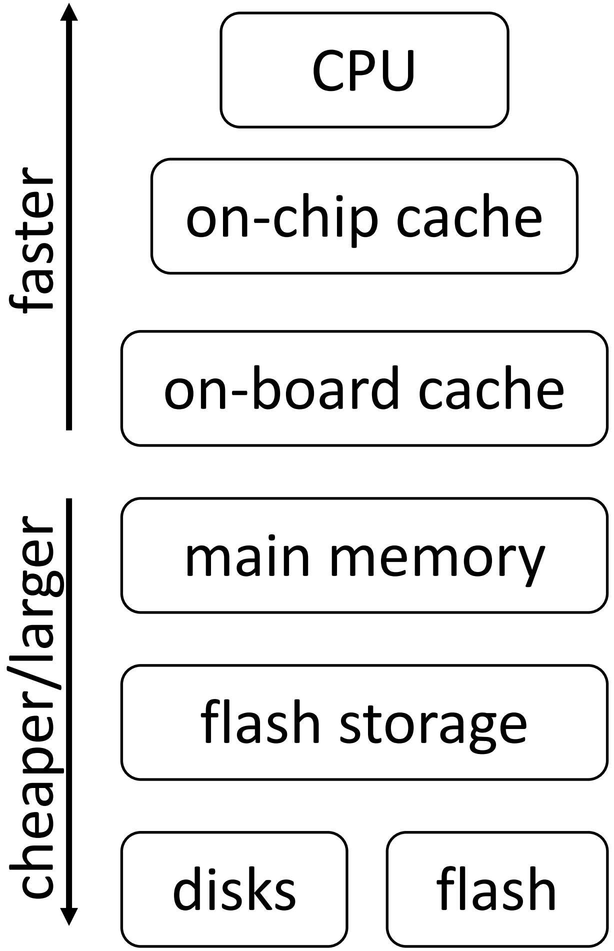
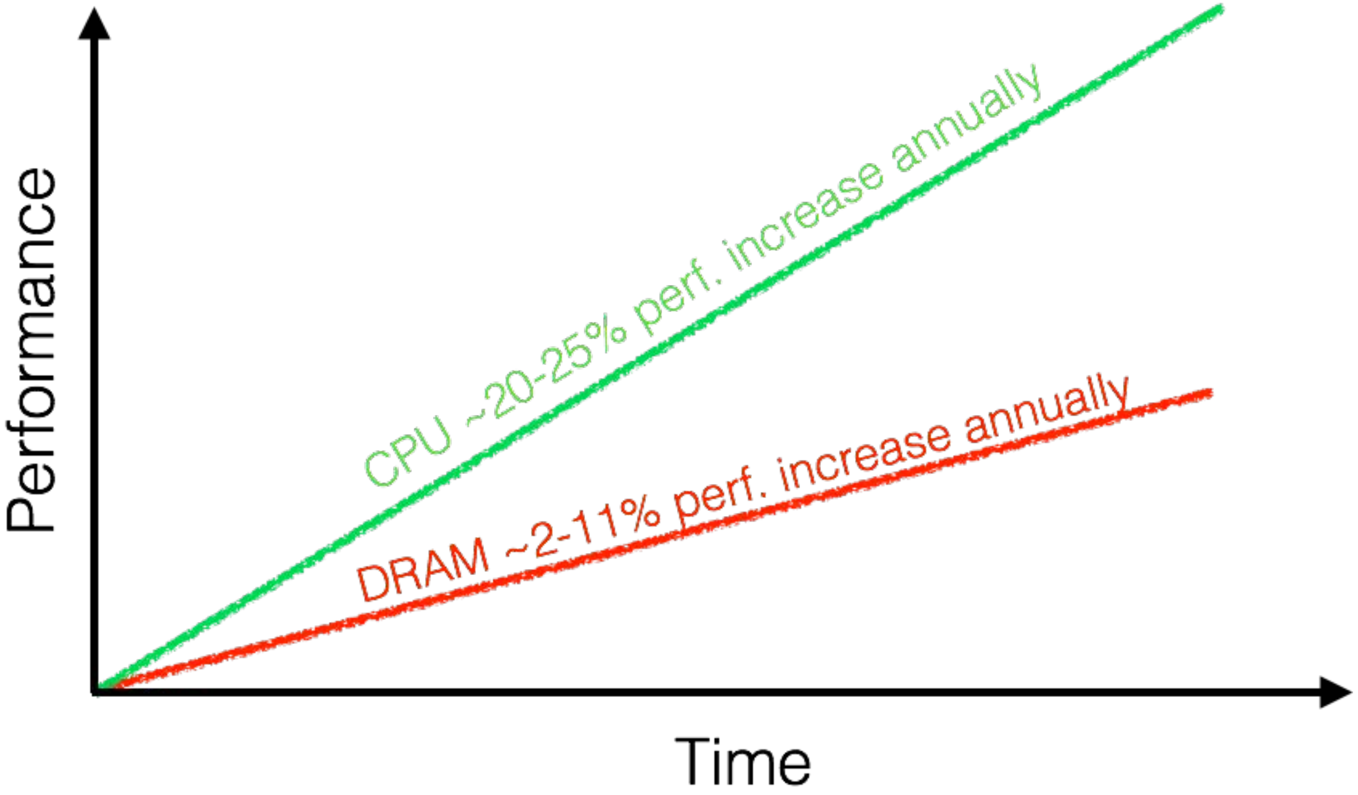
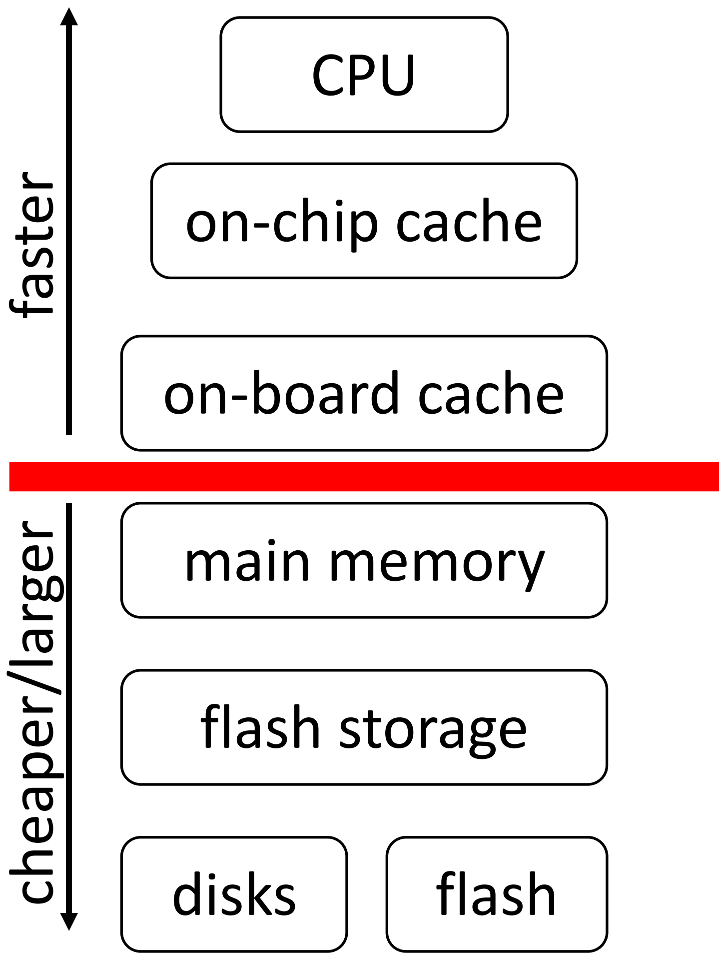
the first collection of technical visionary research on a data-intensive scientific discovery

