BOSTON UNIVERSITY

CS 561: Data Systems Architectures

class 2

Data Systems 101

Prof. Manos Athanassoulis

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

some reminders

no smartphones

no laptop

class summary

2 classes per week & OH/Labs 5 days per week

each student

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

project 0 (individual project) + project 1 (group project)

systems or research project (group project)

proposal + mid-semester report + final report/presentation

AND

project 0

A small implementation project to sharpen dev skills

independent project

project 1

A project about the two fundamental architectures: row-stores vs. column-stores

groups of 3

OR

systems project

groups of 3

implementation-heavy C/C++ project

research project

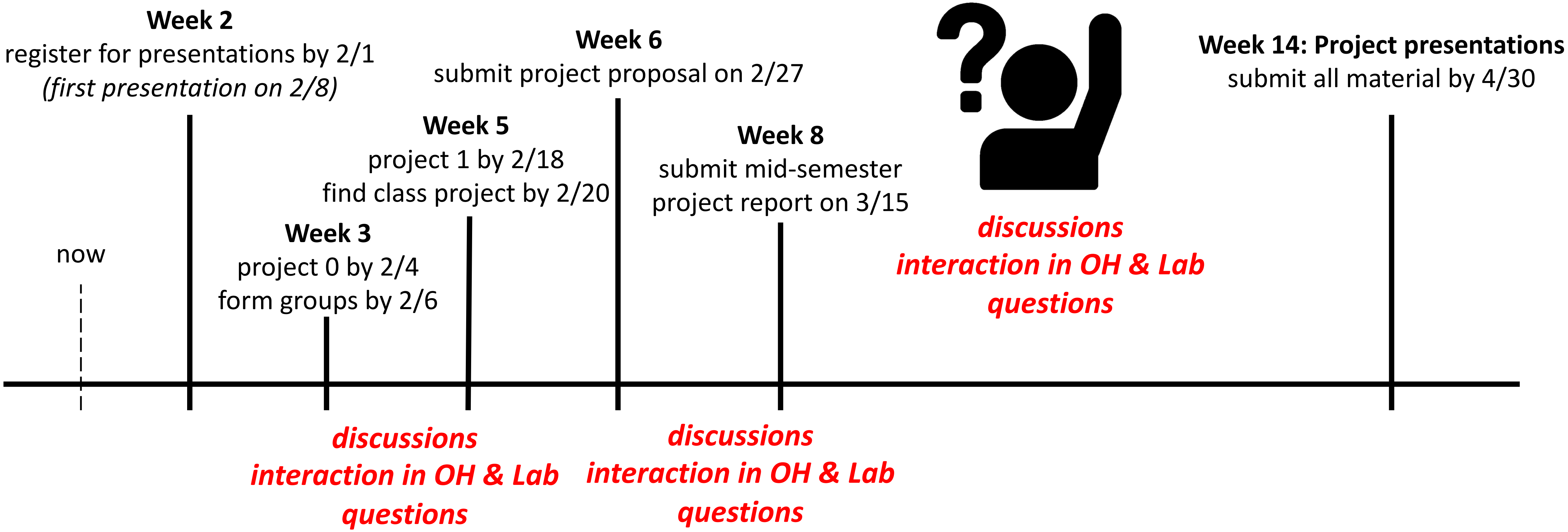
groups of 3

pick a subject (list will be available)

design & analysis

experimentation

class timeline



now

Week 2
register for presentations by 2/1
(first presentation on 2/8)

Week 3
project 0 by 2/4
form groups by 2/6

discussions
interaction in OH & Lab
questions

Week 5
project 1 by 2/18
find class project by 2/20

Week 6
submit project proposal on 2/27

discussions
interaction in OH & Lab
questions

Week 8
submit mid-semester
project report on 3/15

discussions
interaction in OH & Lab
questions

Week 14: Project presentations
submit all material by 4/30

Piazza

all discussions & announcements

http://piazza.com/bu/spring2022/cs561/

also available on class website

I have added everyone who already registered!

Please double-check!

big data

(it’s not only about size)

size (volume)

rate (velocity)

sources (variety)

The 3 V’s

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

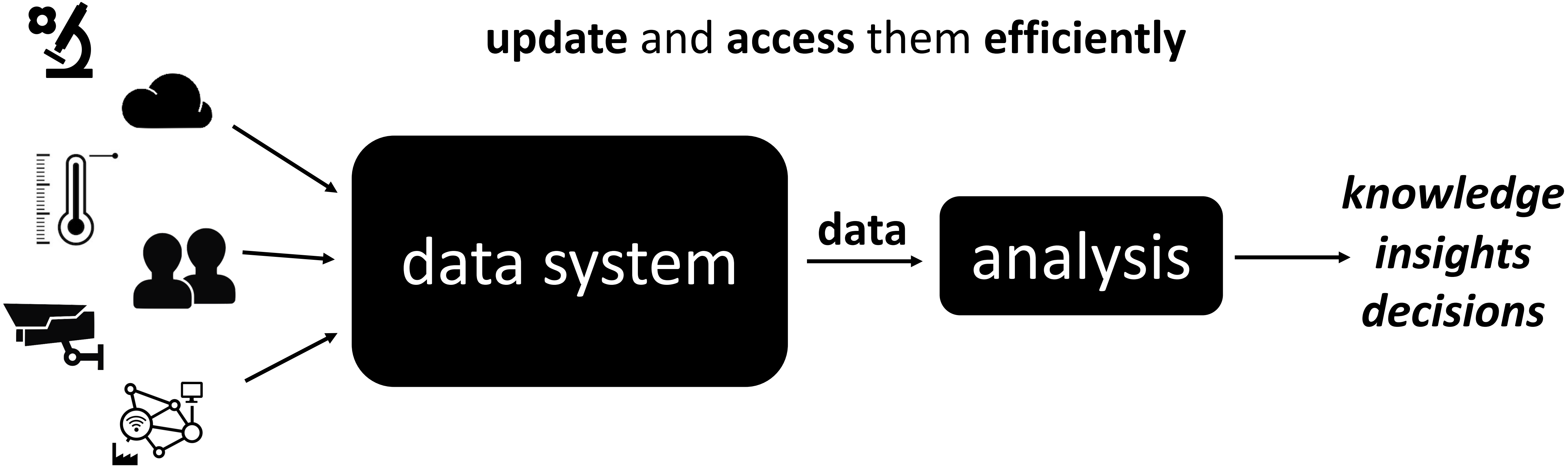
scientific experiments

sensors

social

Internet-of-Things

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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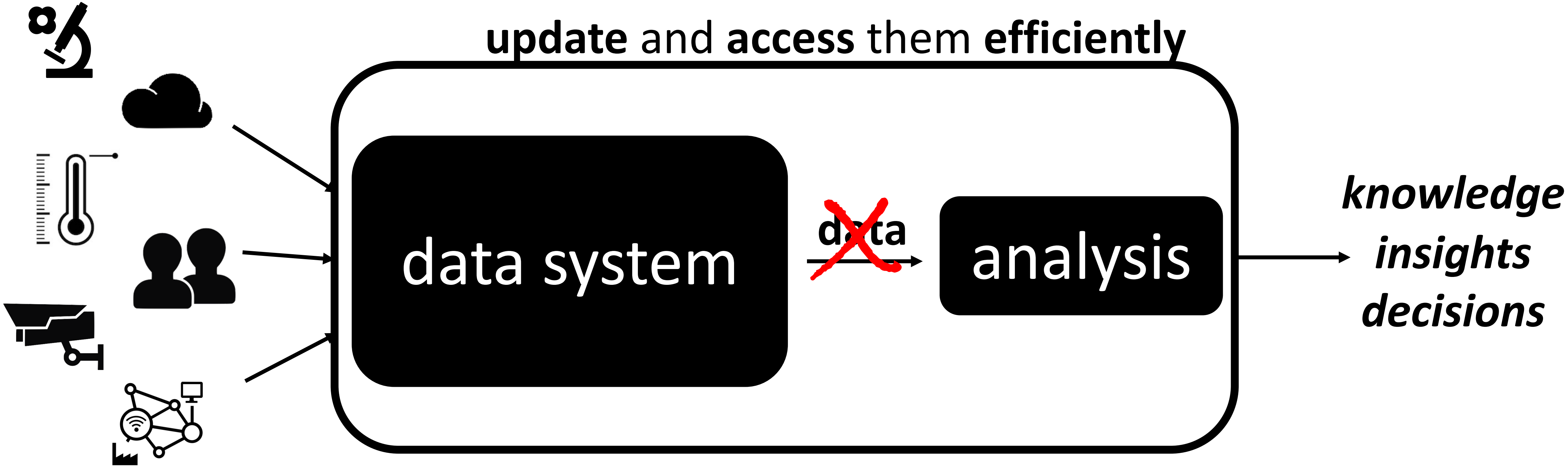

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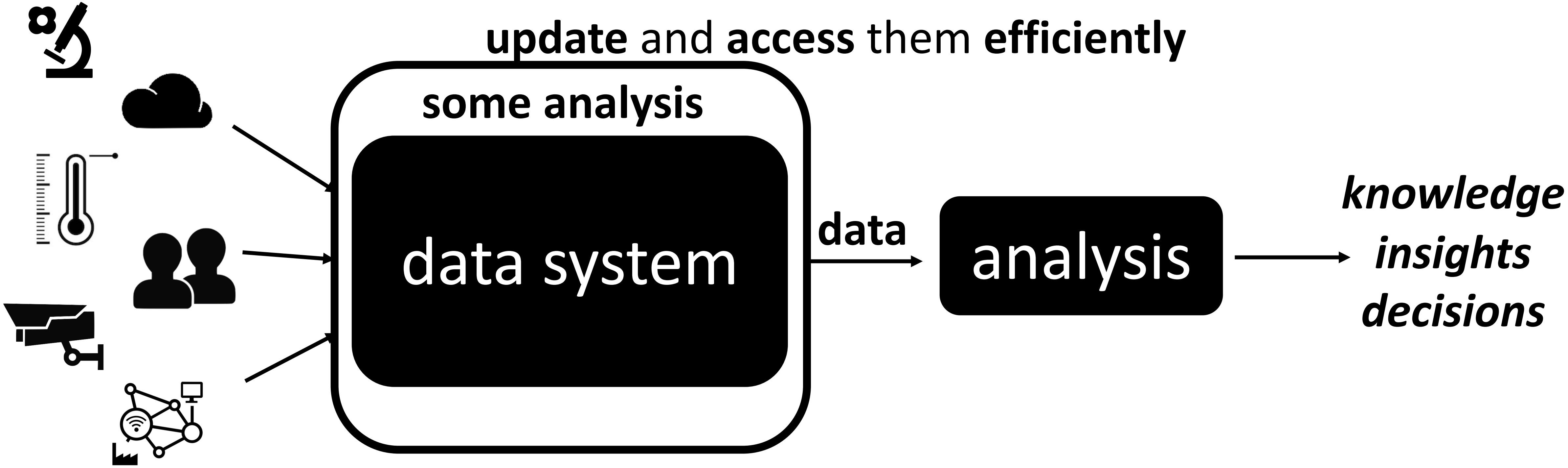
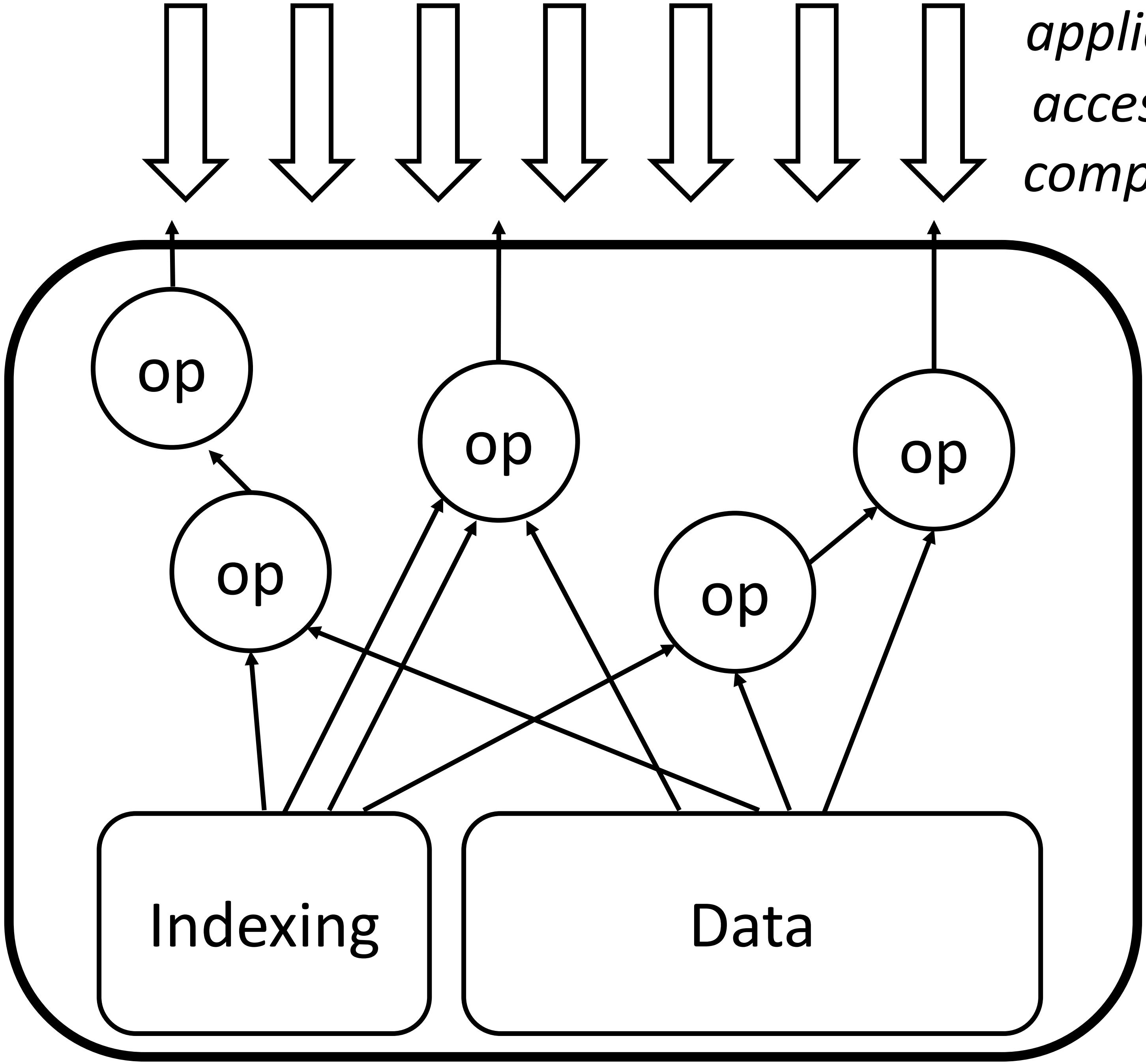
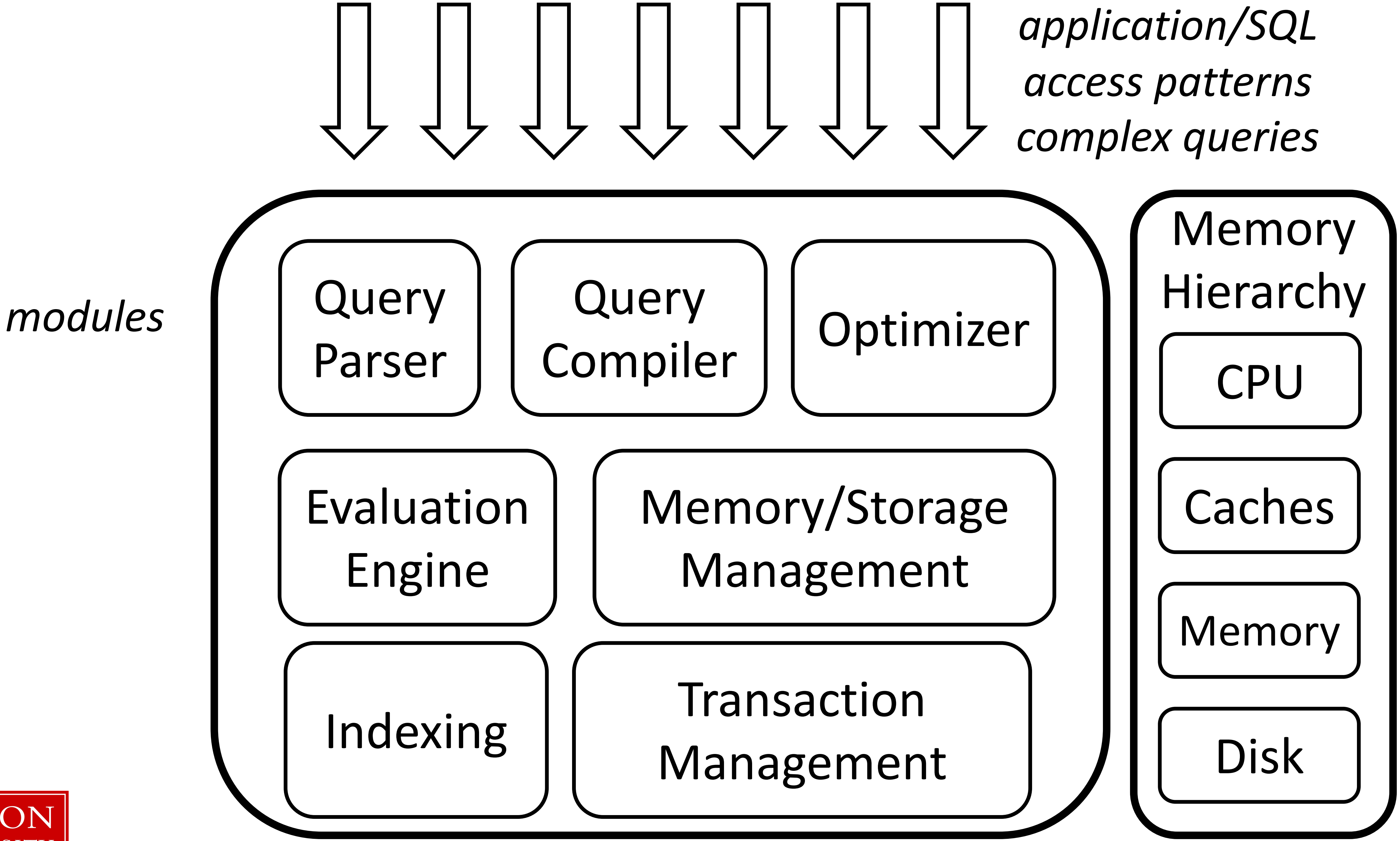


