CS 6530: Advanced Database Systems Fall 2024

Lecture 02
Data system architecture

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Some reminders…

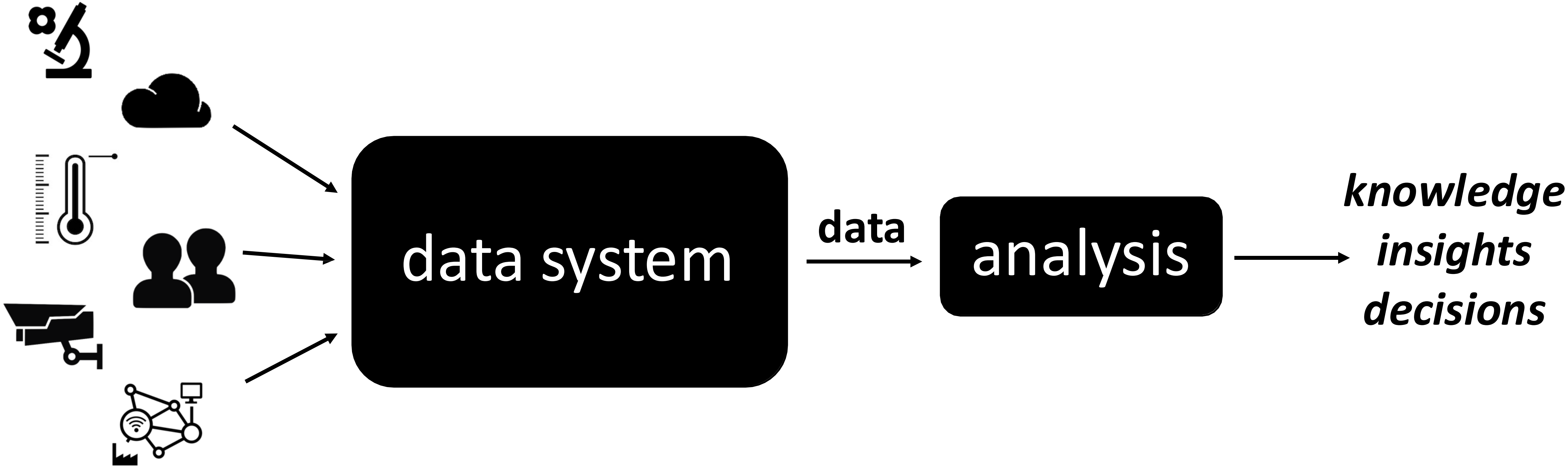
no smartphones

no laptop

Data system architecture essentials

Acknowledgement: Slides taken from Prof. Manos Athanassoulis, BU

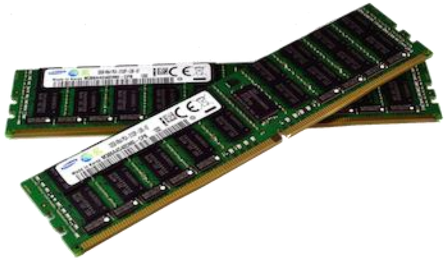
A **data system** is a large software system that **stores data**, and provides the **interface** to **update** and **access** them **efficiently**



Growing need for tailored systems

new applications

new hardware

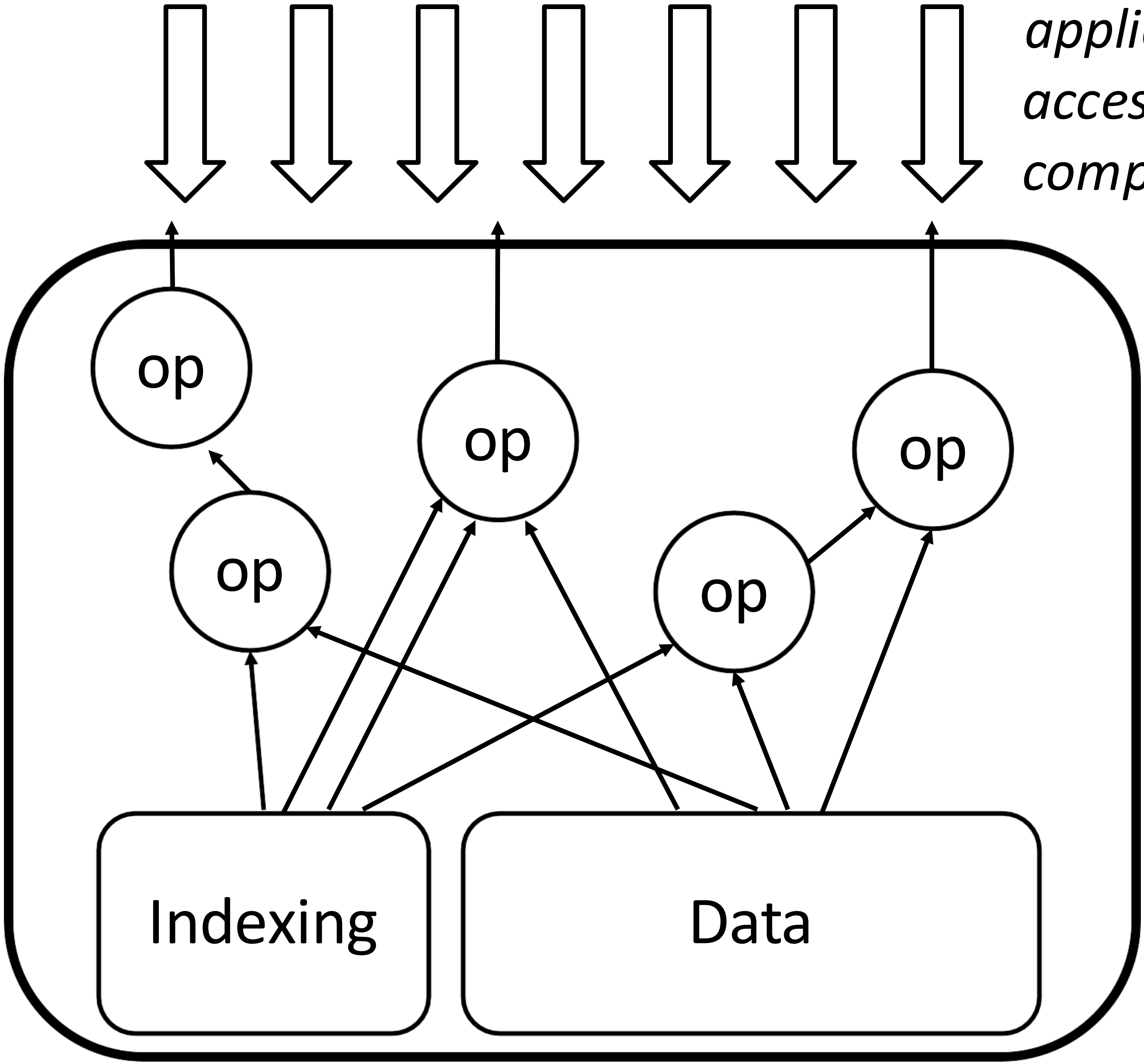


more data

Data system, what’s inside?

application/SQL
access patterns
complex queries

algorithms
and
operators



op

op

op

op

op

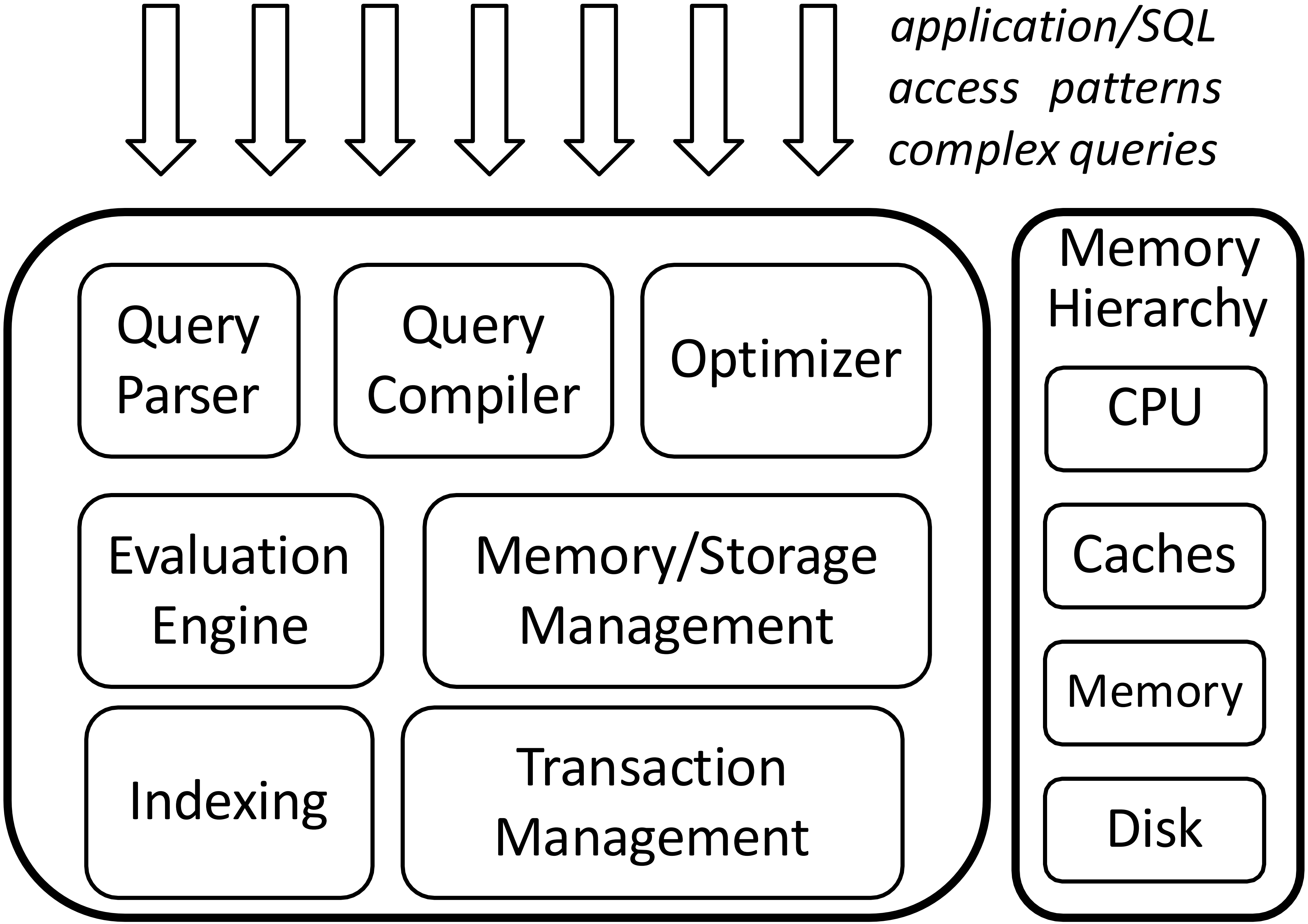
op

Indexing

Data

application/SQL
access patterns
complex queries

modules



Query Parser

Query Compiler

Optimizer

Evaluation Engine

Memory/Storage Management

Indexing

Transaction Management

Memory Hierarchy

CPU

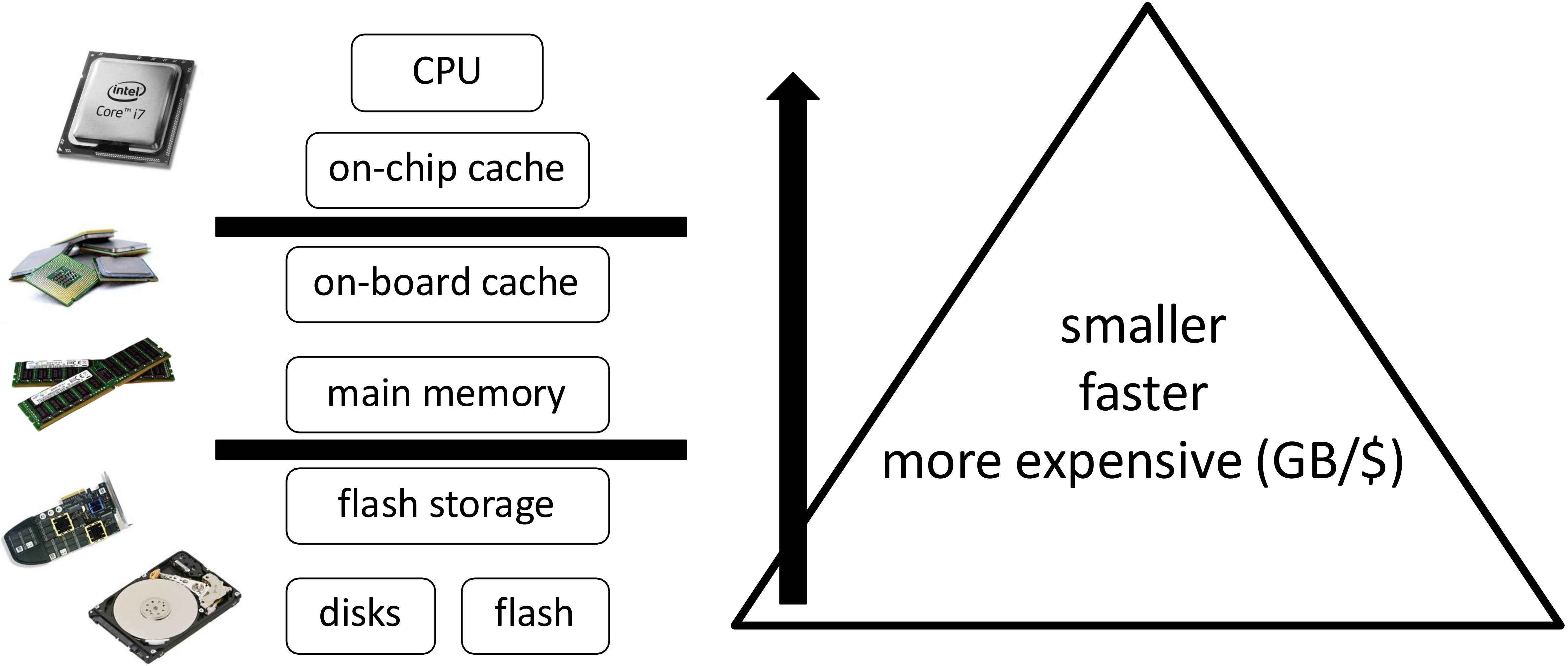
Caches

Memory

Disk

Data system, what’s underneath?