memory wall

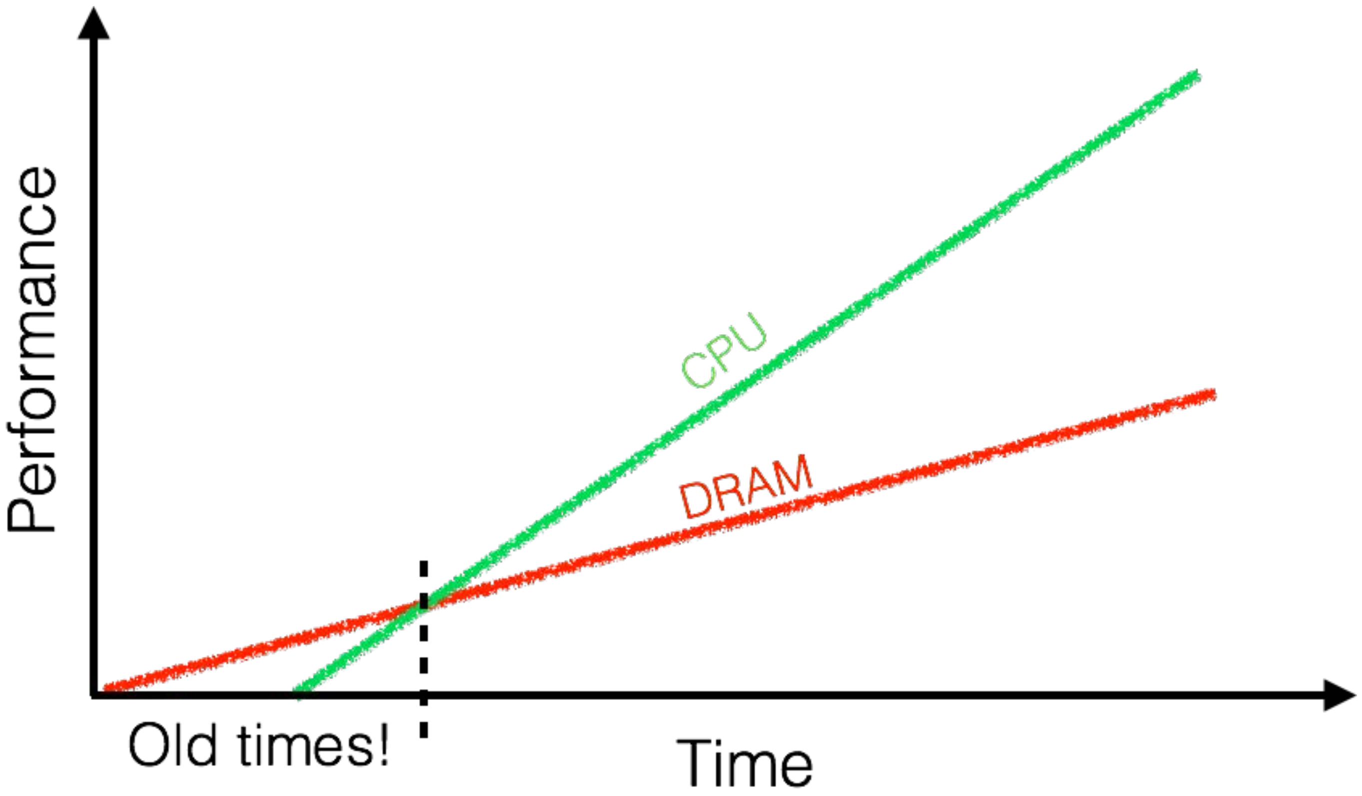

faster
cheaper/larger
CPU
on-chip cache
on-board cache
main memory
flash storage
disks
flash


Performance
CPU ~20-25% perf. increase annually
DRAM ~2-11% perf. increase annually
Time

memory wall



faster
cheaper/larger
CPU
on-chip cache
on-board cache
main memory
flash storage
disks
flash



Performance
CPU
DRAM
Old times!
Time

cache/memory misses

CPU

on-chip cache

on-board cache

main memory

flash storage

disks | flash

cache miss: looking for something that is not in the cache

memory miss: looking for something that is not in memory

what happens if I miss?

data movement

CPU

on-chip cache

on-board cache

main memory

flash storage

disks | flash

data go through
all necessary levels

also read
unnecessary data

Photo by Gary Dineen/NBAE via Getty Images

need to read only X
read the whole page

X page

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data movement

CPU

on-chip cache

on-board cache

main memory

flash storage

data go through
all necessary levels

also read
unnecessary data

Photo by Gary Dineen/NBAE via Getty Images

need to read only X
read the whole page

X page

remember!
disk is millions (mem, hundreds) times slower than CPU

page-based access & random access

query x<7

size=120 bytes

memory (memory level N)

disk (memory level N+1)

1, 5, 12, 24, 23

2, 7, 13, 9, 8

10, 11, 6, 14, 15

page size = 5*8 = 40 bytes

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page-based access & random access

$ 40 bytes

query x<7

scan

output

1, 5, 12, 24, 23

1, 5

size=120 bytes

memory (memory level N)

disk (memory level N+1)

1, 5, 12, 24, 23

2, 7, 13, 9, 8

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10, 11, 6, 14, 15

page size = 5*8 = 40 bytes

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page-based access & random access

$ 40 bytes

query x<7

scan

output

1, 5, 12, 24, 23

2, 7, 13, 9, 8

1, 5, 2

size=120 bytes

memory (memory level N)

disk (memory level N+1)

1, 5, 12, 24, 23

2, 7, 13, 9, 8

10, 11, 6, 14, 15

page size = 5*8 = 40 bytes

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page-based access & random access

