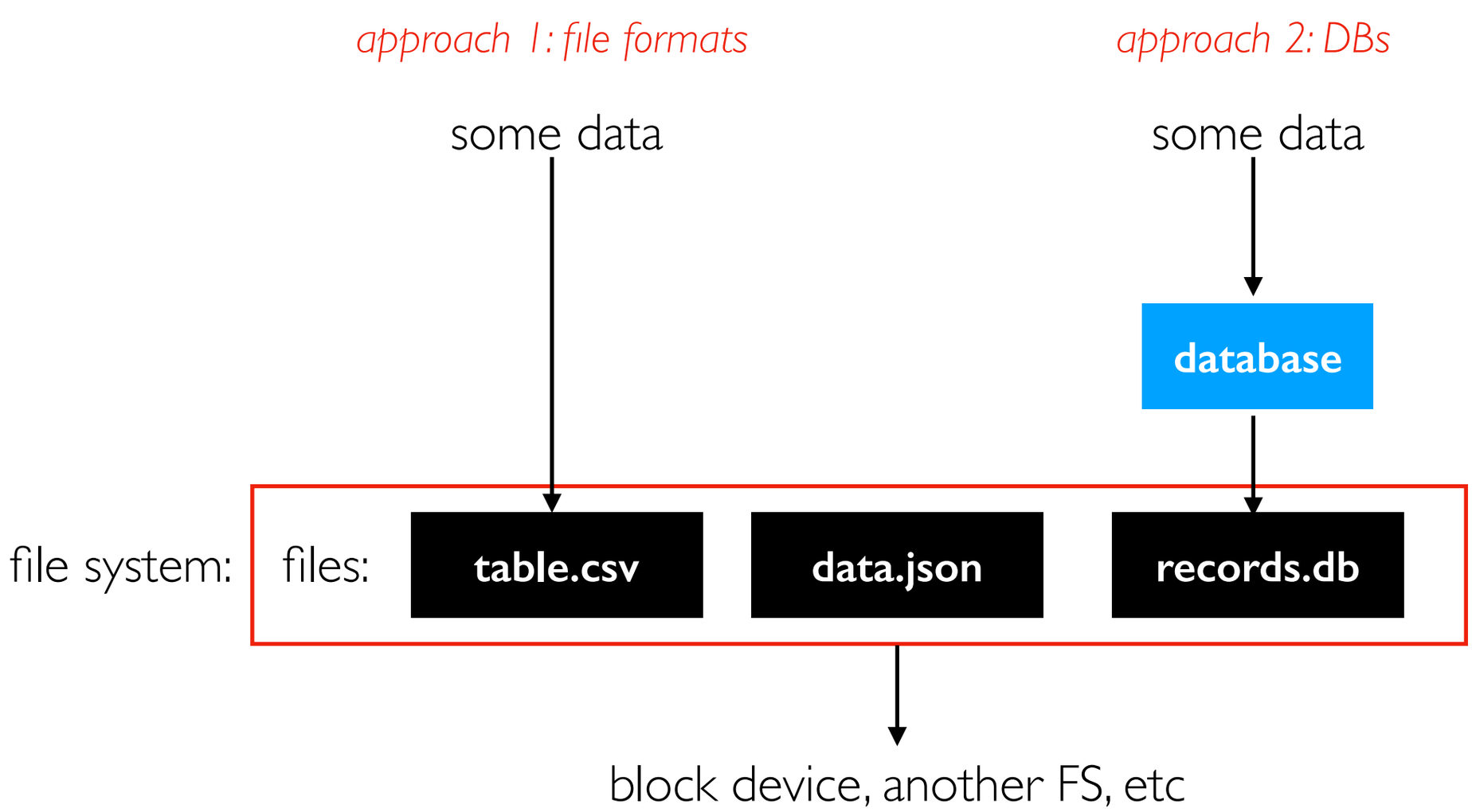
[544] Formats and Databases

Tyler Caraza-Harter

File systems let us give names to sequences of bytes (files) and hierarchically organize those files (via directories). We usually want some structure for those bytes.



Outline

File Formats

- row oriented vs. column oriented
- text vs. binary
- compression
- schemas

Databases

File Layout

Goals

- efficient input/output from storage (large enough reads/writes, sequential accesses)
- minimize parsing/deserialization computation time

Assumptions

- many file systems will try to map consecutive bytes of a file to consecutive blocks on a storage device (but note that in some cases sequential file I/O becomes random disk I/O)
- need to clarify assumptions about how code will access the data (for example, one whole column? a row at a time?)

```
ACW00011604  17.1167  -61.7833   10.1    ST JOHNS COOLIDGE FLD
ACW00011647  17.1333  -61.7833   19.2    ST JOHNS
AE000041196  25.3330   55.5170   34.0    SHARJAH INTER. AIRP          GSN     41196
AEM00041194  25.2550   55.3640   10.4    DUBAI INTL                           41194
AEM00041217  24.4330   54.6510   26.8    ABU DHABI INTL                       41217
AEM00041218  24.2620   55.6090  264.9    AL AIN INTL                          41218
AF000040930  35.3170   69.0170 3366.0    NORTH-SALANG                 GSN     40930
AFM00040938  34.2100   62.2280  977.2    HERAT                                40938
AFM00040948  34.5660   69.2120 1791.3    KABUL INTL                           40948
AFM00040990  31.5000   65.8500 1010.0    KANDAHAR AIRPORT                     40990
AG000060390  36.7167    3.2500   24.0    ALGER-DAR EL BEIDA           GSN     60390
AG000060590  30.5667    2.8667  397.0    EL-GOLEA                     GSN     60590
AG000060611  28.0500    9.6331  561.0    IN-AMENAS                    GSN     60611
AG000060680  22.8000    5.4331 1362.0    TAMANRASSET                  GSN     60680
AGE00135039  35.7297    0.6500   50.0    ORAN-HOPITAL MILITAIRE
AGE00147704  36.9700    7.7900  161.0    ANNABA-CAP DE GARDE
AGE00147705  36.7800    3.0700   59.0    ALGIERS-VILLE/UNIVERSITE
AGE00147706  36.8000    3.0300  344.0    ALGIERS-BOUZAREAH
```