Memory hierarchy



CPU

on-chip cache

on-board cache

main memory

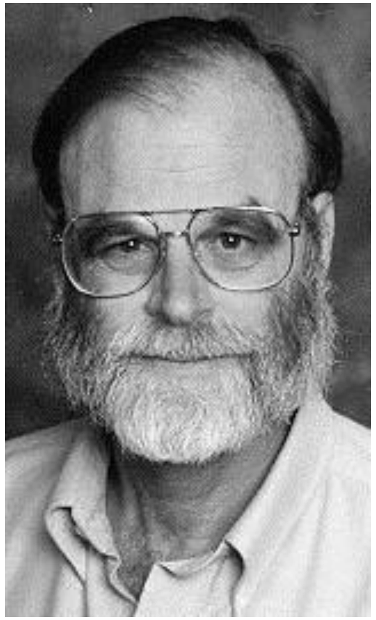
flash storage

disks

flash

smaller
faster
more expensive (GB/$)

Memory hierarchy (by Jim Gray)

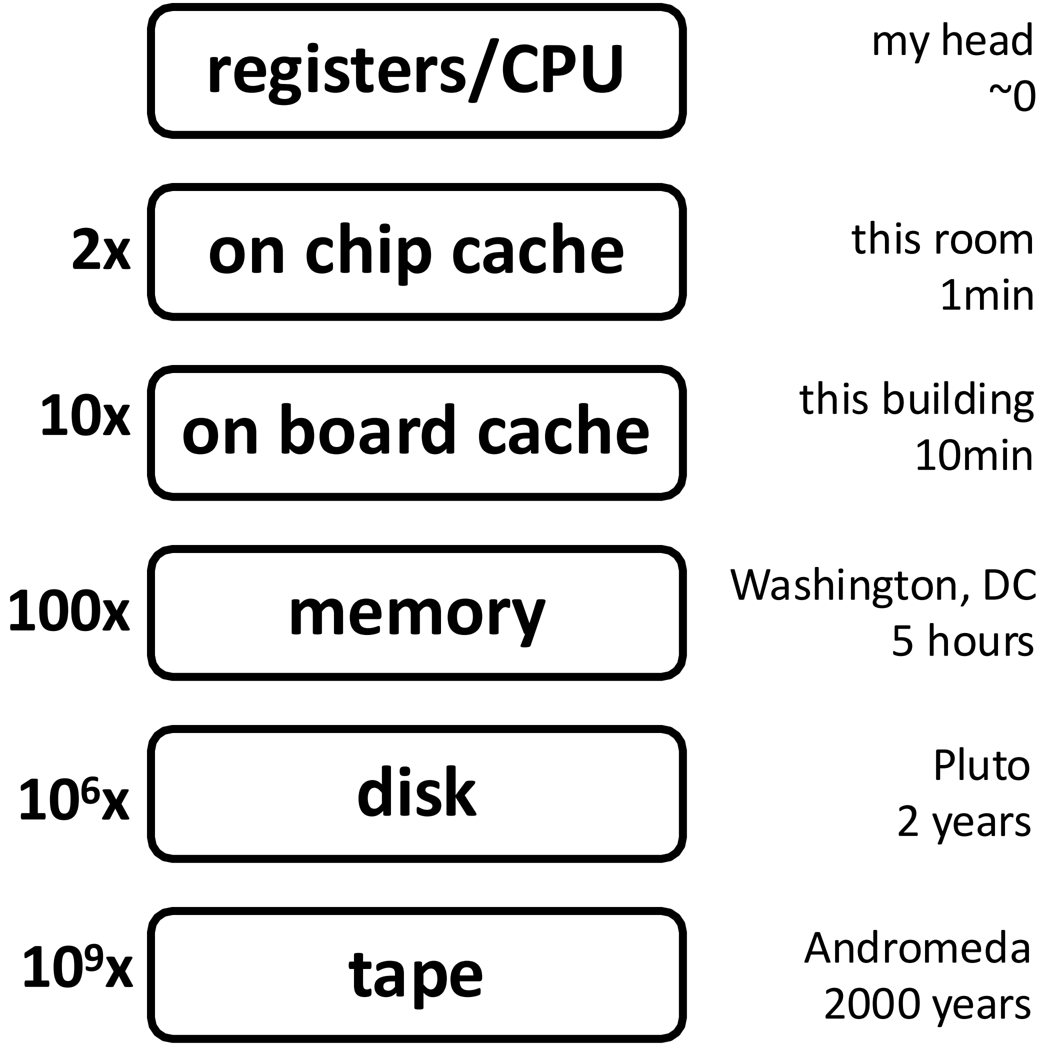


Jim Gray, IBM, Tandem, Microsoft, DEC

"The Fourth Paradigm" is based on his vision

ACM Turing Award 1998

ACM SIGMOD Edgar F. Codd Innovations award 1993

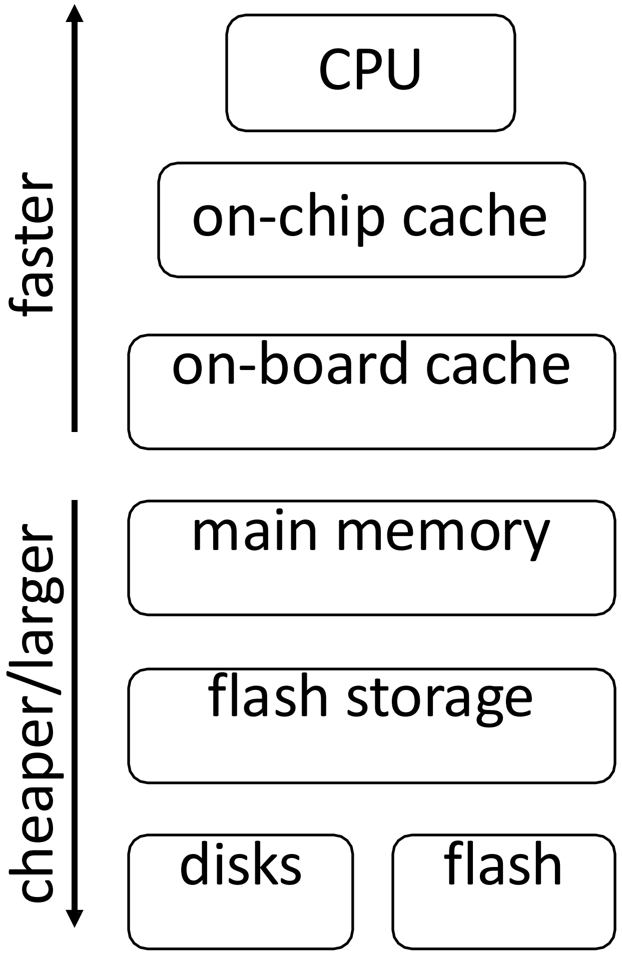


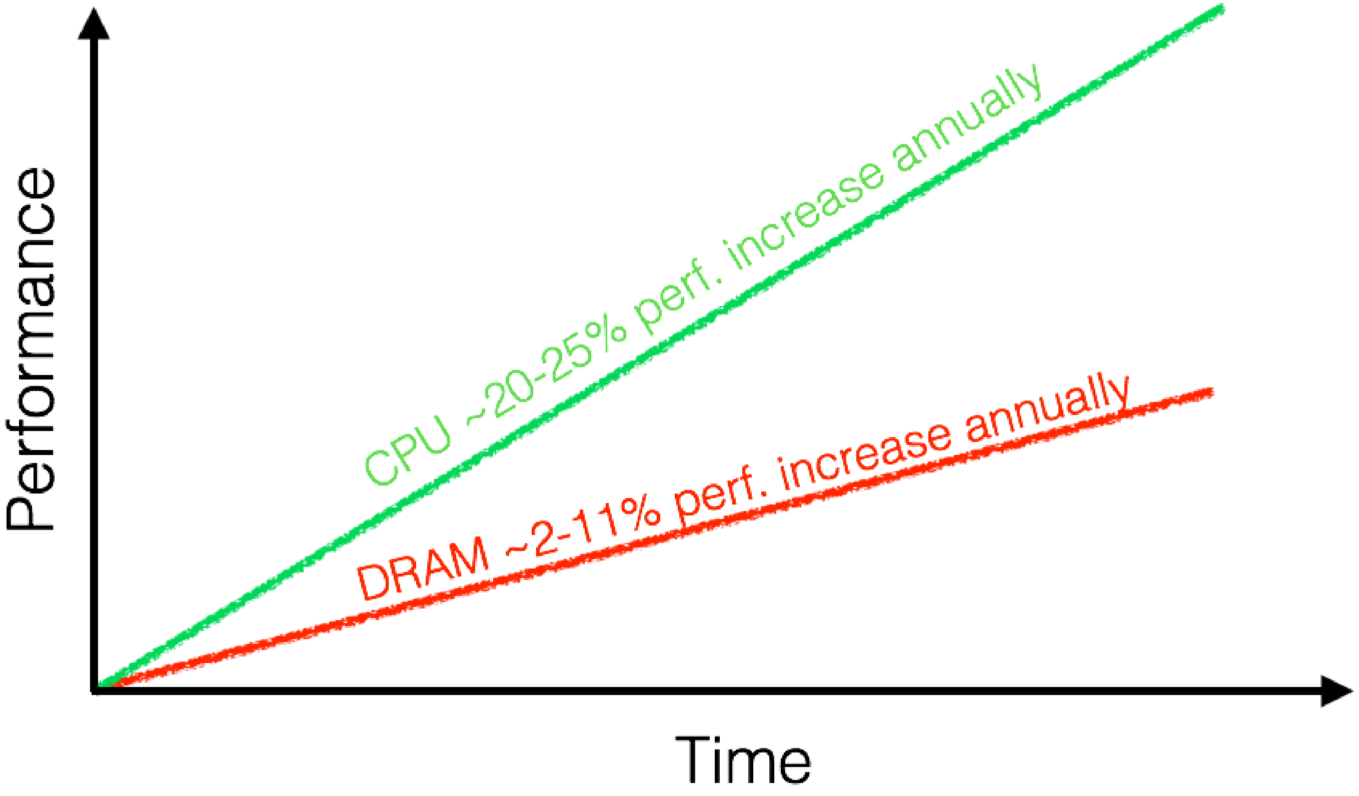
	registers/CPU	my head ~0
2x	**on chip cache**	this room 1min
10x	**on board cache**	this building 10min
100x	**memory**	Washington, DC 5 hours
10^6x	**disk**	Pluto 2 years
10^9x	**tape**	Andromeda 2000 years

