CS 265

Big Data & AI Systems

NoSQL | Neural Networks | Image AI | LLMs | Data Science

Scope: End-to-end AI systems
Topics: LLMs, Context, Agents, RAG
Inspiration: Research + Industry
Technical: Storage/Computation/Self-designing
Projects:

Systems (LLM core, or design)
Research (LLM compiler, RAG, Image, Fine-tuning, Context Management)
Research is open to 165 & systems students but eventually open to all

Timeline:

5 weeks of introduction
then reading research papers

Goals: Develop to an “AI systems person”
Info: http://daslab.seas.harvard.edu/classes/cs265/

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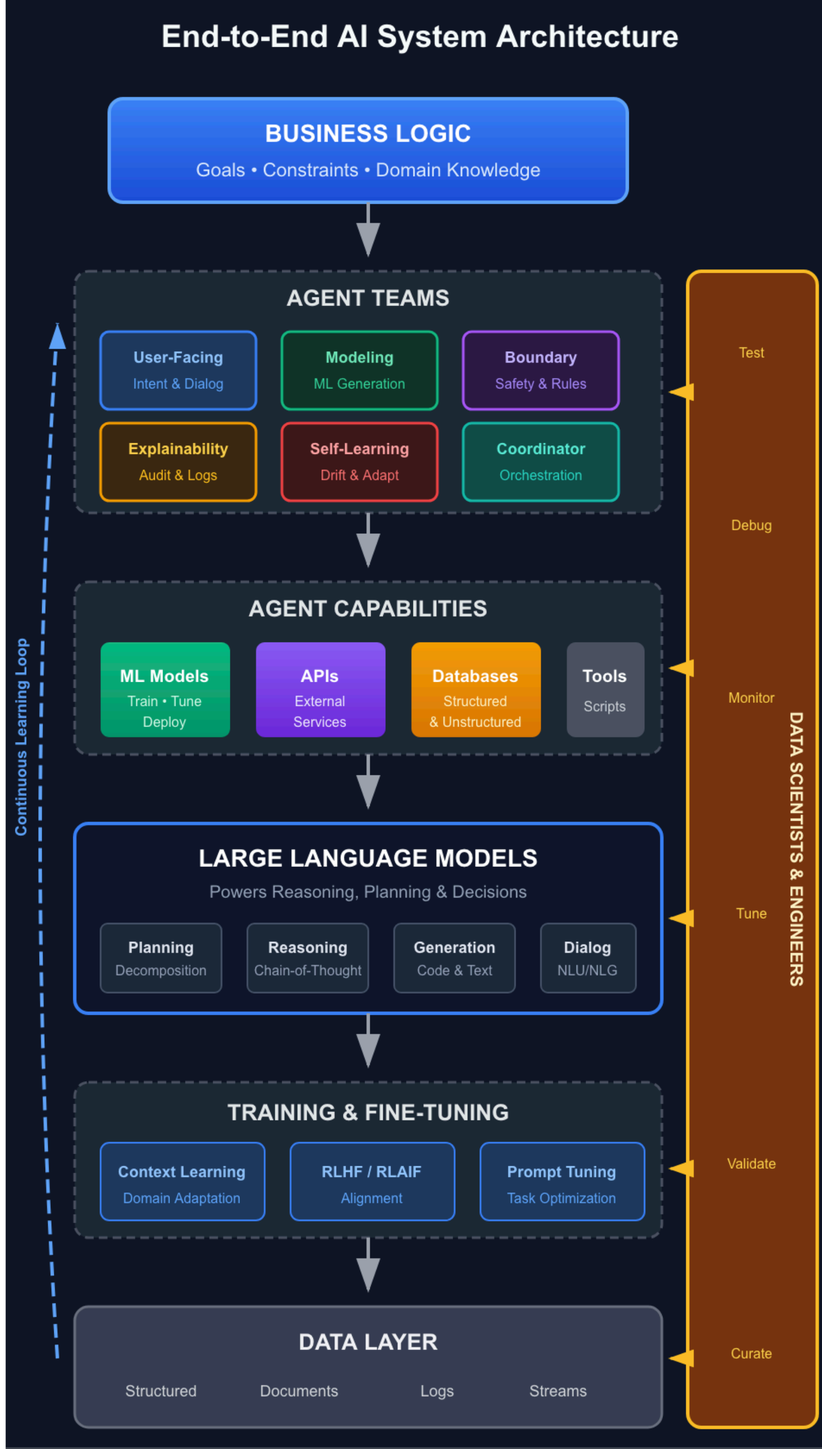

A TYPICAL BIG DATA TASK

image analysis: e.g., detect the number of horses

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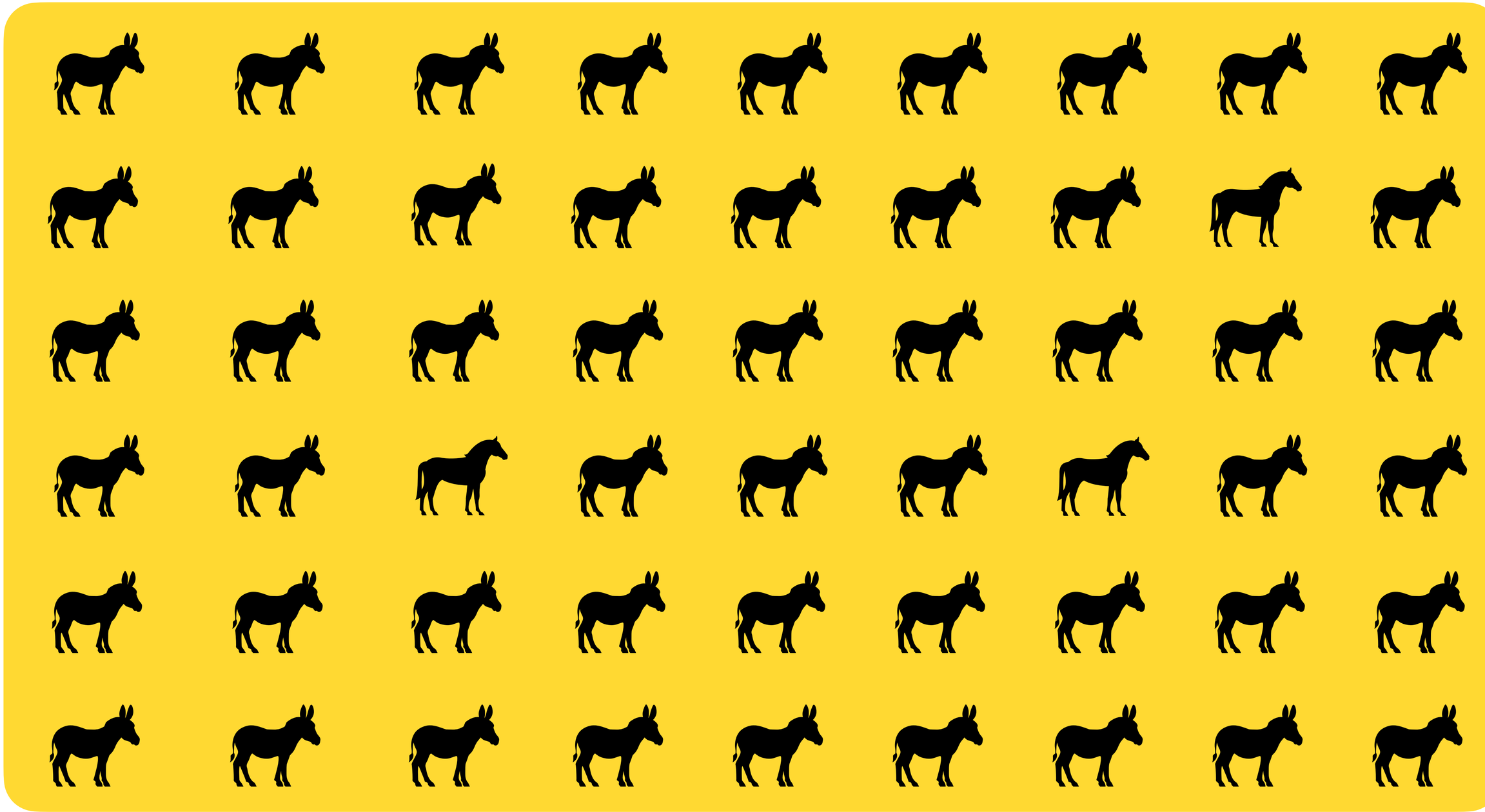
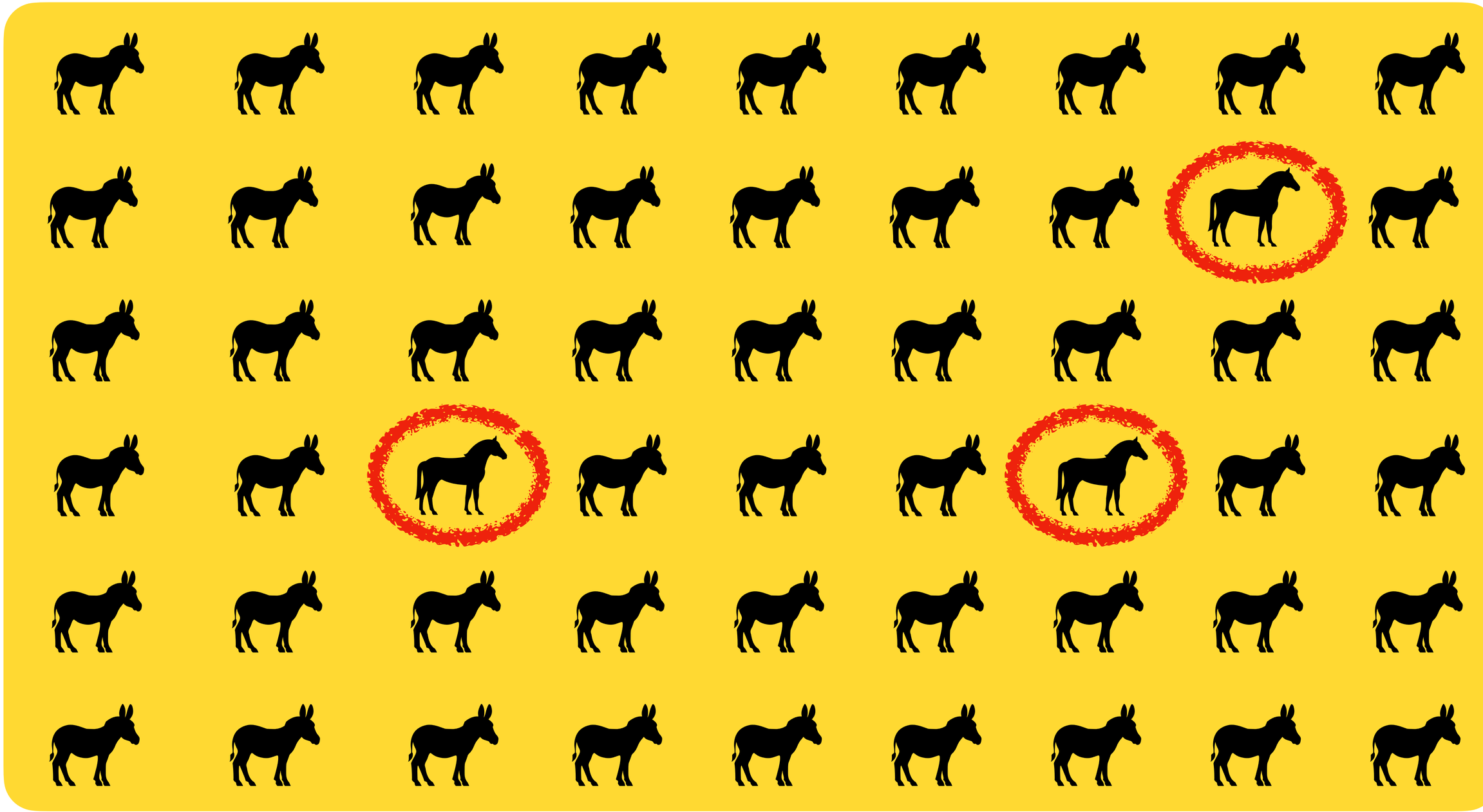


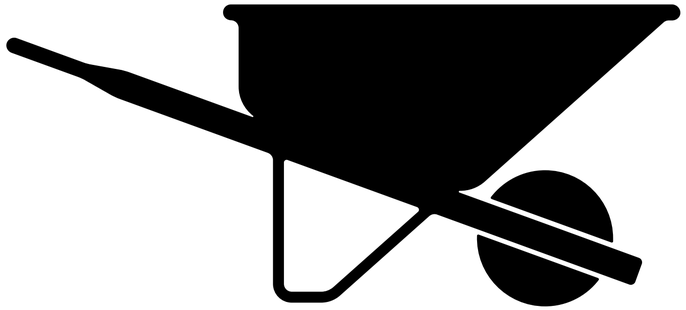


The core problem:

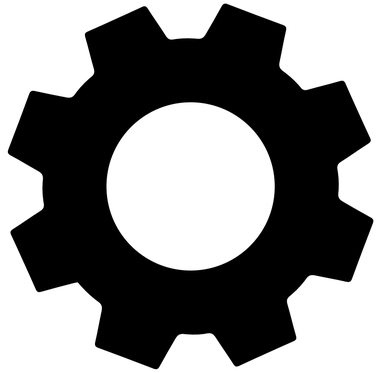
The size and organization of the data

Three steps in big data regardless of application

STORE



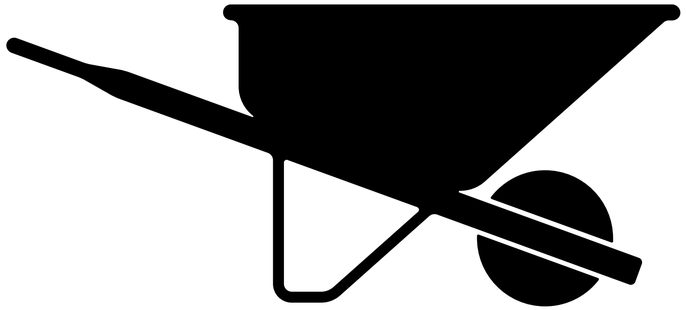
MOVE



PROCESS

Three steps in big data regardless of application

STORE



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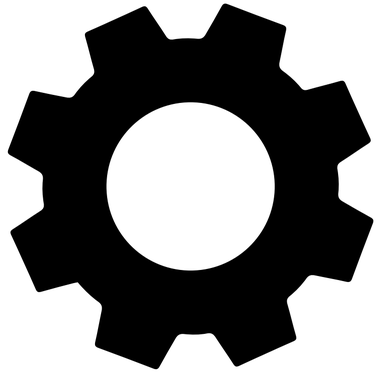

PROCESS

How fast we can move and process data depends on the storage design decisions

50-80% of end-to-end time is due to storage-related decisions

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learning outcome
Fundamentals of storage

data structures, SQL, NoSQL, Agents, LLMs, RAG, Data Science, Image AI

learning outcome
Fundamentals of storage

data structures, SQL, NoSQL, *Agents, LLMs, RAG, Data Science, Image AI*

same set of principles across all fields (performance: design & implementation)

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from algorithms to systems

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This class helps with:

software (systems) engineering jobs
joining data-driven startups
starting with research

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software (systems) engineering jobs
joining data-driven startups
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This class does not help with:

using systems

it helps with designing and building systems

First ~5 weeks:

Background on basic systems concepts (storage)
Intro into the concept of self-designing systems

Systems for: RAG, Image AI, LLMs

What is a data system?

A data system is an end-to-end software system that:
manages storage, data movement, and provides access to data

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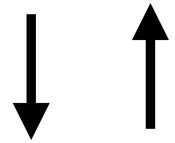
A system is a complex set of components

interacting in harmony depending on the context

exposing as little as possible complexity to users

declarative interface

ask ‘’what’’ you want



data* system

the system decides
“how” to best store
and access data

declarative interface

ask ‘’what’’ you want

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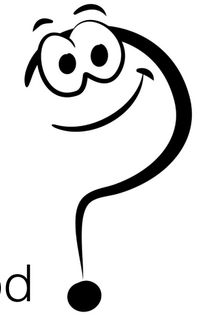


why is this good

~6 decades of research

started with IBM, Microsoft, Oracle, Teradata,etc.
and a gazillion start-ups today

declarative interface
ask ‘’what’’ you want

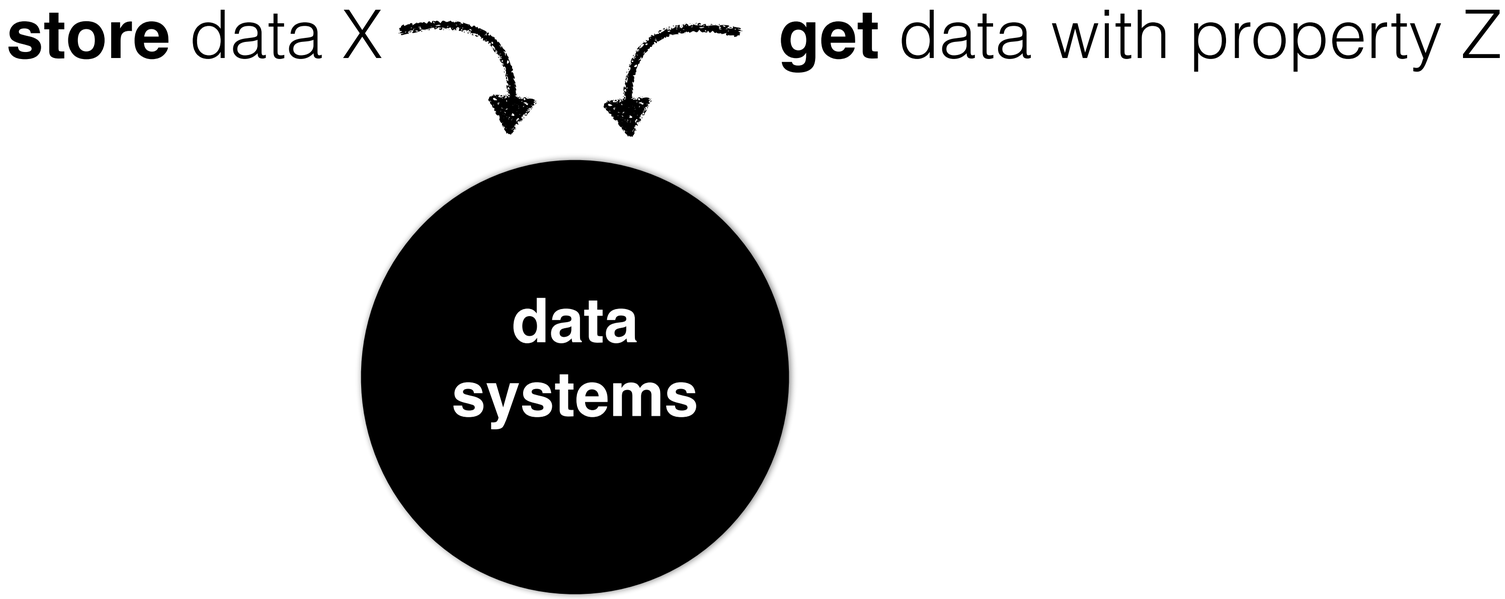
data* system

the system decides
“how” to best store
and access data

why is this good

1. For decades: data systems = SQL DBs
   but with big data, the need for fast data systems is drastically broader than SQL

broader than SQL



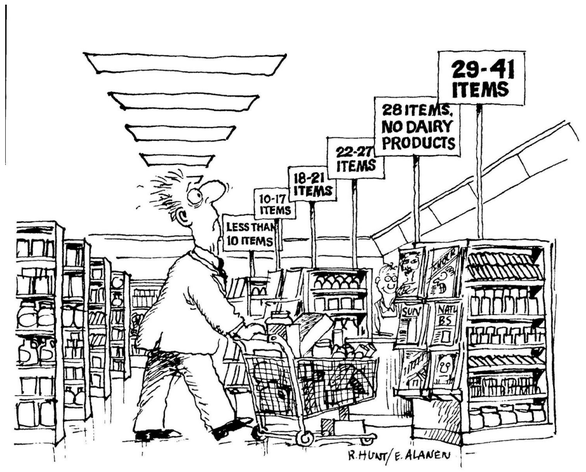
broader than SQL

big data apps

data systems

ANALYTICS

AI



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broader than SQL

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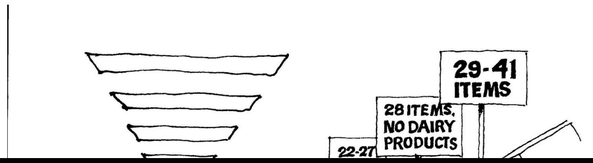

New data systems to handle new requirements

broader than SQL

TRANSACTIONS

Deposit money to my bank account

Transfer money from … to…

broader than SQL

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ANALYTICS

How much do customers
of X spent on average every month?

broader than SQL

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ANALYTICS

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of X spent on average every month?

AI

Is this transaction legal?

Should we give a loan to customer X?

SOCIAL NETWORKS: REVIEWS/POSTS

How many costumers on average
leave a 4 star review or better?

broader than SQL

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Is this new review a legitimate one?

broader than SQL

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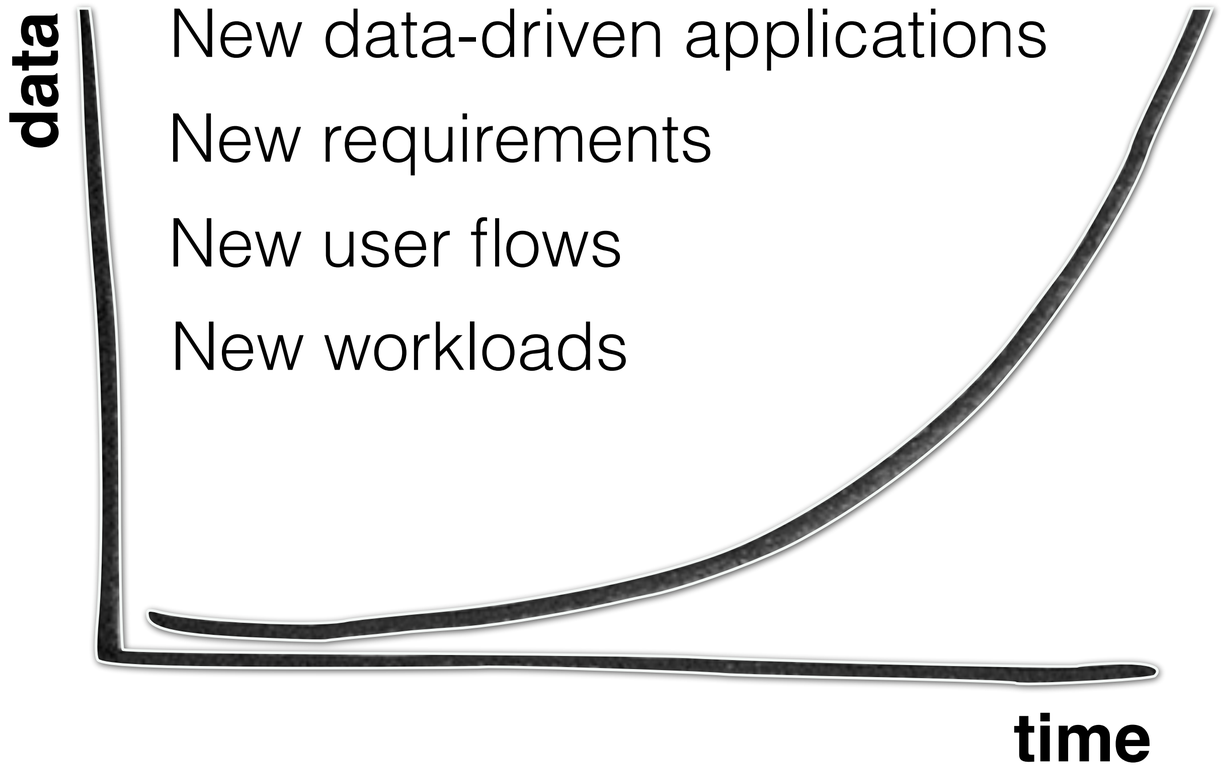
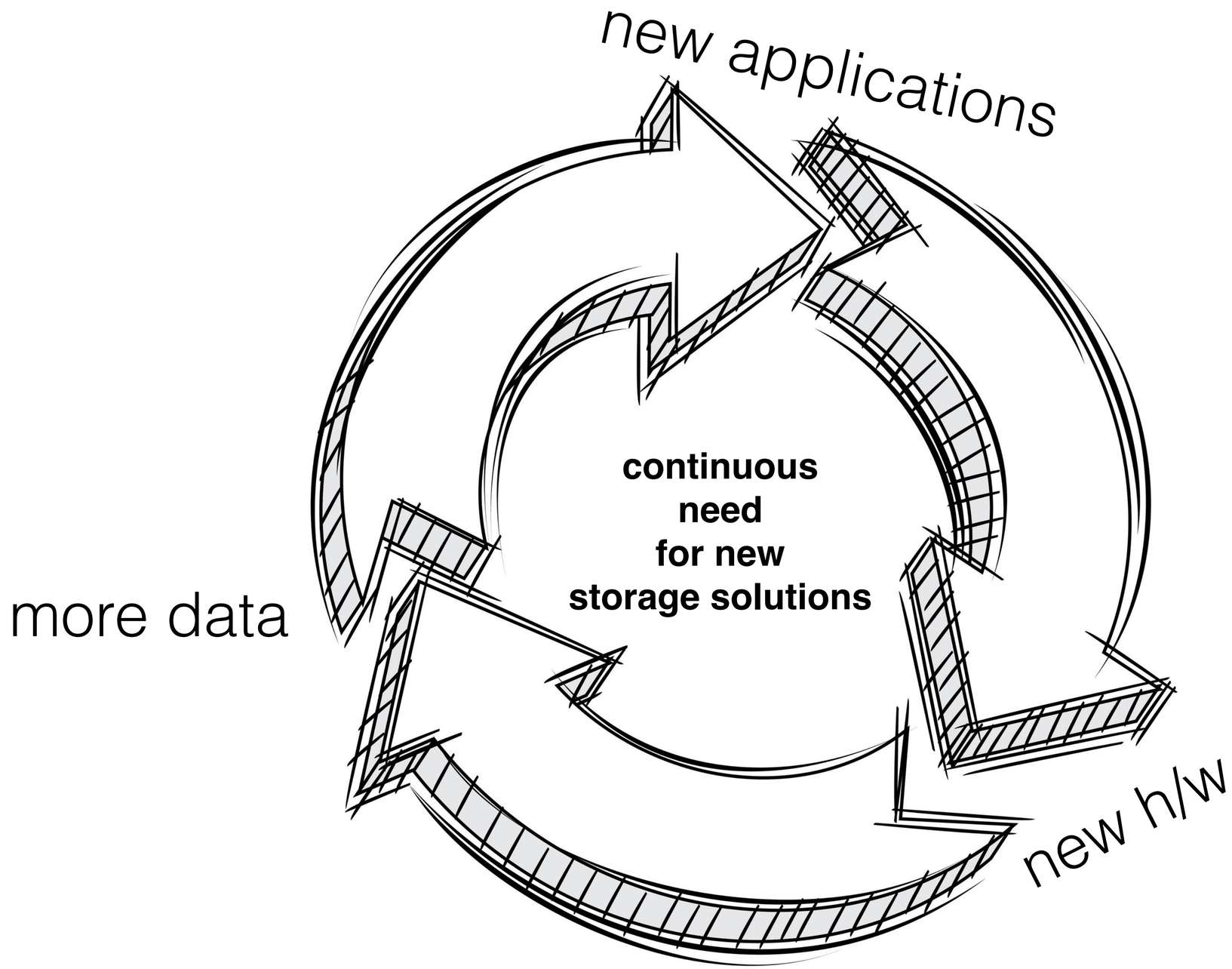
COMMUTING