data system, what’s inside?

application/SQL
access patterns
complex queries

algorithms
and
operators





application/SQL
access patterns
complex queries

modules

Query Parser

Query Compiler

Optimizer

Evaluation Engine

Memory/Storage Management

Indexing

Transaction Management

Memory Hierarchy

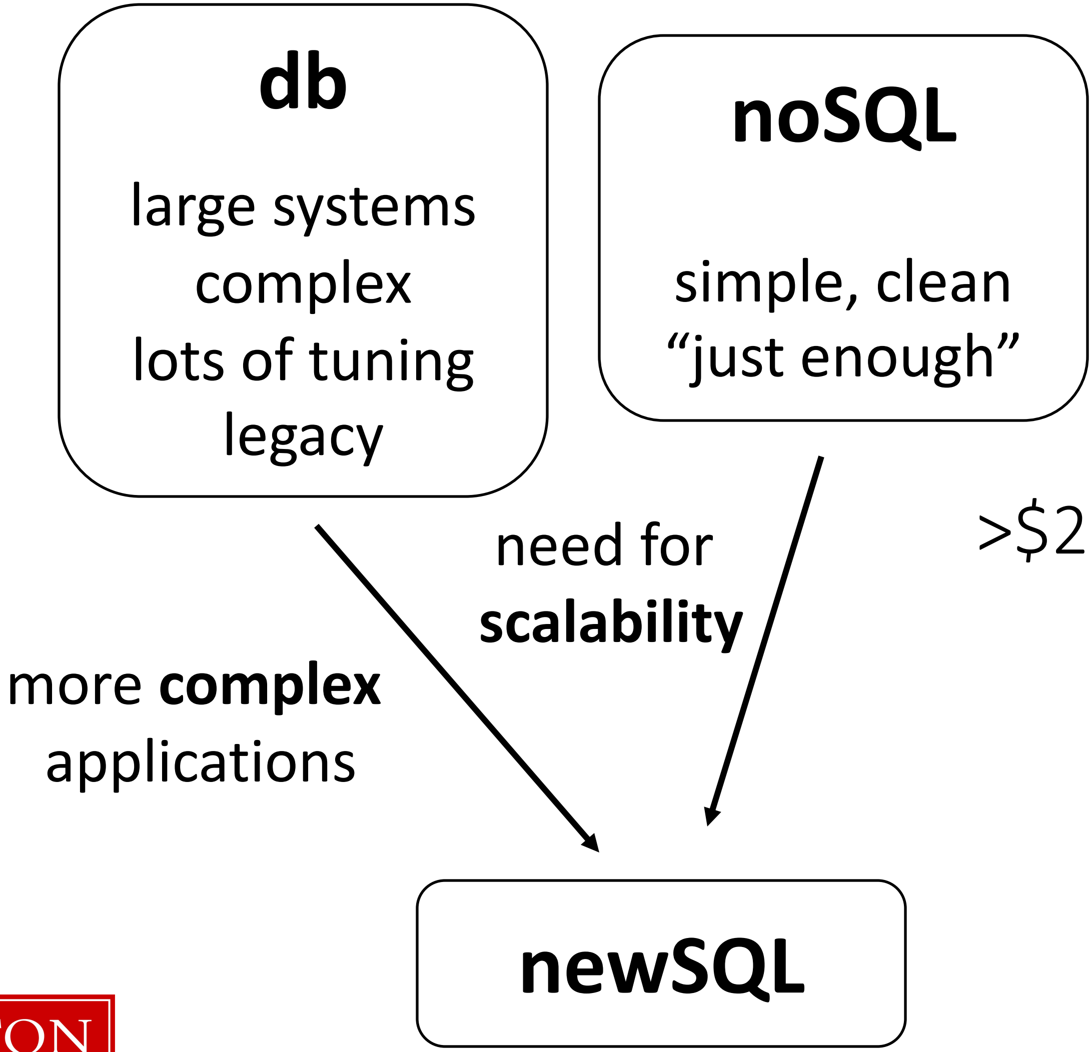
CPU

Caches

Memory

Disk

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]

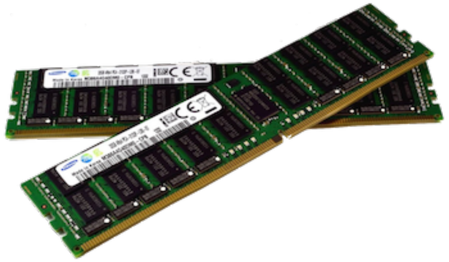
$3B by 2020, growing at 20% every year

[Forrester, 2016]

growing need for tailored systems

new applications

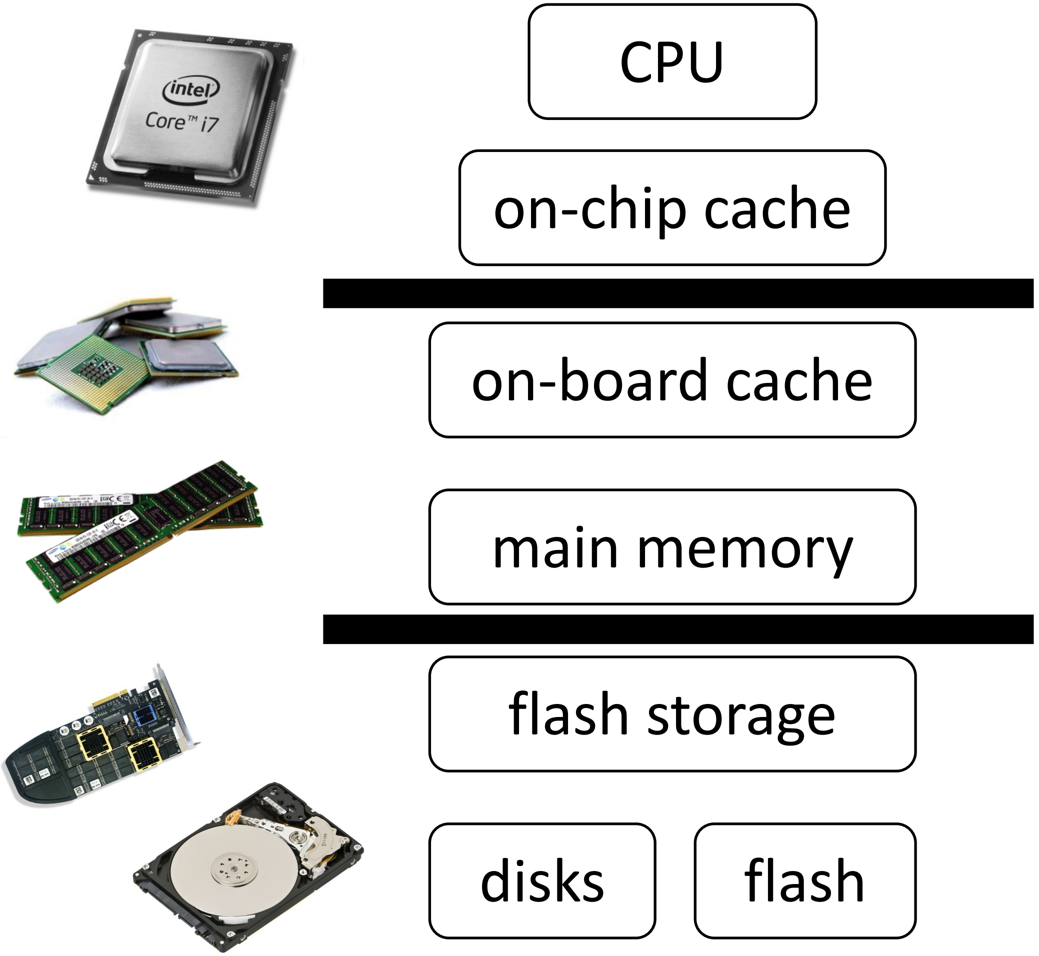
new hardware



more data

data system, what’s underneath?

memory hierarchy



CPU

on-chip cache

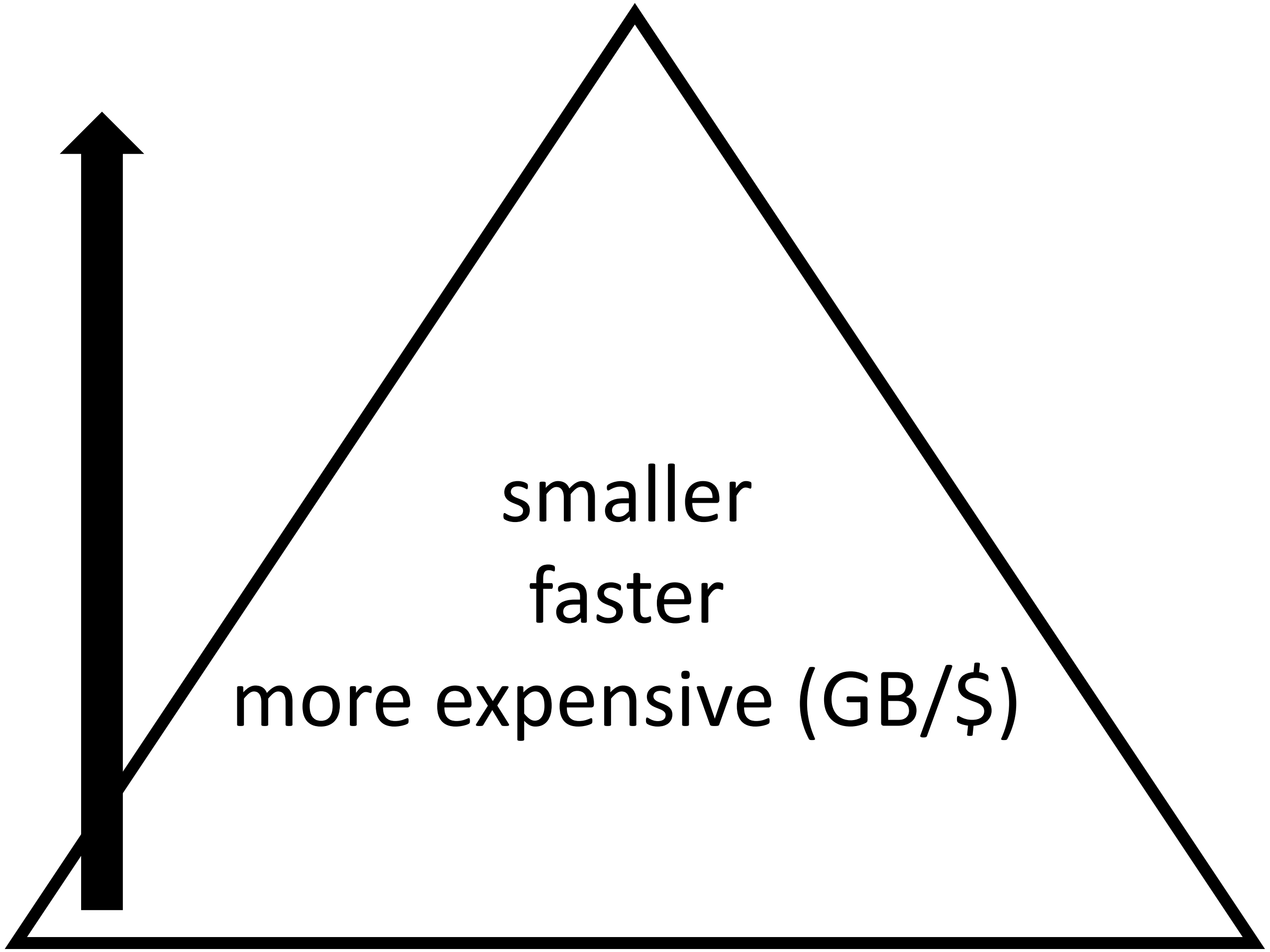
on-board cache

main memory

flash storage

disks

flash

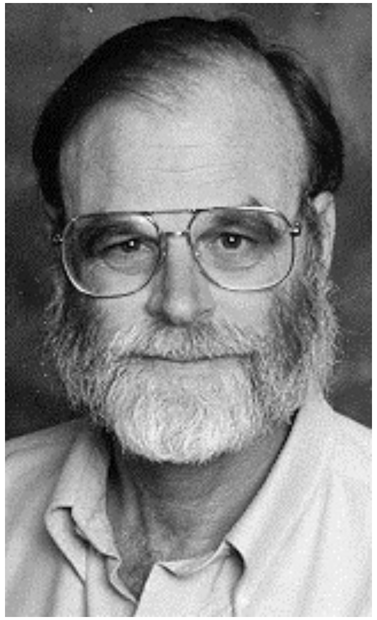


smaller

faster

more expensive (GB/$)

memory hierarchy (by Jim Gray)