Memory hierarchy and latencies

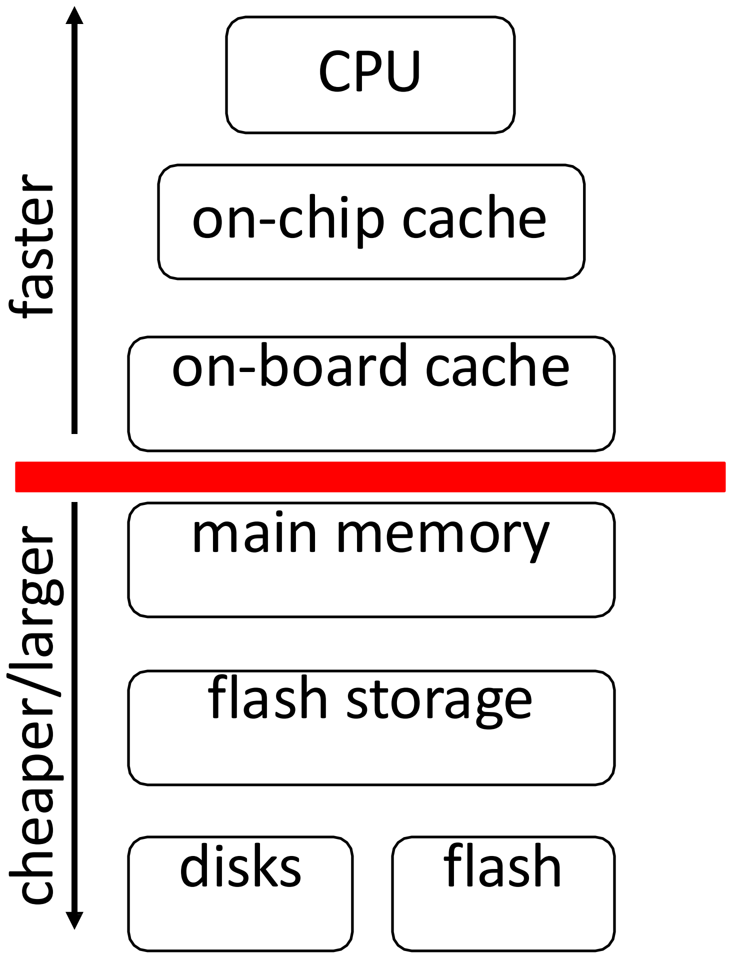
Memory	Size	Latency	Bandwidth
L1 cache	32 KB	1 nano sec	1 TB/sec
L2 cache	256 KB	4 nano sec	1 TB/sec (shared by cores)
L3 cache	8 MB or more	~30-40 nano sec	> 400 GB/sec
Main memory DDR DIMM	4 GB to 1 TB	~80-100 nano sec	100 GB/sec
I/O devices on memory bus	6 TB	100X-1000X slower than memory	25 GB/sec
I/O devices on PCIe bus	Limited only by cost	Milli sec – minutes	GB-TB/hour (depends on HW and distance)

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

CPU

on-chip cache

on-board cache

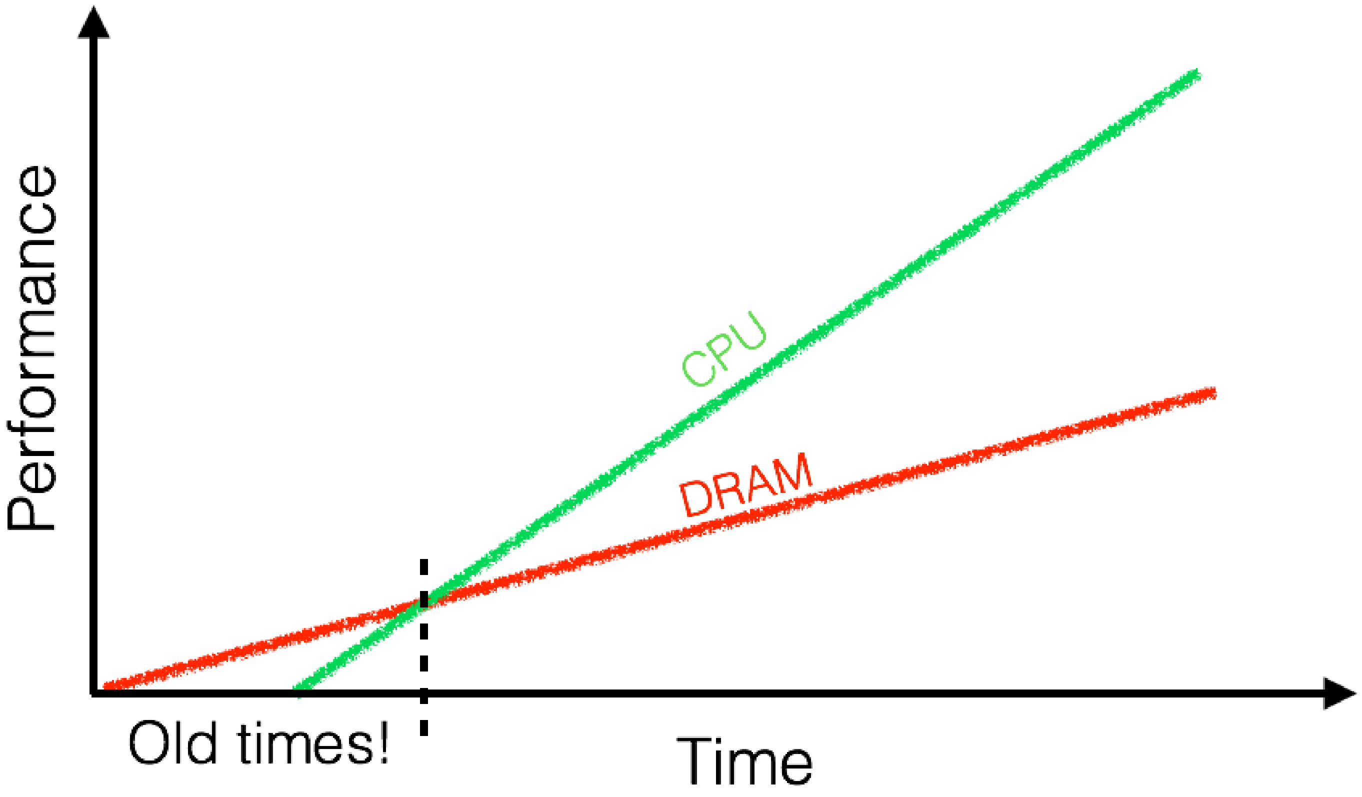
main memory

flash storage

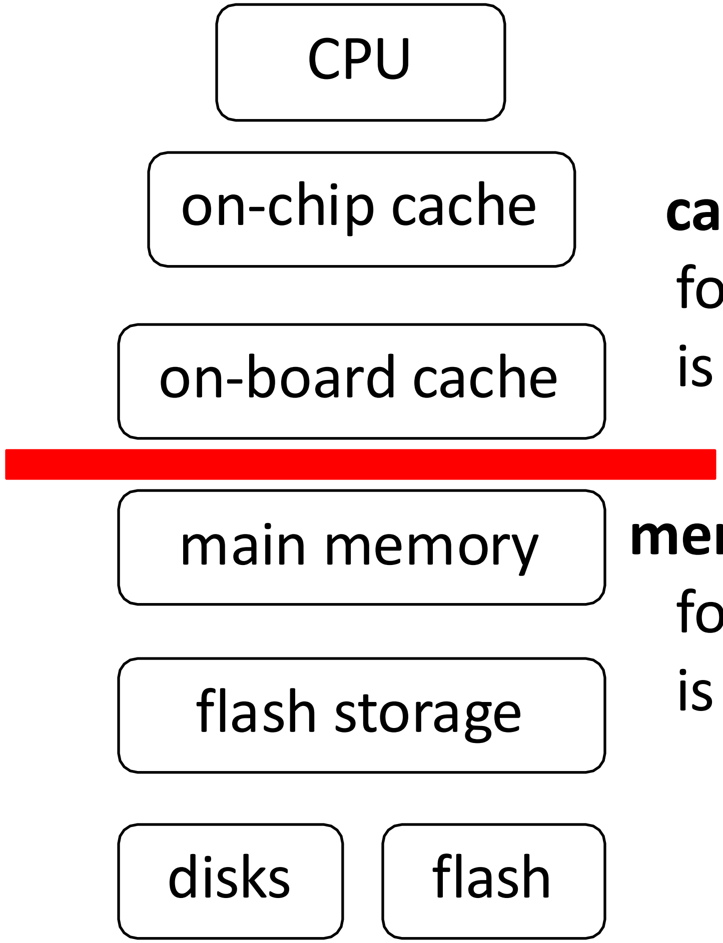
disks

flash

cheaper/larger



Cache/memory misses



CPU

on-chip cache

on-board cache

main memory

flash storage

disks

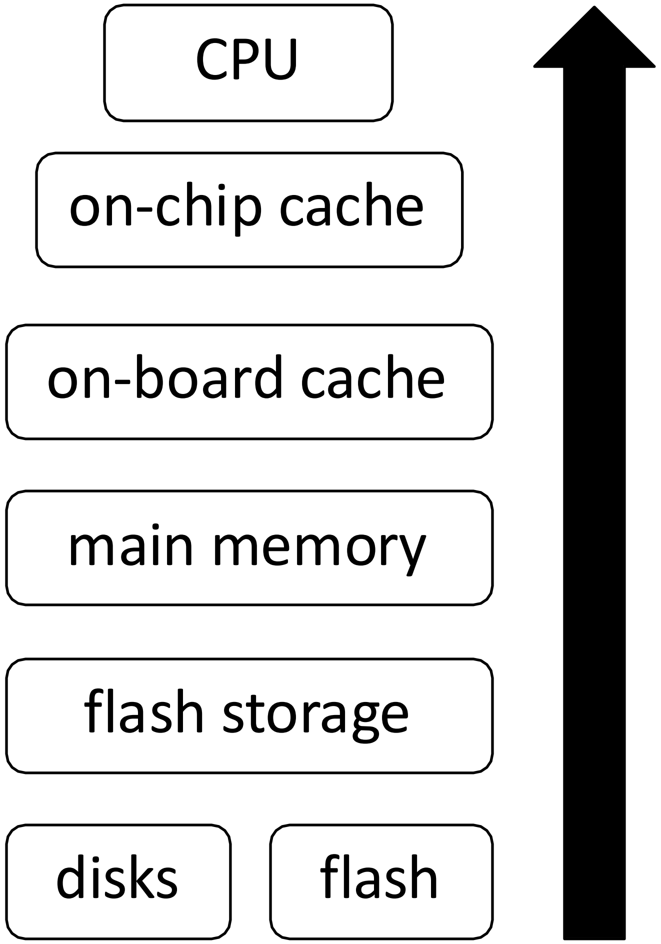
flash

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

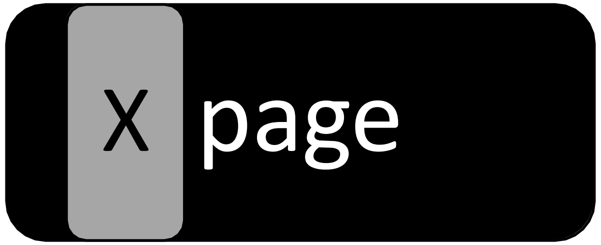


data go through
all necessary levels

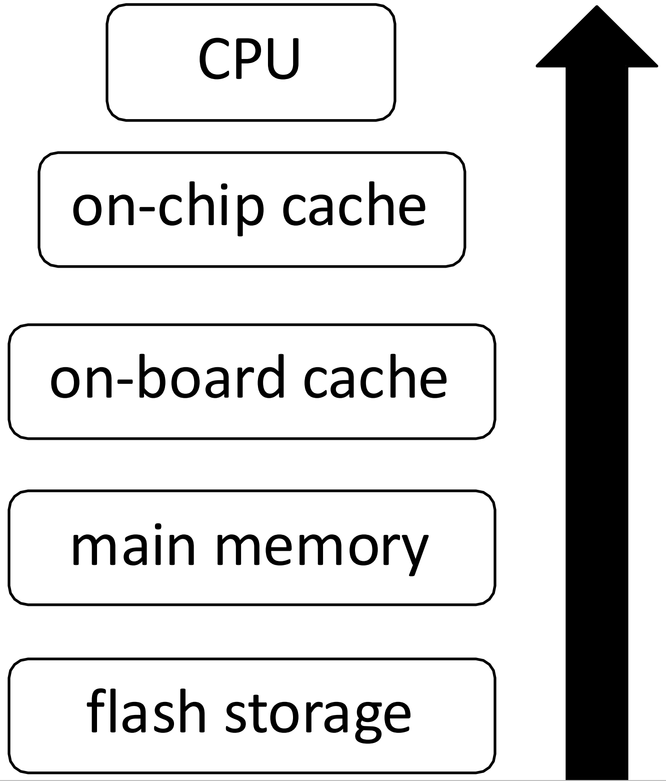
also read
unnecessary data

Photo by Gary Dineen/NBAE via Getty Images

need to read only X
read the whole page



Data movement



CPU

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data go through
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need to read only X
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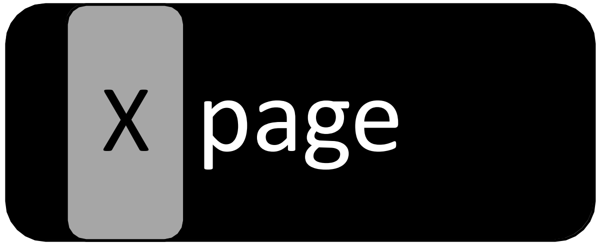