ghcnd-stations.txt

bad: need to read everything to access any one column

good: just read the one block containing the row

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Major access patterns

- transactions processing: *reading/changing a row (or few rows) as needed by an application* (note: "transaction" has other meanings for databases as well -- more later...)
- analytics processing: *computing over many rows for specific columns*

Row-Oriented vs. Column-Oriented Layout

col1	col2	col3
1	5	A
2	6	B
3	7	C
4	8	D

row-oriented file: 1 5 A 2 6 B 3 7 C 4 8 D

col-oriented file: 1 2 3 4 5 6 7 8 A B C D

position in file

Row-Oriented vs. Column-Oriented Layout

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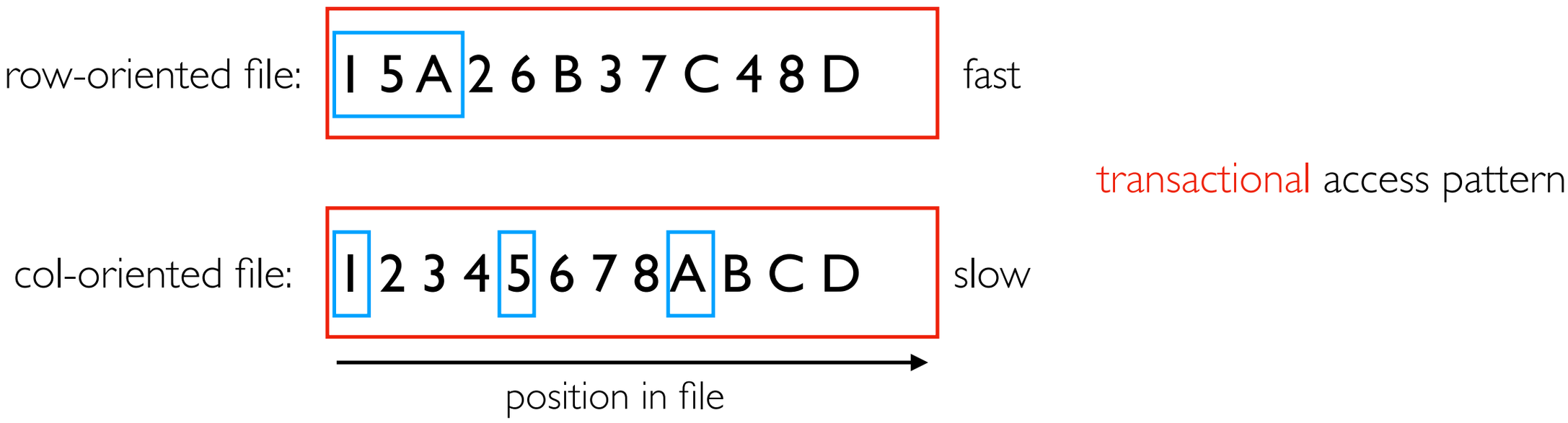

transactional access pattern

Row-Oriented vs. Column-Oriented Layout

col1	col2	col3
1	5	A
2	6	B
3	7	C
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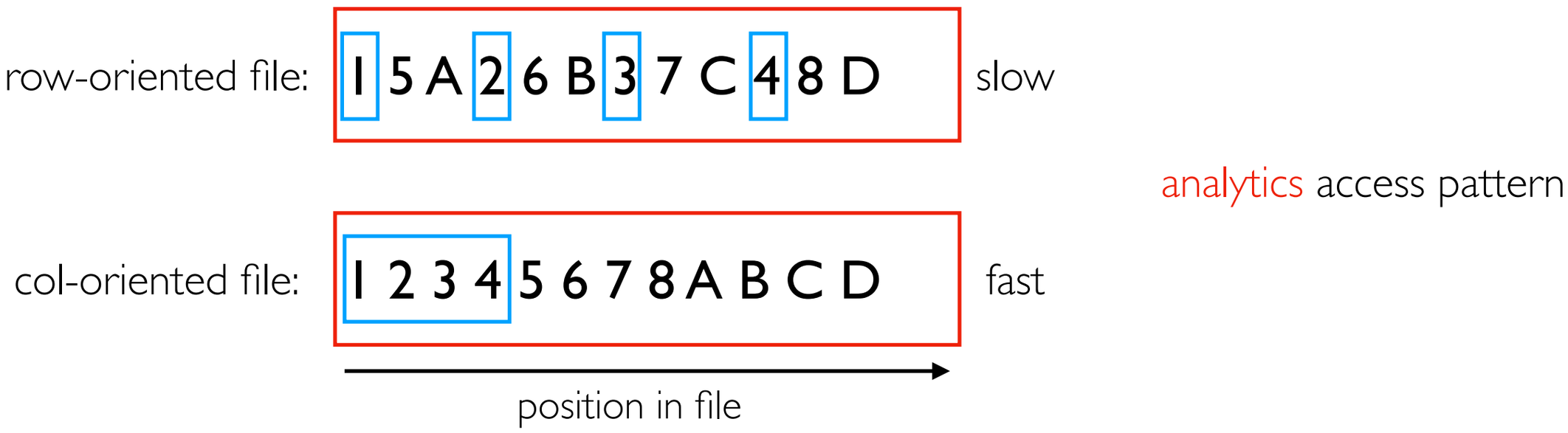