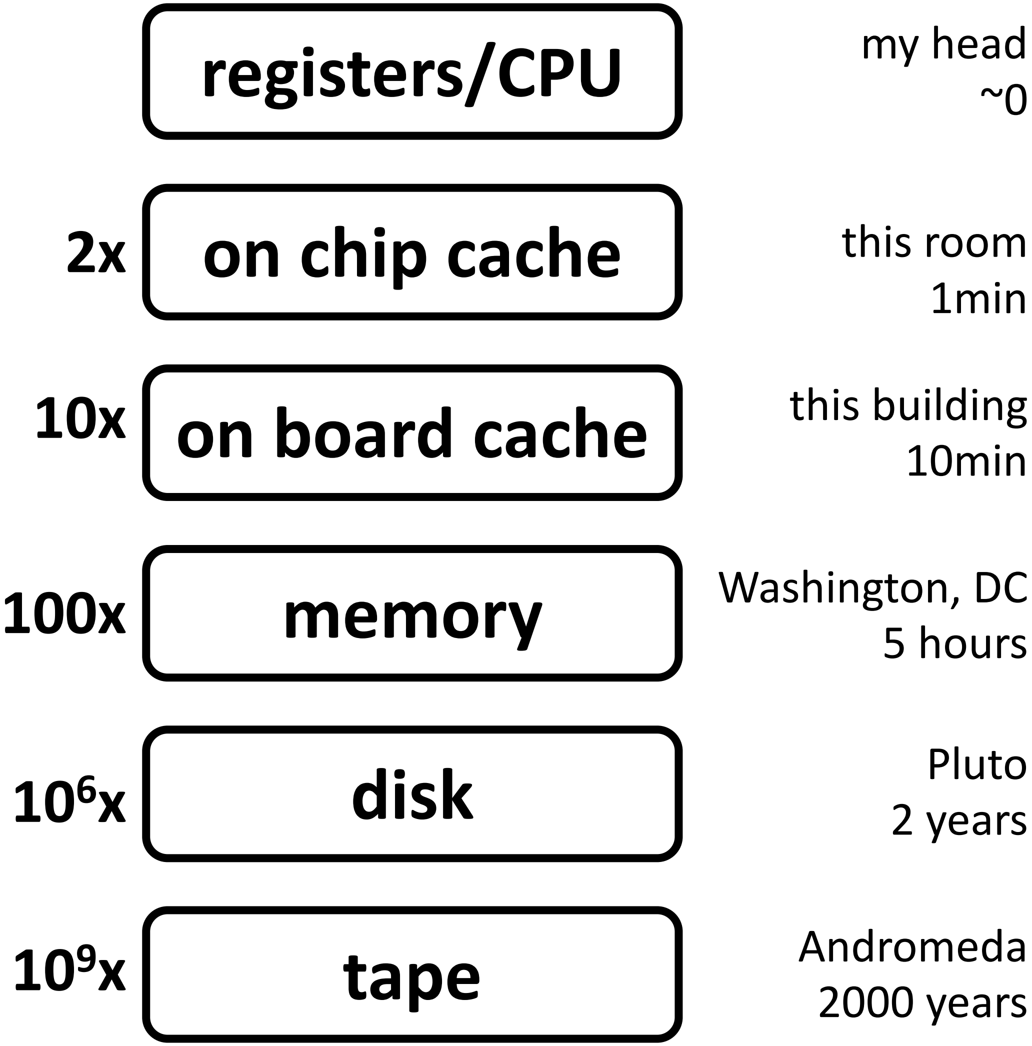


Jim Gray, IBM, Tandem, Microsoft, DEC

“The Fourth Paradigm” is based on his vision

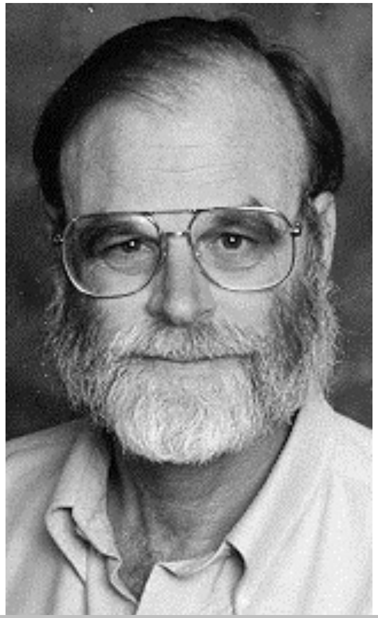
ACM Turing Award 1998

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

memory hierarchy (by Jim Gray)



registers/CPU my head ~0

2x **on chip cache** this room 1min

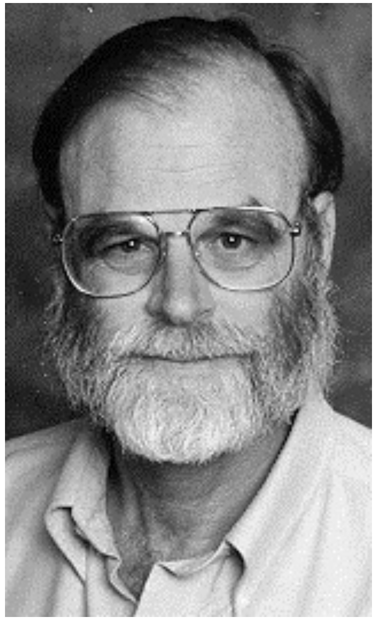
10x **on board cache** this building 10min

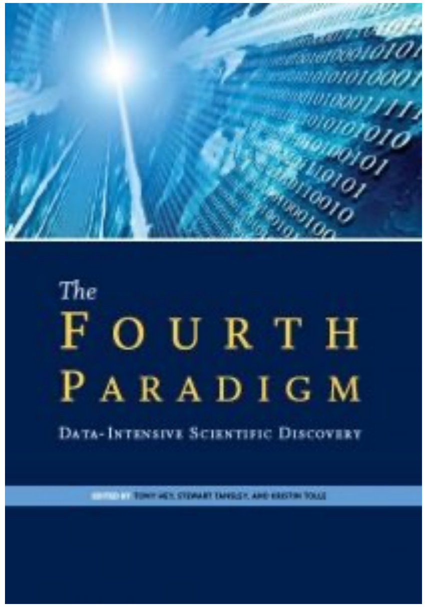
tape?

sequential-only magnetic storage

still a multi-billion industry

Jim Gray (a great scientist and engineer)




The
FOURTH
PARADIGM
DATA-INTENSIVE SCIENTIFIC DISCOVERY
EDITED BY TONY HEY, STEWART TANSLEY, AND KRISTIN TOLLE

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

Jim Gray, IBM, Tandem, Microsoft, DEC
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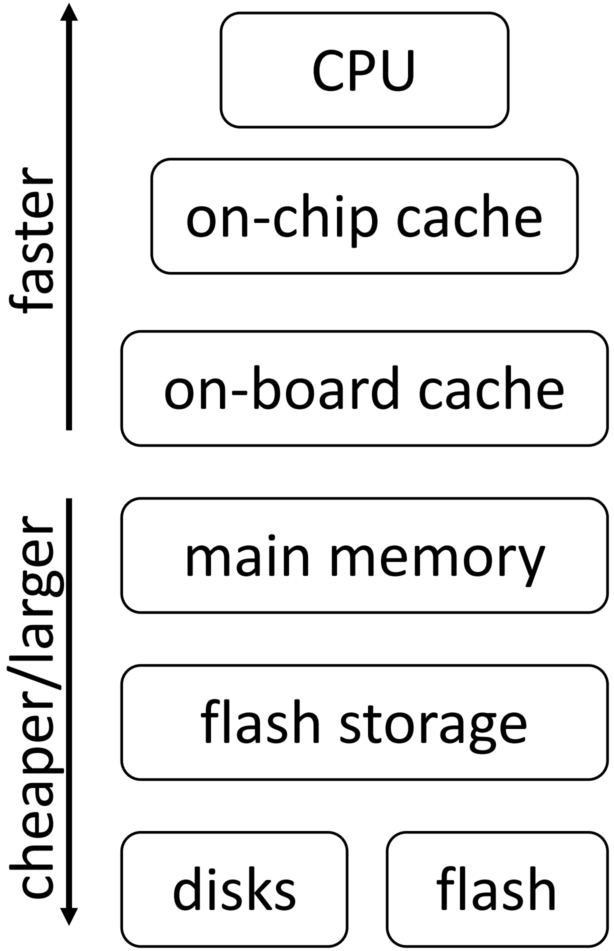
memory wall