Compute price for next Uber ride



The need for data systems grows with data


new applications
more data
continuous
need
for new
storage solutions
new h/w

2. As data grows, having the right data system
for each application is increasingly more critical

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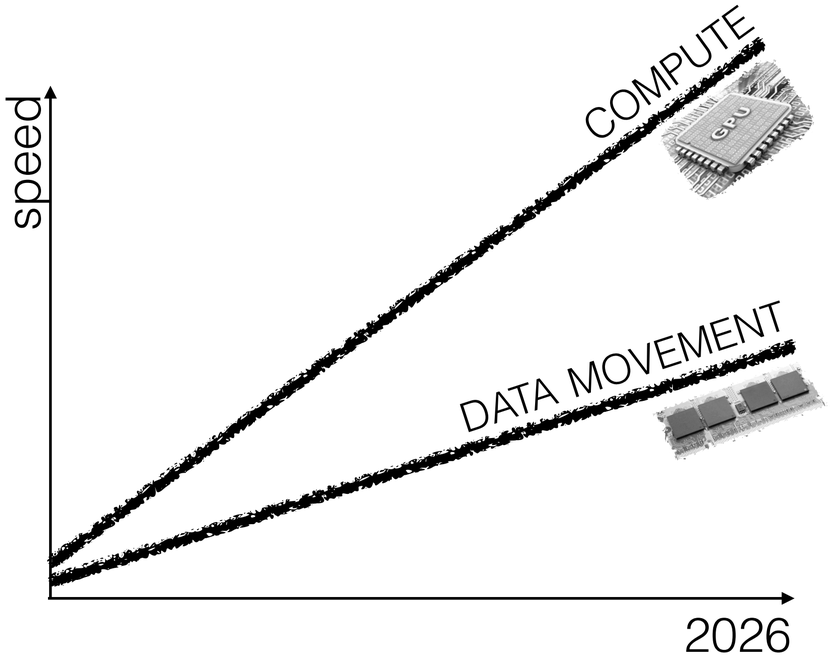
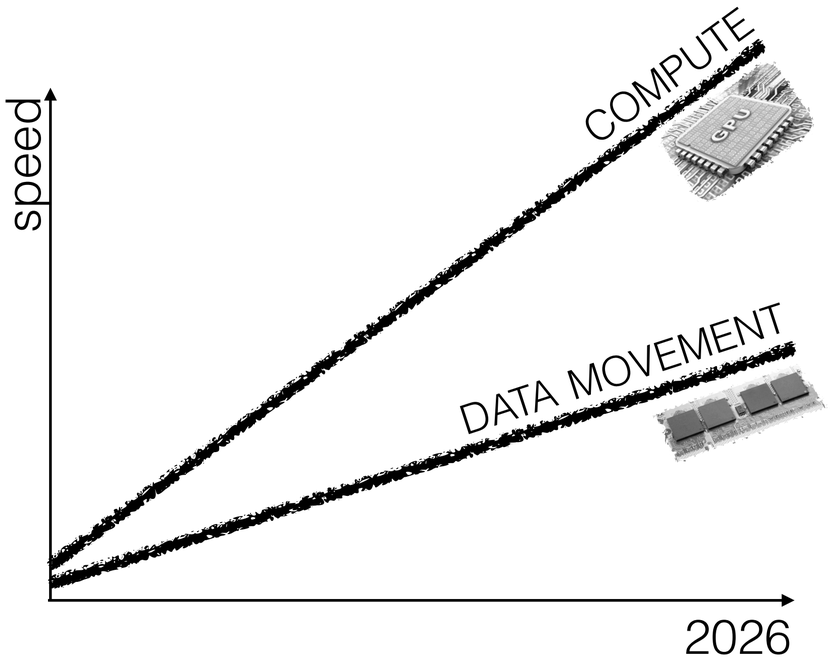
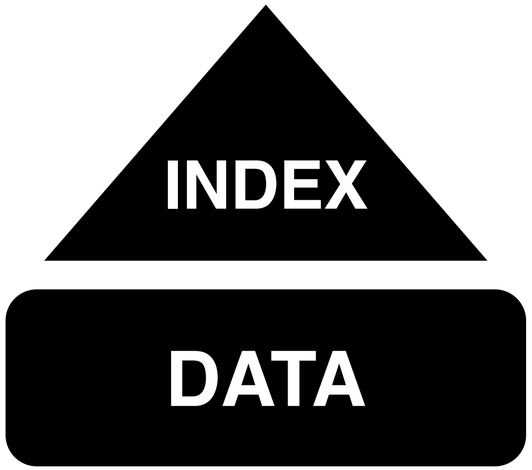
system architecture
it starts with storage

the right data system





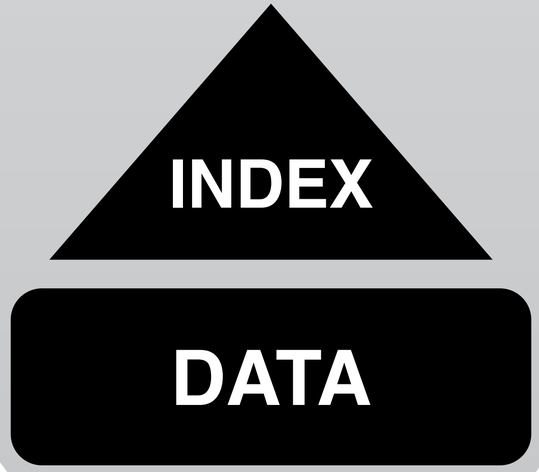
System architecture design gets more complex with bigger data and new diverse hardware



HOW TO STORE DATA

ALGORITHMS

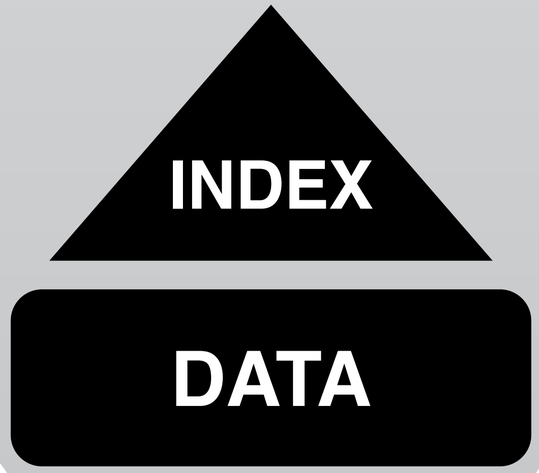
data structure decisions define
the algorithms that access data



ALGORITHMS

unordered

[7,4,2,6,1,3,9,10,5,8]



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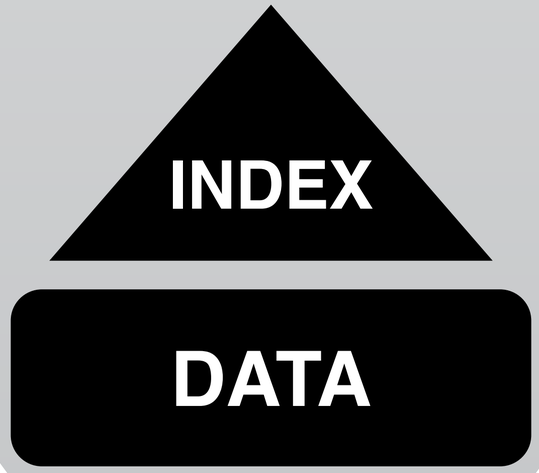

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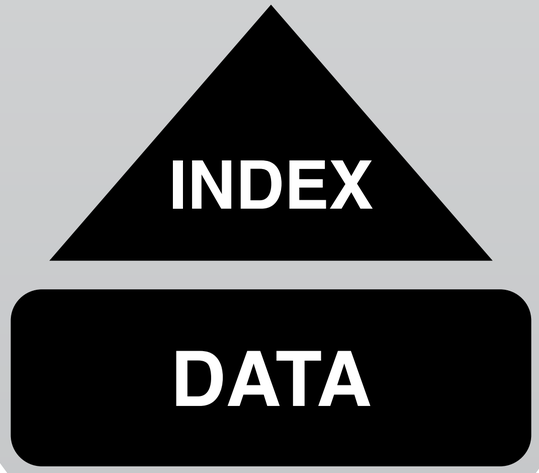
ALGORITHMS



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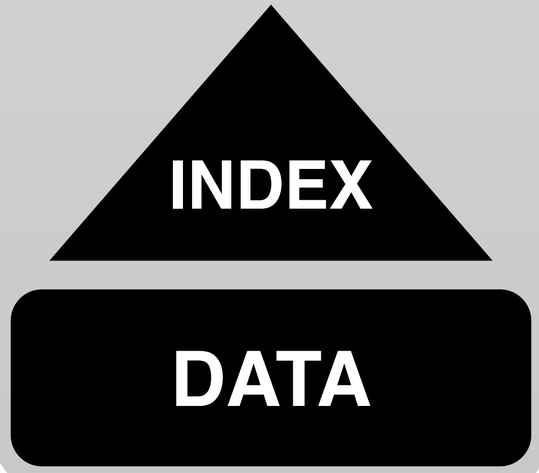
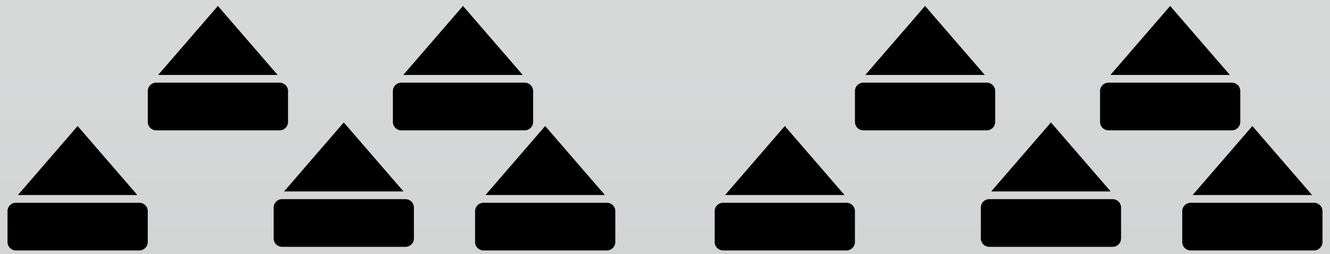
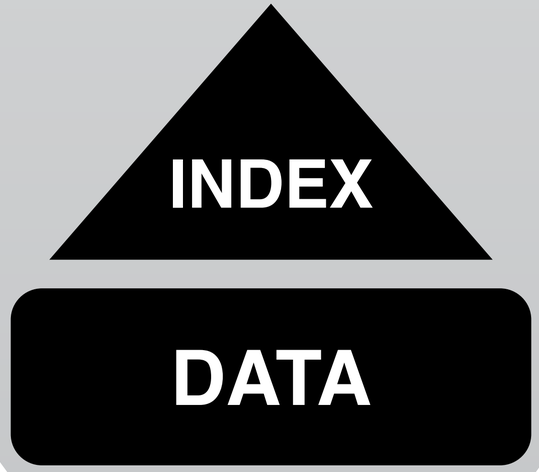
ALGORITHMS