analytics access pattern

Row-Oriented vs. Column-Oriented Layout

col1	col2	col3
1	5	A
2	6	B
3	7	C
4	8	D

row-oriented file: **1 5 A 2 6 B 3 7 C 4 8 D** CSV

Demo: CSV vs. parquet...

col-oriented file: **1 2 3 4 5 6 7 8 A B C D** Parquet

position in file

Row-Oriented vs. Column-Oriented Layout

TopHat...

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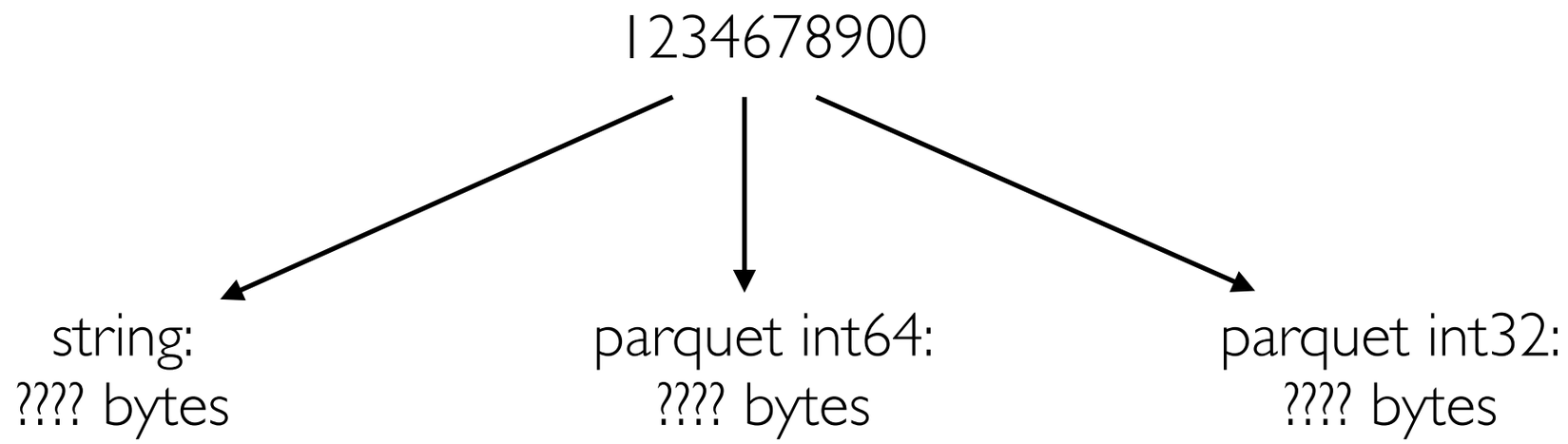
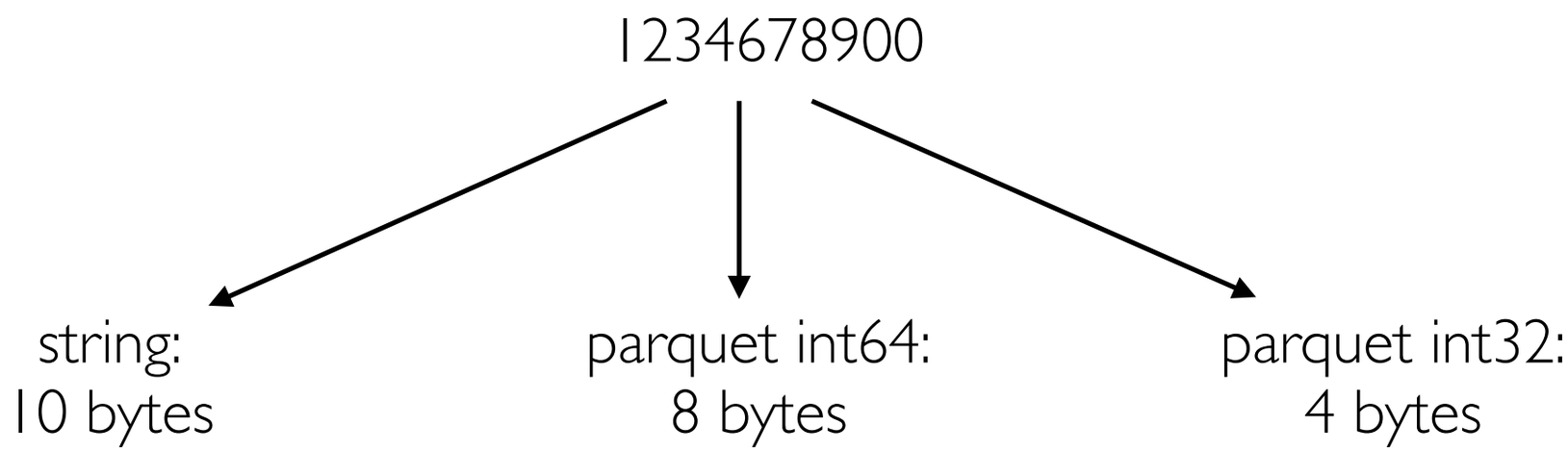
Text vs. Binary



