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# CS 591: Data Systems Architectures

class 2

# Data Systems 101

Prof. Manos Athanassoulis

http://manos.athanassoulis.net/classes/CS591

# some reminders

no smartphones

no laptop

# class effort summary

2 classes per week / OH 4 days per week

**each student**

1 presentation/discussion lead + 2 reviews per week

(5 long and the rest short, can skip 3)

systems or research project + mid-semester report

***expect to work several hours every week***

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## systems project

implementation-heavy C/C++ project

group of 1-2

## research project

group of 3-4

pick a subject (list will be available)

design & analysis

experimentation

# class timeline

now

Week 2 – register for presentations by 1/31
**first presentation on 2/5**

Week 4 (or earlier) – form your groups by 2/15

***discussions***
***interaction in OH***
***questions***

Week 7 – submit your project report on 3/8

***discussions***
***interaction in OH***
***questions***

Week 15 – Project presentations
submit all material by 4/30

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# Piazza

all discussions & announcements

http://piazza.com/bu/spring2019/cs591a1/

also available on class website

17 already registered!

register so we can reach you easily

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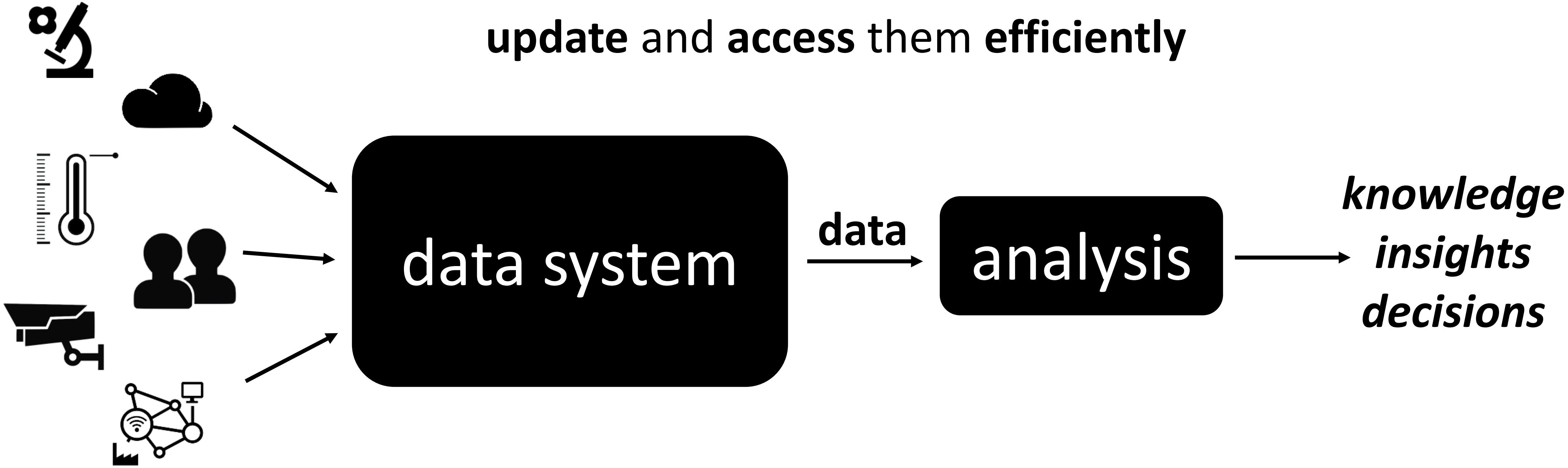
a **data system** is a large software system that **stores data**, and provides the **interface** to **update** and **access** them **efficiently**

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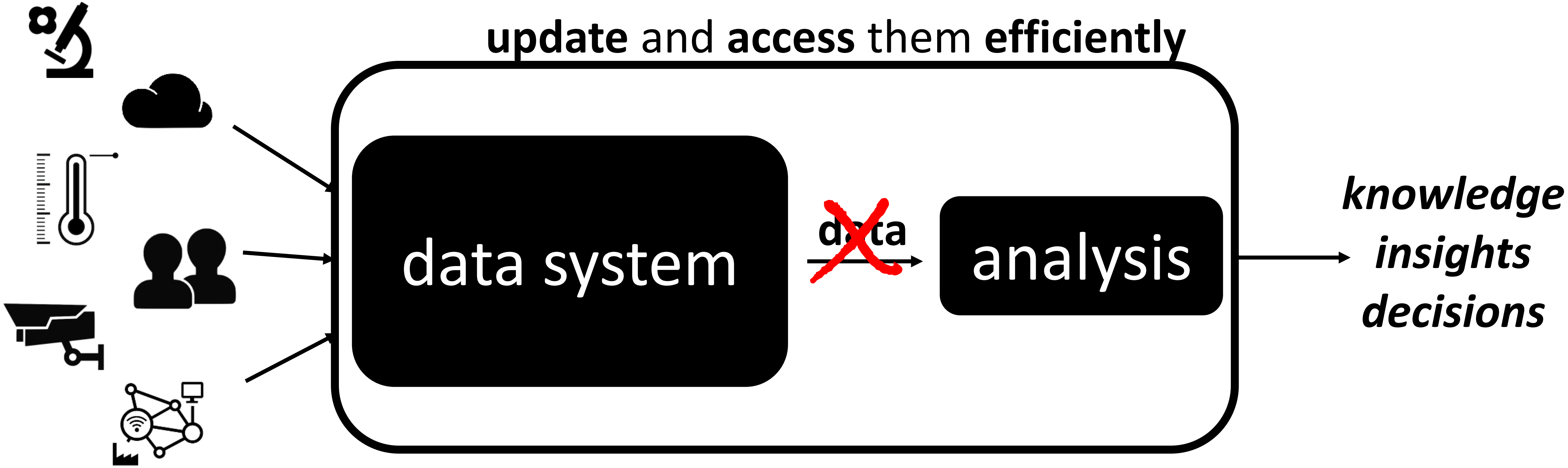