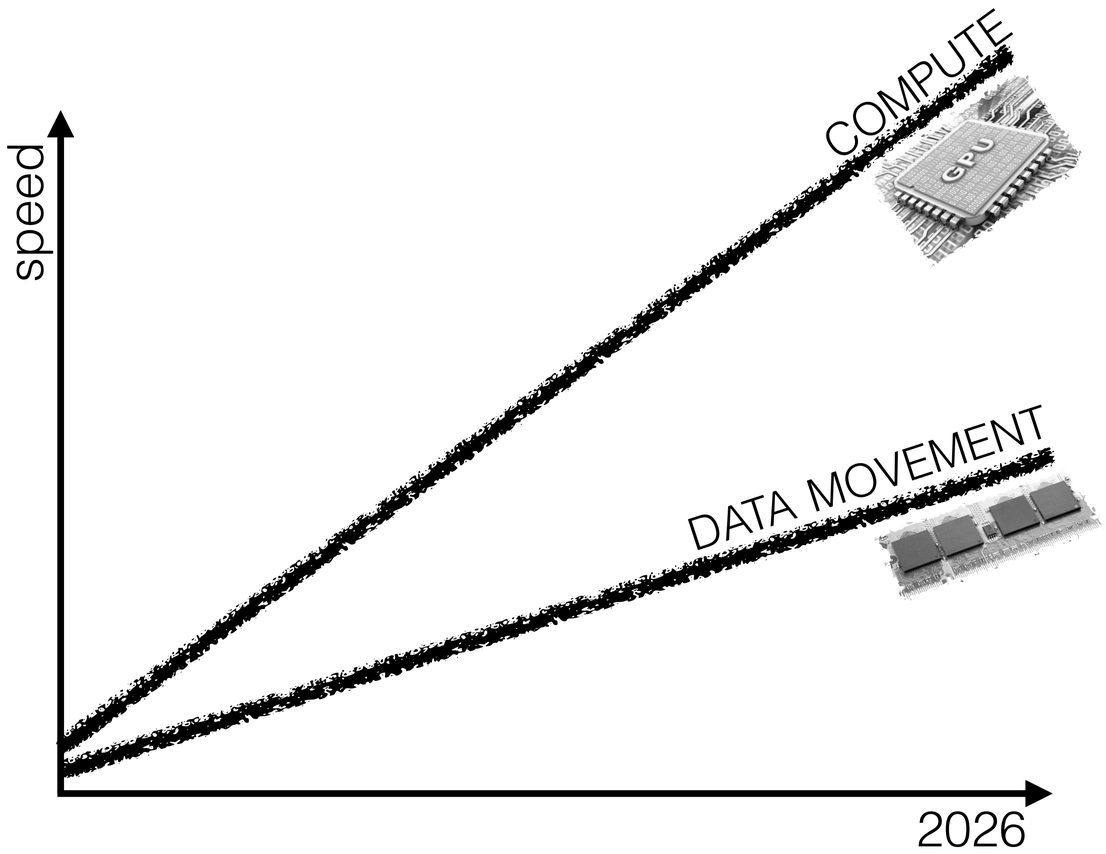


SYSTEMS

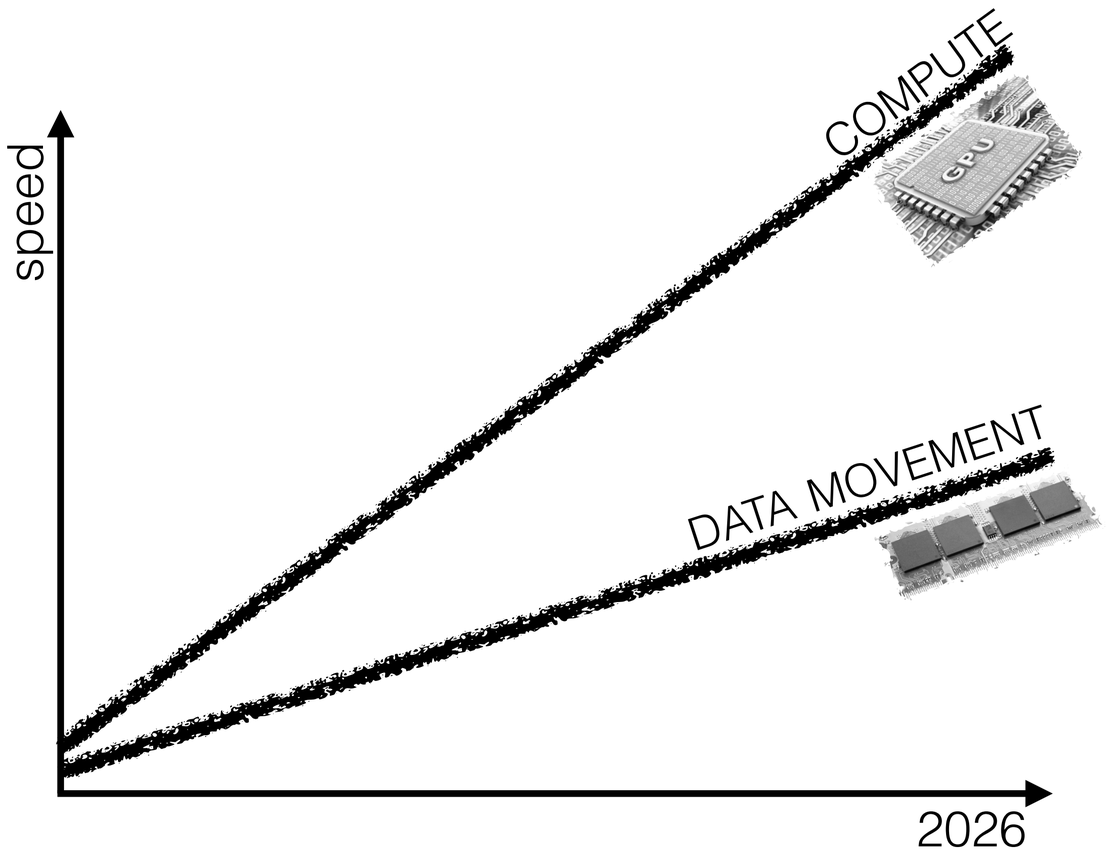


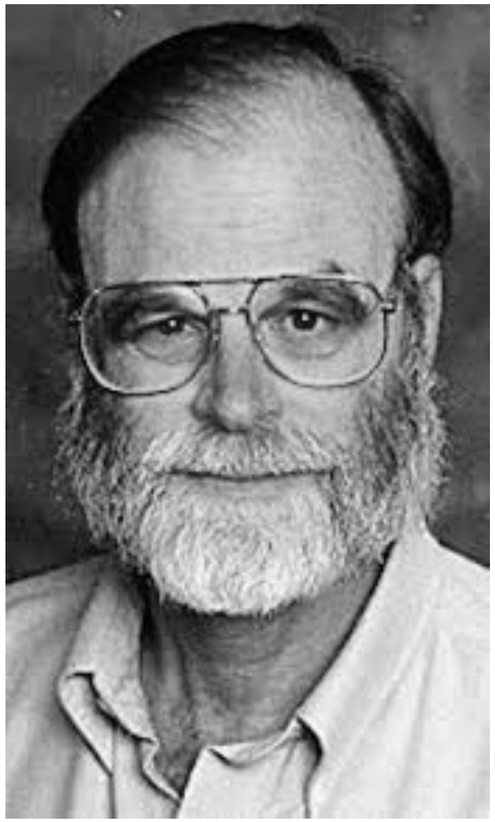
ALGORITHMS





DATA STRUCTURES DEFINE PERFORMANCE





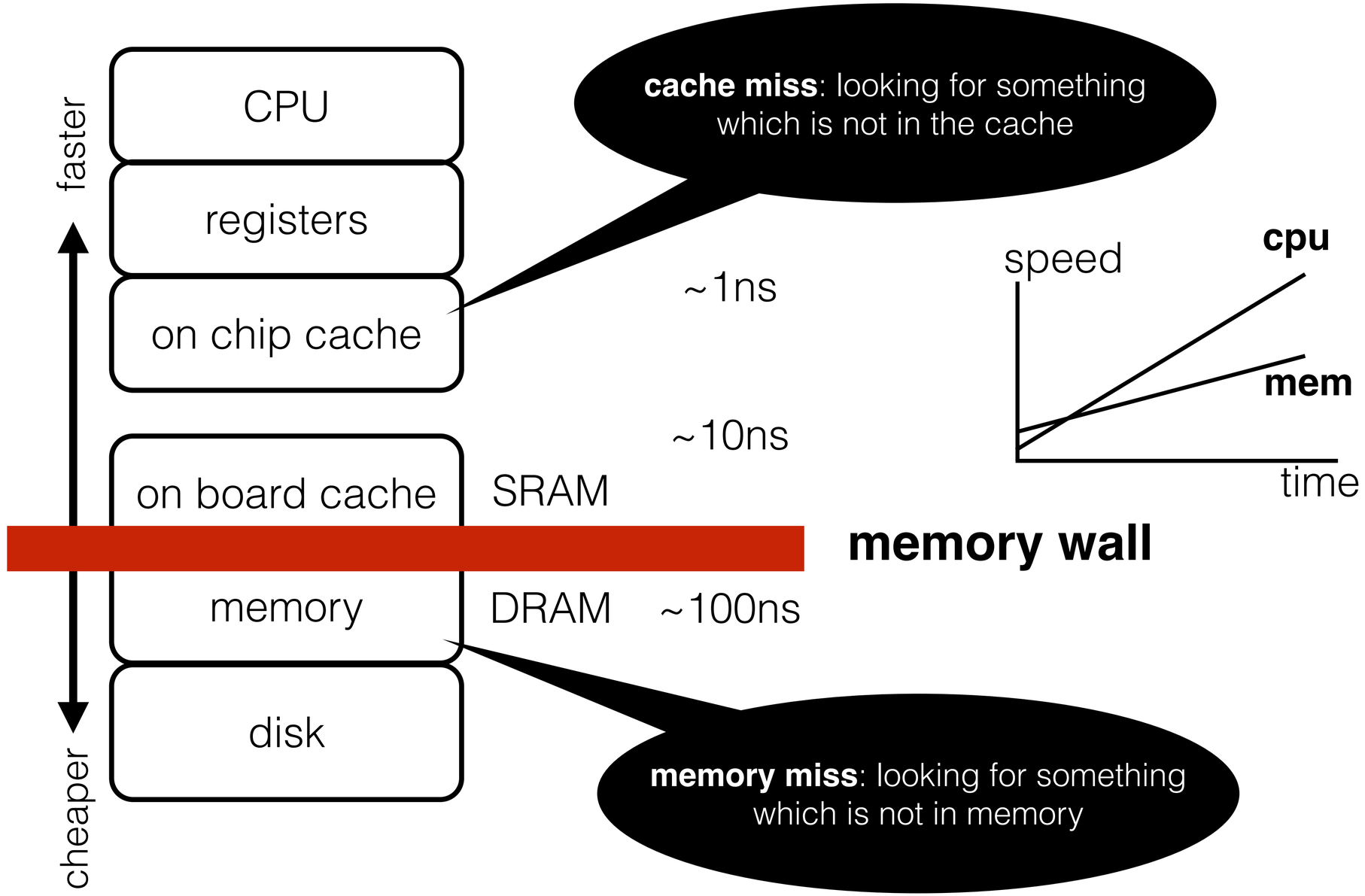
register = this room

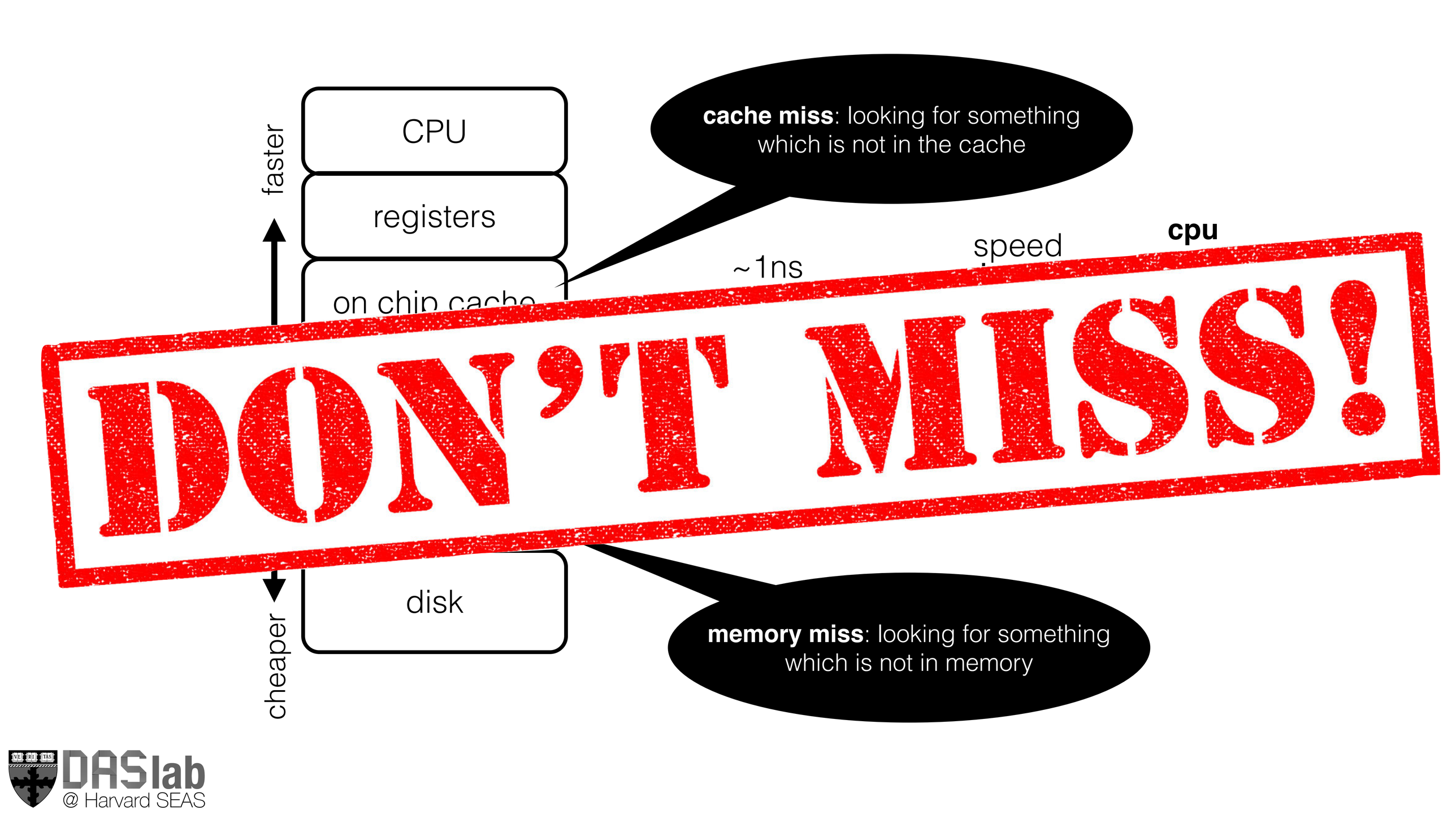
caches = this city

memory = nearby city

disk = Pluto

Jim Gray, Turing Award 1998


CPU
registers
on chip cache
on board cache
memory
disk
faster
cheaper
~1ns
~10ns
SRAM
DRAM
~100ns
cache miss: looking for something which is not in the cache
memory miss: looking for something which is not in memory
memory wall
speed
cpu
mem
time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cache miss: looking for something which is not in the cache
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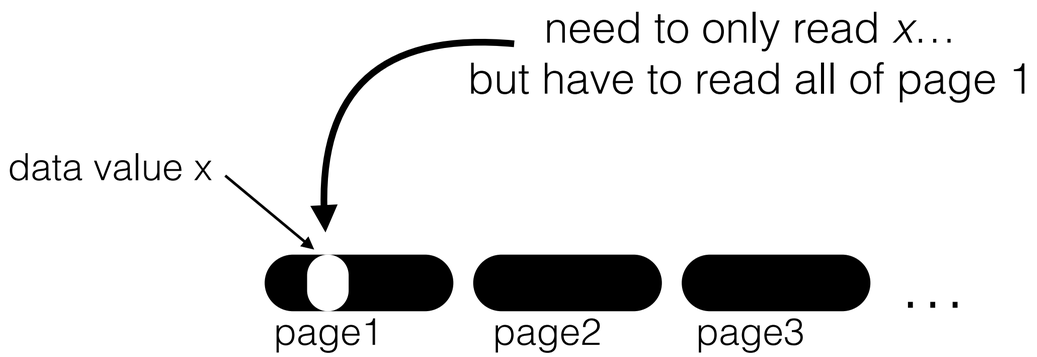