faster

cheaper/larger

CPU

on-chip cache

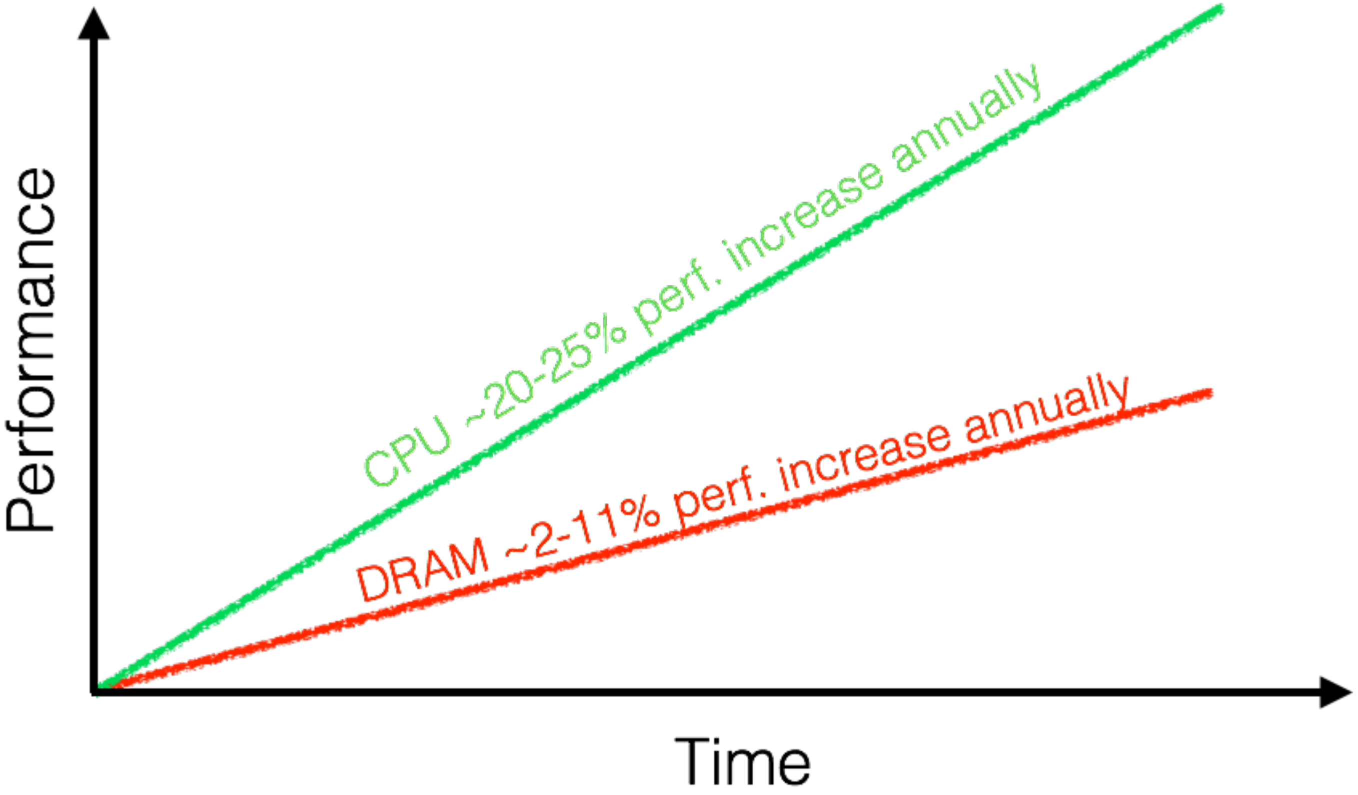
on-board cache

main memory

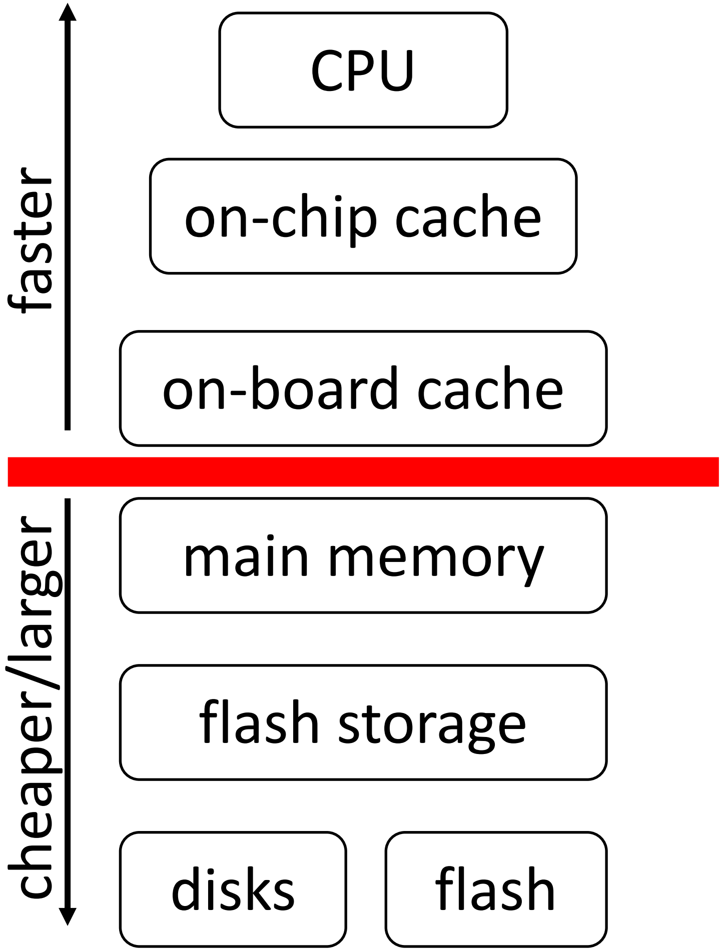
flash storage

disks

flash



memory wall



faster

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on-chip cache

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flash storage

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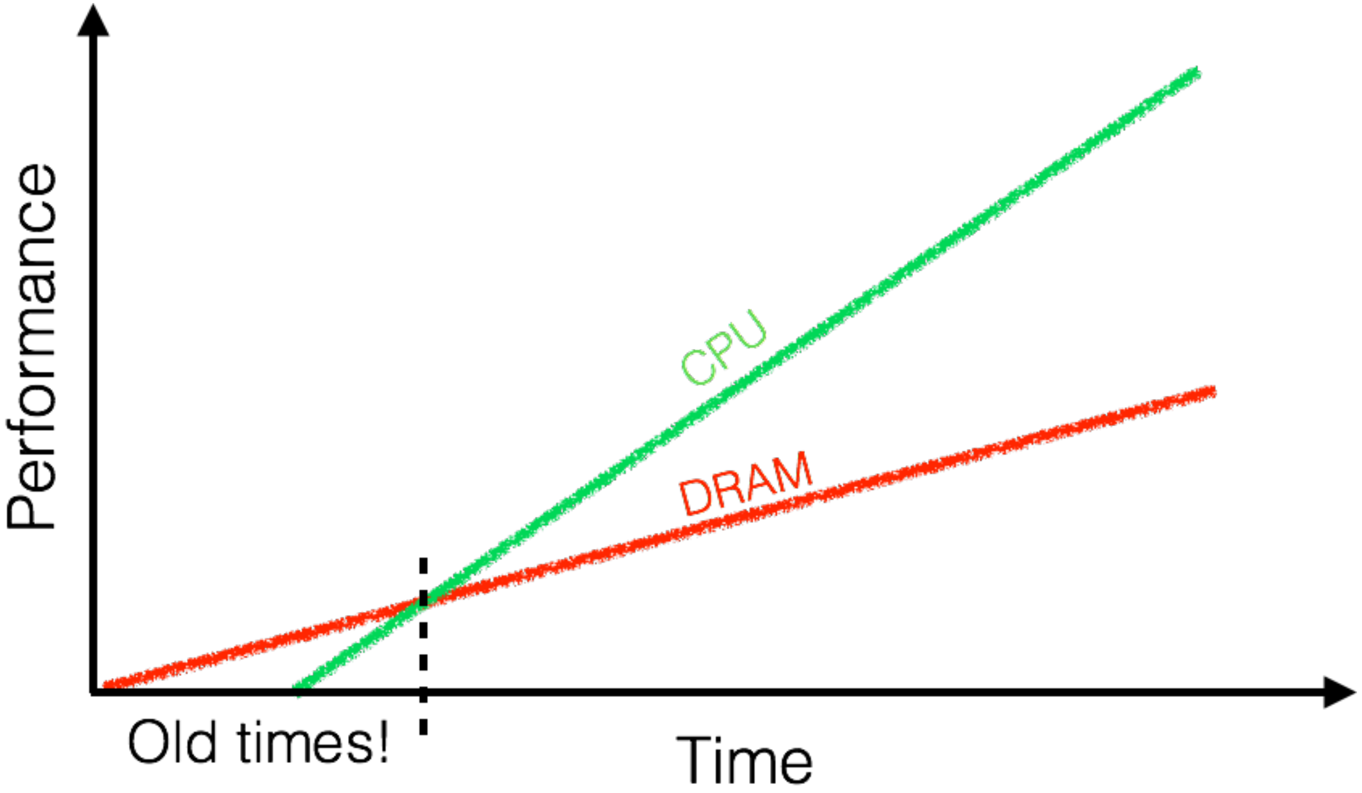
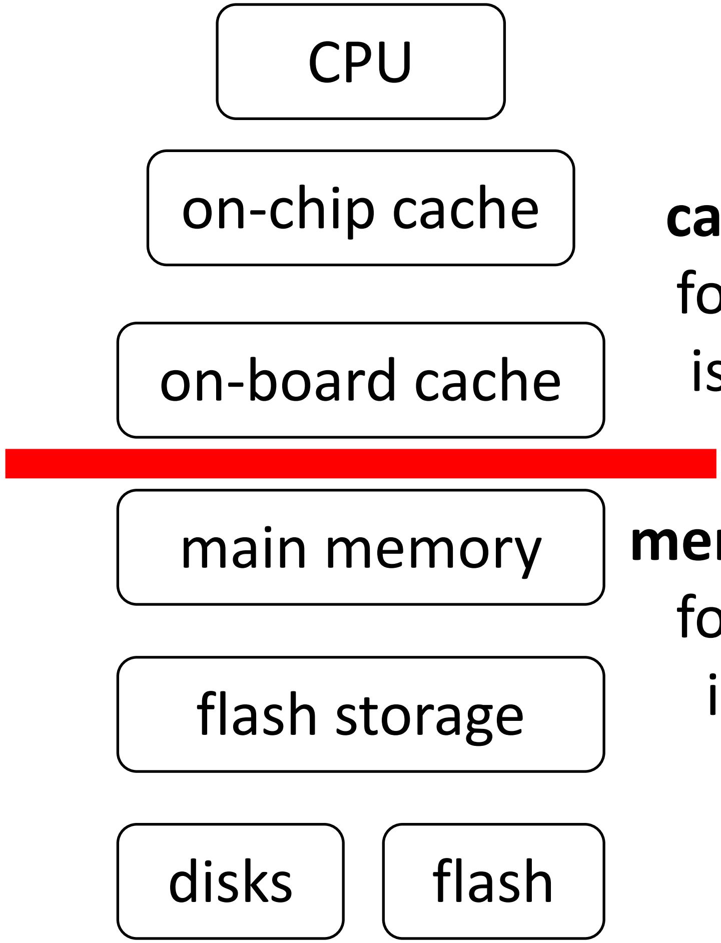
cheaper/larger



cache/memory misses

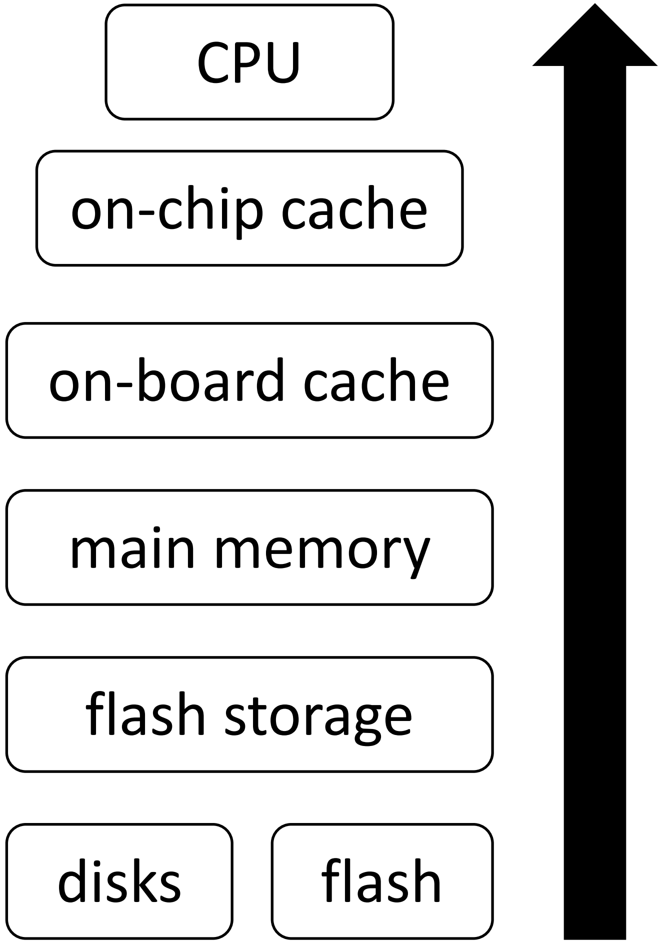


cache miss: looking for something that is not in the cache

memory miss: looking for something that is not in memory

what happens if I miss?

data movement

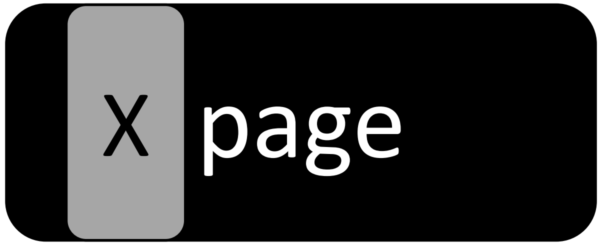


data go through all necessary levels

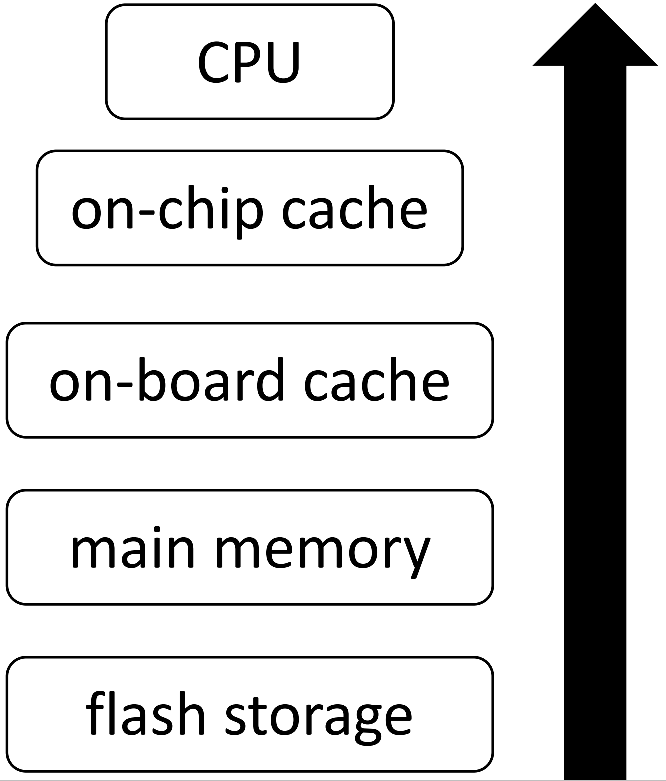
also read ***unnecessary*** data

Photo by Gary Dineen/NBAE via Getty Images

need to read only X
read the whole page



data movement



data go through
all necessary levels

also read
unnecessary data

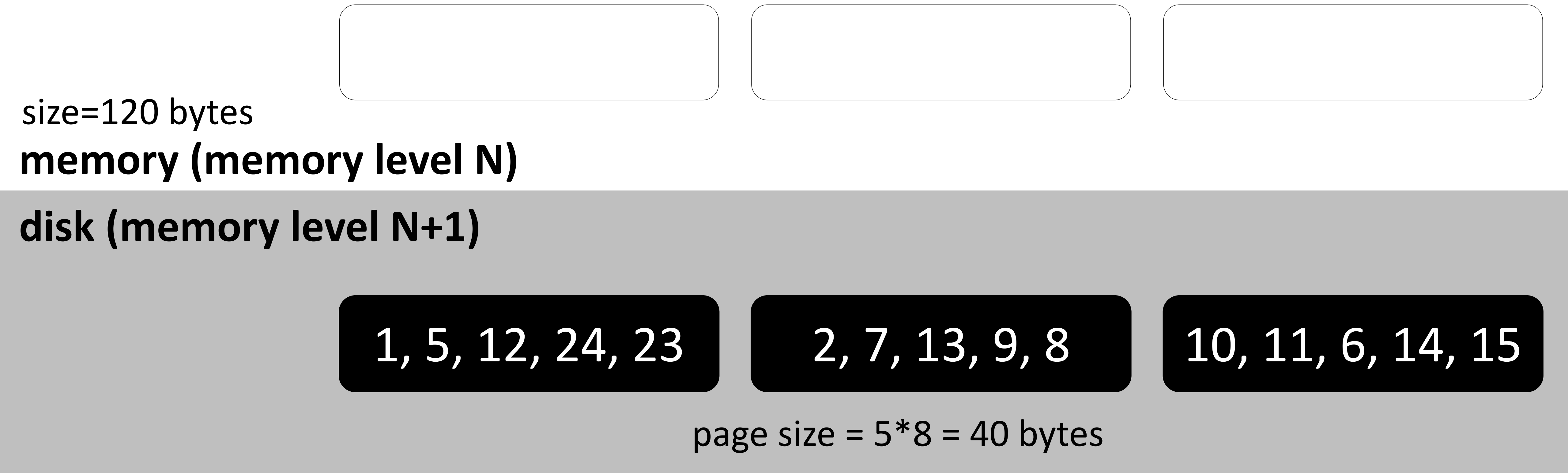
Photo by Gary Dineen/NBAE via Getty Images

need to read only X
read the whole page

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

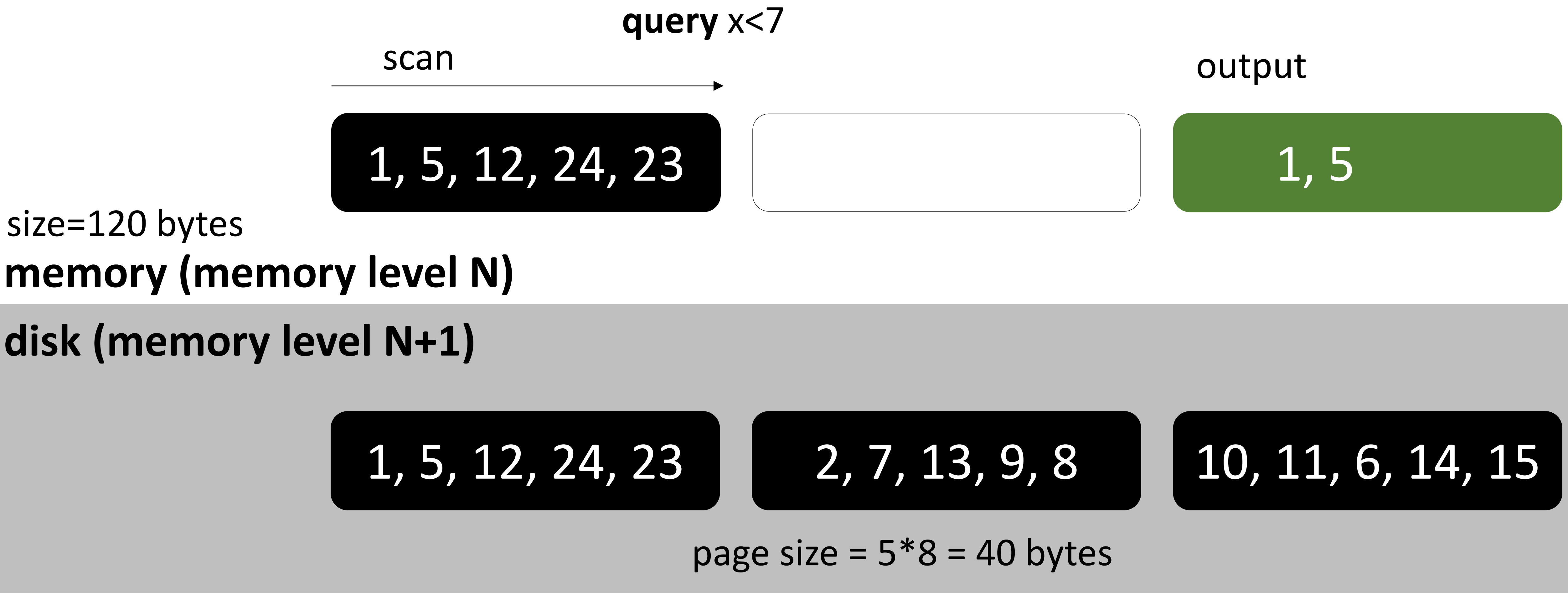
2, 7, 13, 9, 8

10, 11, 6, 14, 15

page size = 5*8 = 40 bytes

page-based access & random access

$ 40 bytes



query x<7

scan

output

1, 5, 12, 24, 23

1, 5

size=120 bytes

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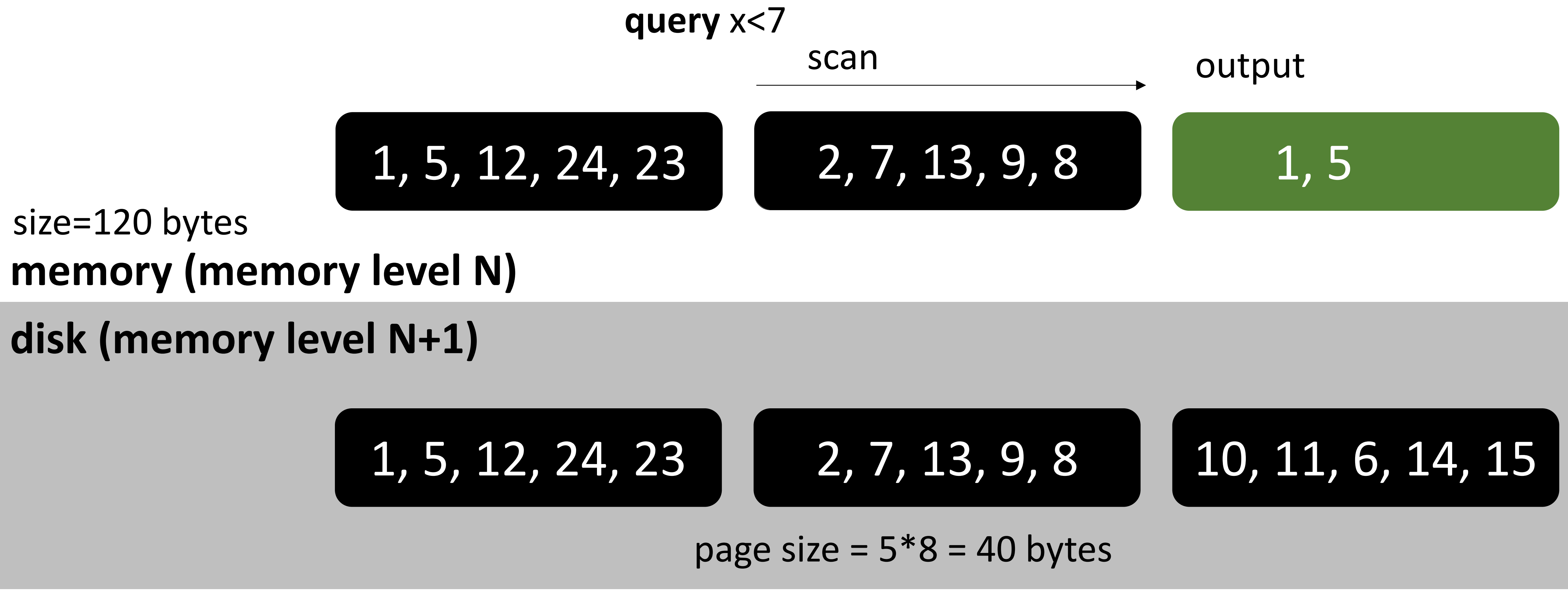