Text vs. Binary



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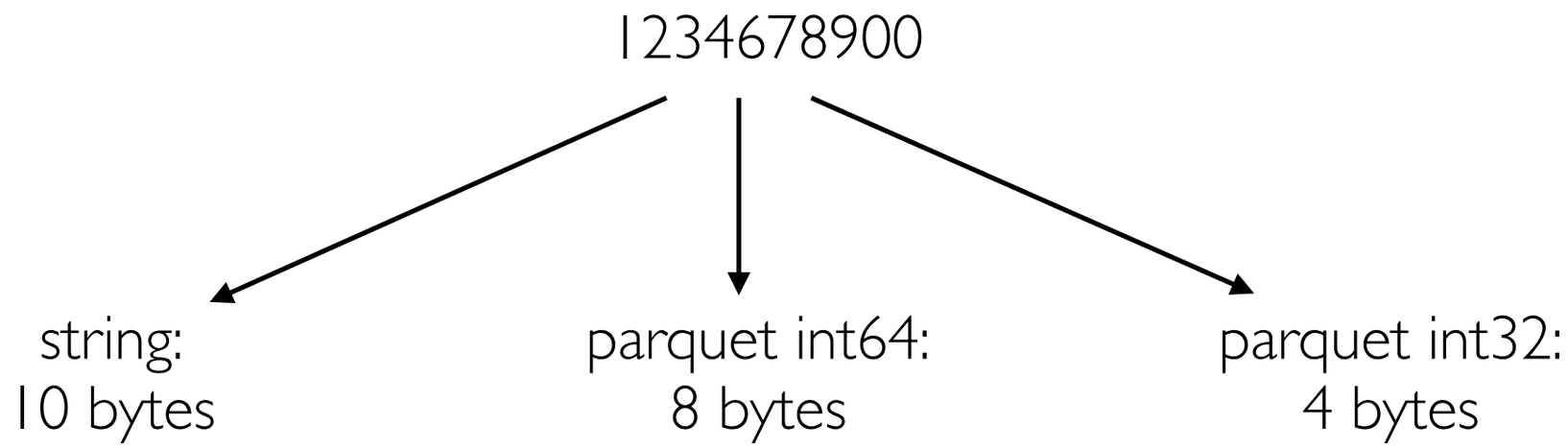