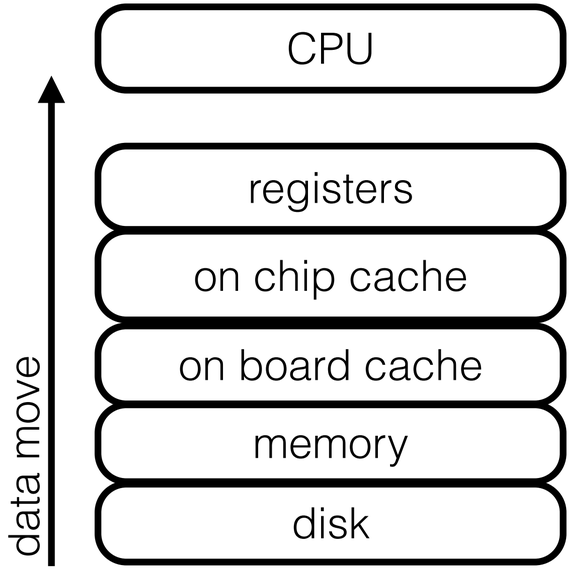
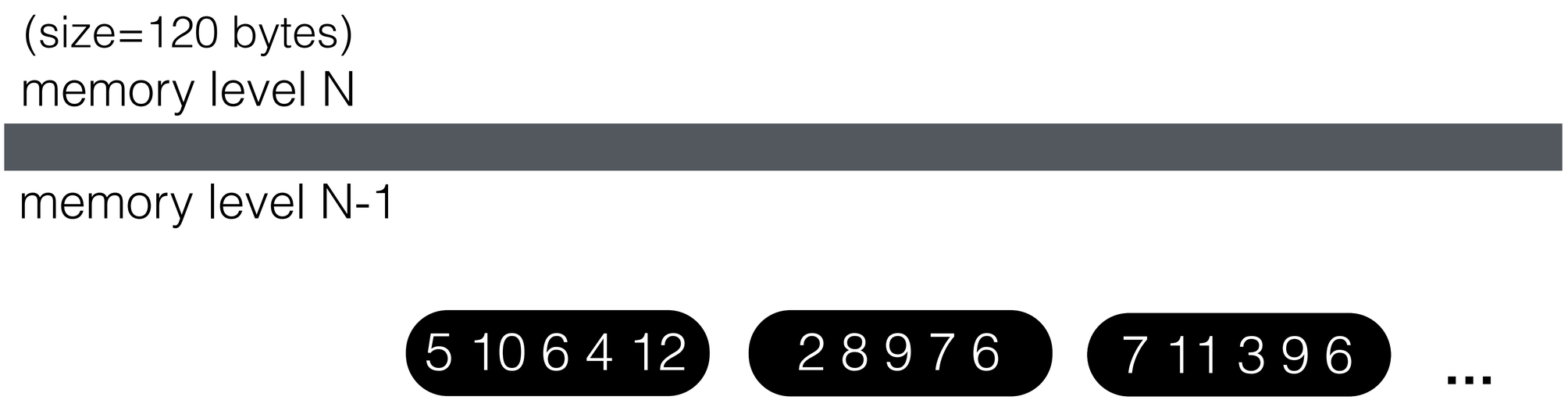
DON'T MISS!


need to only read *x*…
but have to read all of page 1
data value x
page1
page2
page3
…


CPU
registers
on chip cache
on board cache
memory
disk
data move

query x<5



page size: 5x8 bytes

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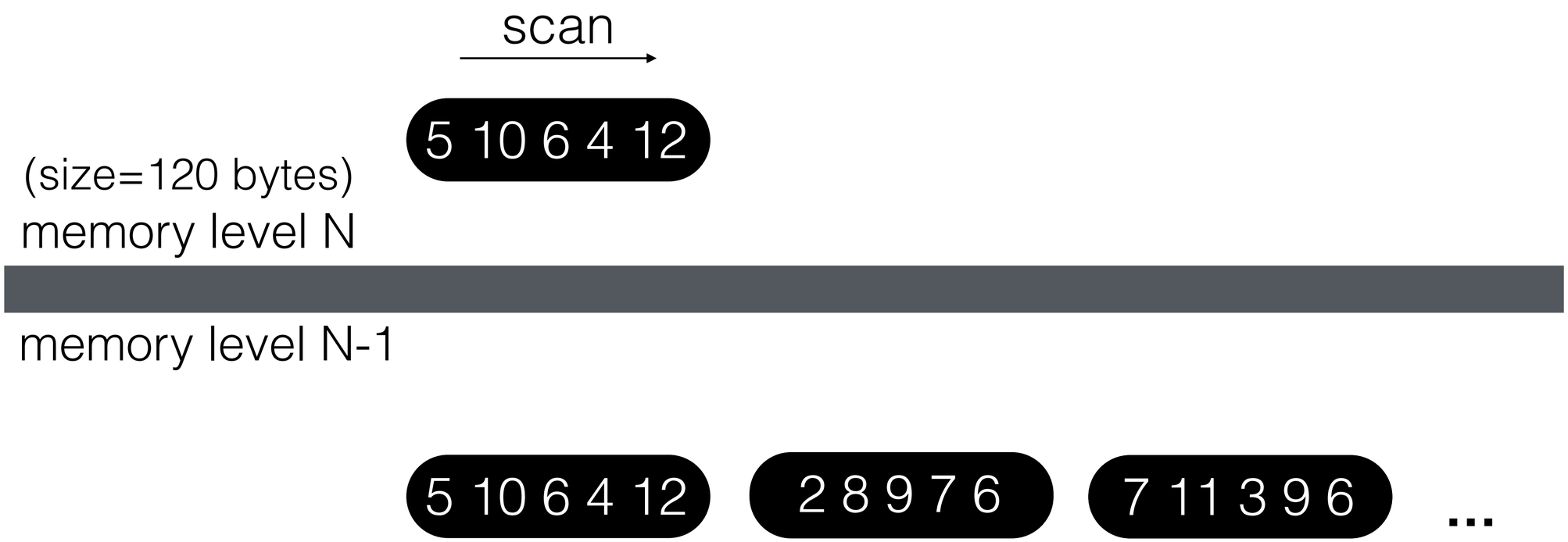

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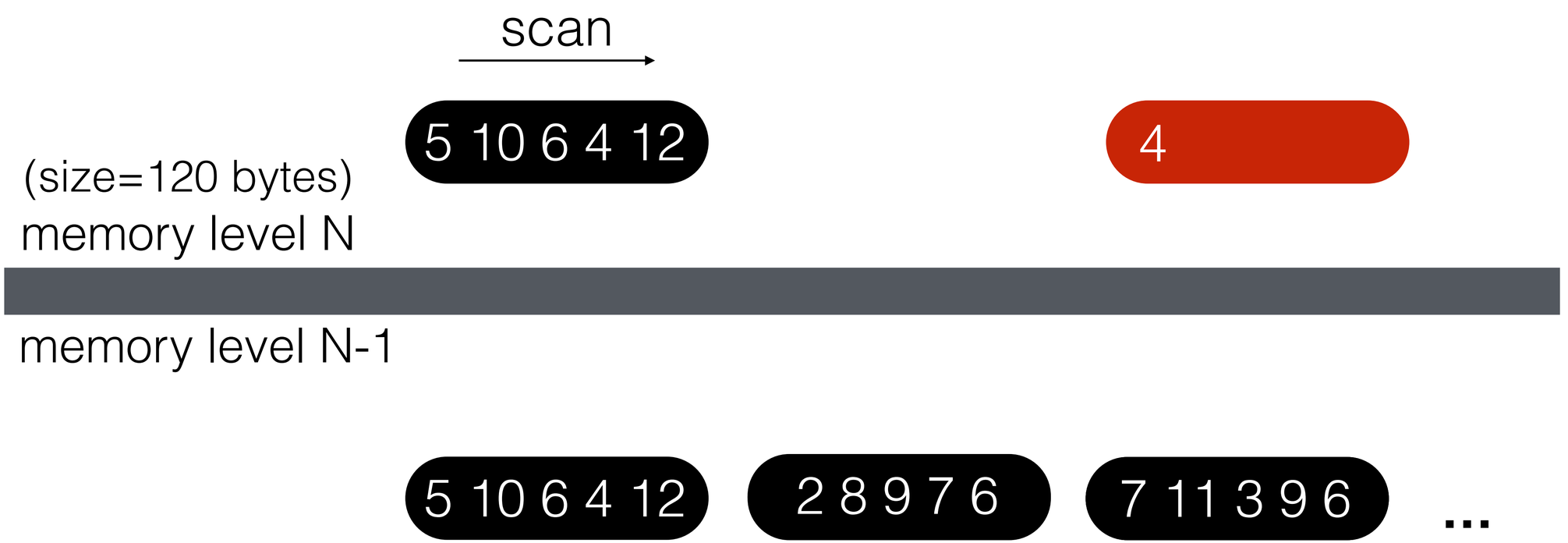

page size: 5x8 bytes

40 bytes

query x<5

scan

5 10 6 4 12

4

(size=120 bytes)
memory level N

memory level N-1

5 10 6 4 12

2 8 9 7 6

7 11 3 9 6

...

page size: 5x8 bytes

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80 bytes

query x<5

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an oracle gives us the positions