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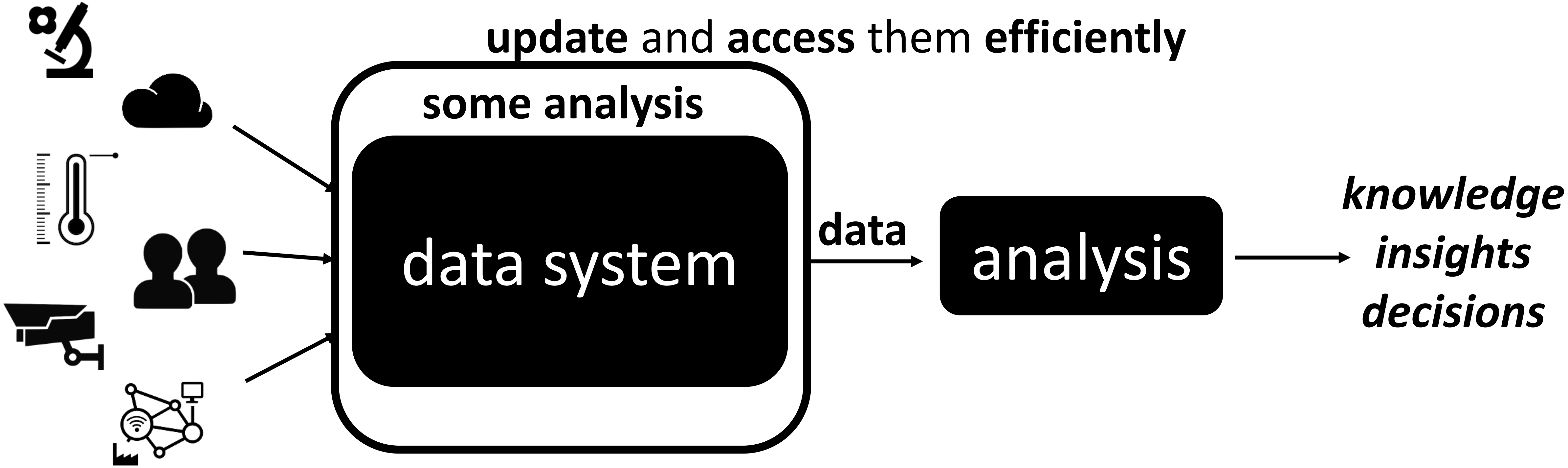
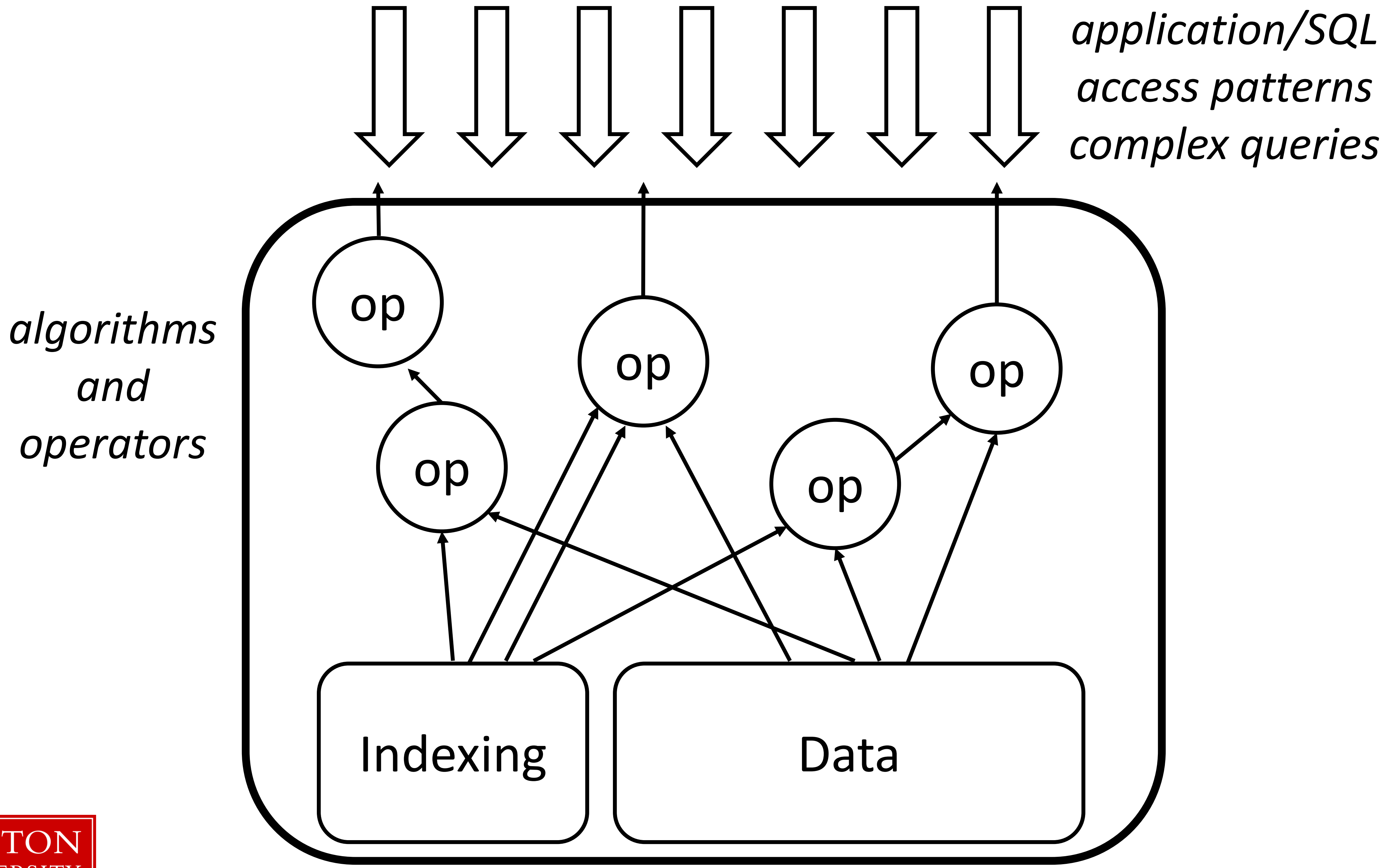