$ 80 bytes

query x<7

scan → output

1, 5, 12, 24, 23 | 2, 7, 13, 9, 8 | 1, 5, 2

size=120 bytes

memory (memory level N)

disk (memory level N+1)

1, 5, 12, 24, 23 | 2, 7, 13, 9, 8 | 10, 11, 6, 14, 15

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10, 11, 6, 14, 15

2, 7, 13, 9, 8

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10, 11, 6, 14, 15

page size = 5*8 = 40 bytes

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page-based access & random access

$ 80 bytes

query x<7

scan

output

10, 11, 6, 14, 15	2, 7, 13, 9, 8	1, 5, 2, 6

size=120 bytes

memory (memory level N)

disk (memory level N+1)

1, 5, 12, 24, 23	2, 7, 13, 9, 8	10, 11, 6, 14, 15

page size = 5*8 = 40 bytes

page-based access & random access

$ 120 bytes

query x<7

scan →

output

10, 11, 6, 14, 15

2, 7, 13, 9, 8

1, 5, 2, 6

size=120 bytes

memory (memory level N)

disk (memory level N+1)

1, 5, 12, 24, 23

2, 7, 13, 9, 8

10, 11, 6, 14, 15

page size = 5*8 = 40 bytes

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what if we had an oracle (perfect index)?

page-based access & random access

query x<7

size=120 bytes

memory (memory level N)

disk (memory level N+1)

1, 5, 12, 24, 23

2, 7, 13, 9, 8

10, 11, 6, 14, 15

page size = 5*8 = 40 bytes

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$ 40 bytes

page-based access & random access

query x<7

oracle

output

1, 5, 12, 24, 23

1, 5

size=120 bytes

memory (memory level N)

disk (memory level N+1)

1, 5, 12, 24, 23

2, 7, 13, 9, 8

10, 11, 6, 14, 15

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page-based access & random access

$ 40 bytes

query x<7

oracle

output

1, 5, 12, 24, 23

2, 7, 13, 9, 8

1, 5

size=120 bytes

memory (memory level N)

disk (memory level N+1)

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page-based access & random access

$ 40 bytes

query x<7

oracle

output

1, 5, 12, 24, 23

2, 7, 13, 9, 8

1, 5, 2

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page-based access & random access

$ 80 bytes

query x<7

oracle

output

1, 5, 12, 24, 23

2, 7, 13, 9, 8

1, 5, 2

size=120 bytes

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10, 11, 6, 14, 15

page size = 5*8 = 40 bytes

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$ 80 bytes

page-based access & random access

query x<7

oracle

output

10, 11, 6, 14, 15

2, 7, 13, 9, 8

1, 5, 2

size=120 bytes

memory (memory level N)

disk (memory level N+1)

1, 5, 12, 24, 23

2, 7, 13, 9, 8

10, 11, 6, 14, 15

page size = 5*8 = 40 bytes

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$ 80 bytes

page-based access & random access

query x<7

oracle

output

10, 11, 6, 14, 15

2, 7, 13, 9, 8

1, 5, 2, 6

size=120 bytes

memory (memory level N)

disk (memory level N+1)

1, 5, 12, 24, 23

2, 7, 13, 9, 8

10, 11, 6, 14, 15

page size = 5*8 = 40 bytes

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page-based access & random access

$ 120 bytes

query x<7

was the oracle helpful?

oracle

output

10, 11, 6, 14, 15	2, 7, 13, 9, 8	1, 5, 2, 6

size=120 bytes

memory (memory level N)

disk (memory level N+1)

1, 5, 12, 24, 23	2, 7, 13, 9, 8	10, 11, 6, 14, 15

page size = 5*8 = 40 bytes

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when is the oracle helpful?

for which query would an oracle help us?

how to decide whether to use the oracle?

1, 5, 12, 24, 23

2, 7, 13, 9, 8

10, 11, 6, 14, 15

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how we store data

layouts, indexes

every **byte** counts

overheads and tradeoffs

know the **query**

access path selection

index
design space

rules of thumb

sequential access

read one block; consume it completely; discard it; read next;

hardware can predict and start prefetching

prefetching can exploit full memory/disk bandwidth

random access

read one block; consume it partially; discard it; (may re-use);

read random next;

ideal random access?

the one that helps us **avoid a large number of accesses** (random or sequential)

the language of efficient systems: C/C++

why?

low-level control over hardware

make decisions about physical data placement and consumptions

fewer assumptions

the language of efficient systems: C/C++

why?