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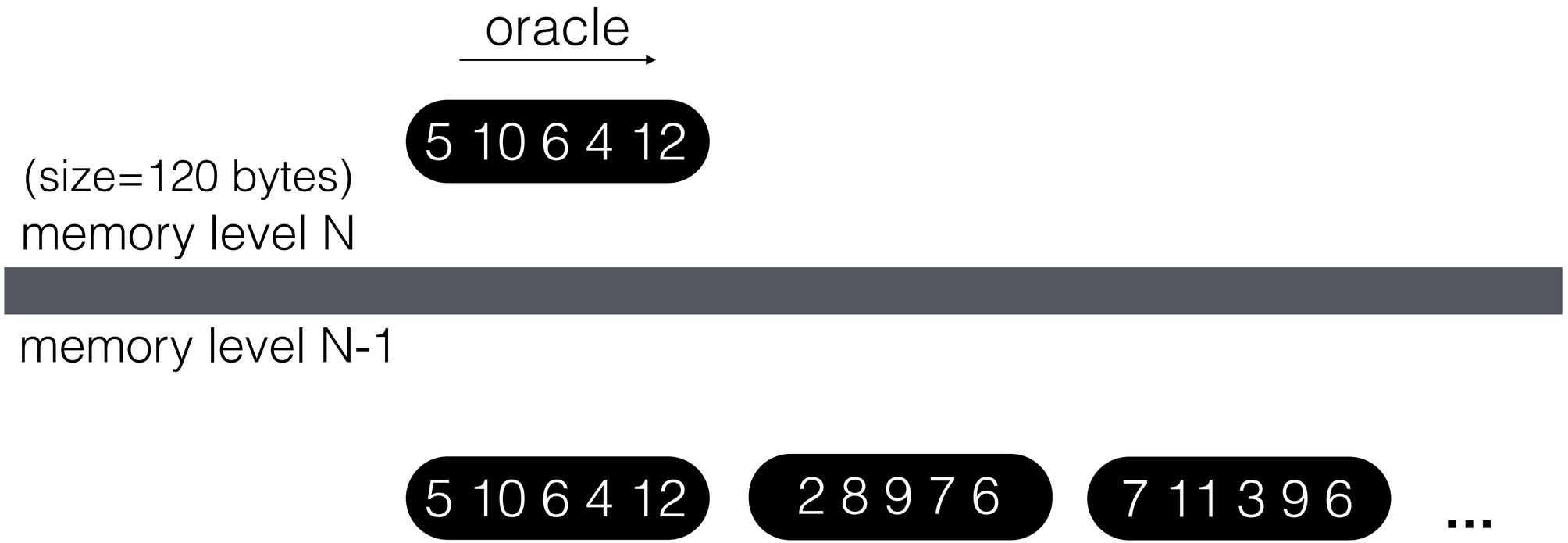

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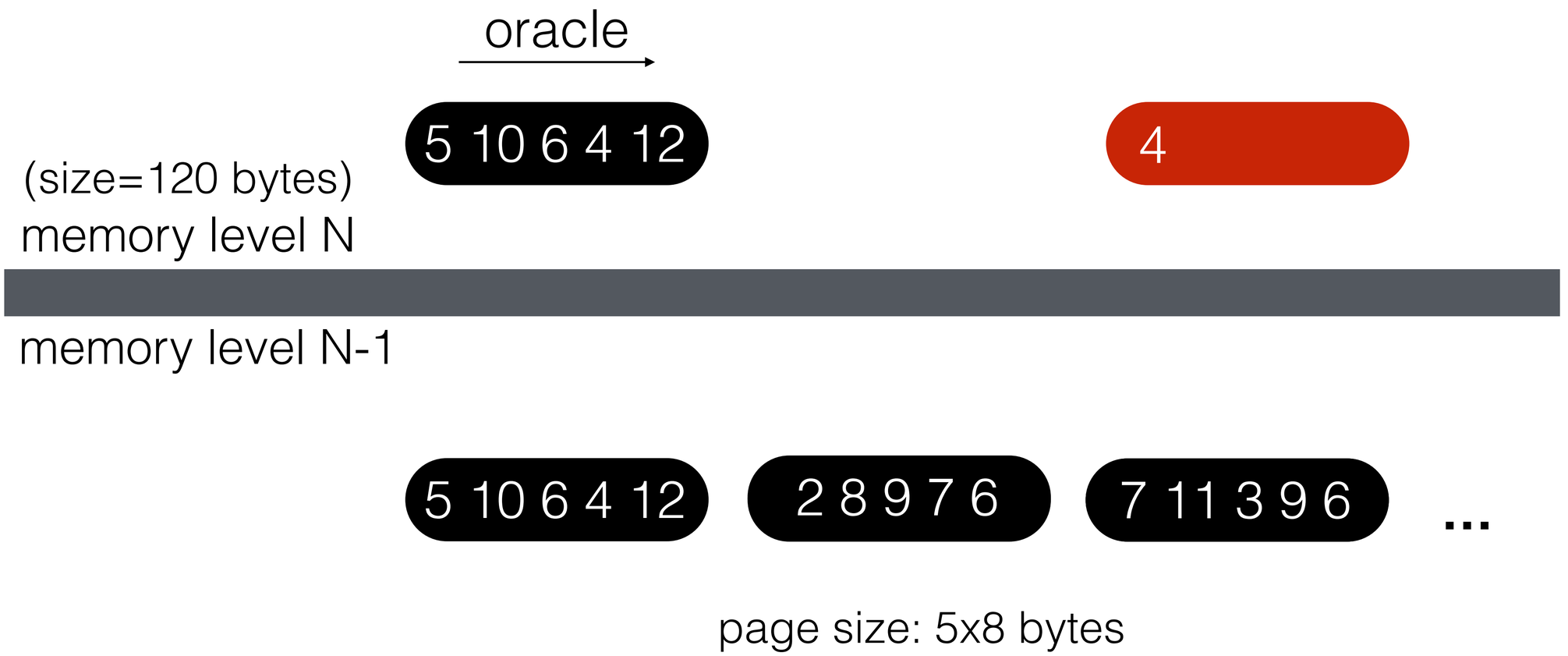

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memory level N-1

5 10 6 4 12

2 8 9 7 6

7 11 3 9 6

...

page size: 5x8 bytes

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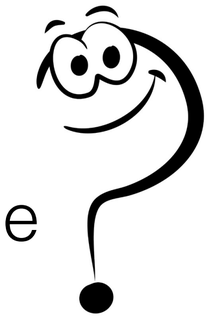
when does it make sense to have an oracle
how can we minimize the cost



e.g., **query** x<5

5 10 6 4 12 | 2 8 9 7 6 | 7 11 3 9 6 | ...

algorithm/system design = not just computation

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Is there maybe a perfect system? Nope…