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scan

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2, 7, 13, 9, 8

1, 5

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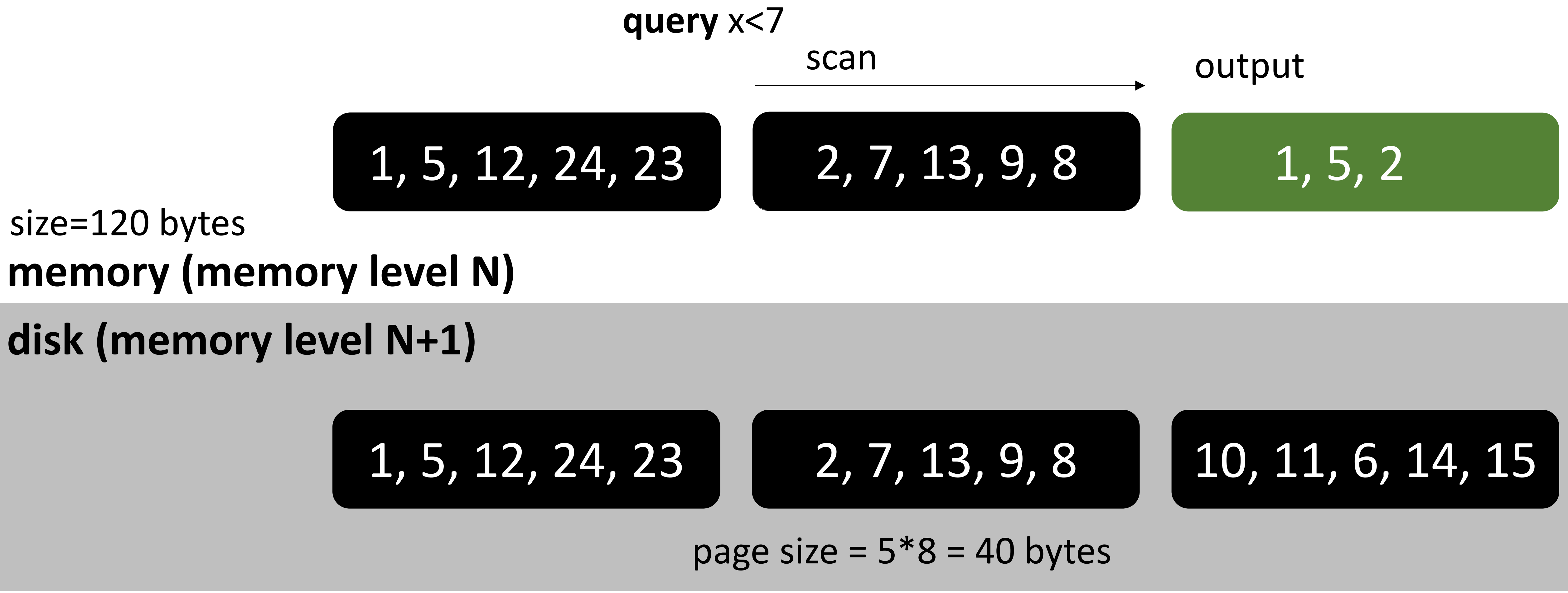


query x<7

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

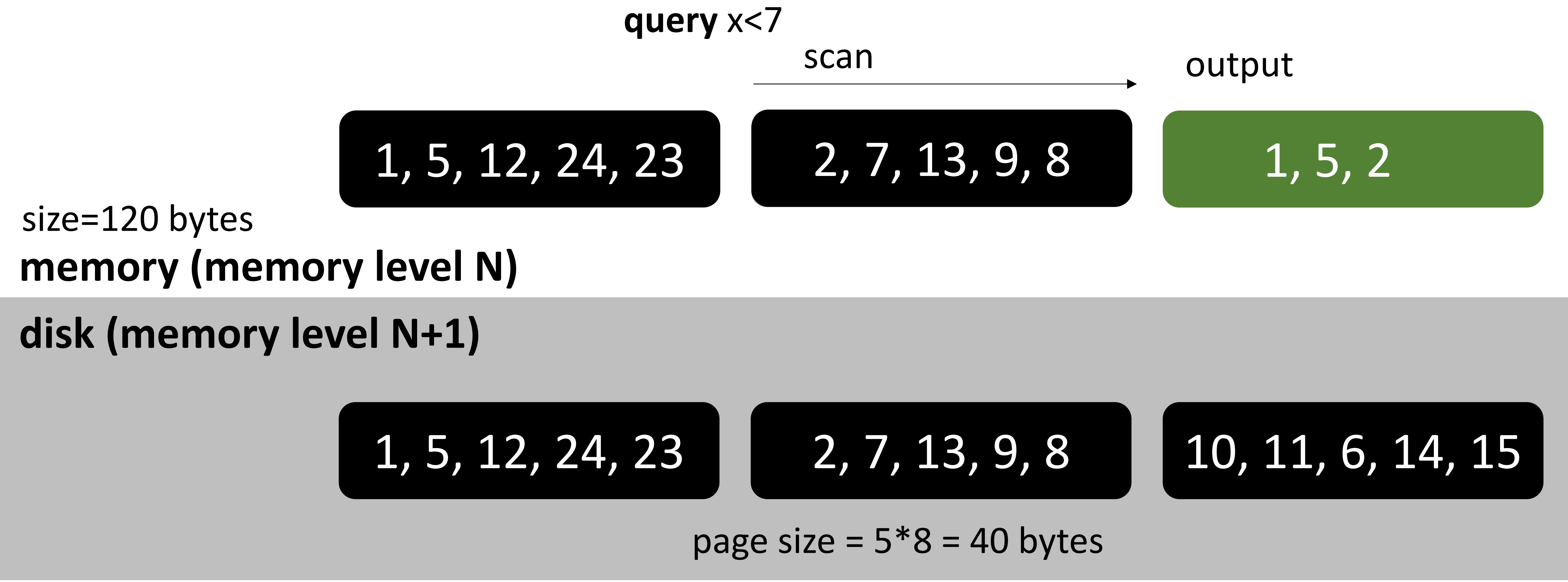
2, 7, 13, 9, 8

10, 11, 6, 14, 15

page size = 5*8 = 40 bytes

$ 80 bytes

page-based access & random access



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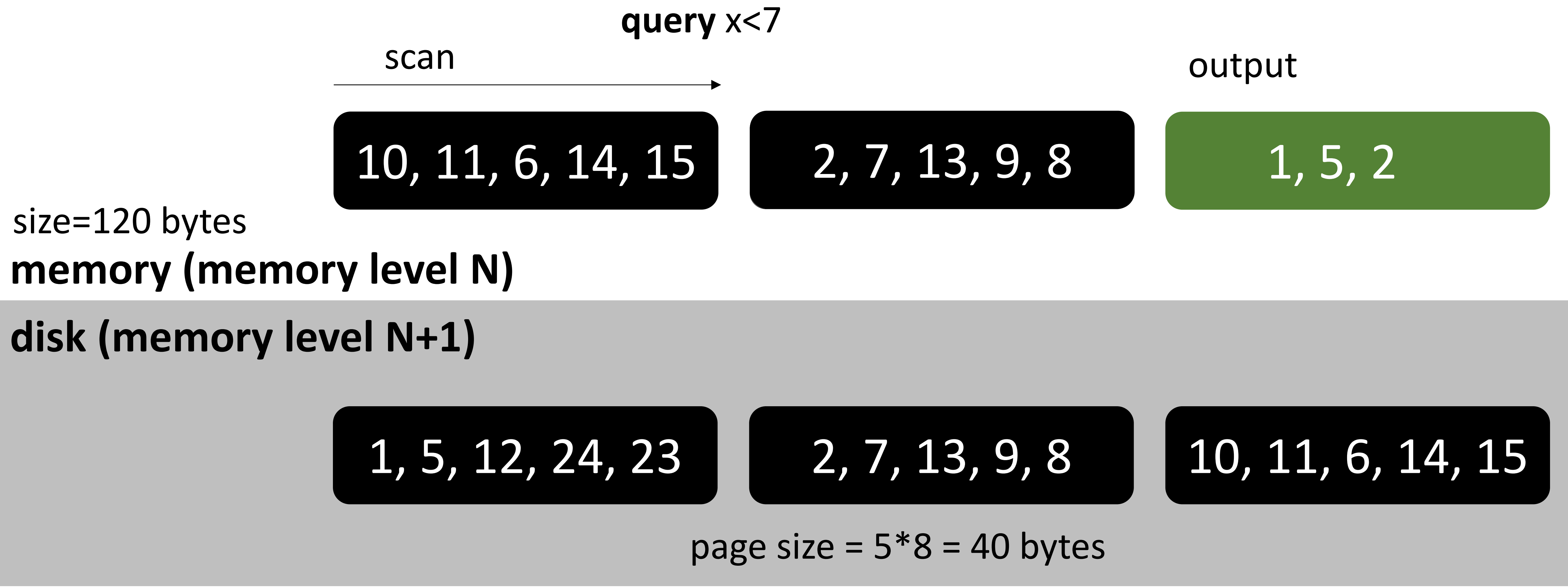

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scan

output

10, 11, 6, 14, 15

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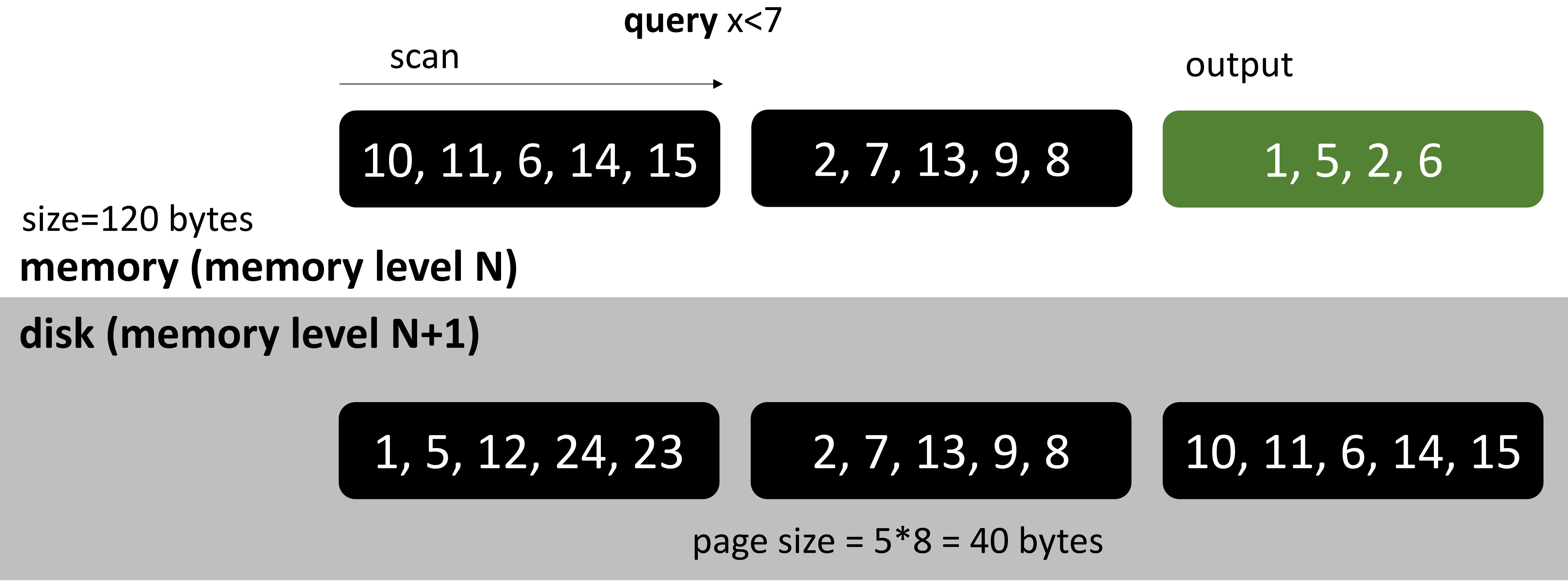

query x<7

scan

output

10, 11, 6, 14, 15

2, 7, 13, 9, 8

1, 5, 2, 6

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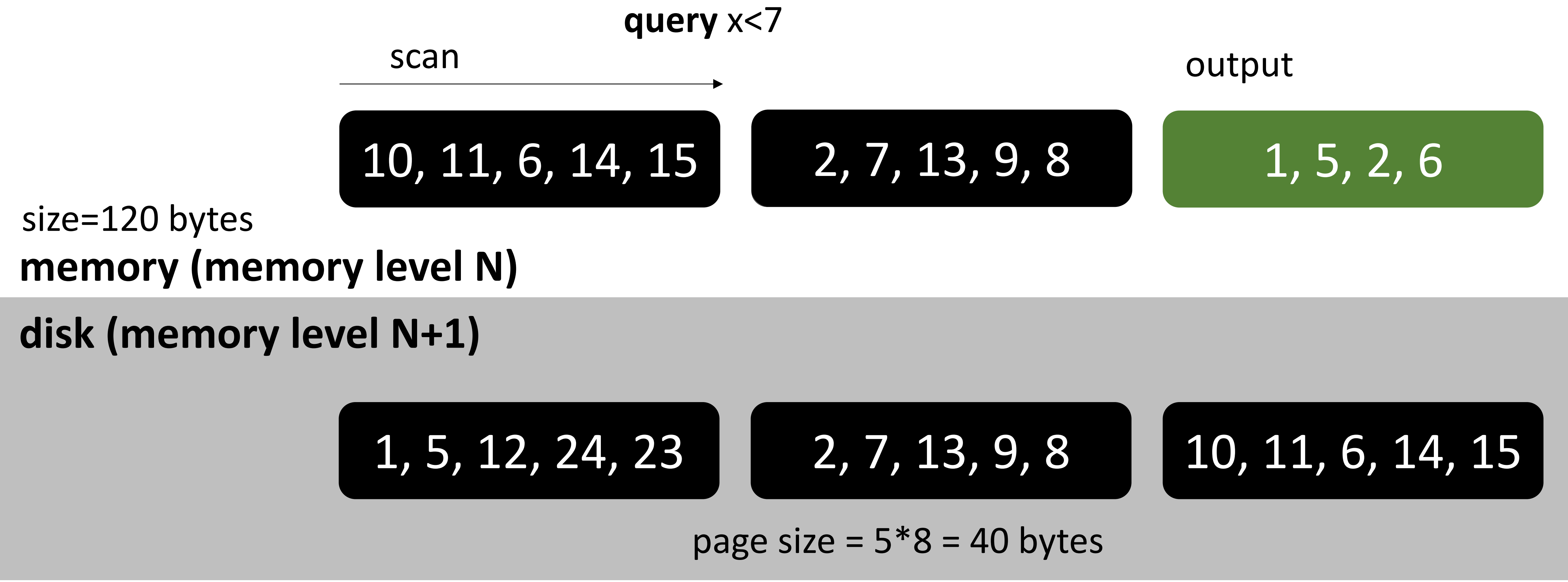