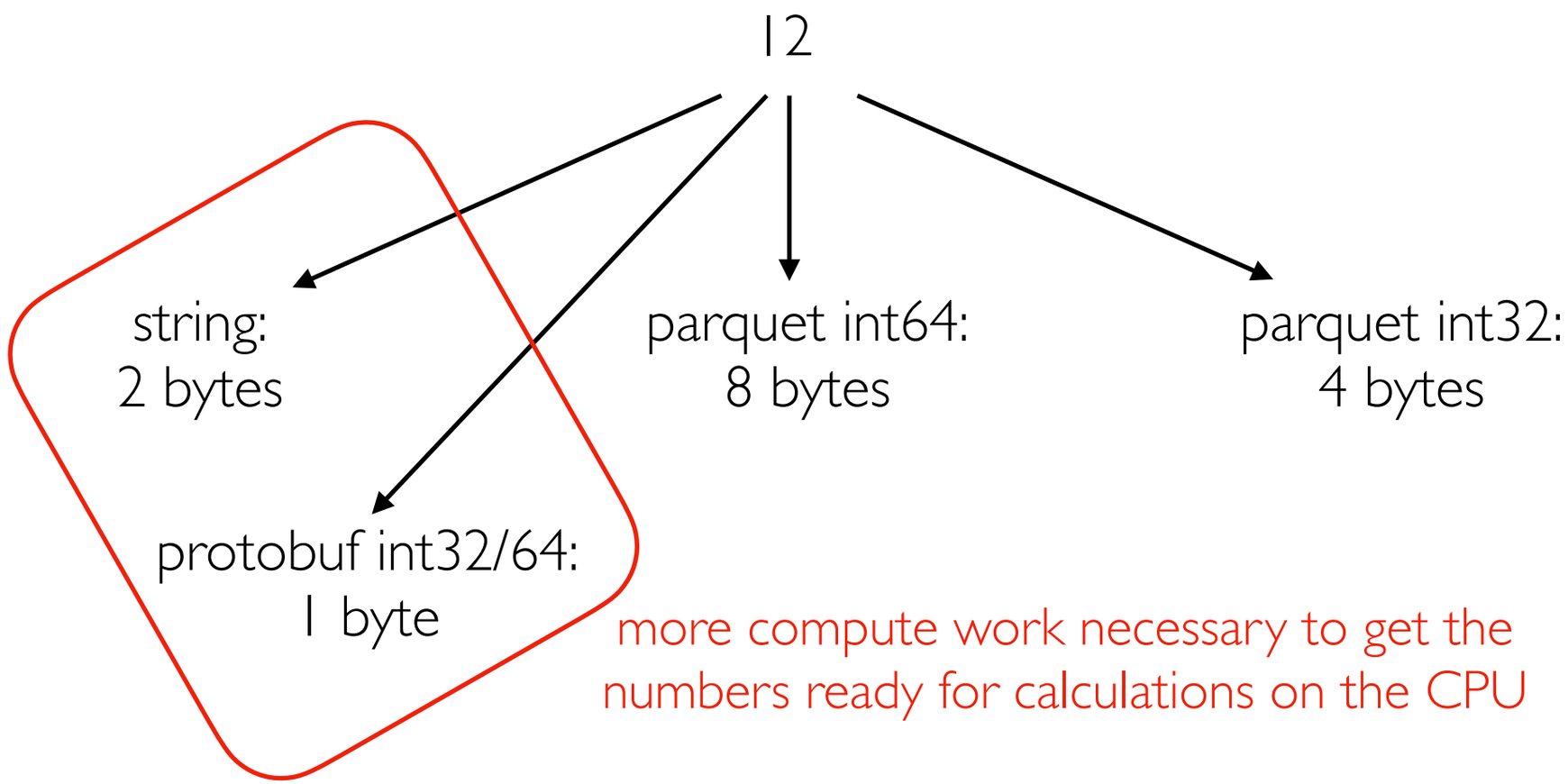

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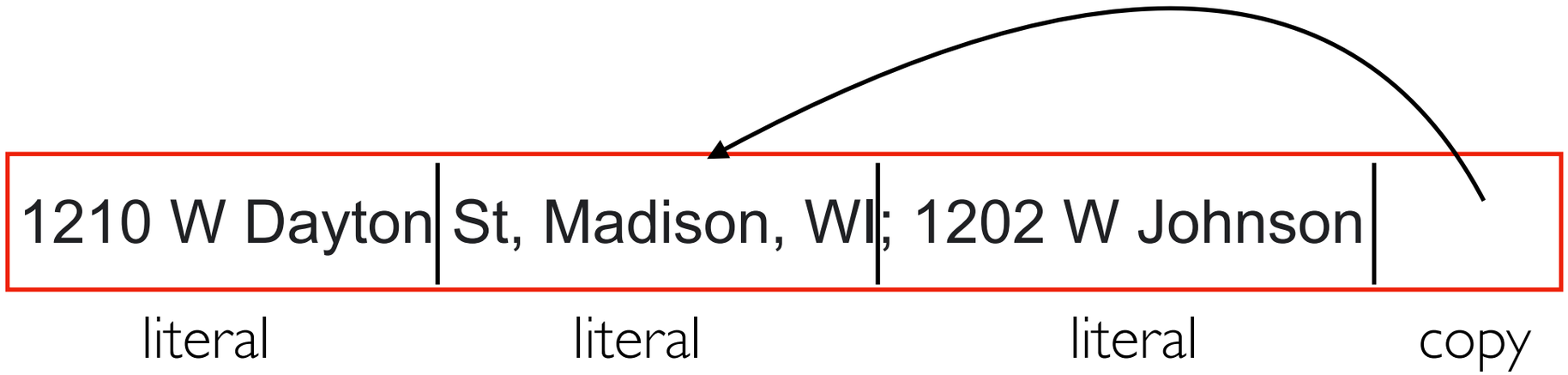
Compression

Idea: avoid repeating yourself

- repetitive datasets are more compressible
- more compute time finding repetition => better compression ratio (original/compressed size)

Example: snappy compression (parquet default):

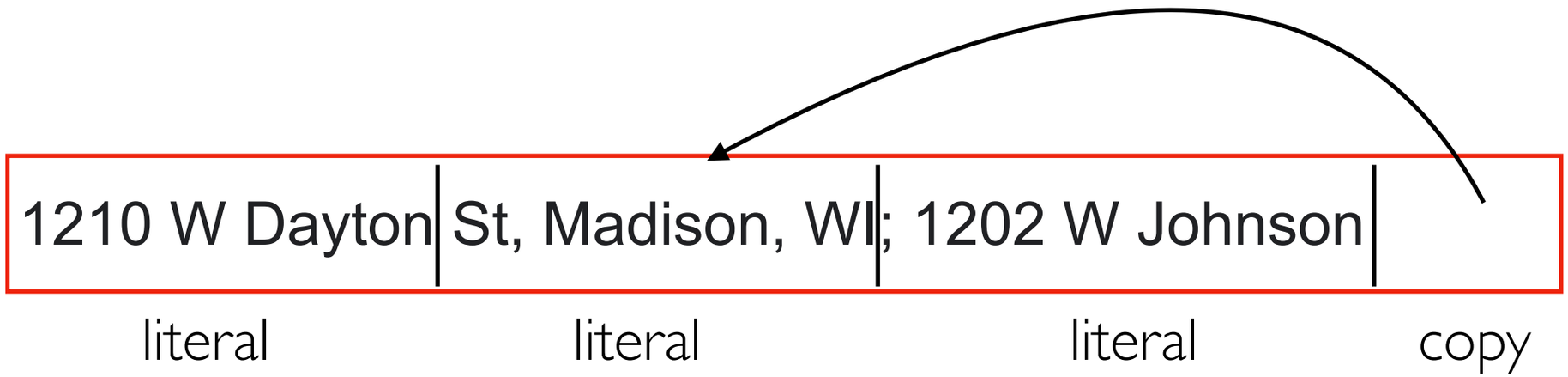


"[Snappy] does not aim for maximum compression, or compatibility with any other compression library; instead, it aims for very high speeds and reasonable compression."