basic CS265 logistics

learning outcome
Fundamentals of storage

data structures, SQL, NoSQL, Agents, LLMs, RAG, Data Science, Image AI

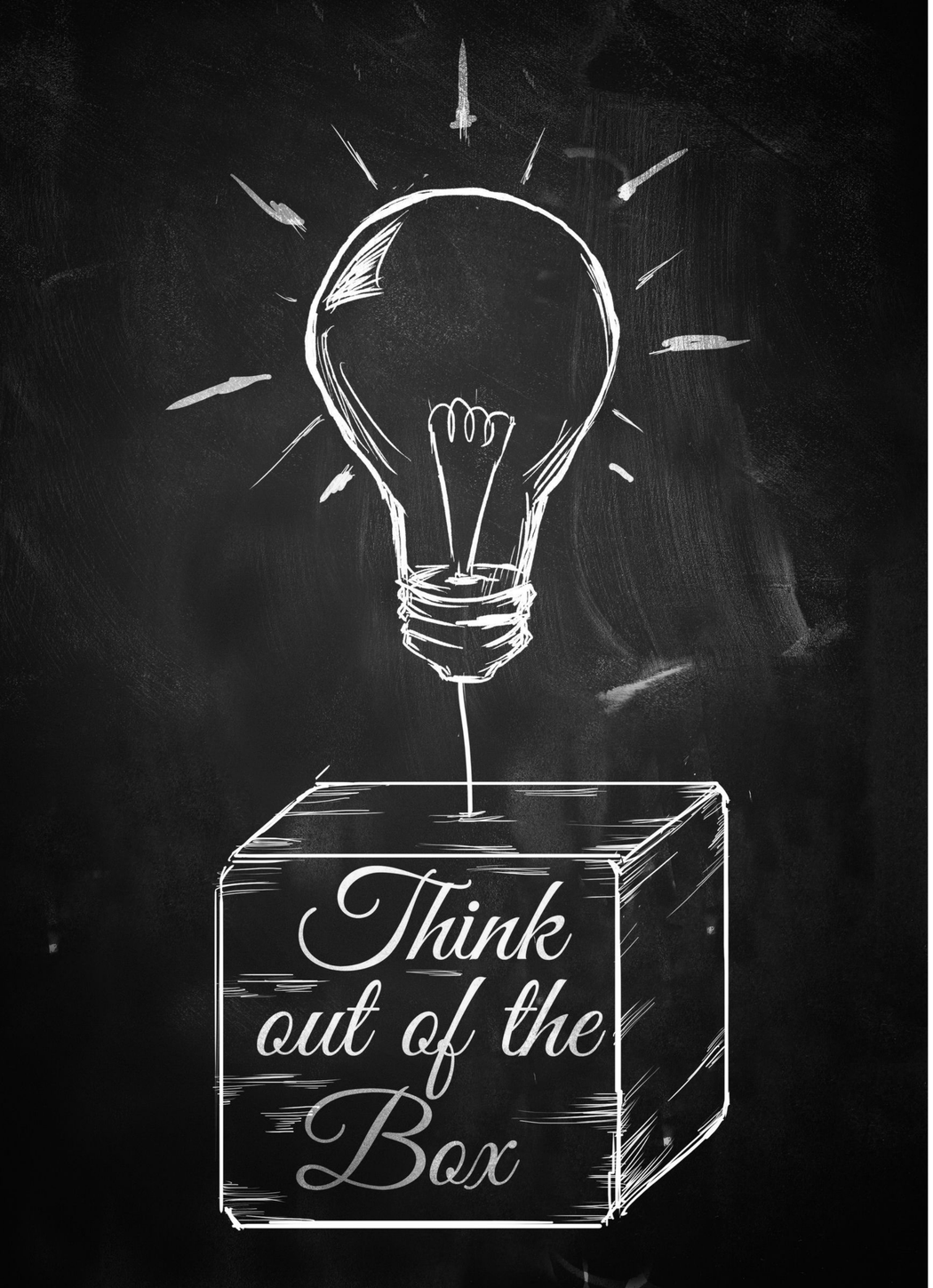
learning outcome

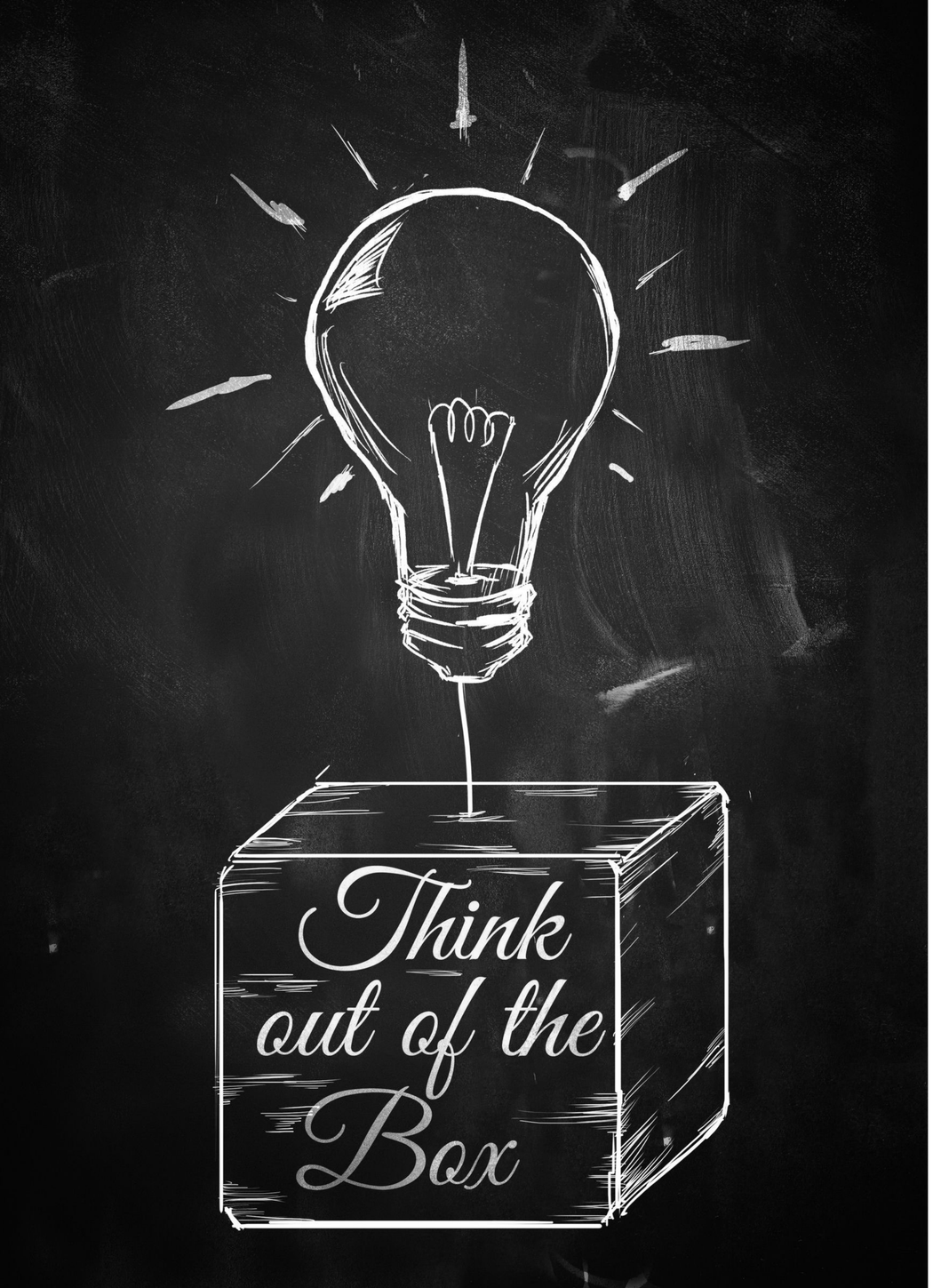
Fundamentals of storage

data structures, SQL, NoSQL, Agents, LLMs, RAG, Data Science, Image AI

Self-designing systems

Automated system design: cloud cost, hardware, data & app requirements


Think
out of the
Box



first ~5 weeks: Stratos & TFs

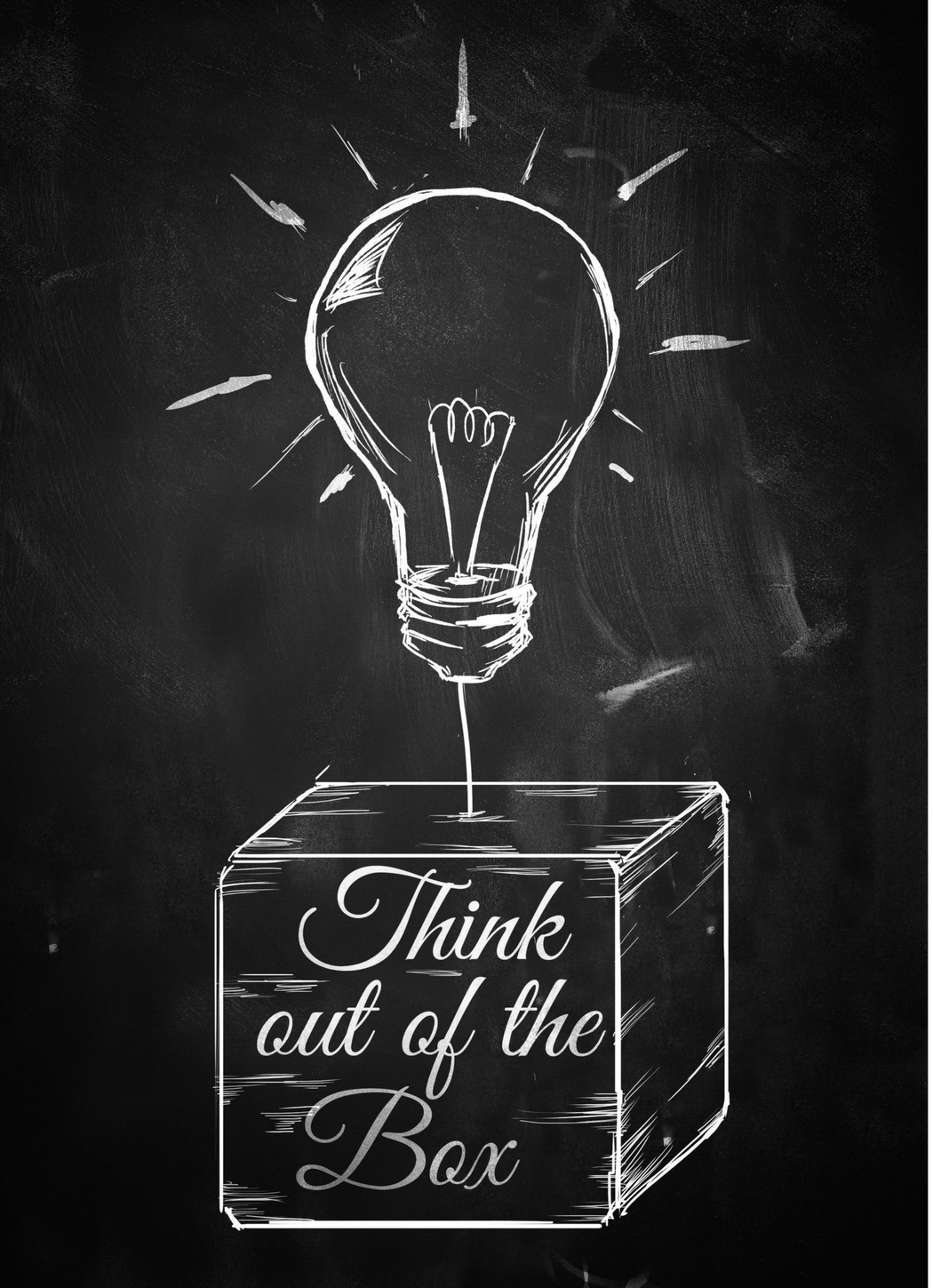
Basic background

Self-designing systems

LLM systems

Image AI systems

Research thinking



first ~5 weeks: Stratos & TFs
Basic background
Self-designing systems
LLM systems
Image AI systems
Research thinking

afterwards:
Students present research papers
One paper per class (ML systems)
In-class research/systems discussion
Research reviews
Research/systems projects

Recent Research Papers

Each student:

In-class discussions/1 presentation

review and slides should focus on

what is the problem
why is it important
why is it hard
why existing solutions do not work
what is the core intuition for the solution
solution step by step
does the paper prove its claims
exact setup of analysis/experiments
are there any gaps in the logic/proof
possible next steps

* follow a few citations to gain more background

learn to judge constructively

learn to present

learn to prepare slides

Each student:

In-class discussions/1 presentation

review and slides should focus on

what is the problem
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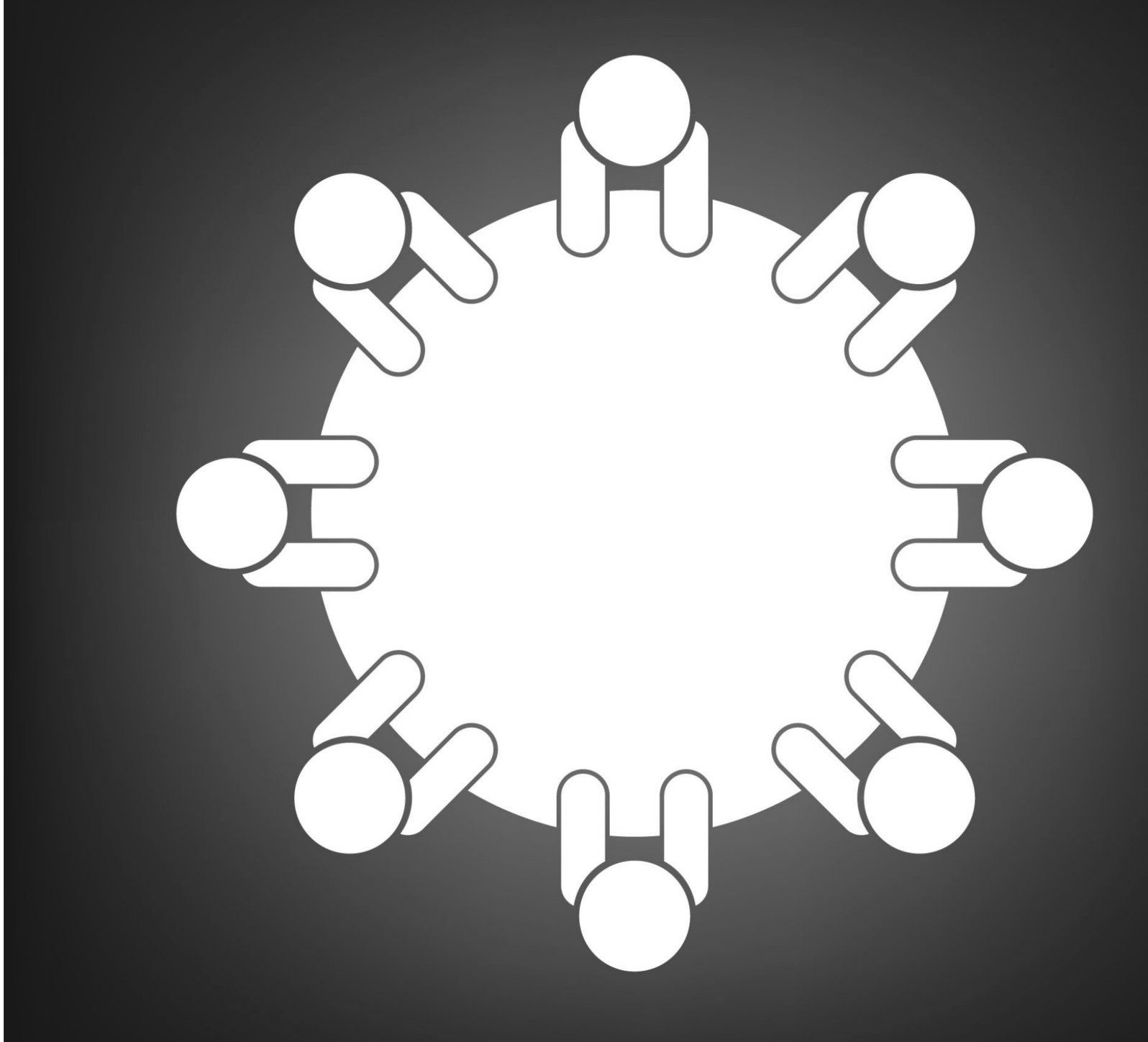
In class discussions
is a critical component
and learning outcome

Think creatively
Fail quickly
Incrementally solve

DailyOH/labs in person,
Sat/Sun remote Labs
Friday remote OH



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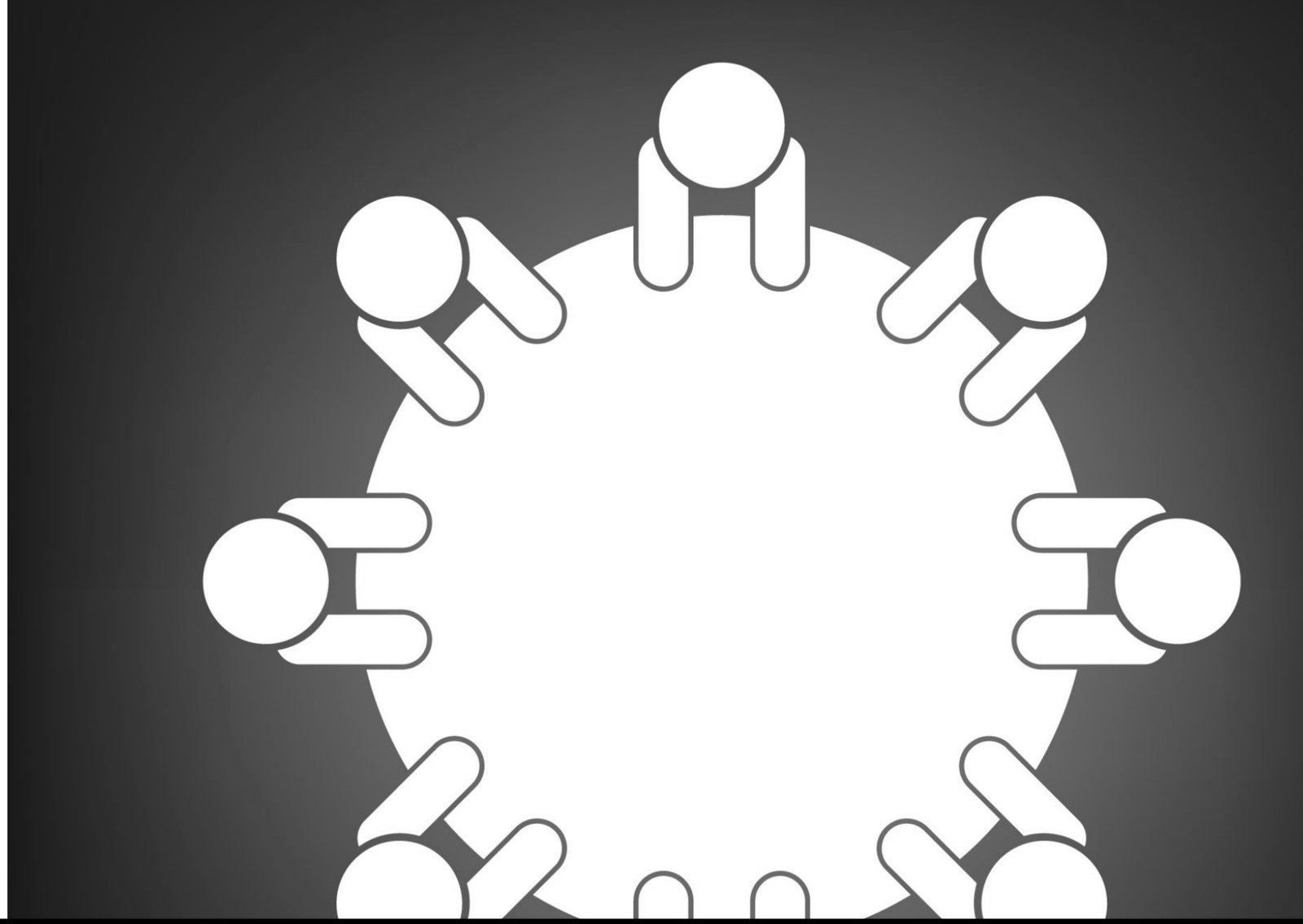

There is no such thing as a wrong question/answer!!!!

semester project: due in the end of semester + a midway check in (end of March,10%)

systems project

research project (publish)

semester project: due in the end of semester + a midway check in (end of March,10%)

systems project

individual project

LLMs, in c/c++

MLsys, in pytorch

research project (publish)

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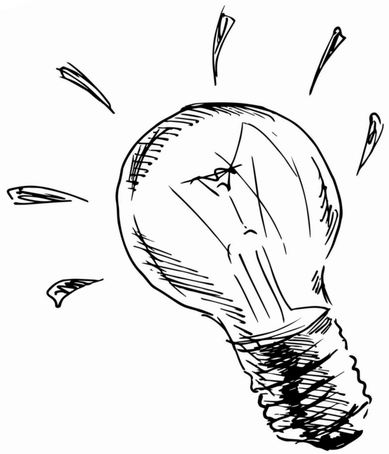
research project (publish)

groups of max three

Adaptivity/Performance

Focus this year:

LLM inference & Fine-tuning, RAG, Image AI



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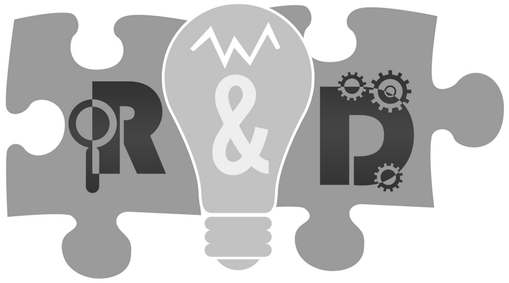

ACM Special Interest Group In Data Management (SIGMOD)
Undergrad Research Competition

first prize in 2016, 2017,
2018, 2019, 2020, 2022

Adaptive Denormalization
Evolving Trees
Splaying LSM-Trees
Adaptive NoSQL
Adaptive Filters
Distributed Deep Learning

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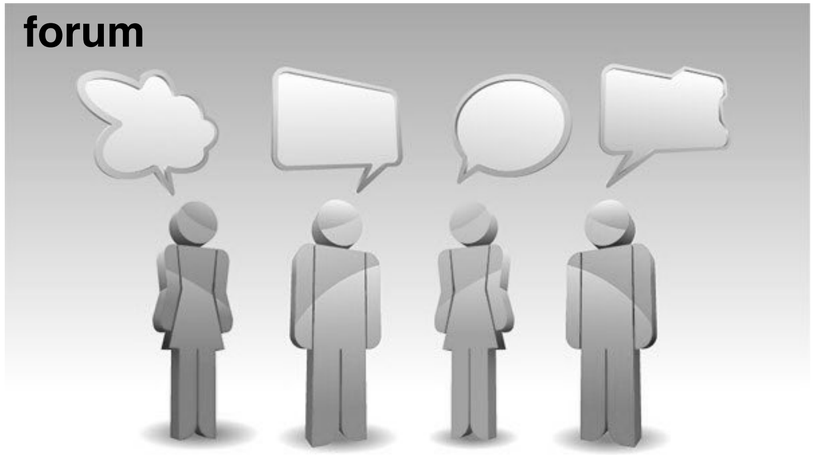
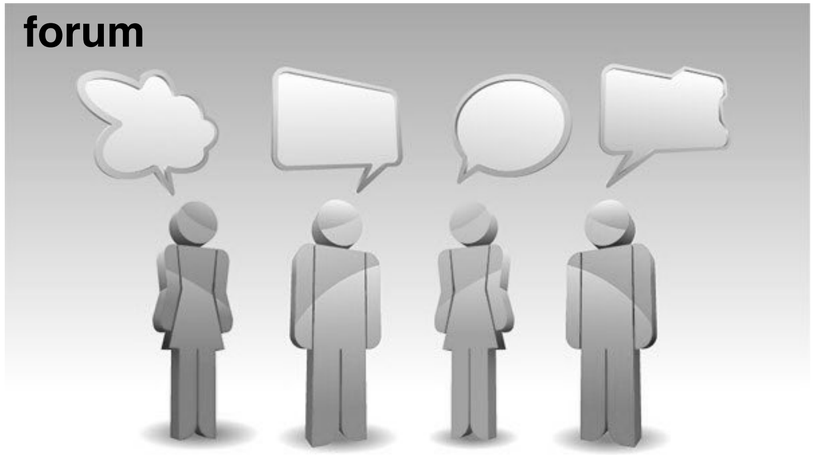


all announcements & discussions

as of week 2

link on class website - check out usage guidelines



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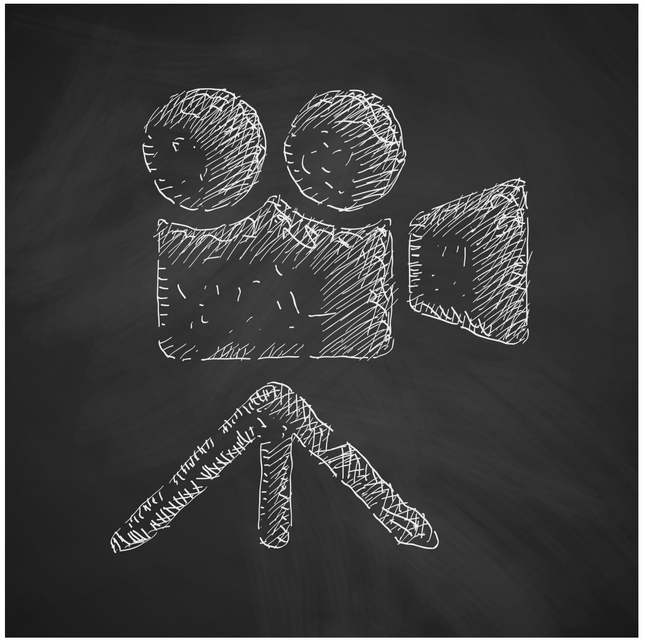
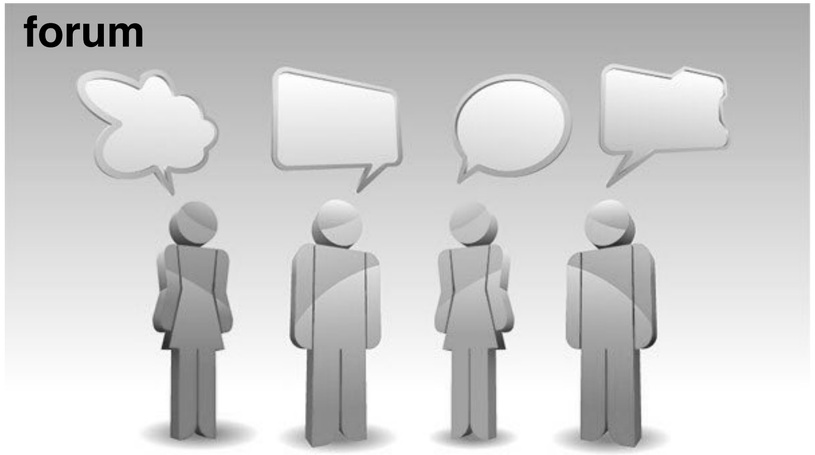


classes are recorded
(links on canvas)



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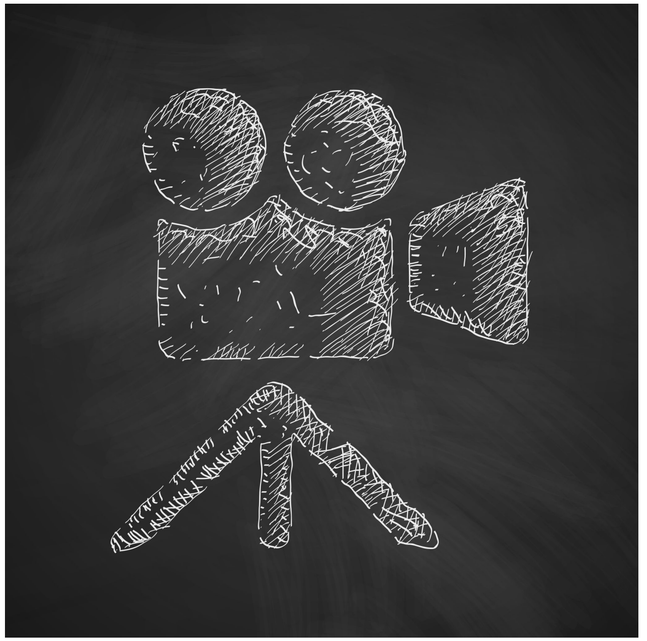

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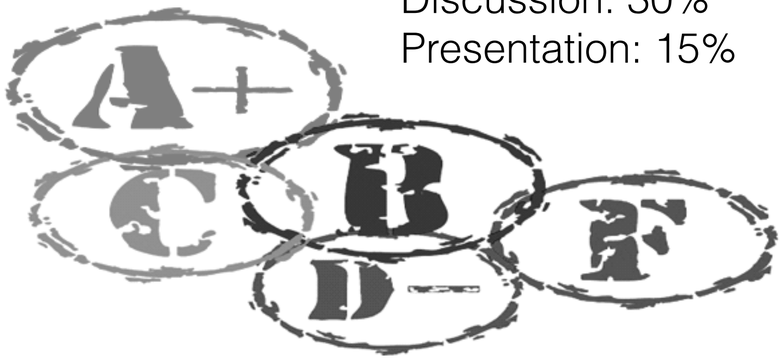
Project: 45%
Midway Check-in:10%
Discussion: 30%
Presentation: 15%



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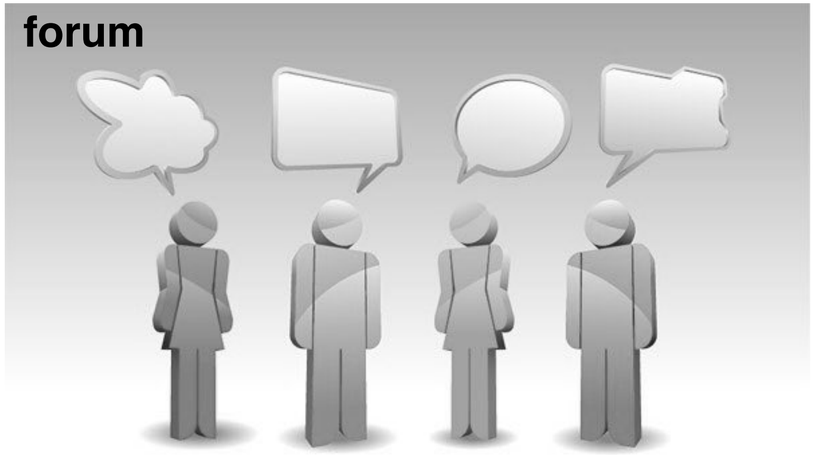

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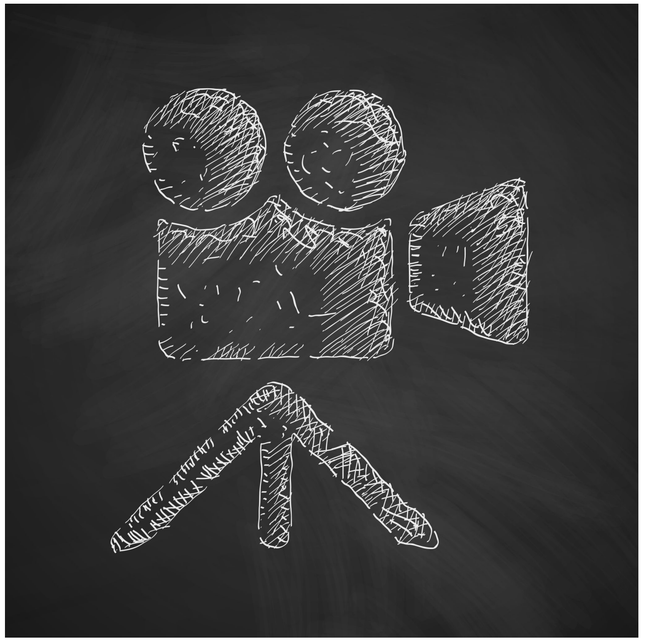

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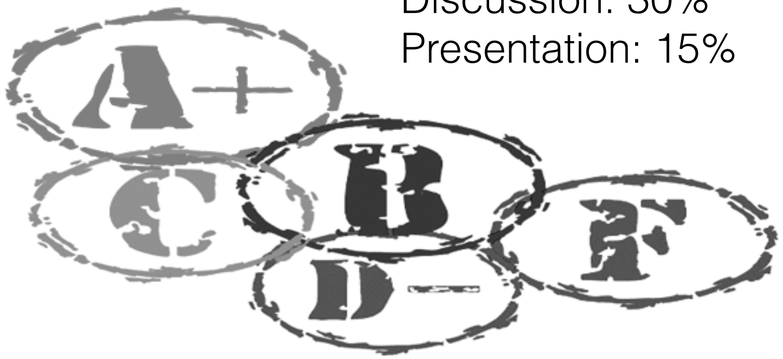

NO LAPTOP/PHONE POLICY
class is based on participation!

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Teaching Fellows

Utku Sirin
Teaching Fellow
(Room: SEAS 4.435)

Konstantinos Kopsinis
Teaching Fellow
(Room: SEAS 4.435)

Qitong Wang
Teaching Fellow
(Room: SEAS 4.435)

Milad Rezaei Hajidehi
Teaching Fellow
(Room: SEAS 4.435)

Prerequisites

knowledge of algorithms, data structures, hardware, systems

Research track:
open to CS165 students
after discussion also CS161 and systems PhDs

Systems track allows taking the class without all prerequisites (but at least CS61)

Check out: syllabus,
project 0, systems projects, online sections

http://daslab.seas.harvard.edu/classes/cs265/

Timeline:

Research papers: 3rd week

New Systems Project: 3rd week

Research projects: 4th week

Plan to start systems/research project end of Feb

Stratos' OH start today - Labs to start on Week 3

CS 265

Big Data & AI Systems

NoSQL | Neural Networks | Image AI | LLMs | Data Science