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1, 5, 2, 6

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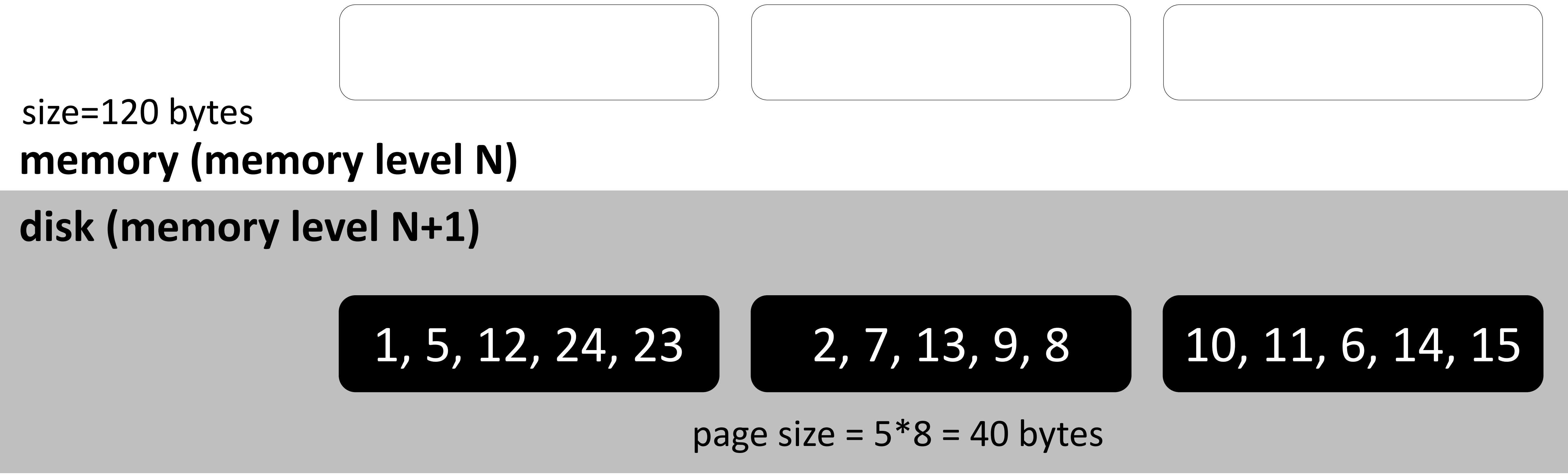
10, 11, 6, 14, 15

page size = 5*8 = 40 bytes

what if we had an oracle (perfect index)?

page-based access & random access

query x<7



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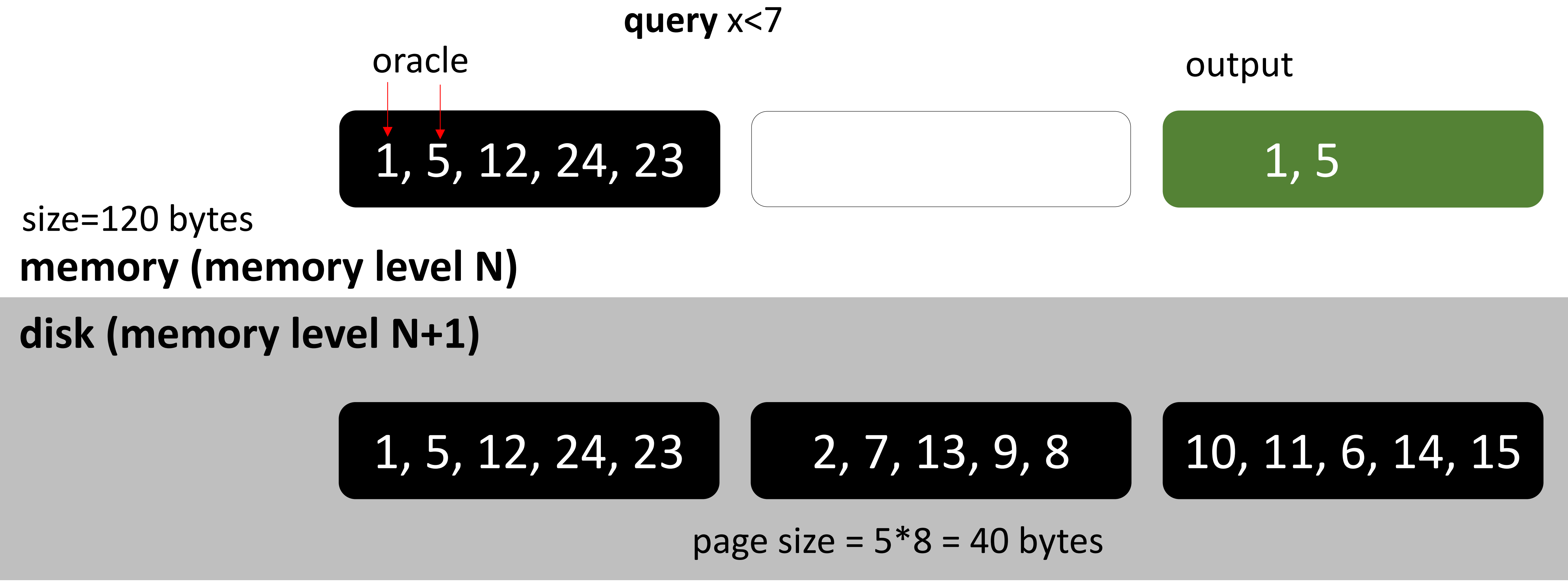
page-based access & random access



query x<7

oracle

1, 5, 12, 24, 23

output

1, 5

size=120 bytes

memory (memory level N)

disk (memory level N+1)

1, 5, 12, 24, 23

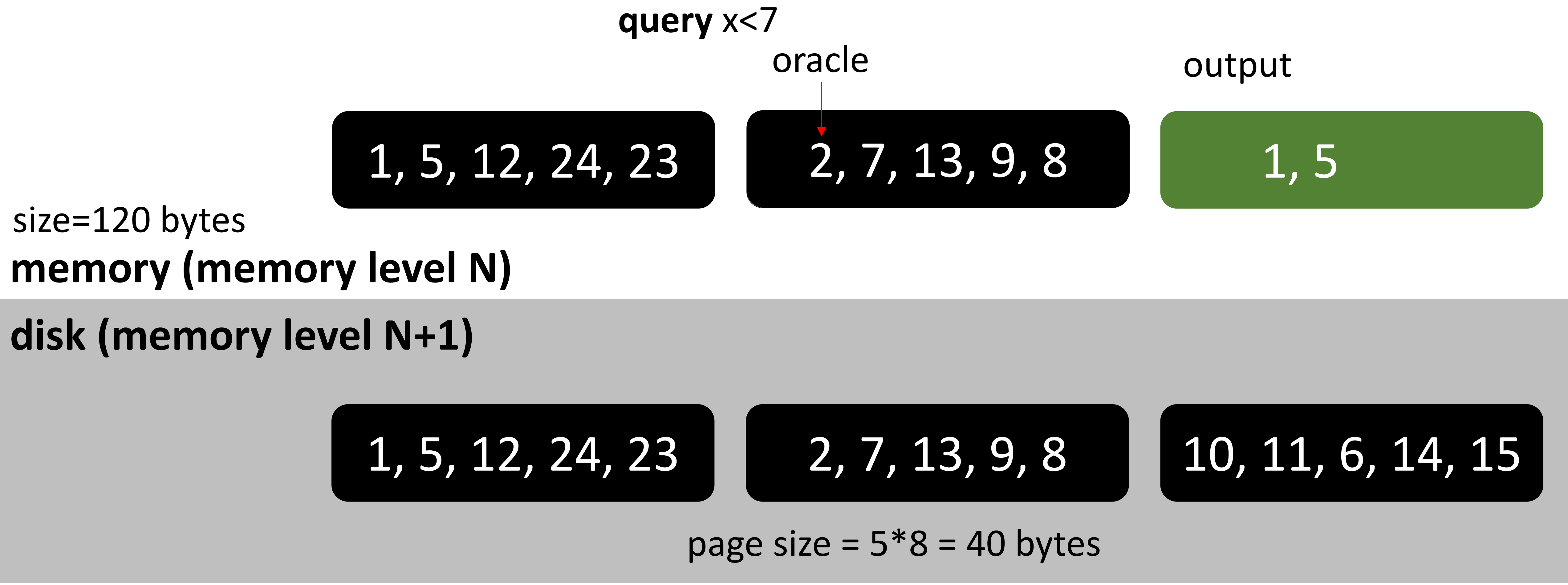
2, 7, 13, 9, 8

10, 11, 6, 14, 15

page size = 5*8 = 40 bytes

$ 40 bytes

page-based access & random access



query x<7

oracle

output

1, 5, 12, 24, 23

2, 7, 13, 9, 8

1, 5

size=120 bytes

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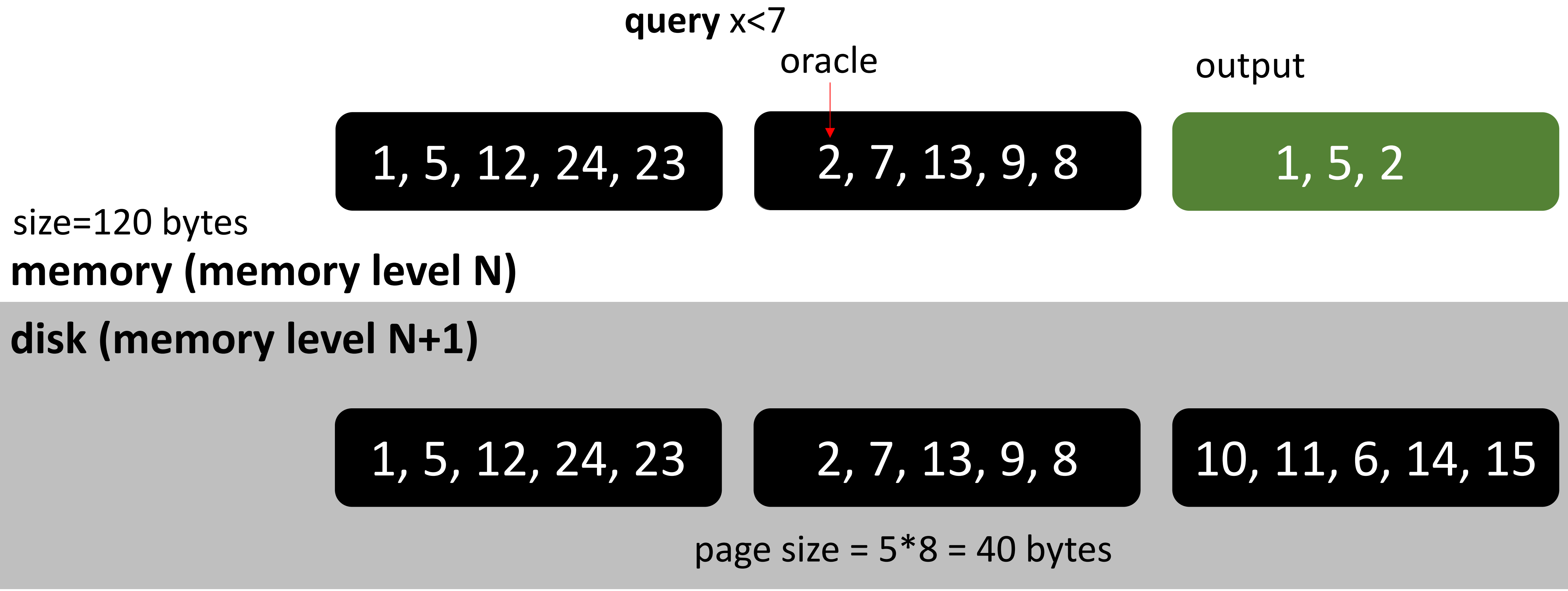
page-based access & random access



query x<7

oracle

output

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2, 7, 13, 9, 8

1, 5, 2

size=120 bytes

memory (memory level N)

disk (memory level N+1)

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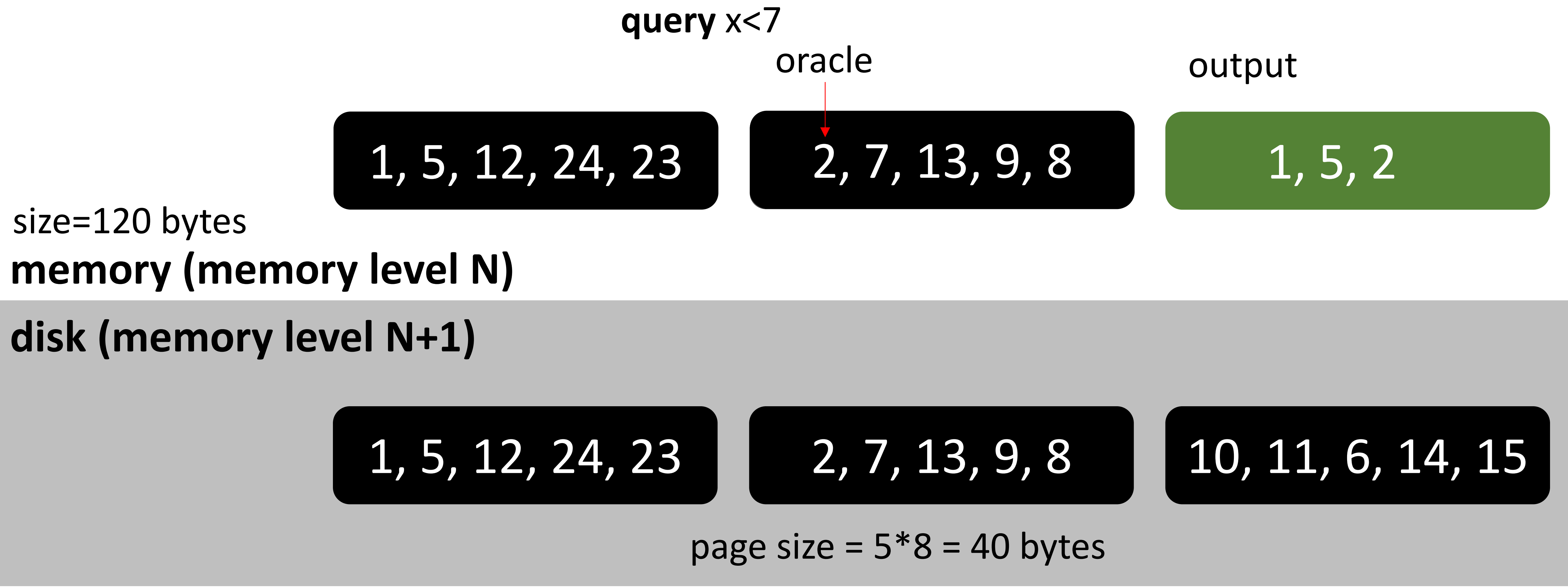
page size = 5*8 = 40 bytes