Snappy documentation

- https://github.com/google/snappy
- https://github.com/google/snappy/blob/main/format_description.txt

Challenge: Small Updates



can't just update this first address in isolation
(need to rewrite other parts of the file)

Compression Window/Block

"the current Snappy compressor works in 32 kB blocks and does not do matching across blocks"

row-oriented file: 1 5 A 2 6 B 3 7 C 4 8 D

col-oriented file: 1 2 3 4 5 6 7 8 A B C D

position in file

will compression generally work better for row-oriented formats or column-oriented formats?

Size vs. Compute Tradeoff

DEMO: `df.to_parquet("????.parquet", compression="????")`

- snappy vs. gzip
- measure compute time with %%time
- measure size with "ls -lh"

Time measurements

- wall-clock time: real-world time that passes
- CPU time: time spent running on CPU
- wall clock time > CPU time (maybe I/O time dominates)
- CPU time > wall clock time (maybe multiple cores used)

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Schemas

Schema: "A description of the structure of some data, including its fields and datatypes." -- Kleppmann

CSVs:

schema specified as a dict

- in the file, everything in text
- pd.read_csv("file.csv", dtype={"col1": str, "col2": int, ...}) # specify schema (annoying)
- pd.read_csv("file.csv", dtype=None) # infer schema (slow, error prone!)

parquet files:

- type specification is part of the file
- no need for very slow schema inference

Outline

File Formats

Databases

- tables and queries
- architecture
- transactions vs. analytics

Tables

tbl_purpose

id	loan_purpose
1	Home purchase
2	Home improvement
3	Refinancing

tbl_state

code	abbr	name
1	AL	Alabama
2	AK	Alaska
4	AZ	Arizona
5	AR	Arkansas
6	CA	California
8	CO	Colorado
9	CT	Connecticut
10	DE	Delaware
…	…	…

string

tbl_action

id	action_taken
1	Loan originated
2	Application approved but not accepted
3	Application denied by financial institution
4	Application withdrawn by applicant
5	File closed for incompleteness
6	Loan purchased by the institution
7	Preapproval request denied by financial
8	Preapproval request approved but not accepted

tbl_loan

id	purpose	action	state	amount	rate
1	2	1	2	20000	5.0
2	1	1	8	300000	3.0
3	1	4	10	450000	3.2
…	…	…	…	…	…

int float

Databases store a collection of tables

- schemas define the columns/types for each table
- IDs/keys let us relate multiple tables
  (for example, the first loan is in Alaska)

Queries

tbl_purpose

id	loan_purpose
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Queries let us

- ask questions about the data
  (like, what is the name of the state with "WI" as an abbreviation)
- make changes to the data
  (like insert Puerto Rico as a row in tbl_state)

SQL

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Structure Query Language (SQL)

- most popular/famous query language
- ask questions about the data: SELECT
- make changes to the data: INSERT, UPDATE, DELETE

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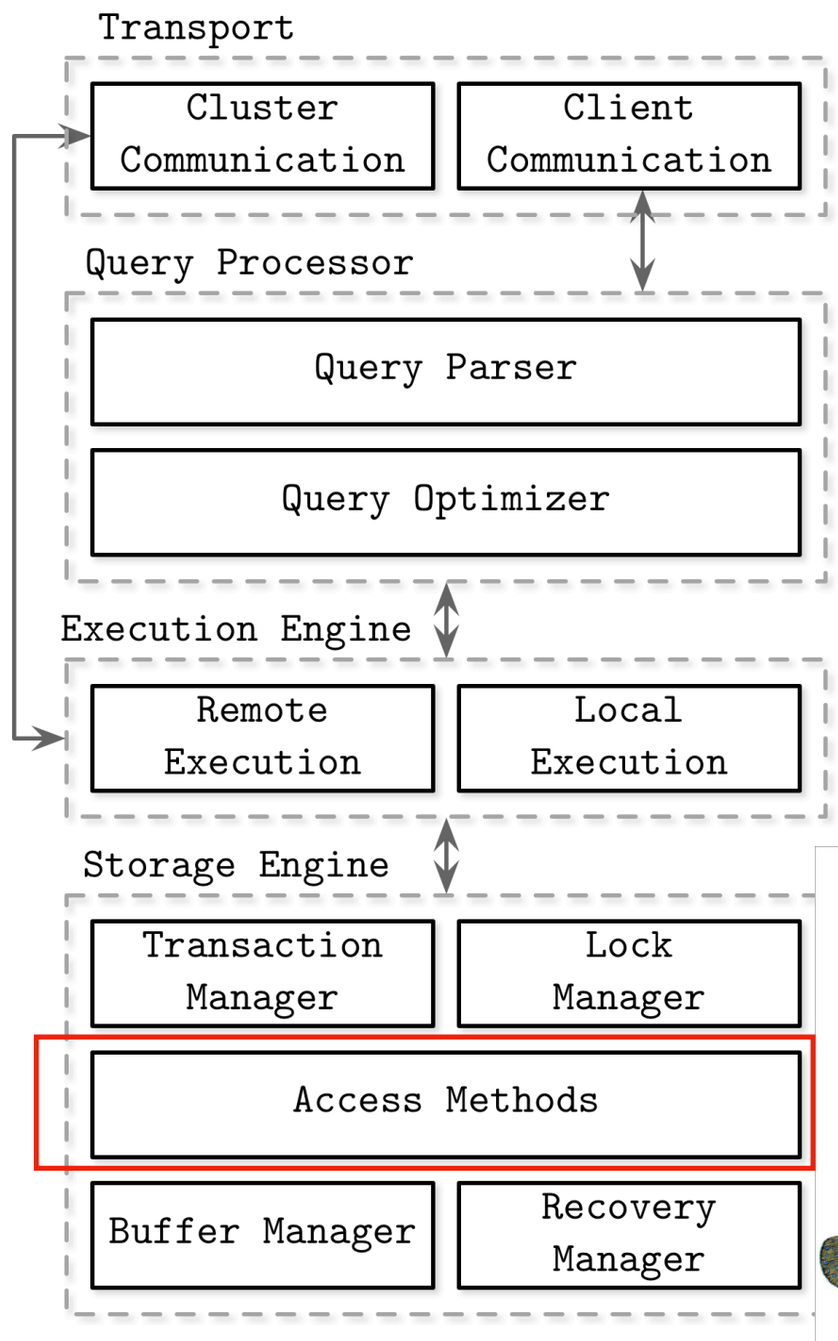
Data Base Management Systems