remember!
disk is millions (mem, hundreds) times slower than CPU

Page-based access & random access

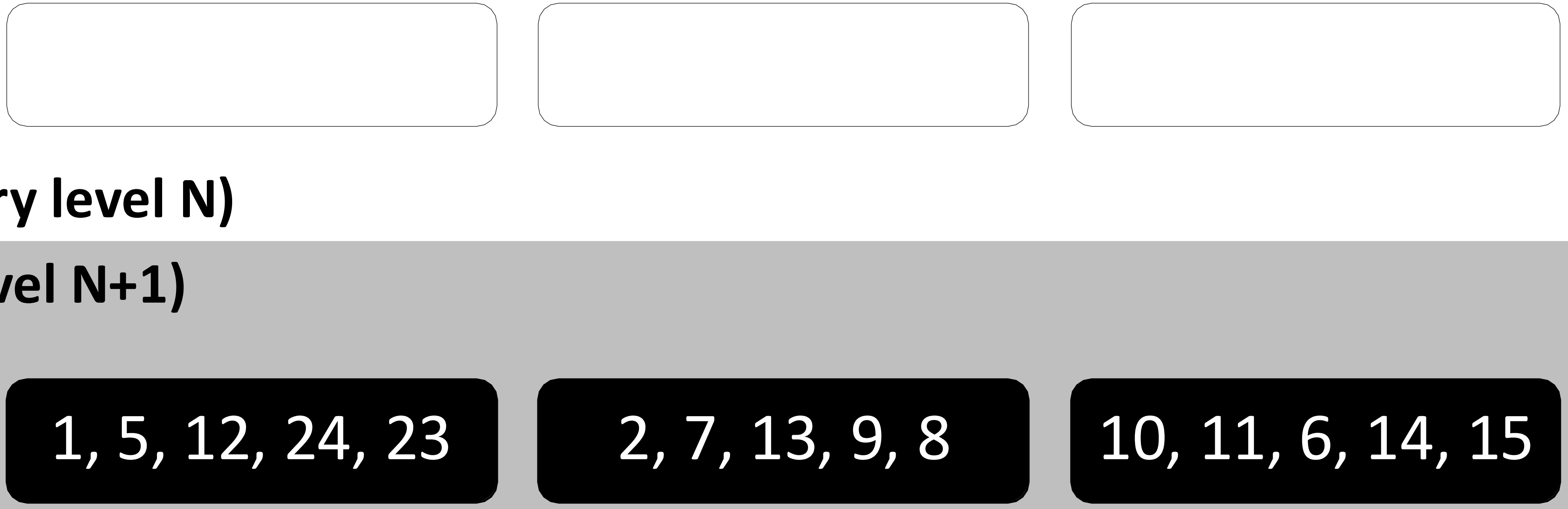
query x<7

scan

size=120 bytes

memory (memory level N)

disk (memory level N+1)



1, 5, 12, 24, 23

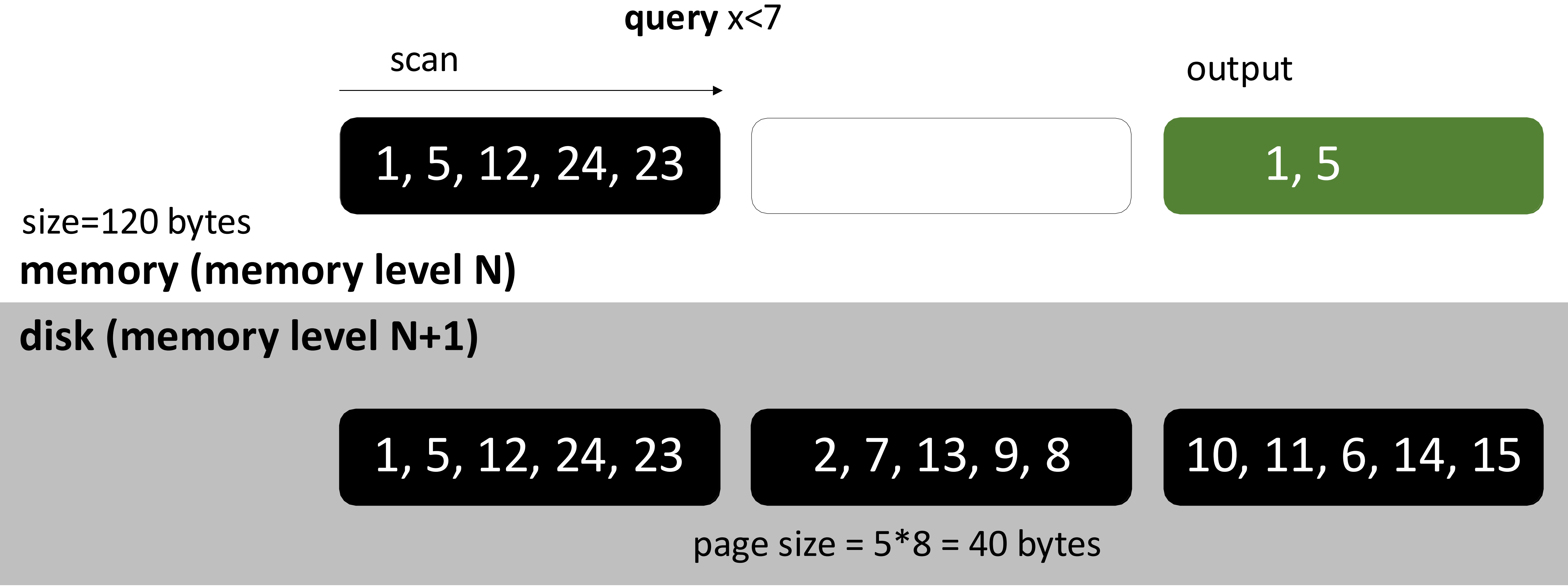
2, 7, 13, 9, 8

10, 11, 6, 14, 15

page size = 5*8 = 40 bytes

$ 40 bytes

Page-based access & random access



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scan

output

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1, 5

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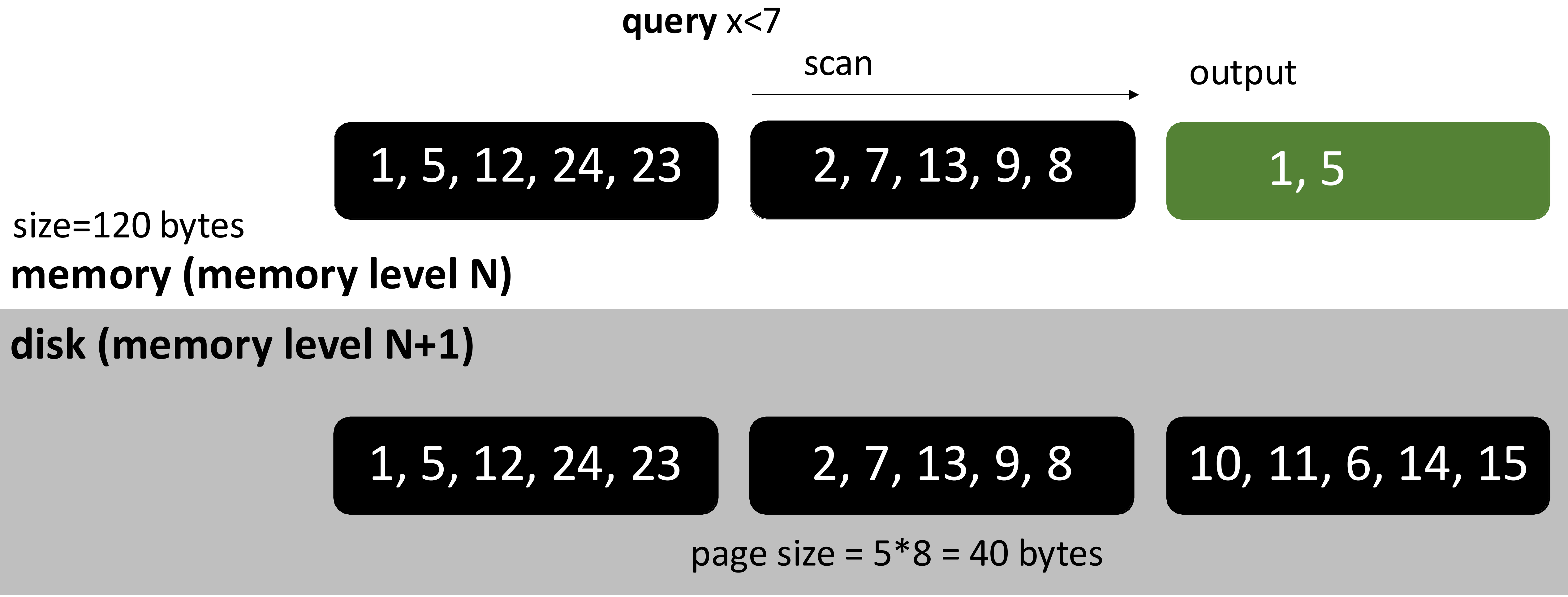

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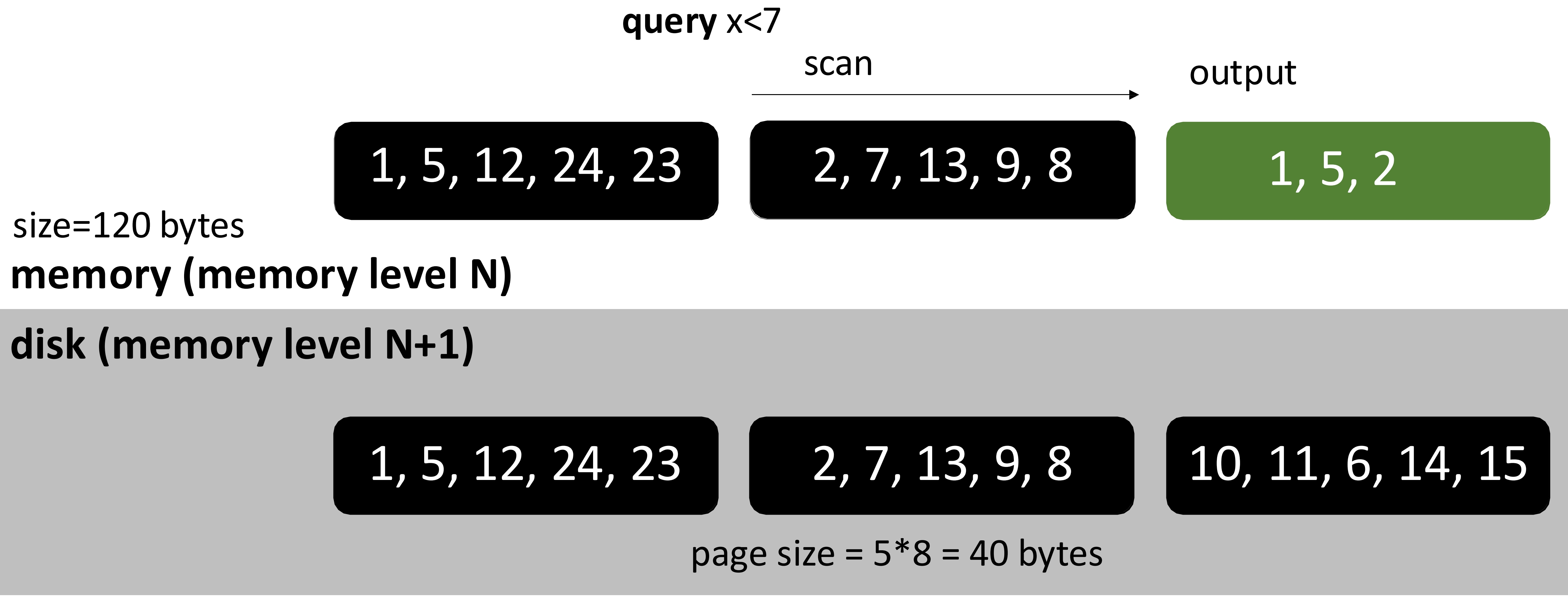