# data system, what’s inside?

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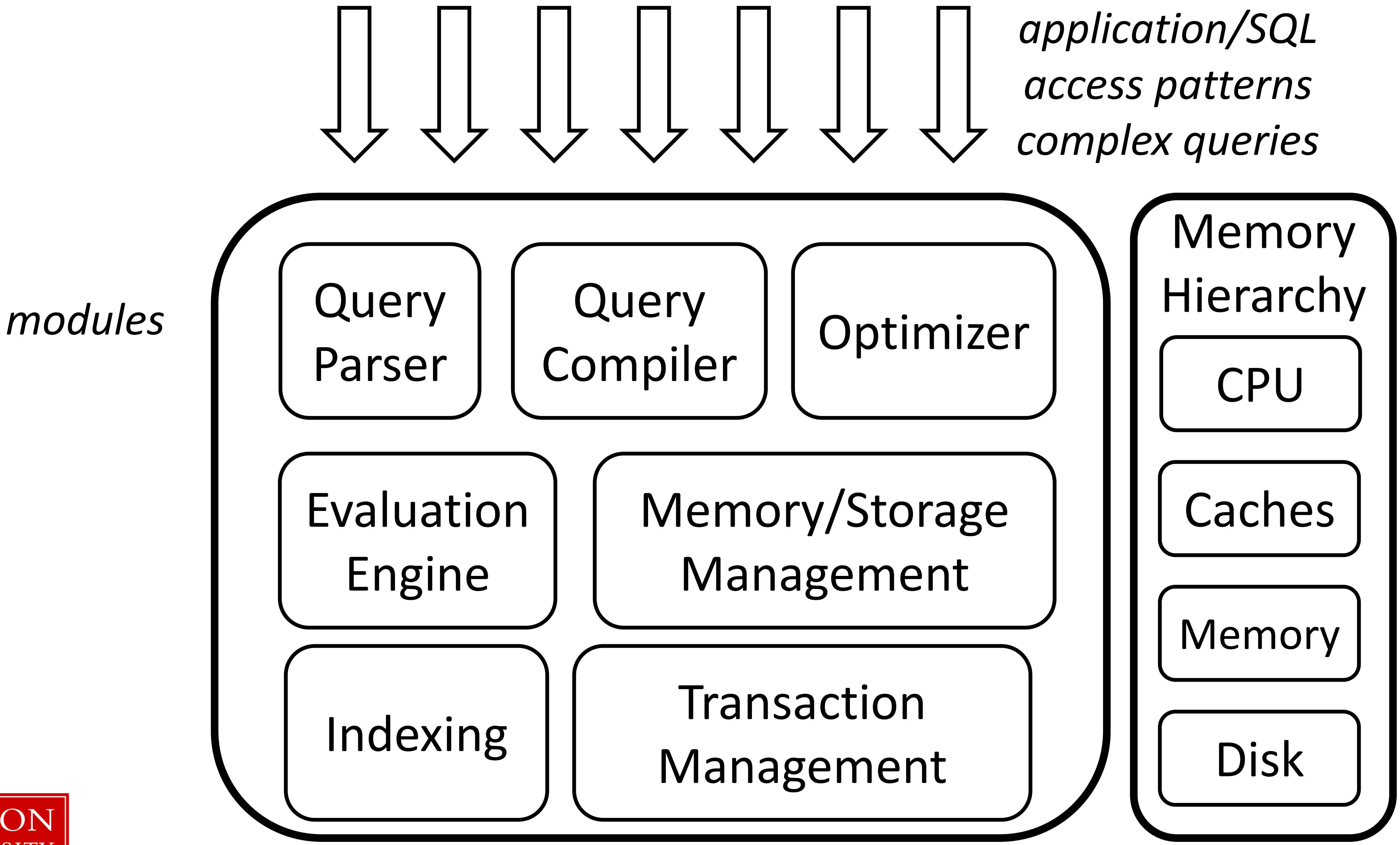


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# growing environment

ORACLE facebook Microsoft IBM Google twitter

**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]**

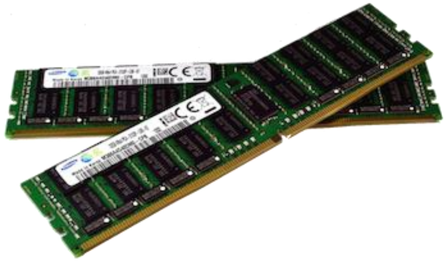
$3B by 2020, growing at 20% every year

[Forrester, 2016]

# *growing need for tailored systems*

new applications

new hardware



more data

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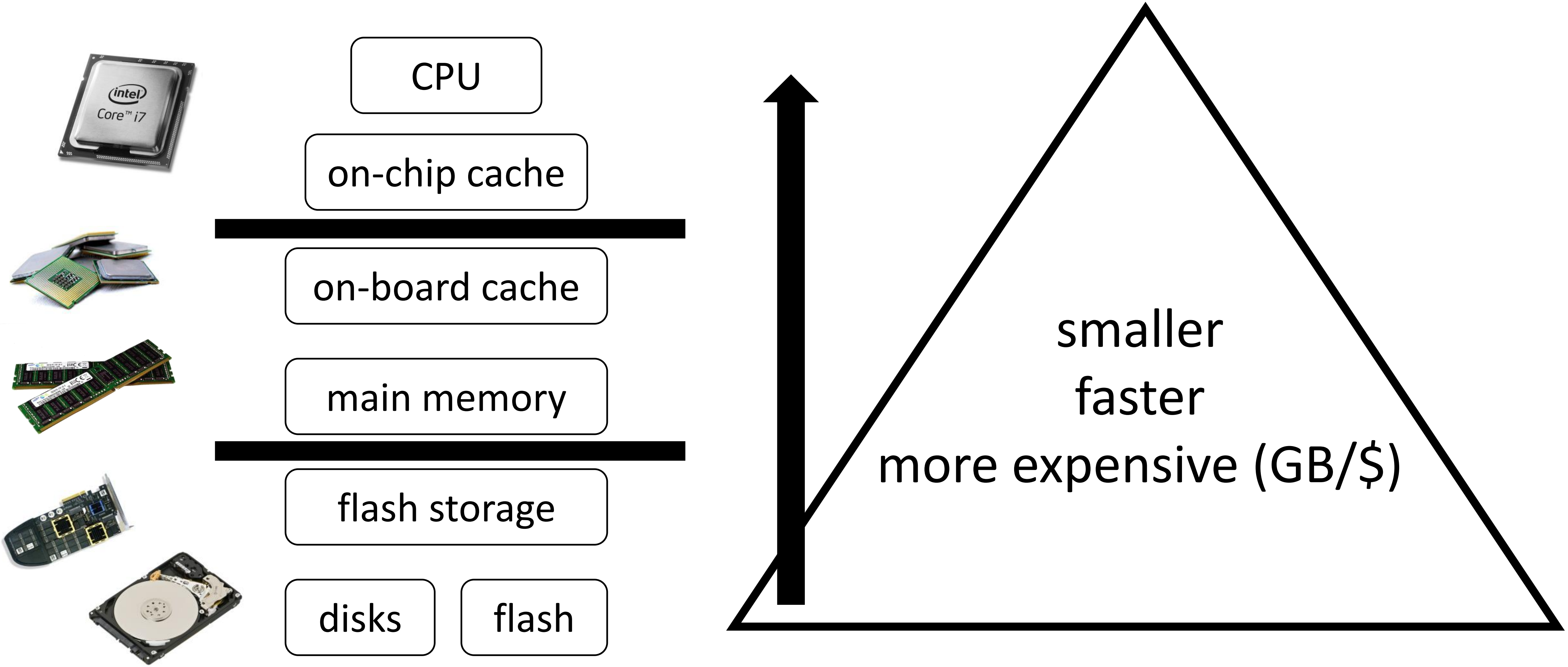
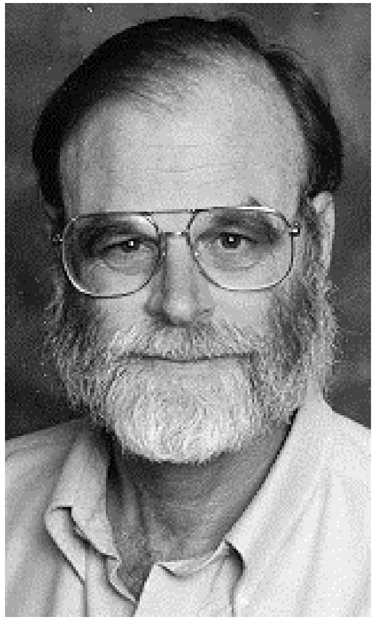
# data system, what’s underneath?