Architecture: *big picture of a system's components/subsystems*

Databases manage all the resources we've learned about:

- storage
- memory
- network
- compute

example database architecture:



storage structures in files

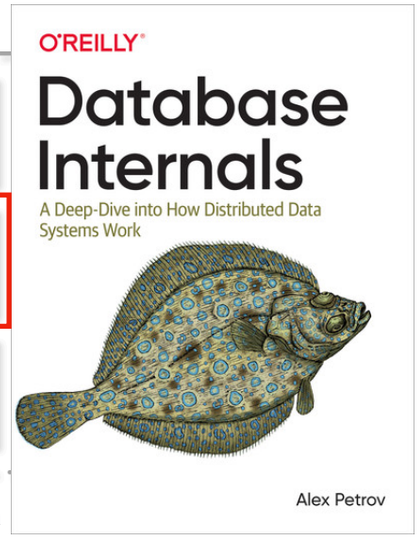


Figure 1-1. Architecture of a database management system (Chapter 1 of Database Internals, by Petrov)

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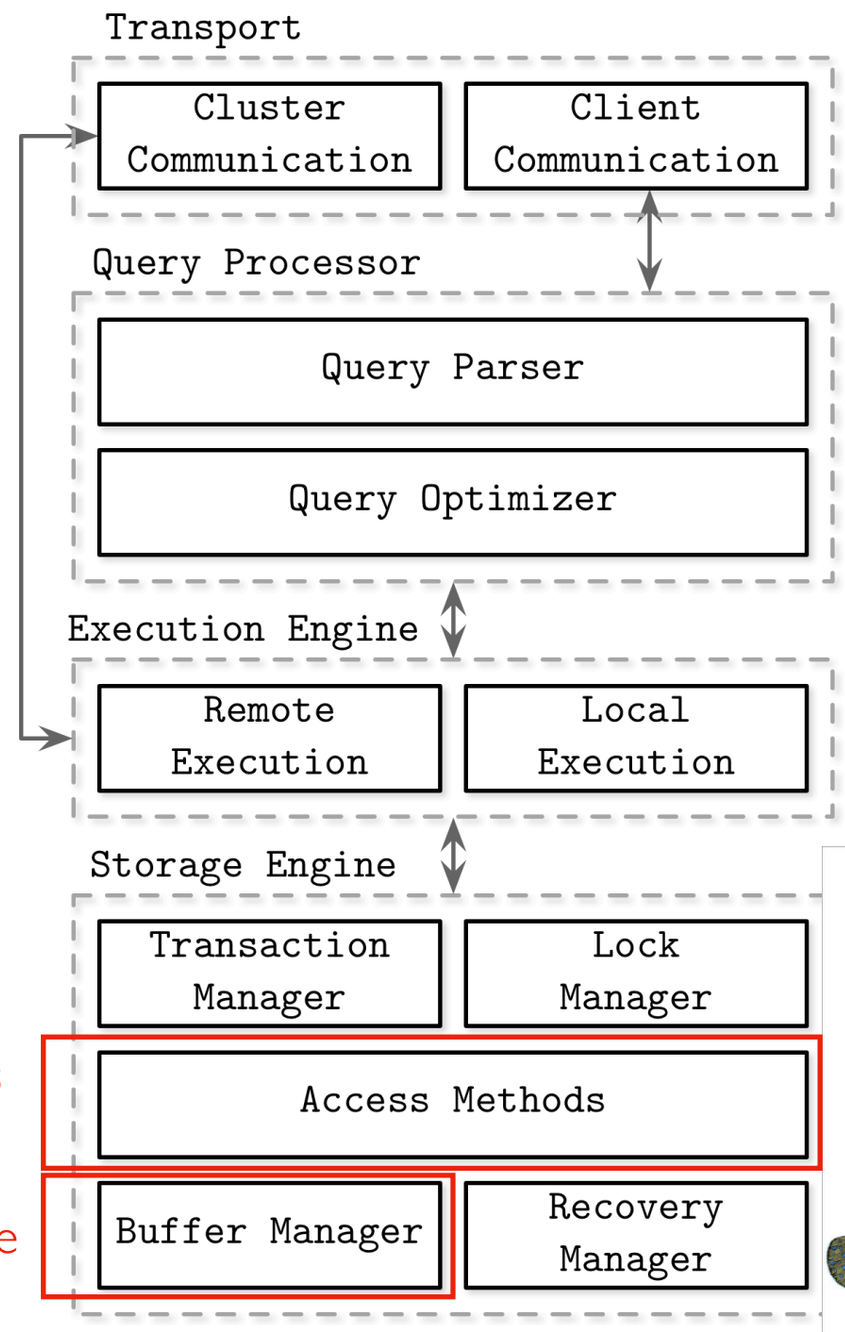