query x<7

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

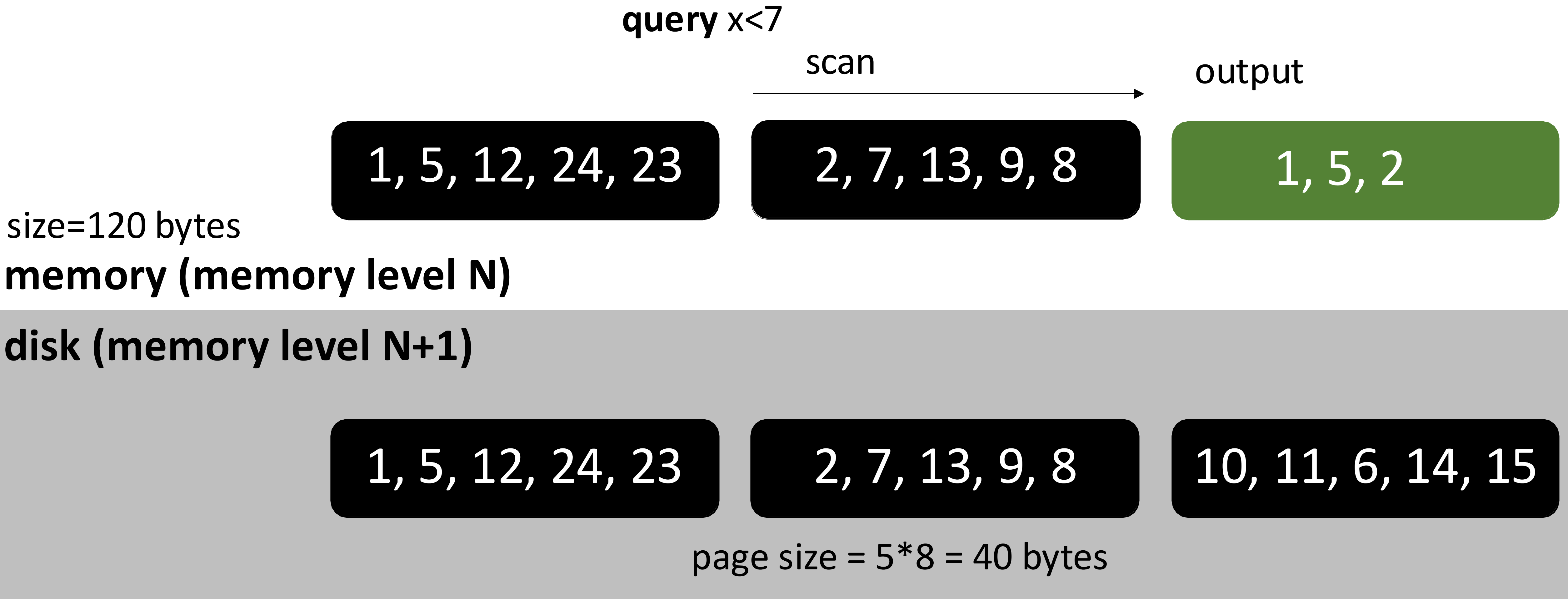
2, 7, 13, 9, 8

10, 11, 6, 14, 15

page size = 5*8 = 40 bytes

$ 80 bytes

Page-based access & random access



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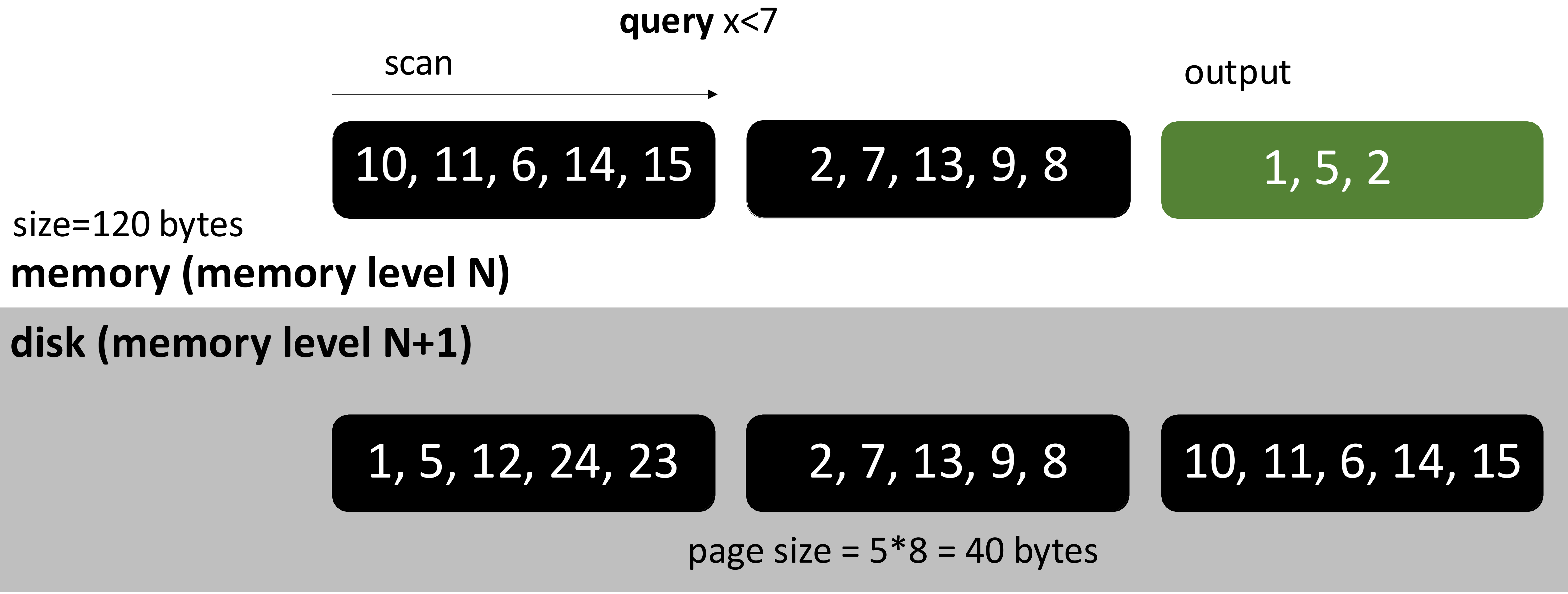

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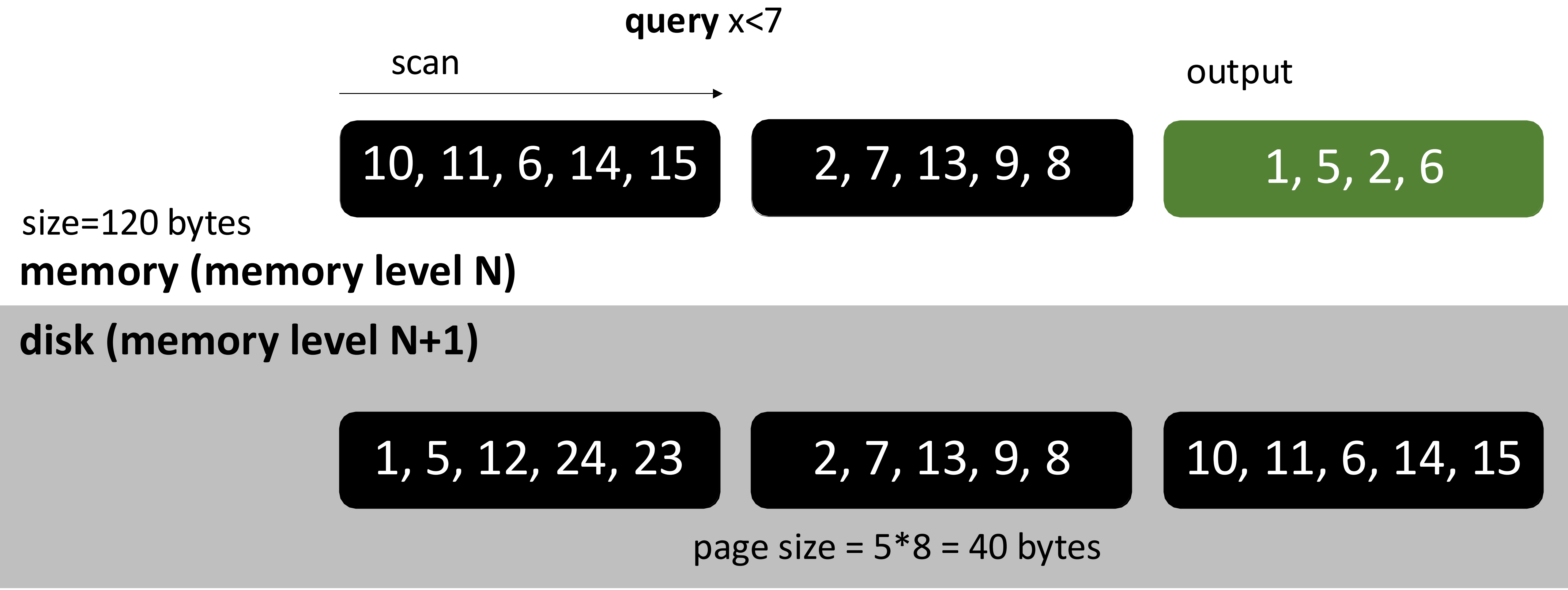

query x<7

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)

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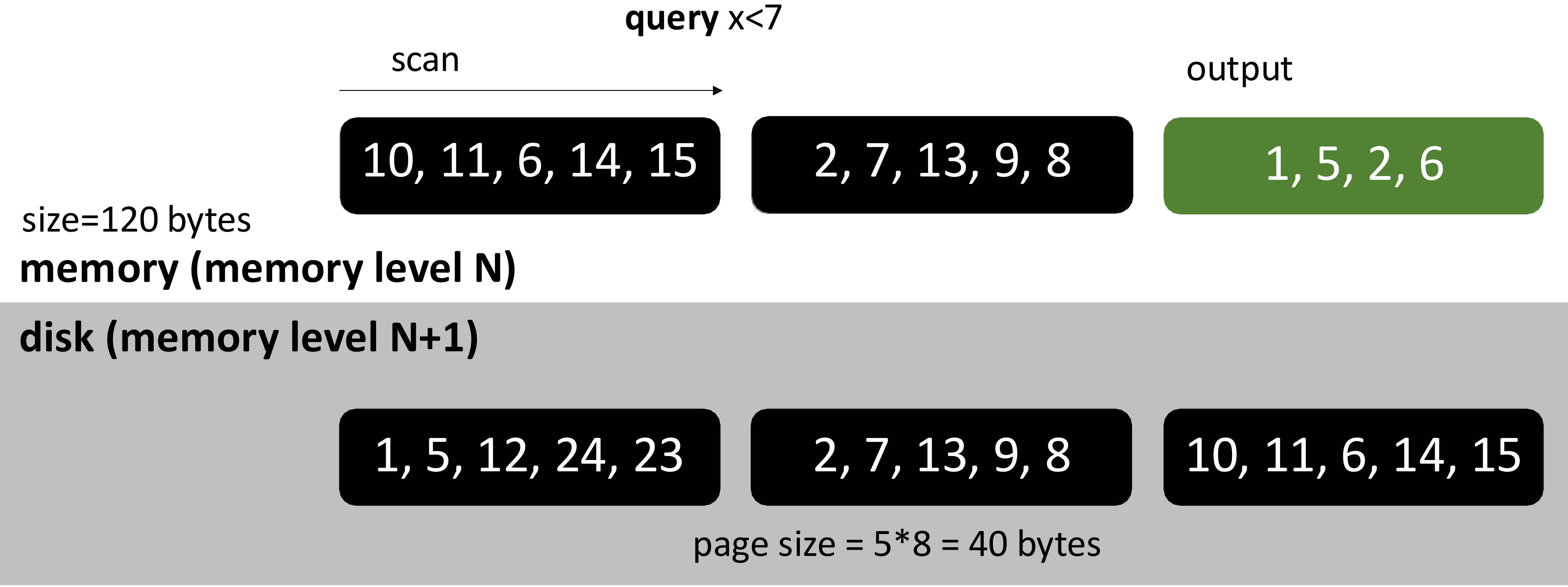
Page-based access & random access



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size=120 bytes

memory (memory level N)

disk (memory level N+1)

1, 5, 12, 24, 23

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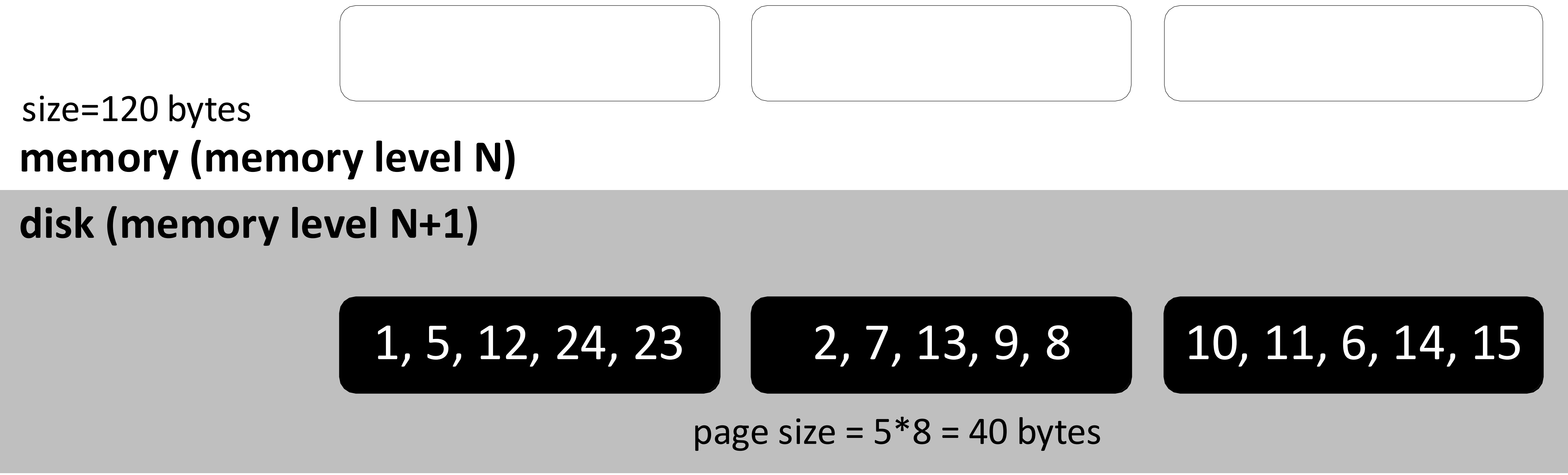
page size = 5*8 = 40 bytes

What if we had an oracle (perfect index)?