# memory hierarchy



# memory hierarchy (by Jim Gray)



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**

| | | |
|---|---|---|
| | **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 |
| **$10^6$x** | **disk** | Pluto 2 years |
| **$10^9$x** | **tape** | Andromeda 2000 years |

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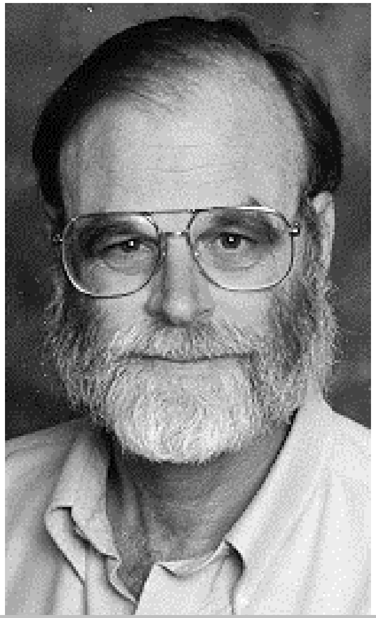
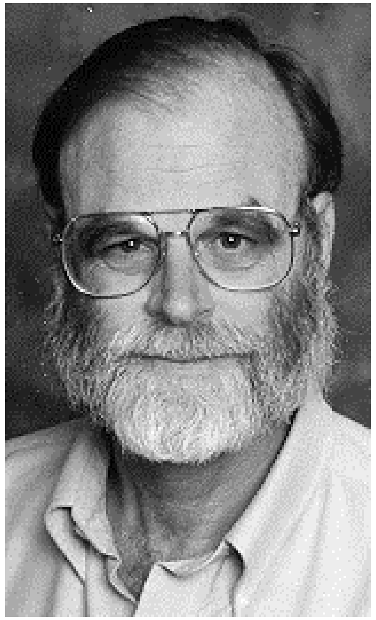
# memory hierarchy (by Jim Gray)

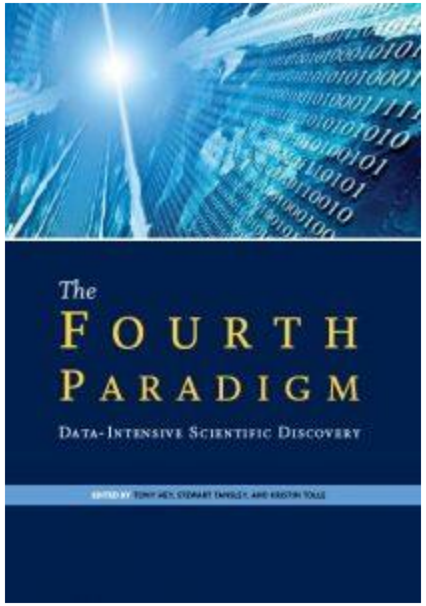


| | | |
|---|---|---|
| | **registers/CPU** | my head<br>~0 |
| **2x** | **on chip cache** | this room<br>1min |
| **10x** | **on board cache** | this building<br>10min |

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

# Jim Gray (a great scientist and engineer)






*the first collection of technical visionary research on a data-intensive scientific discovery*