low-level control over hardware

we want you in the project to make low-level decisions

a “simple” database operator

select operator (scan)

query: value<x
over an array of N slots

qualifying positions

query: value<x
over an array of N slots

data

how to implement it?

```
result = new array[data.size];
j=0;
for (i=0; i<data.size; i++)
    if (data[i]<x)
        result[j++]=i;
```

what if only 0.1% qualifies?

memory

data

result

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how to implement it?

```
result = new array[data.size];
j=0;
for (i=0; i<data.size; i++)
    if (data[i]<x)
        result[j++]=i;
```

qualifying positions

query: value<x
over an array of N slots

data

what if only 0.1% qualifies?

memory

data

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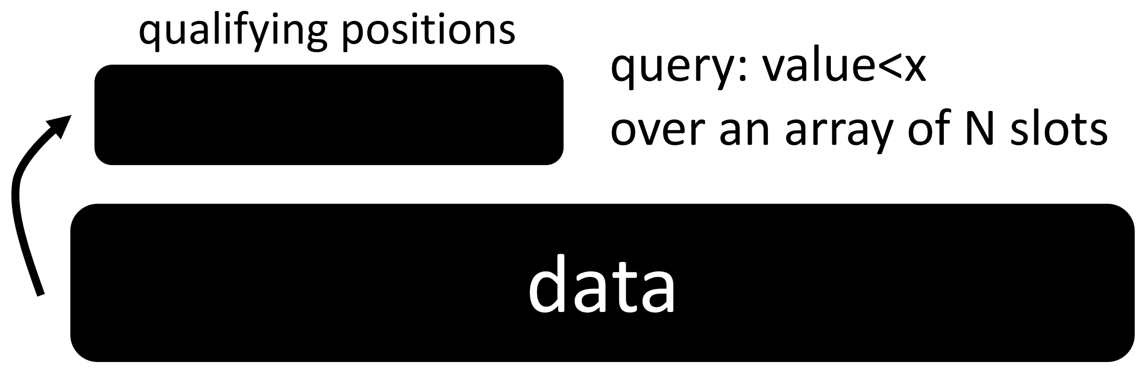
how to implement it?




```
result = new array[data.size];
j=0;
for (i=0; i<data.size; i++)
    if (data[i]<x)
        result[j++]=i;
```

what if 99% qualifies?

how can we know?

branches (if statements)
are bad for the processors,
can we avoid them?

```
result = new array[data.size];
j=0;
for (i=0; i<data.size; i++)
    result[j+=(data[i]<x)]=i;
```

how to bring the values?
(remember we have the positions)

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qualifying positions

query: value<x
over an array of N slots

data

```
result = new array[data.size];
j=0;
for (i=0; i<data.size; i++)
    if (data[i]<x)
        result[j++]=i;
```

what about multi-core?
NUMA? SIMD? GPU?

data

core1 core2 core3 core4

needs coordination!
what about result writing?

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what about having multiple queries?

query1: value<x1
query2: value<x2 …


```
result = new array[data.size];
j=0;
for (i=0; i<data.size; i++)
    if (data[i]<x)
        result[j++]=i;
```

query: value<x
over an array of N slots

data

should I scan?

should I probe an index?

how to decide which one is best?

total data movement
&
computation

how can I prepare?

1) Read background research material

- **Architecture of a Database System**. By J. Hellerstein, M. Stonebraker and J. Hamilton. Foundations and Trends in Databases, 2007
- **The Design and Implementation of Modern Column-store Database Systems**. By D. Abadi, P. Boncz, S. Harizopoulos, S. Idreos, S. Madden. Foundations and Trends in Databases, 2013
- **Massively Parallel Databases and MapReduce Systems**. By Shivnath Babu and Herodotos Herodotou. Foundations and Trends in Databases, 2013

2) Start going over the papers

what to do now?

A) read the syllabus and the website
B) register to piazza
C) register to gradescope
D) register for the presentation (**early next week!**)
E) start submitting paper reviews (week 3)
F) go over the project (next week will be available)
G) start working on the proposal (week 3)

survival guide

class website: https://bu-disc.github.io/CS561/

piazza website: https://piazza.com/bu/spring2021/cs561

presentation registration: https://tinyurl.com/S21-CS561-presentations

gradescope: https://www.gradescope.com/courses/236591 (**2RBY82**)

office hours: Manos (T/Th 2-3pm)
Papon, Aneesh, Ju Hyoung (see in Piazza)

material: papers available from BU network

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CS 561: Data Systems Architectures

class 2

Data Systems 101

next week: modern main-memory data systems

&

semester project