$ 80 bytes

page-based access & random access



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oracle

output

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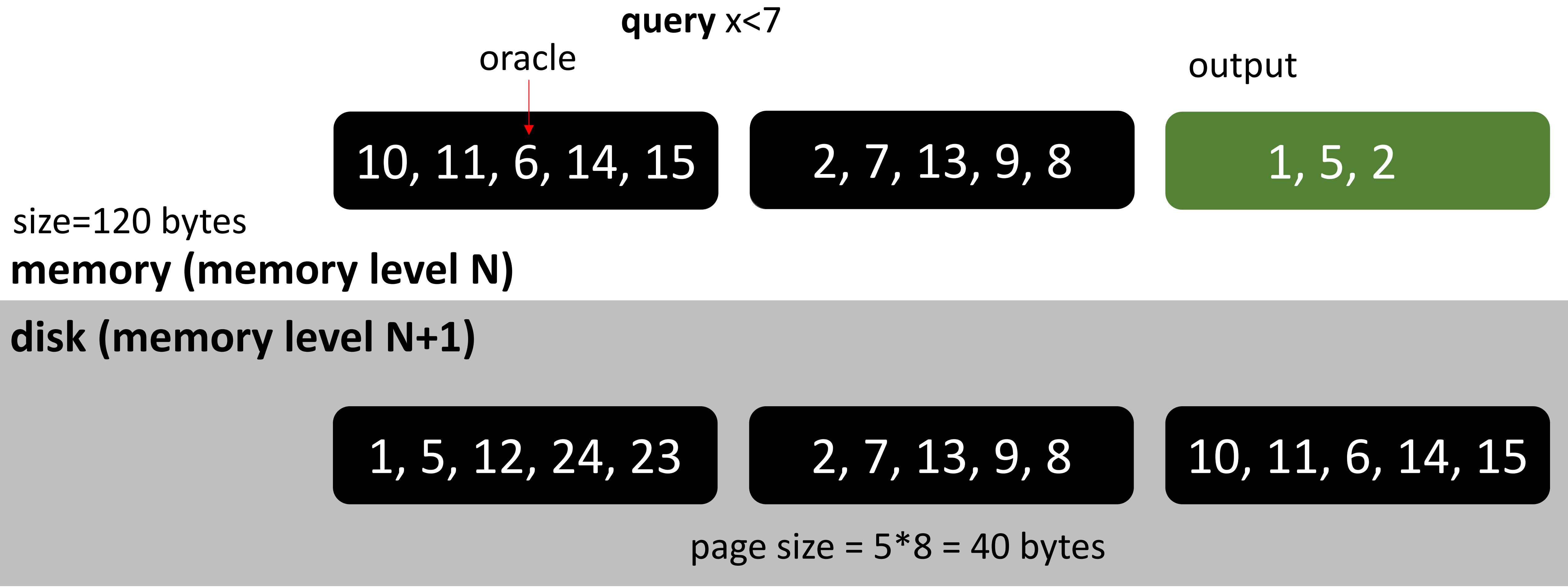

query x<7

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)

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2, 7, 13, 9, 8

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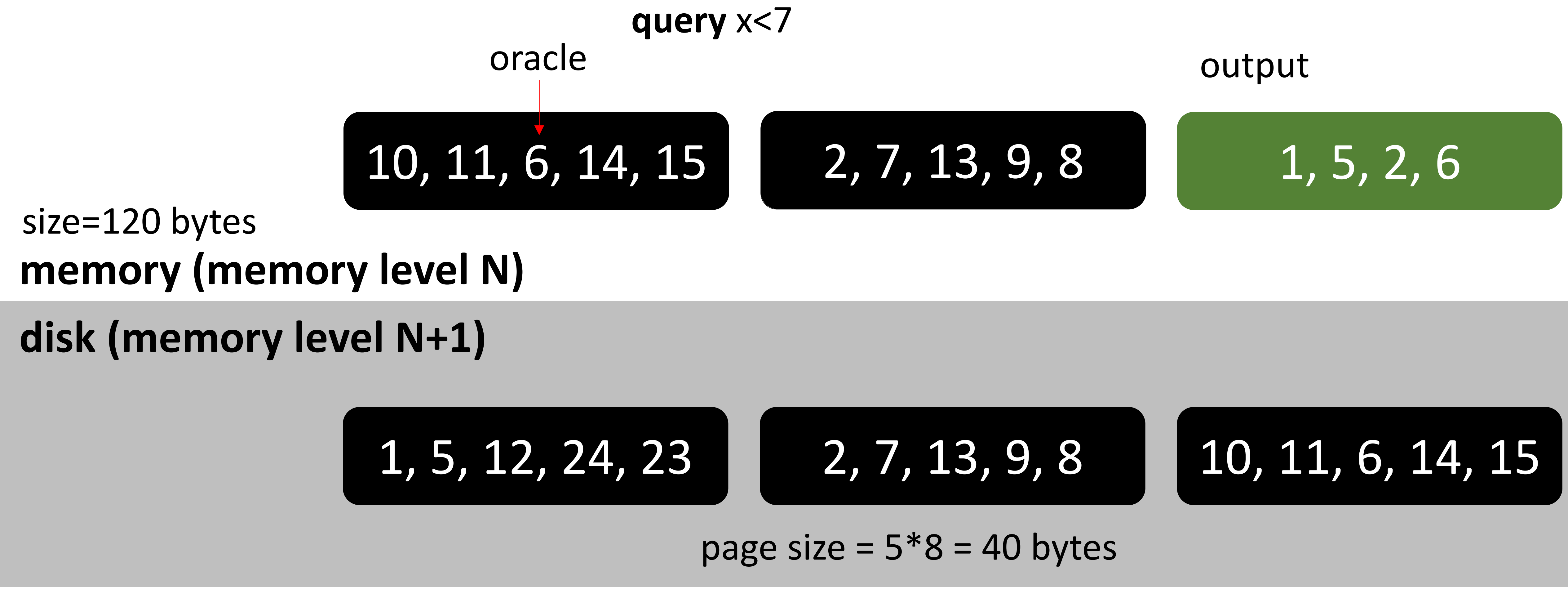
page-based access & random access



query x<7

oracle

10, 11, 6, 14, 15

2, 7, 13, 9, 8

output

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

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page-based access & random access

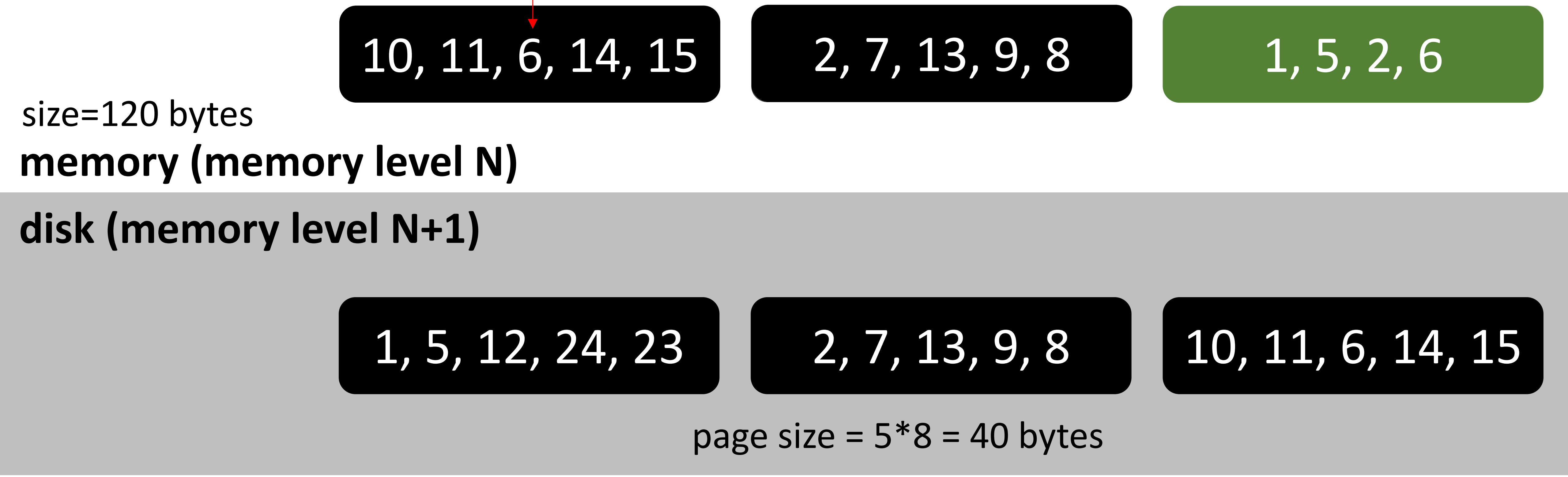
$ 120 bytes

query x<7

was the oracle helpful?

oracle

output



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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

how we store data

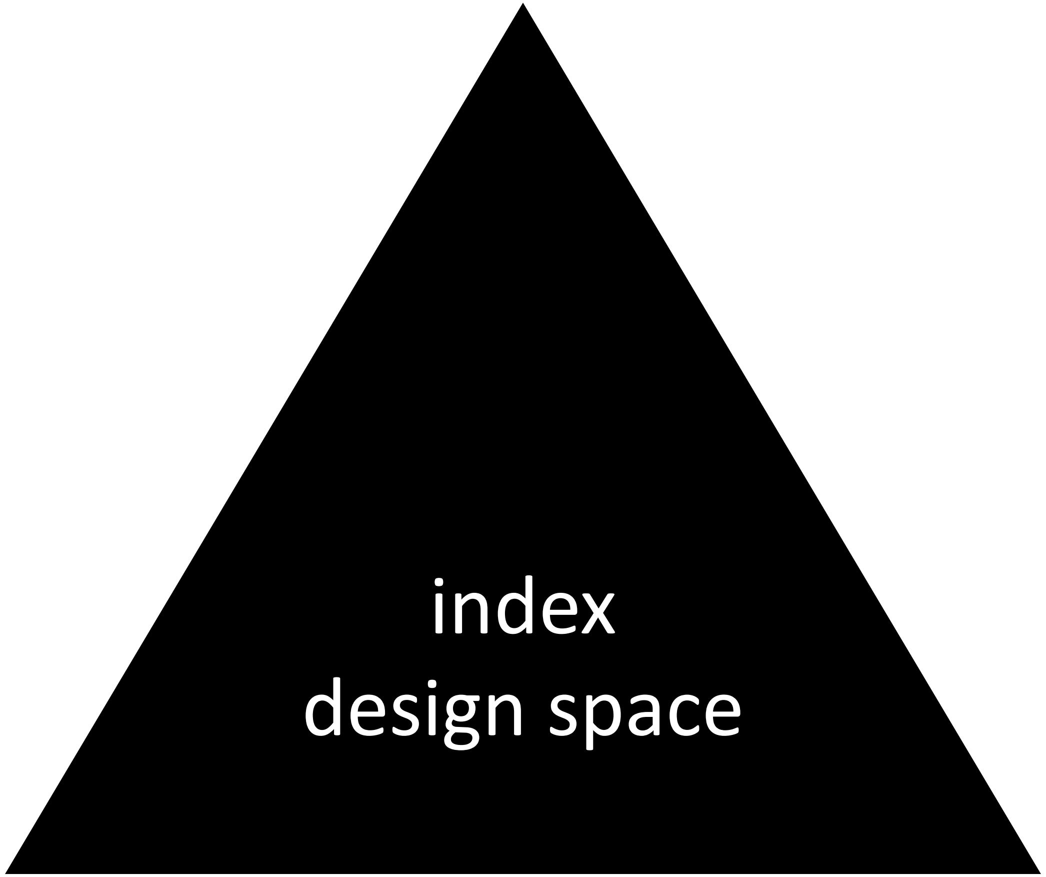
layouts, indexes

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++

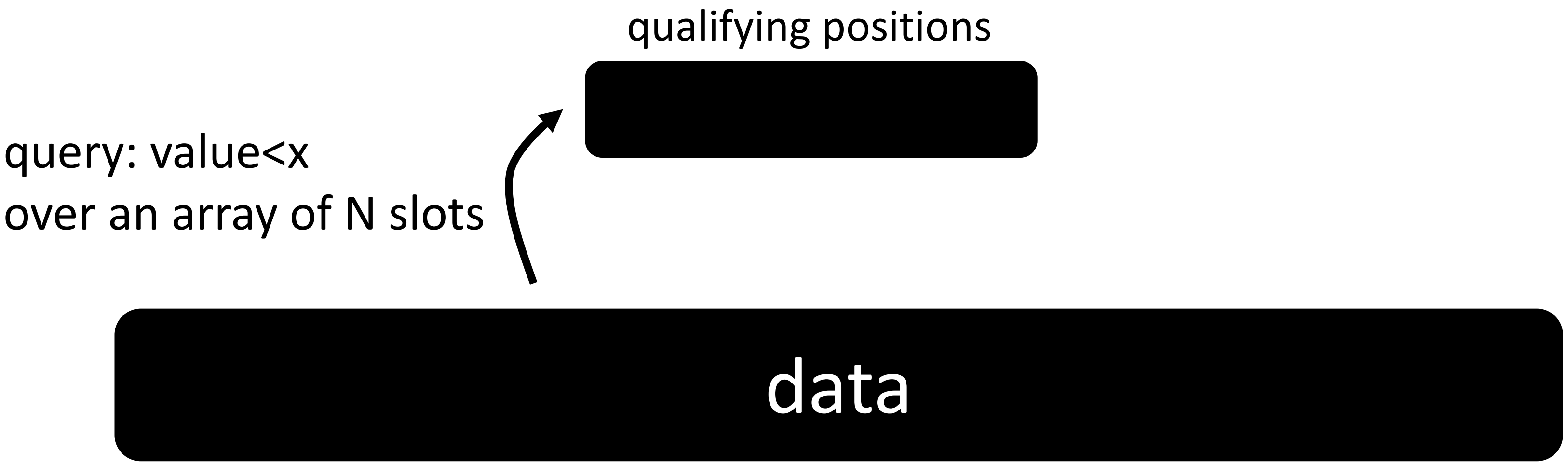
why?