Jim Gray, IBM, Tandem, Microsoft, DEC
"The Fourth Paradigm" is based on his vision
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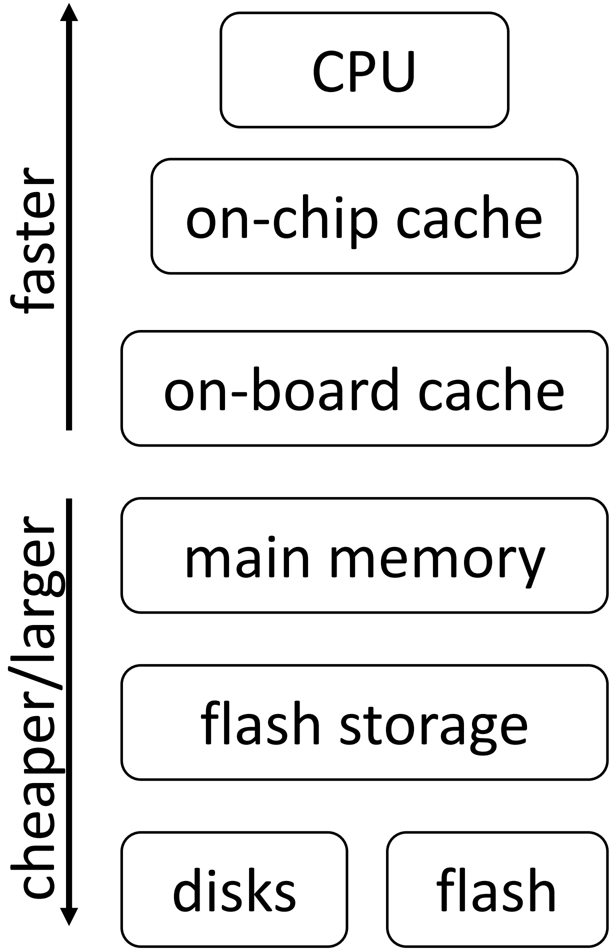
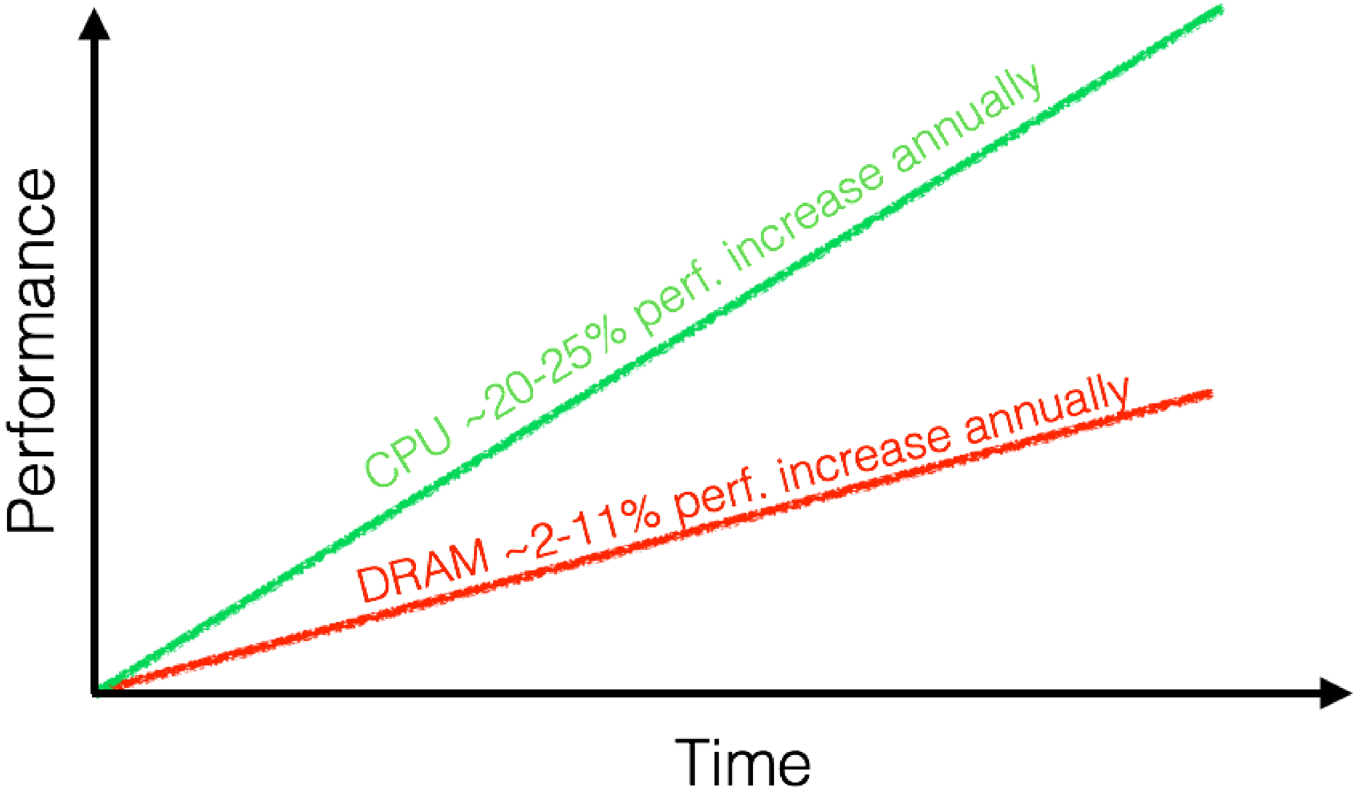
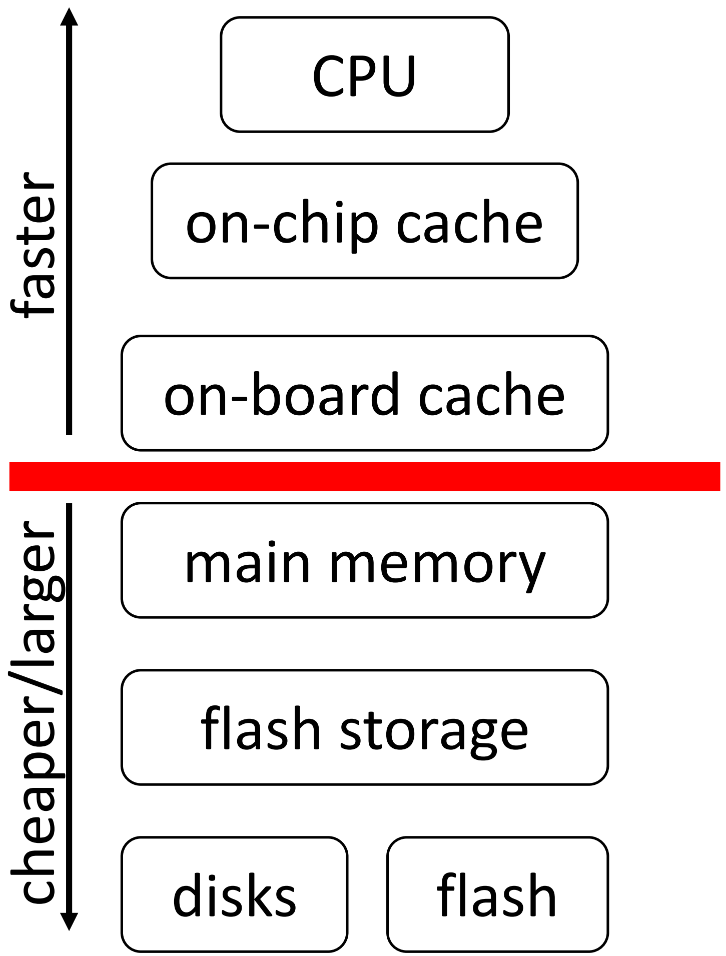
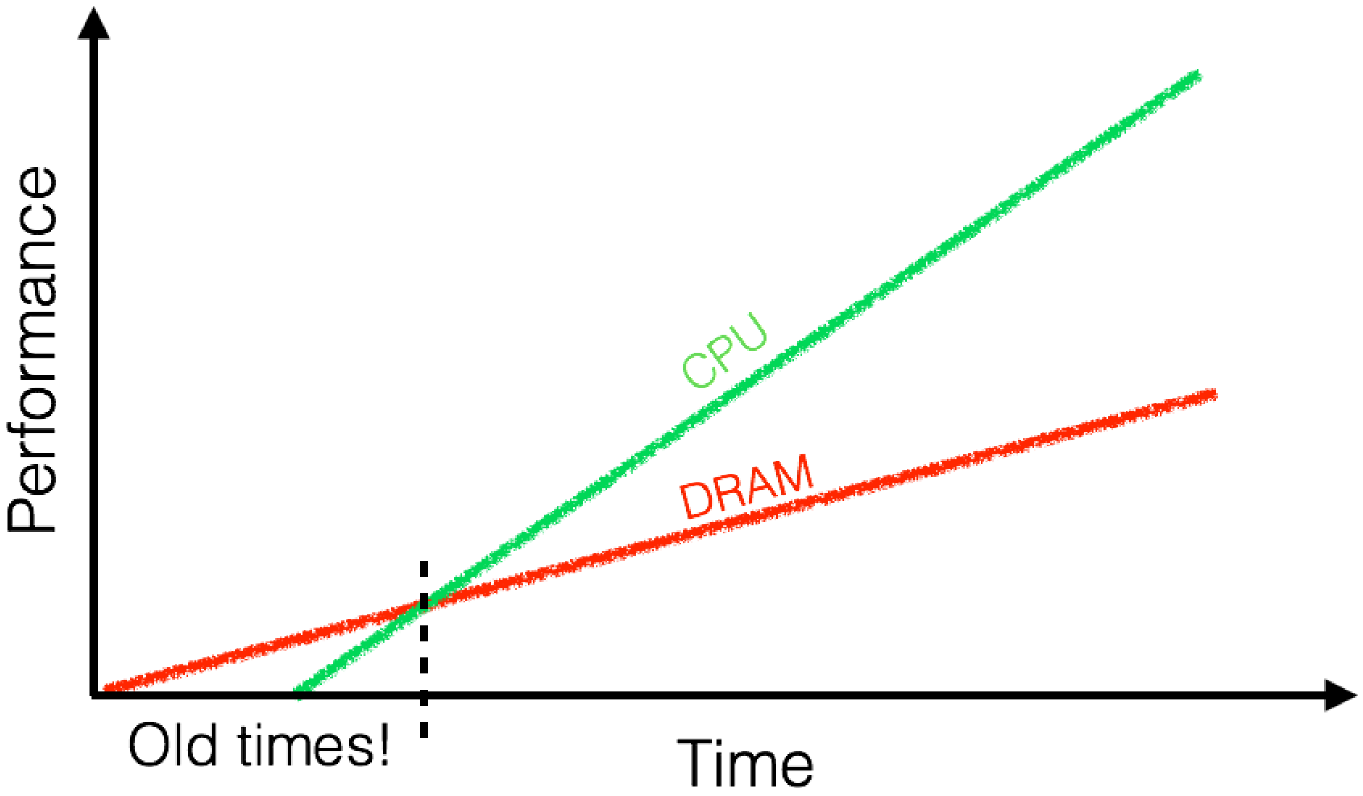
# memory wall