Page-based access & random access

query x<7

scan



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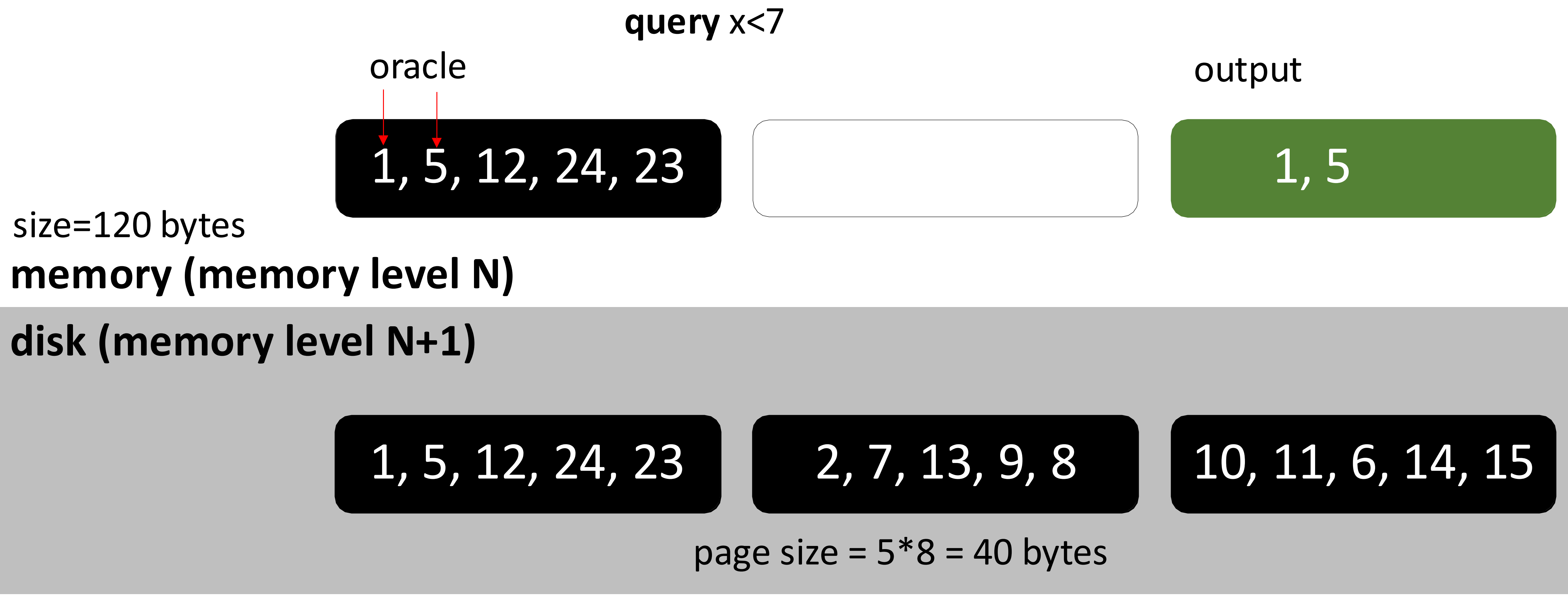

query x<7

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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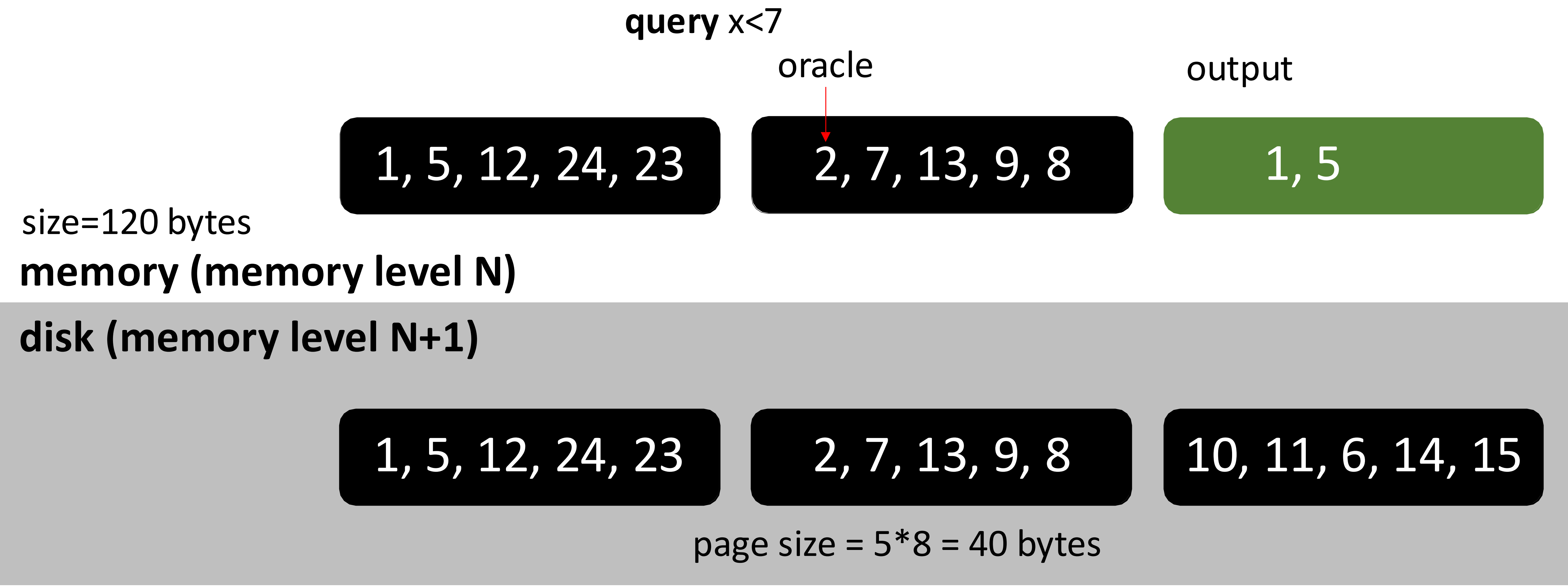
$ 40 bytes

Page-based access & random access



query x<7

oracle

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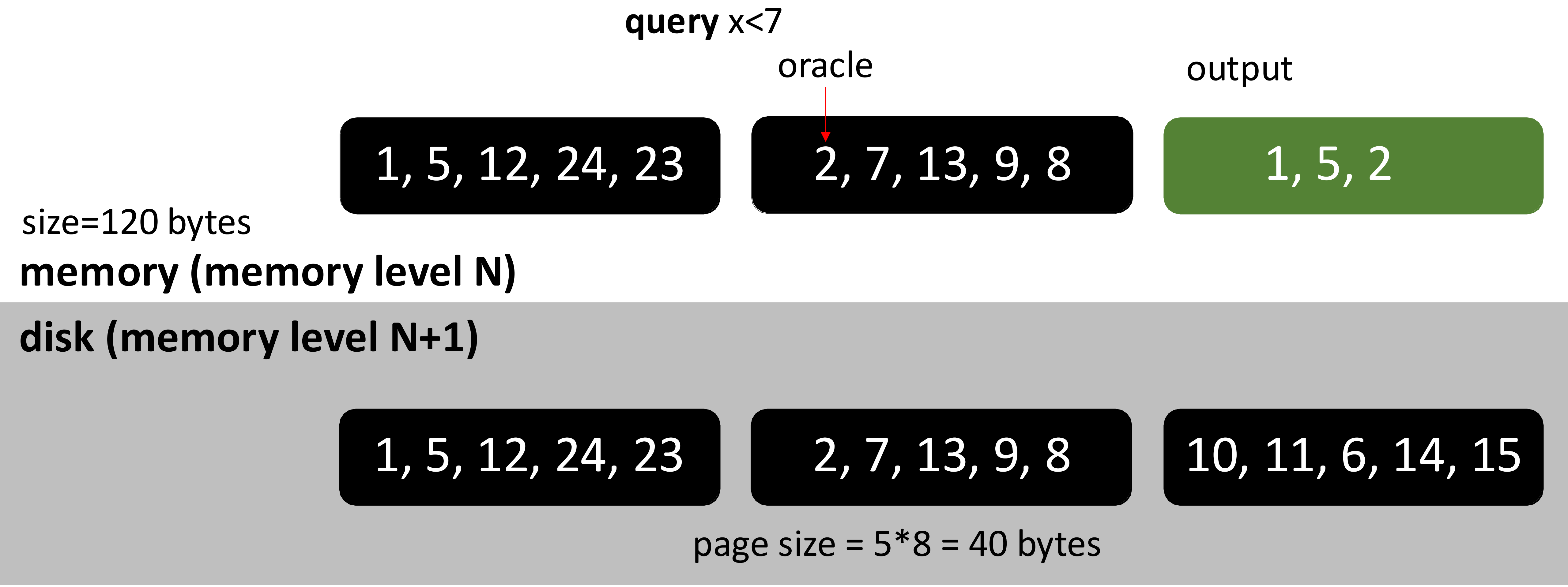

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oracle

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1, 5, 2

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memory (memory level N)

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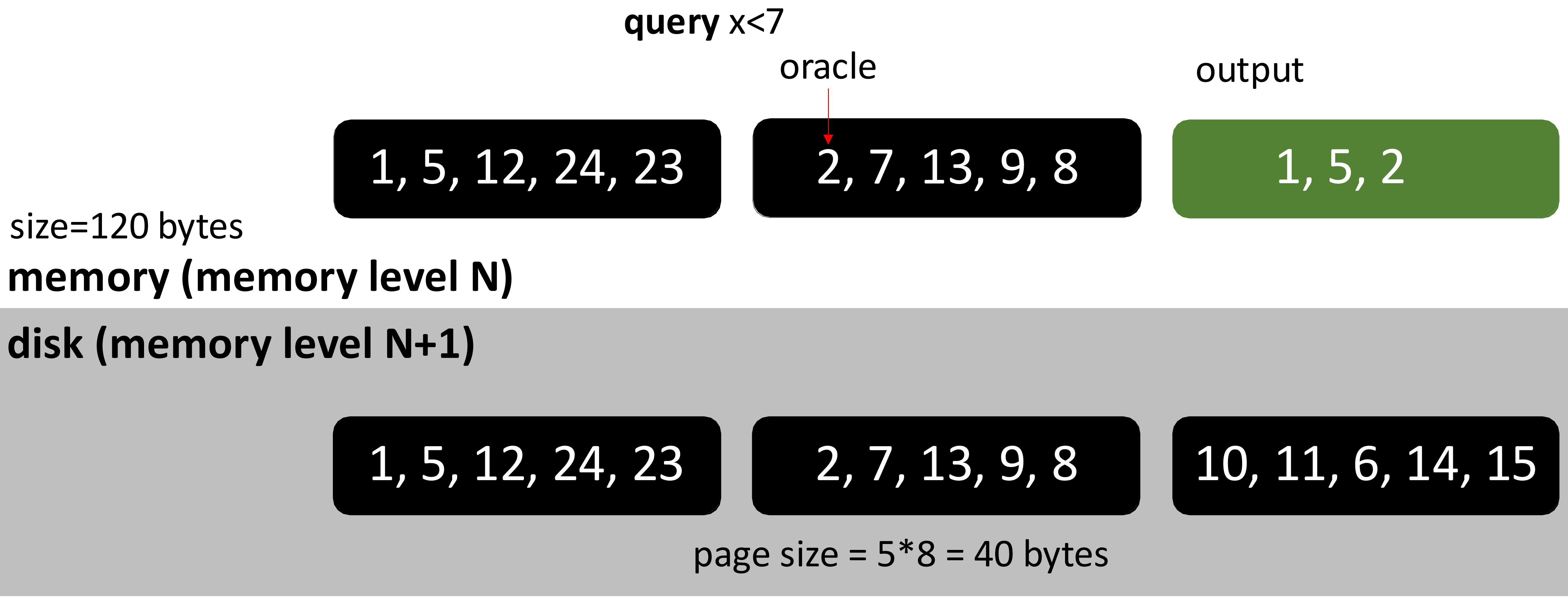
page size = 5*8 = 40 bytes