low-level control over hardware

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

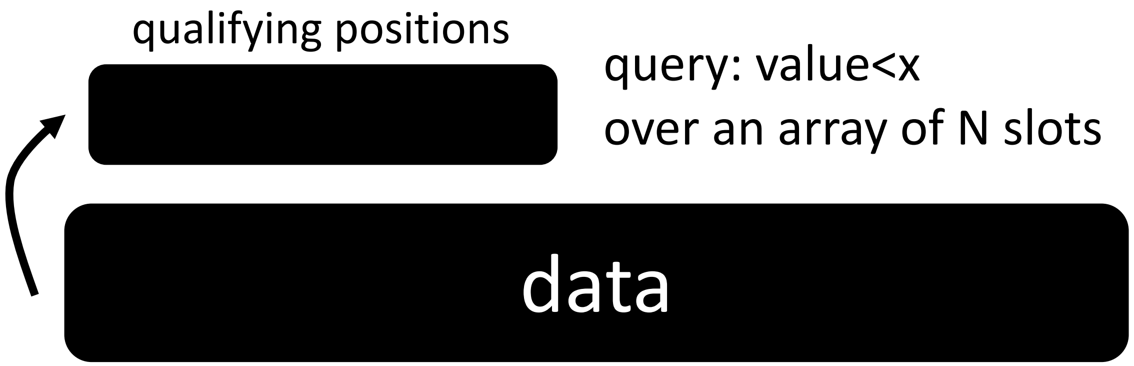
a “simple” database operator

select operator (scan)



query: value<x
over an array of N slots

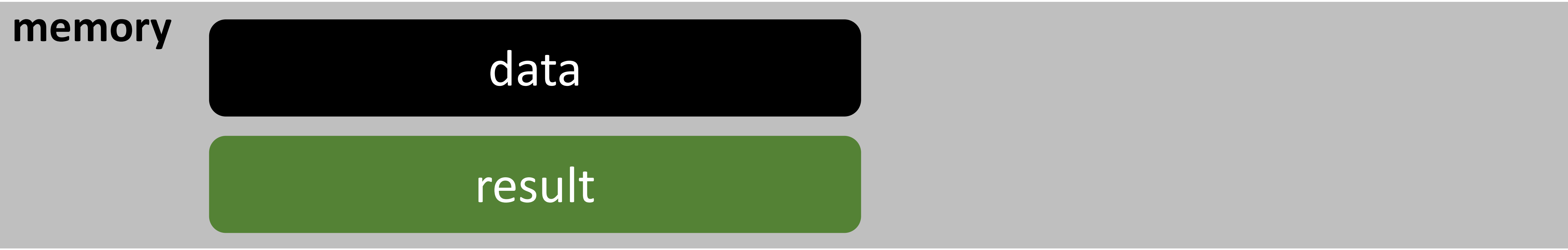
how to implement it?



query: value<x
over an array of N slots

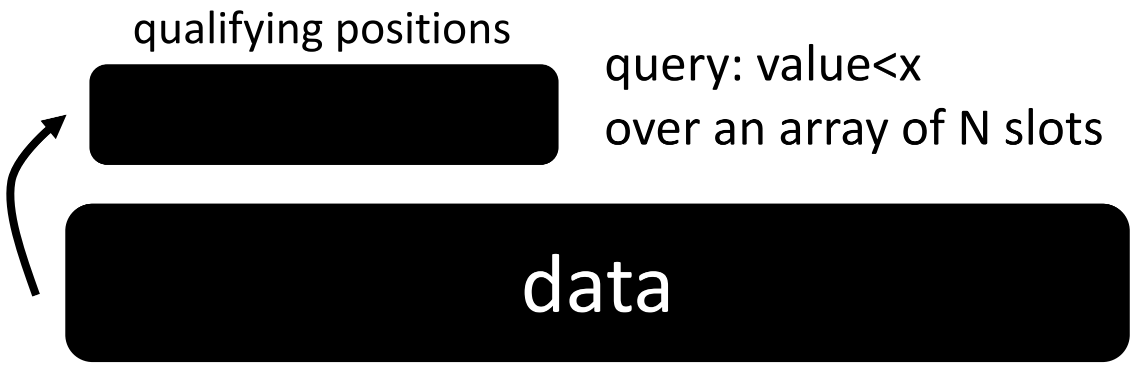
```
result = new array[data.size];
j=0;
for (i=0; i<data.size; i++)
    if (data[i]<x)
        result[j++]=i;
```

what if only 0.1% qualifies?



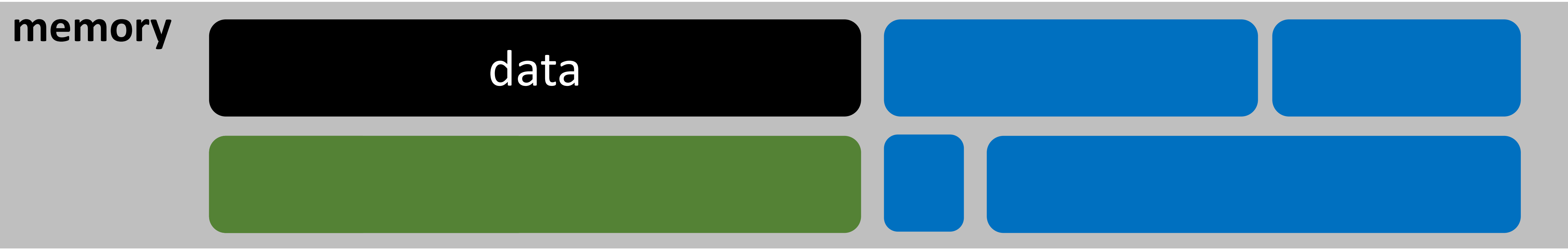
how to implement it?

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



query: value<x
over an array of N slots

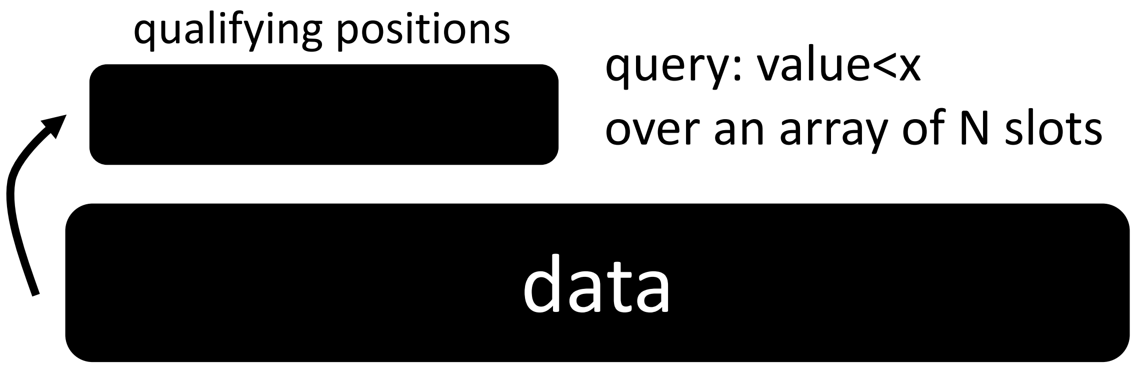
what if only 0.1% qualifies?



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;
```



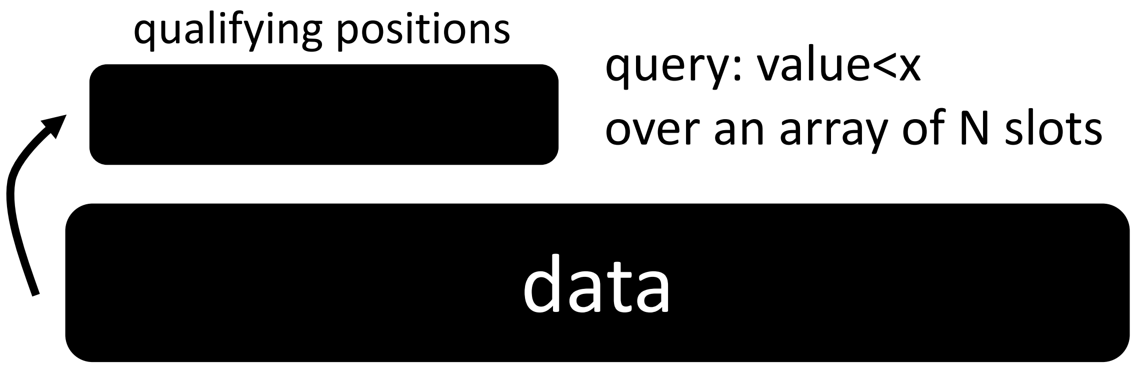
query: value<x
over an array of N slots

what if 99% qualifies?

how can we know?

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

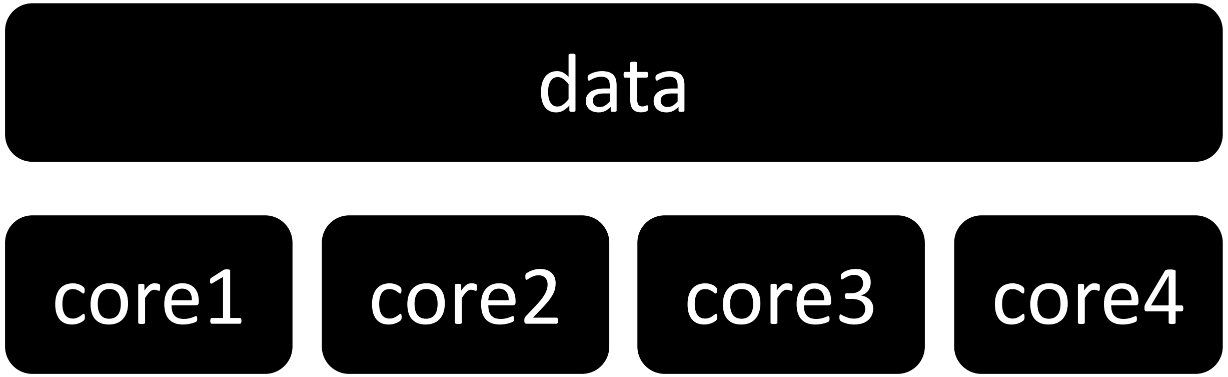
how to bring the values?
(remember we have the positions)



query: value<x
over an array of N slots

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

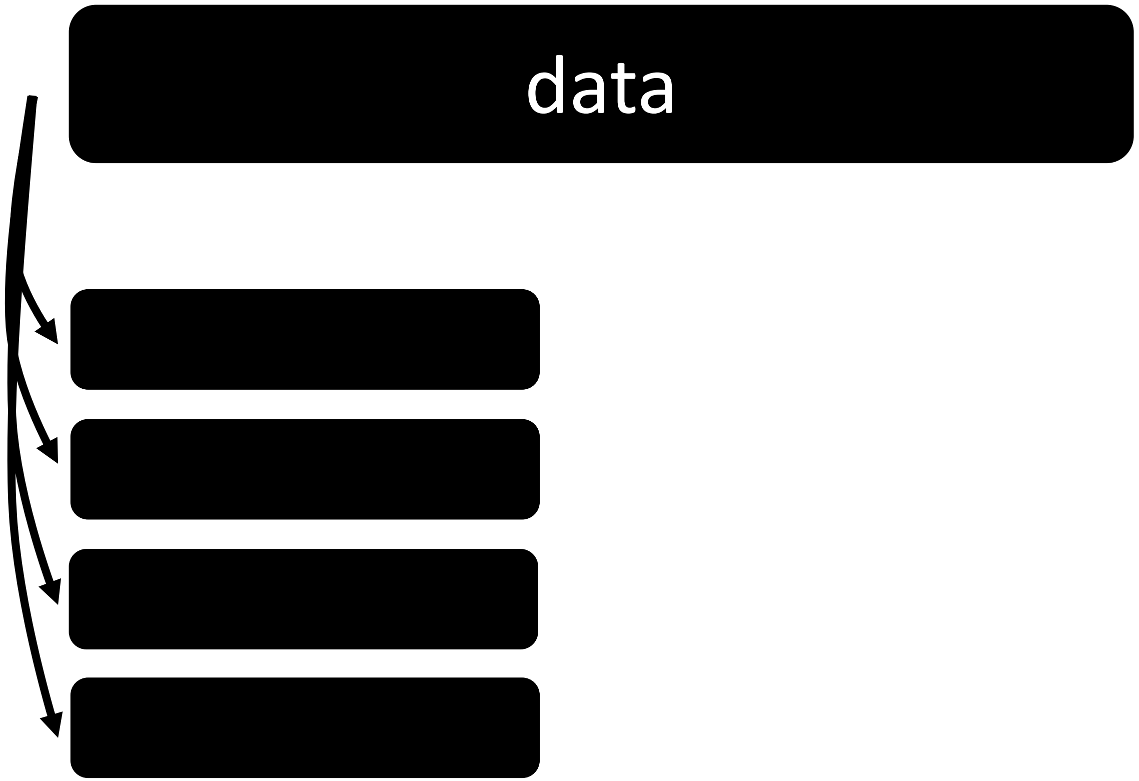
what about multi-core?
NUMA? SIMD? GPU?



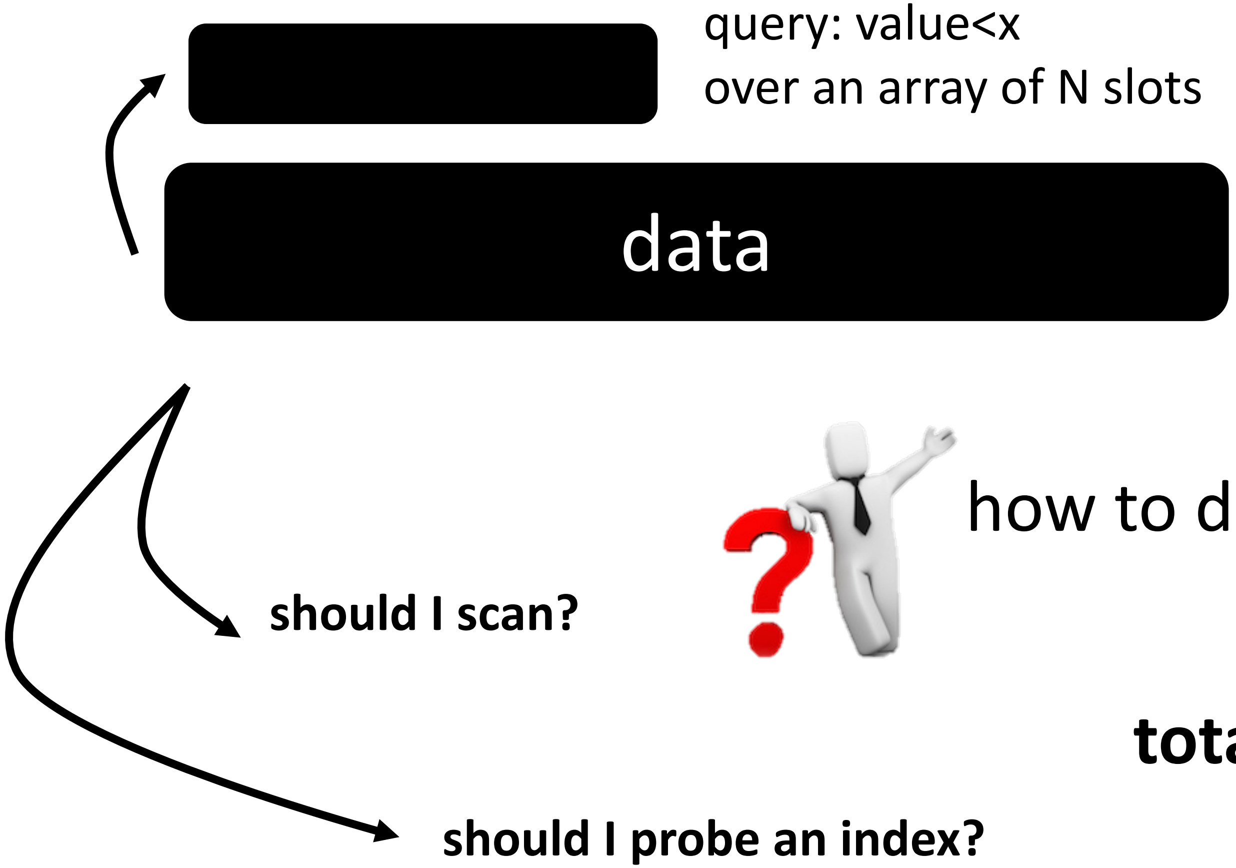
needs coordination!
what about result writing?

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;
```



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 working on project 0
F) start forming groups for project 1 and beyond
G) go over the project (next week will be available)

survival guide

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

piazza website: https://piazza.com/bu/spring2022/cs561

presentation registration: https://tinyurl.com/S22-CS561-presentations

gradescope: https://www.gradescope.com/courses/342653 **(code in Piazza)**

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

material: papers available from BU network

BOSTON UNIVERSITY

CS 561: Data Systems Architectures

class 2

Data Systems 101

next :

modern main-memory data systems

&

semester project