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

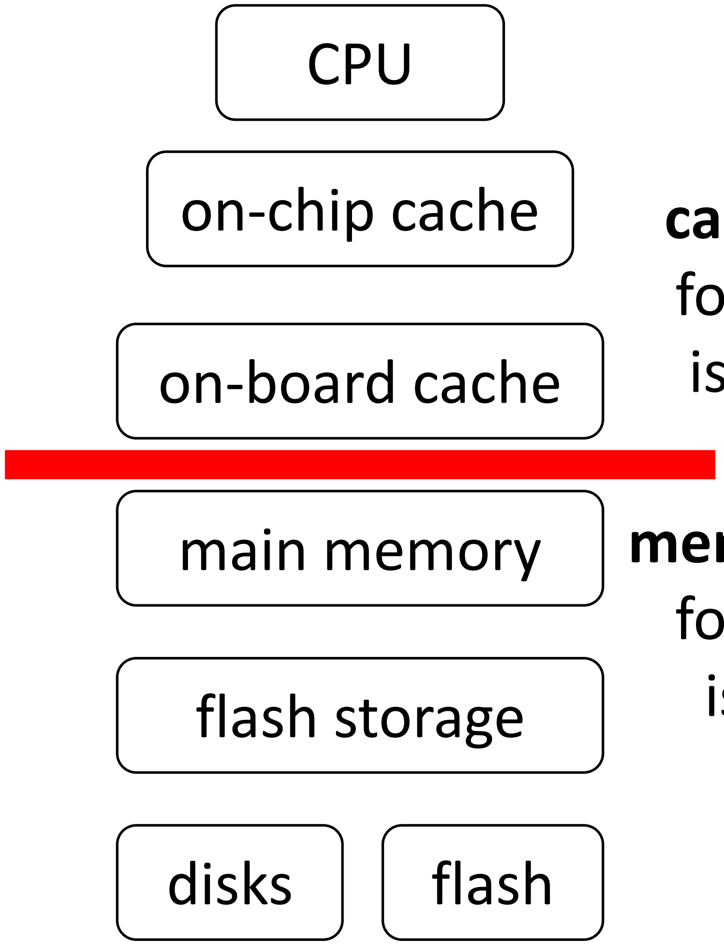

Performance
Time
CPU ~20-25% perf. increase annually
DRAM ~2-11% perf. increase annually

# 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




**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 from NBC

need to read only X
read the whole page

X page

# data movement

CPU

on-chip cache

on-board cache

main memory

flash storage

data go through
all necessary levels

also read
***unnecessary*** data

photo from NBC

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

$ 40 bytes

# page-based access & random access

**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 | 10, 11, 6, 14, 15 |

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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