$ 80 bytes

Page-based access & random access



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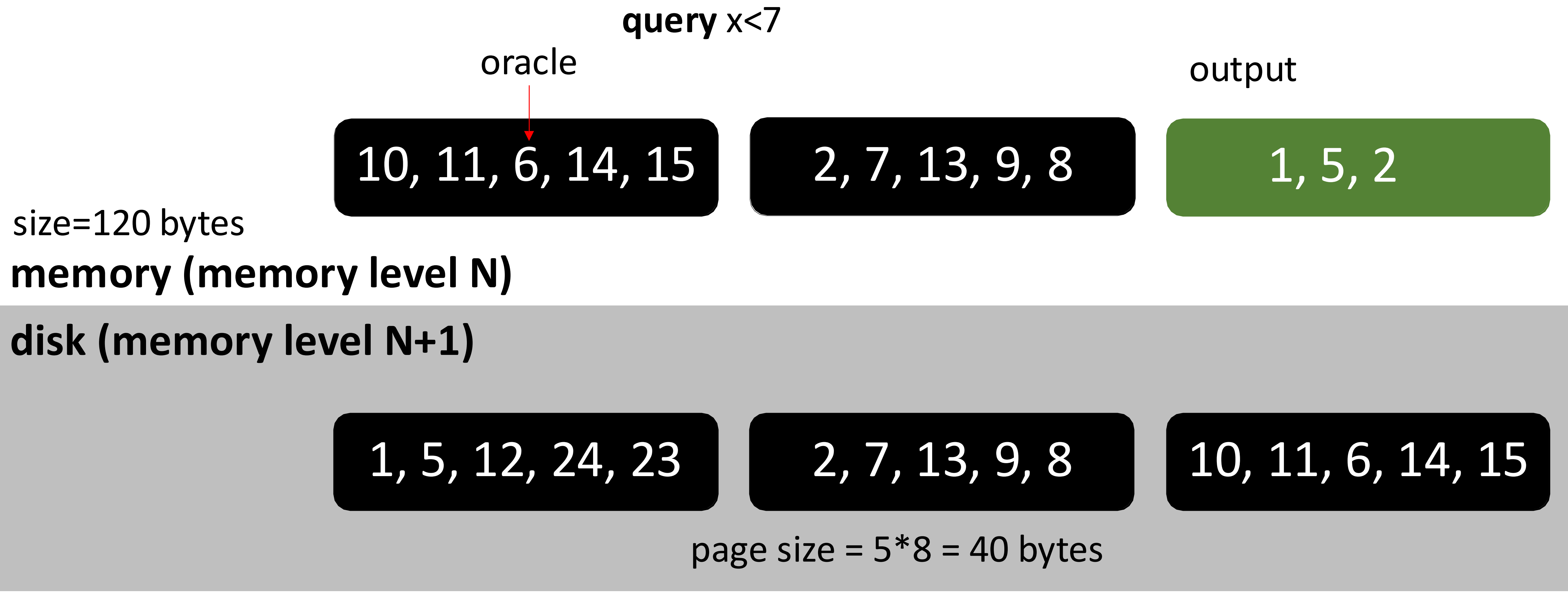

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1, 5, 2

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Page-based access & random access

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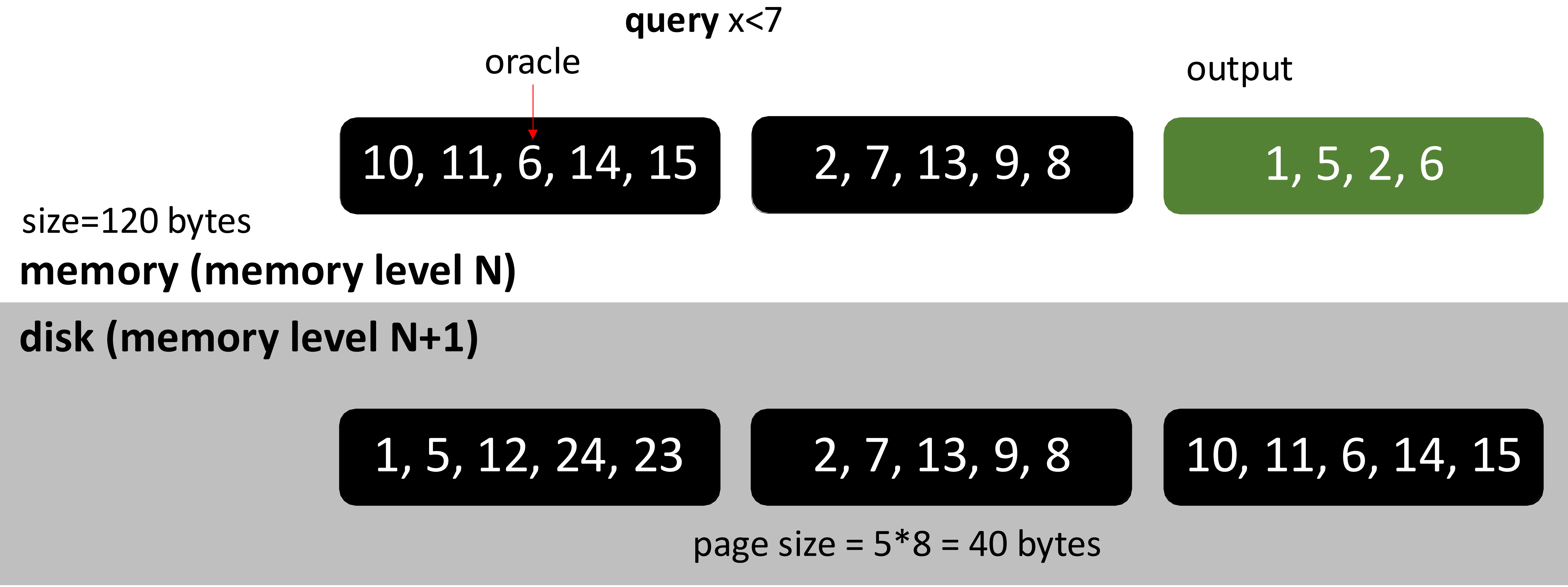

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oracle

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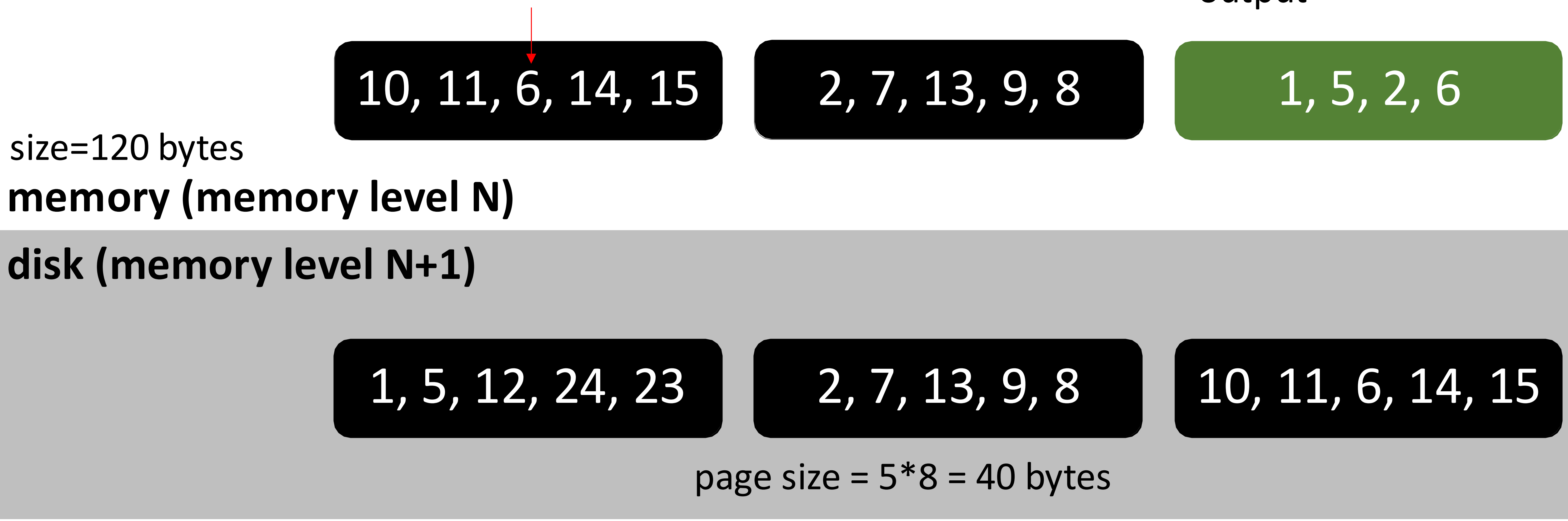
query x<7

was the oracle helpful?



oracle

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disk (memory level N+1)

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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

how we store data

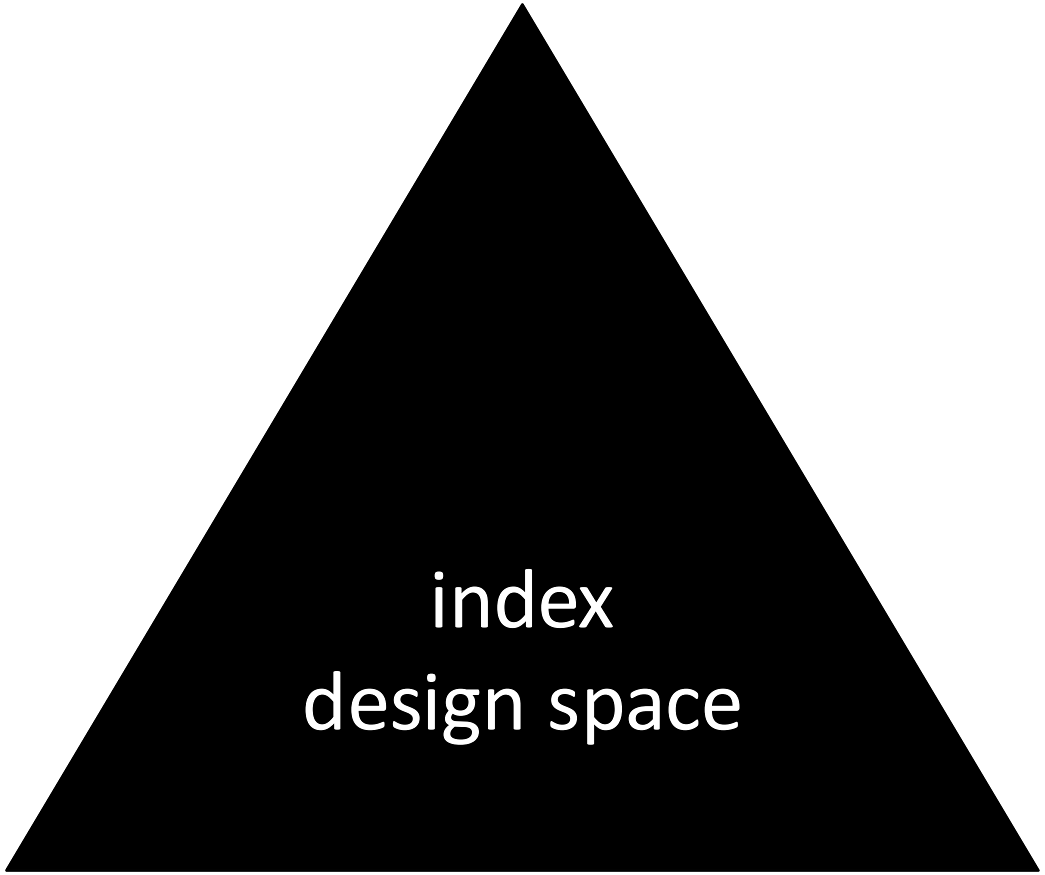
layouts, indexes

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++

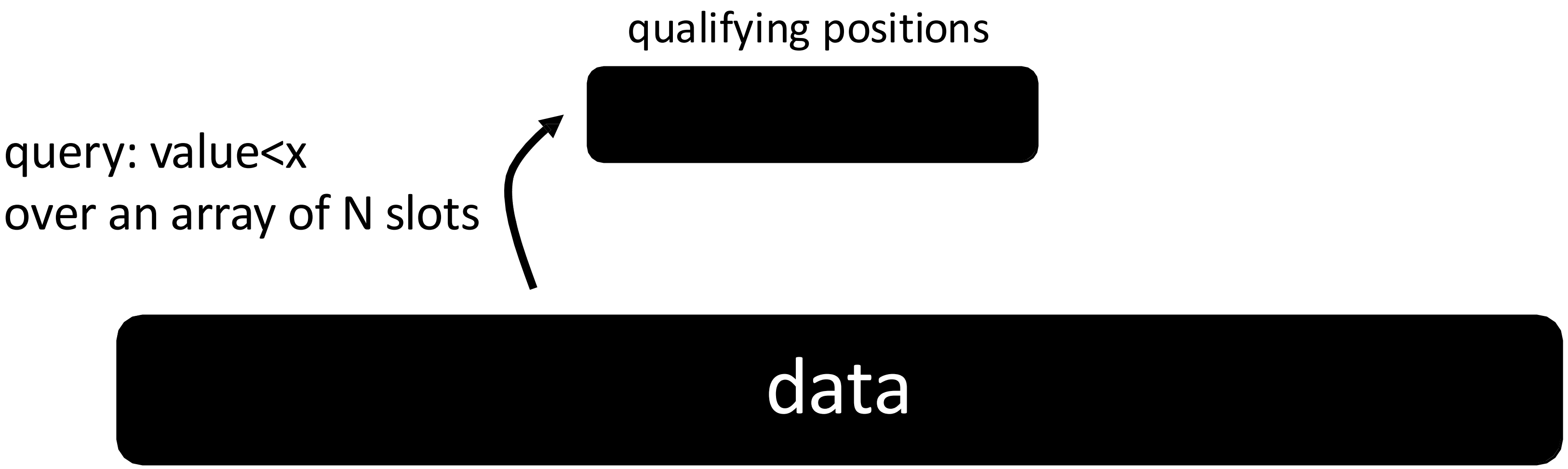
why?