$ 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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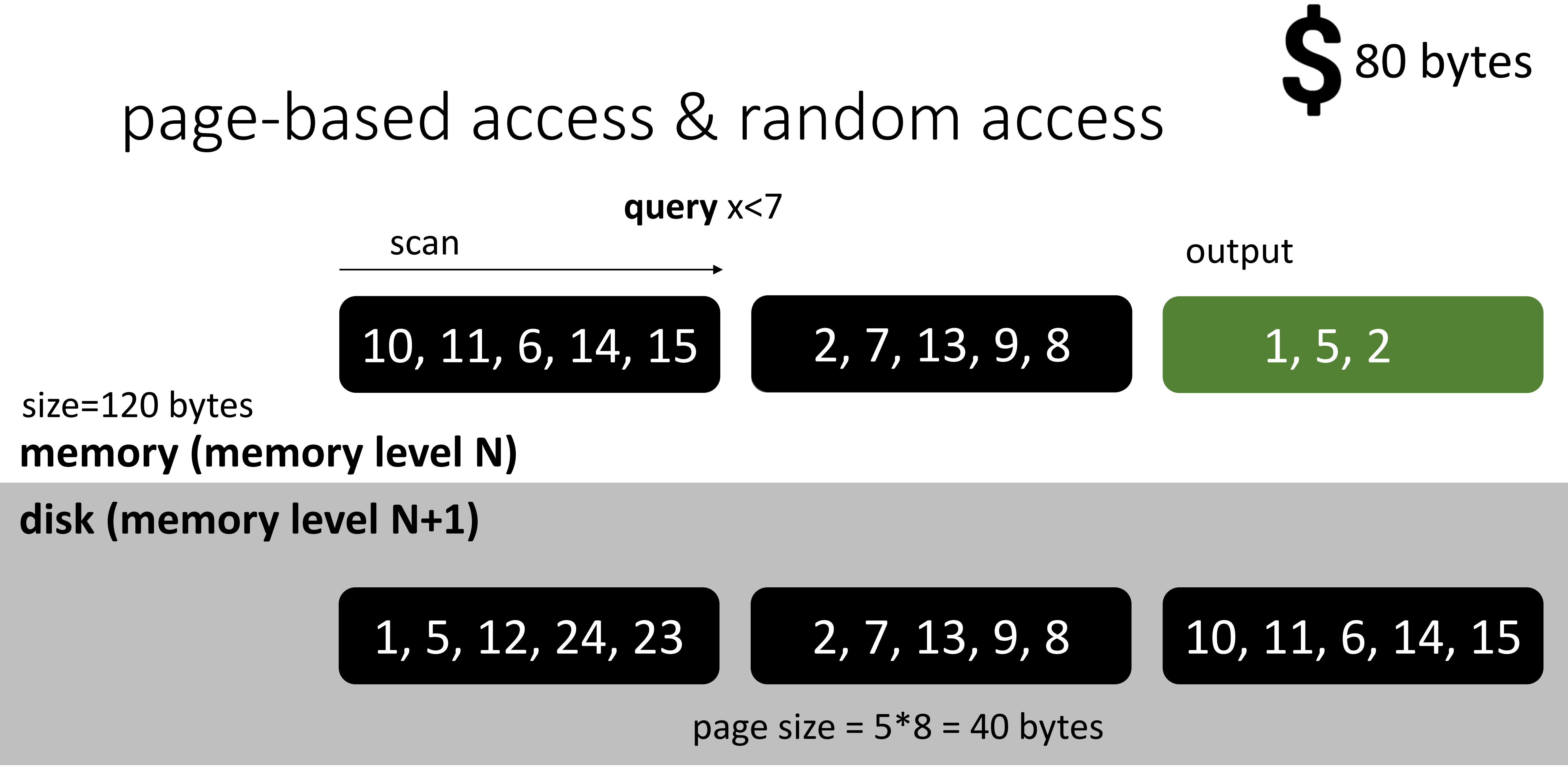


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# page-based access & random access

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scan →

output

10, 11, 6, 14, 15

2, 7, 13, 9, 8

1, 5, 2, 6

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1, 5, 12, 24, 23

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10, 11, 6, 14, 15

page size = 5*8 = 40 bytes

# what if we had an oracle (perfect index)?

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# 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

# page-based access & random access

$ 40 bytes

**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

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page size = 5*8 = 40 bytes

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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

# 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 (classes 5,6)

every **byte** counts

overheads and tradeoffs (classes 11,12)

know the **query**

access path selection (class 10)

index
design space

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# 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)

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# 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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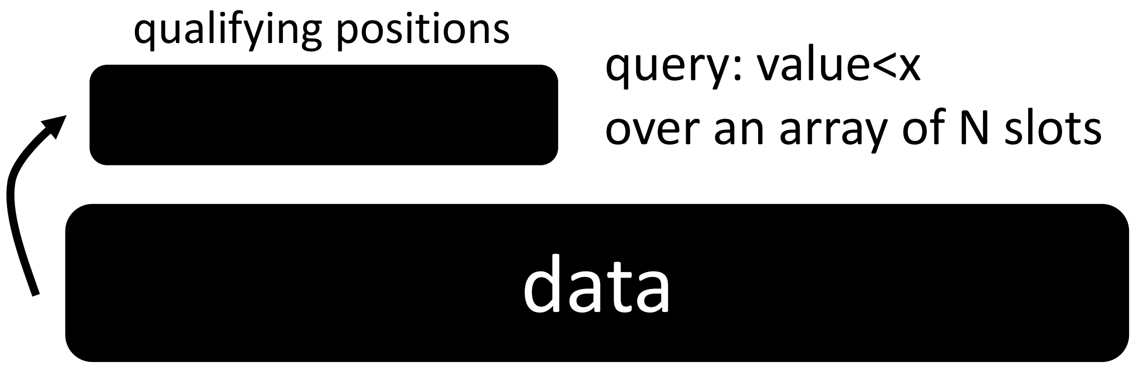
how to implement it?

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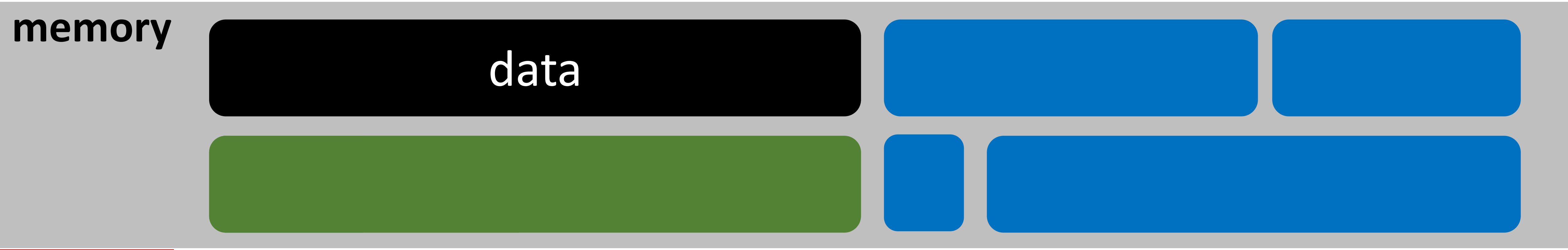
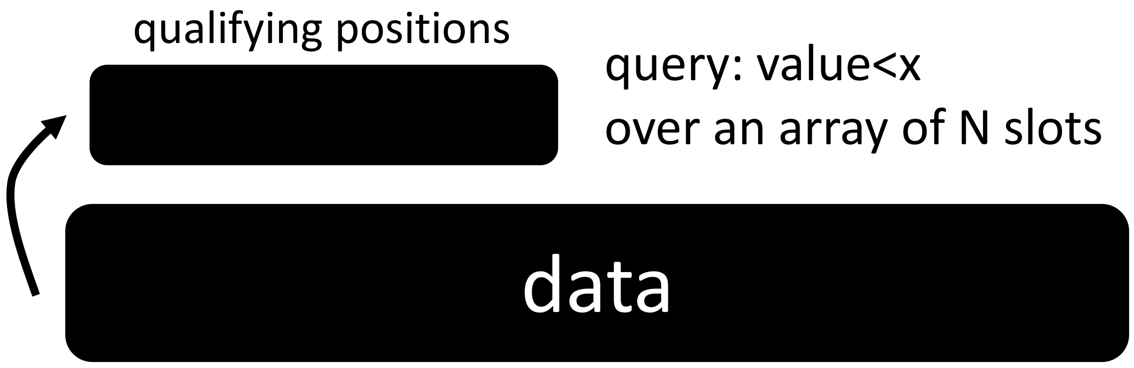


how to implement it?

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

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




**what if 99% qualifies?**

how can we know?

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

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

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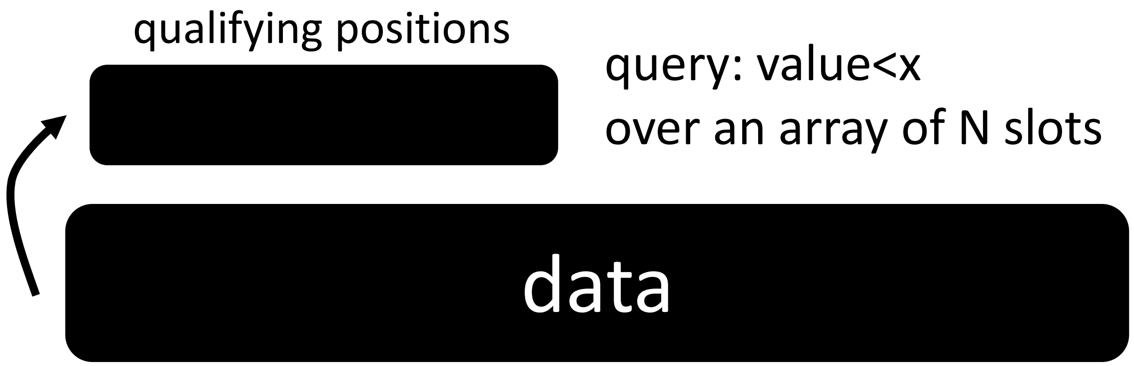
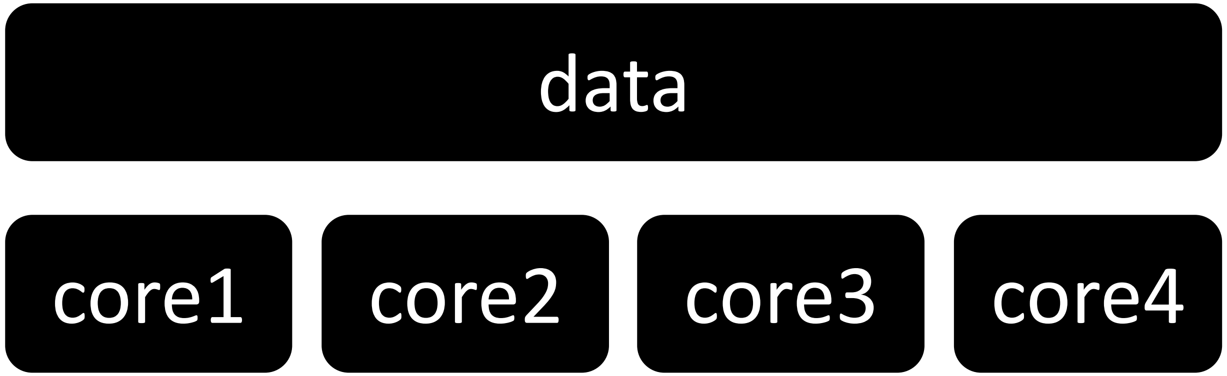



```
result = new array[data.size];
j=0;
for (i=0; i<data.size; i++)
    if (data[i]<x)
        result[j++]=i;
```

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




needs coordination!
what about result writing?

# 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;
```

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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**

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# 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 (**now!**)
E) start submitting paper reviews (week 3)
F) go over the project (end of this week will be available)
G) start working on the mid-semester report (week 3)

# survival guide

**class website:** http://manos.athanassoulis.net/classes/CS591/

**piazza website:** http://piazza.com/bu/spring2019/cs591a1/

**gradescope entry-code:** MR7ZD4

**office hours:** Manos (Tu/Th, 2-3pm), Subhadeep (M/W 2-3pm)

**material:** papers available from BU network

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# CS 591: Data Systems Architectures

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class 2

# Data Systems 101

**next week:** modern main-memory data systems & semester project