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

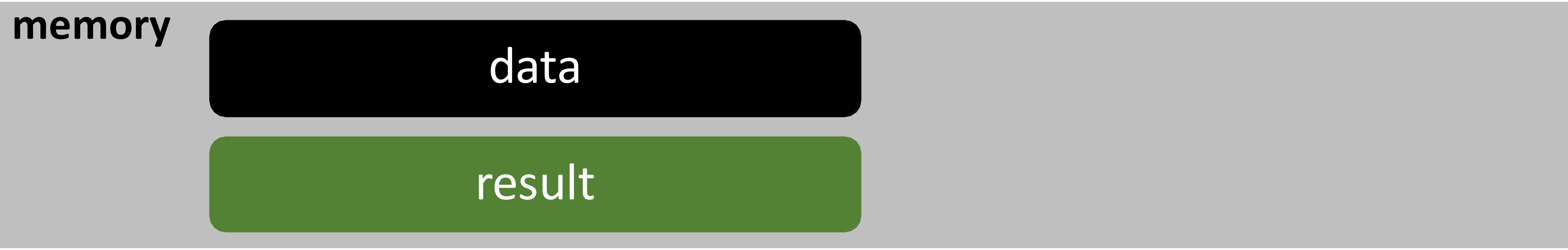
How to implement it?

```
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?

qualifying positions

query: value<x
over an array of N slots

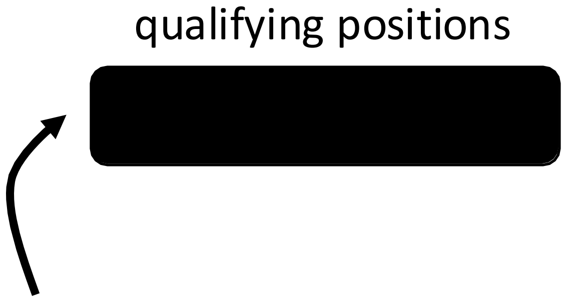


memory

data

result

How to implement it?



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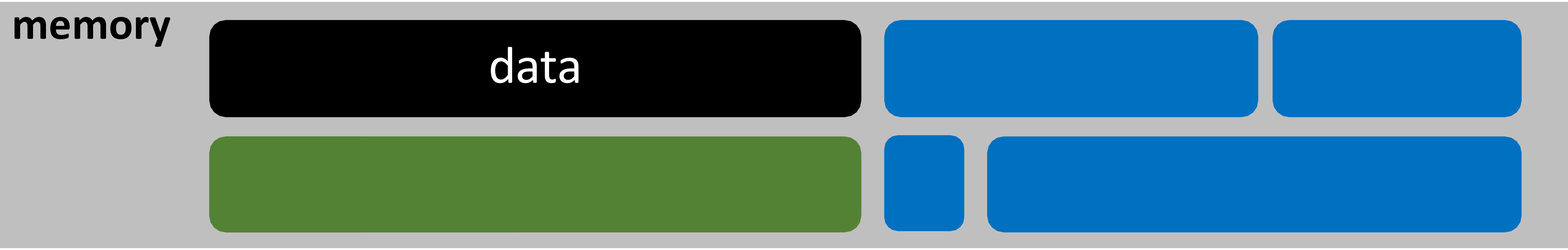

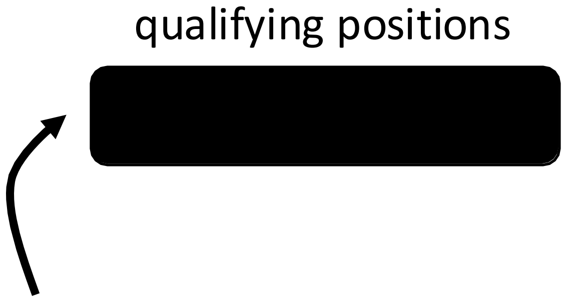

qualifying positions

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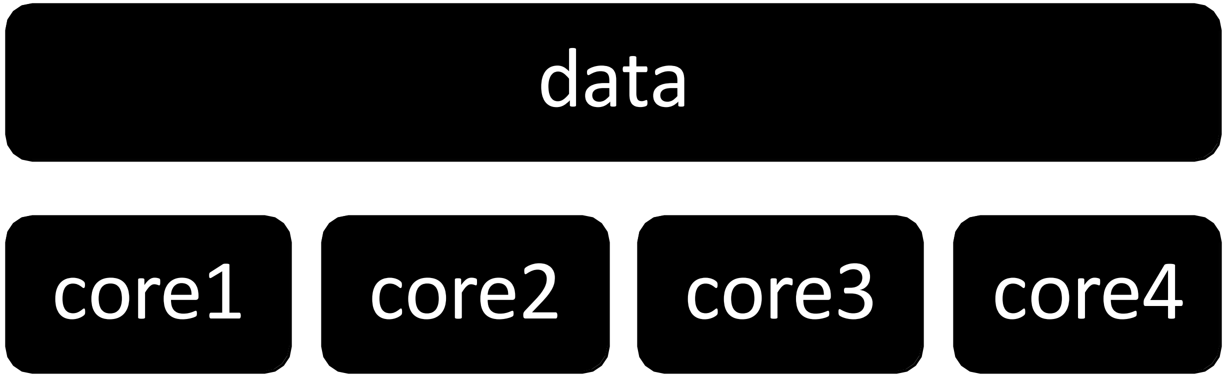
```

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



data

core1 core2 core3 core4

needs coordination!
what about result writing?

What about having multiple queries?

query1: value<x1
query2: value<x2 …

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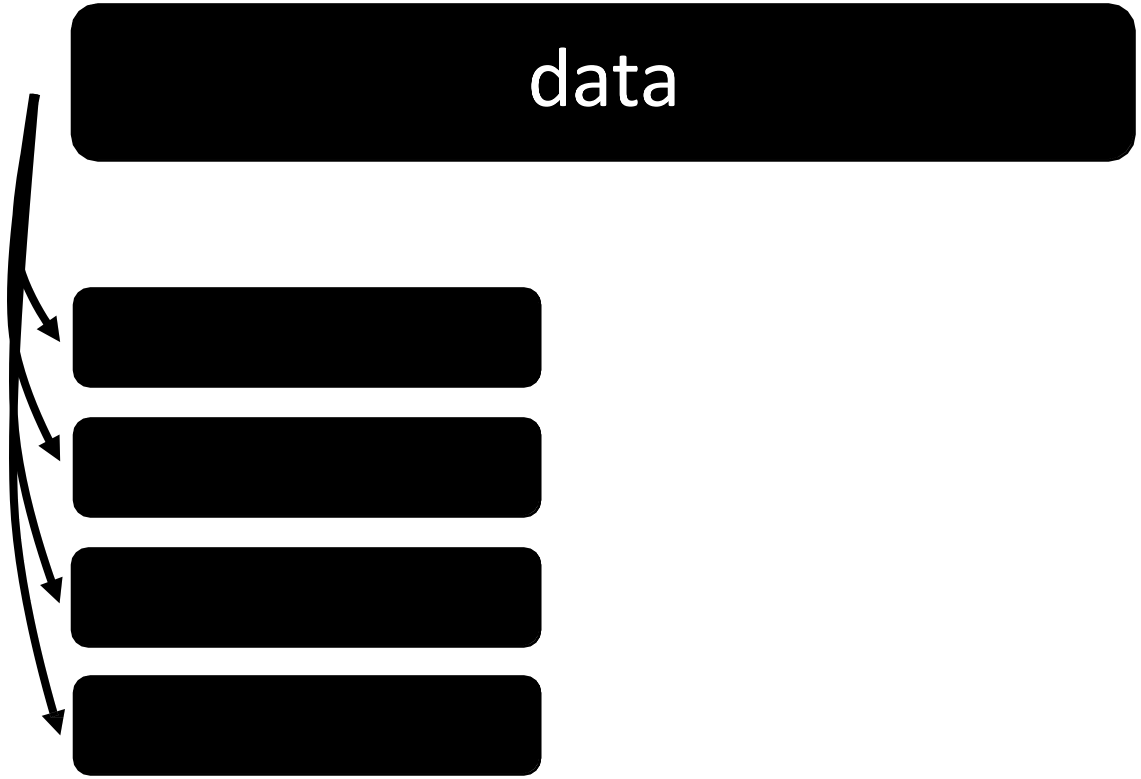
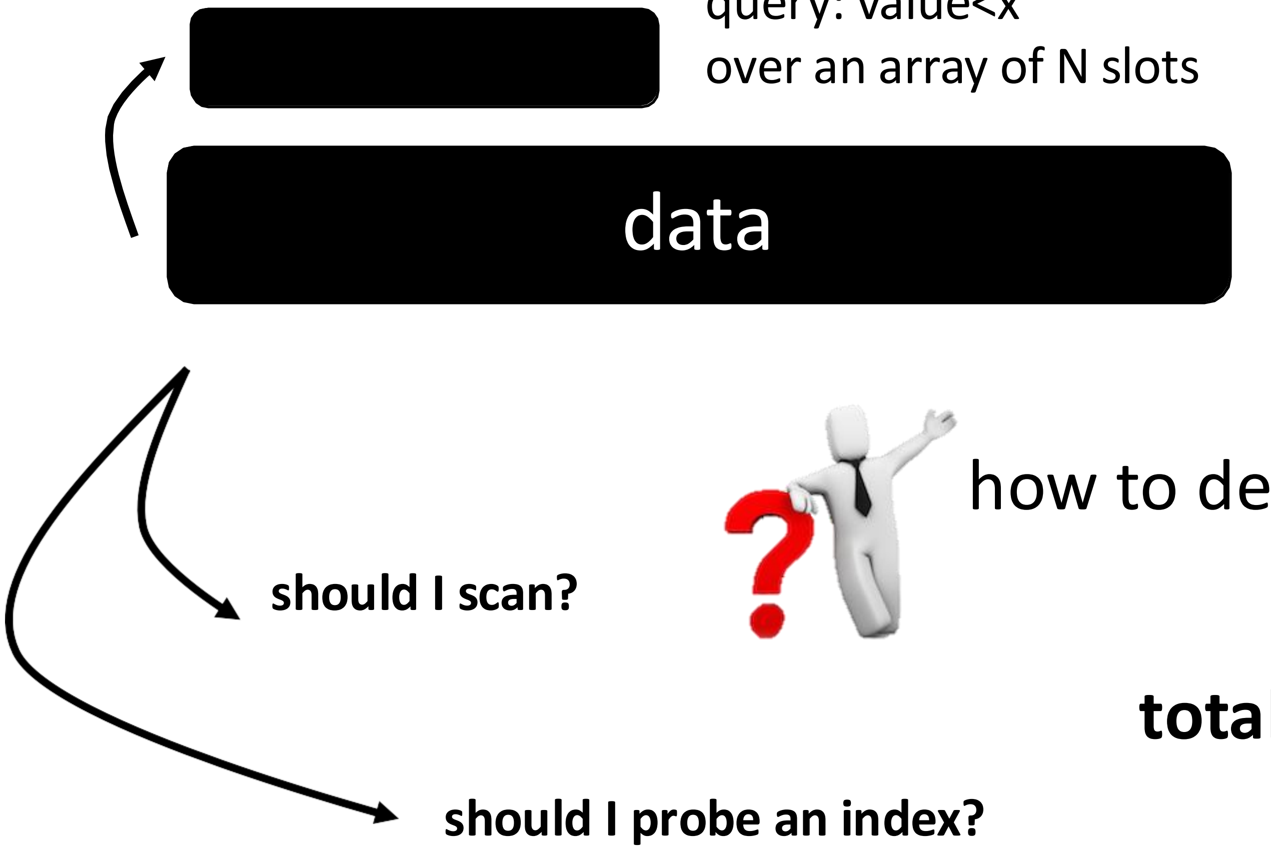
```



data



query: value<x
over an array of N slots

should I scan?

should I probe an index?

how to decide which one is best?

total data movement

&

computation

Next class

- In-memory indexing

Make sure to read the related papers from the reading list