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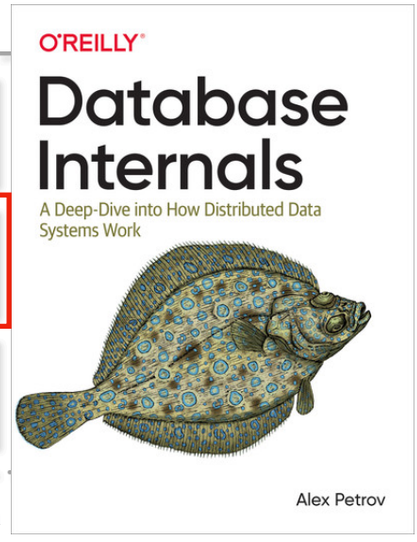

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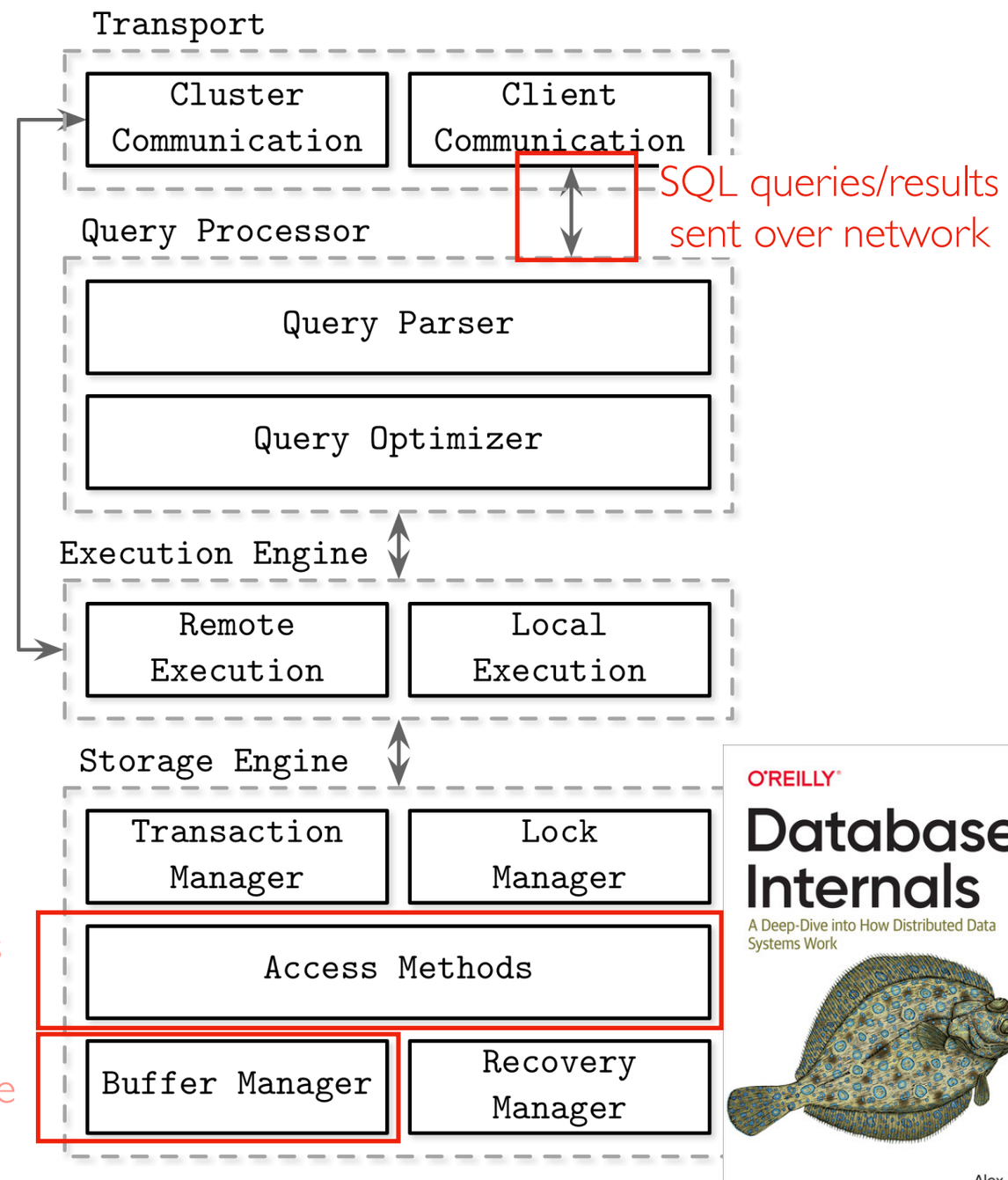

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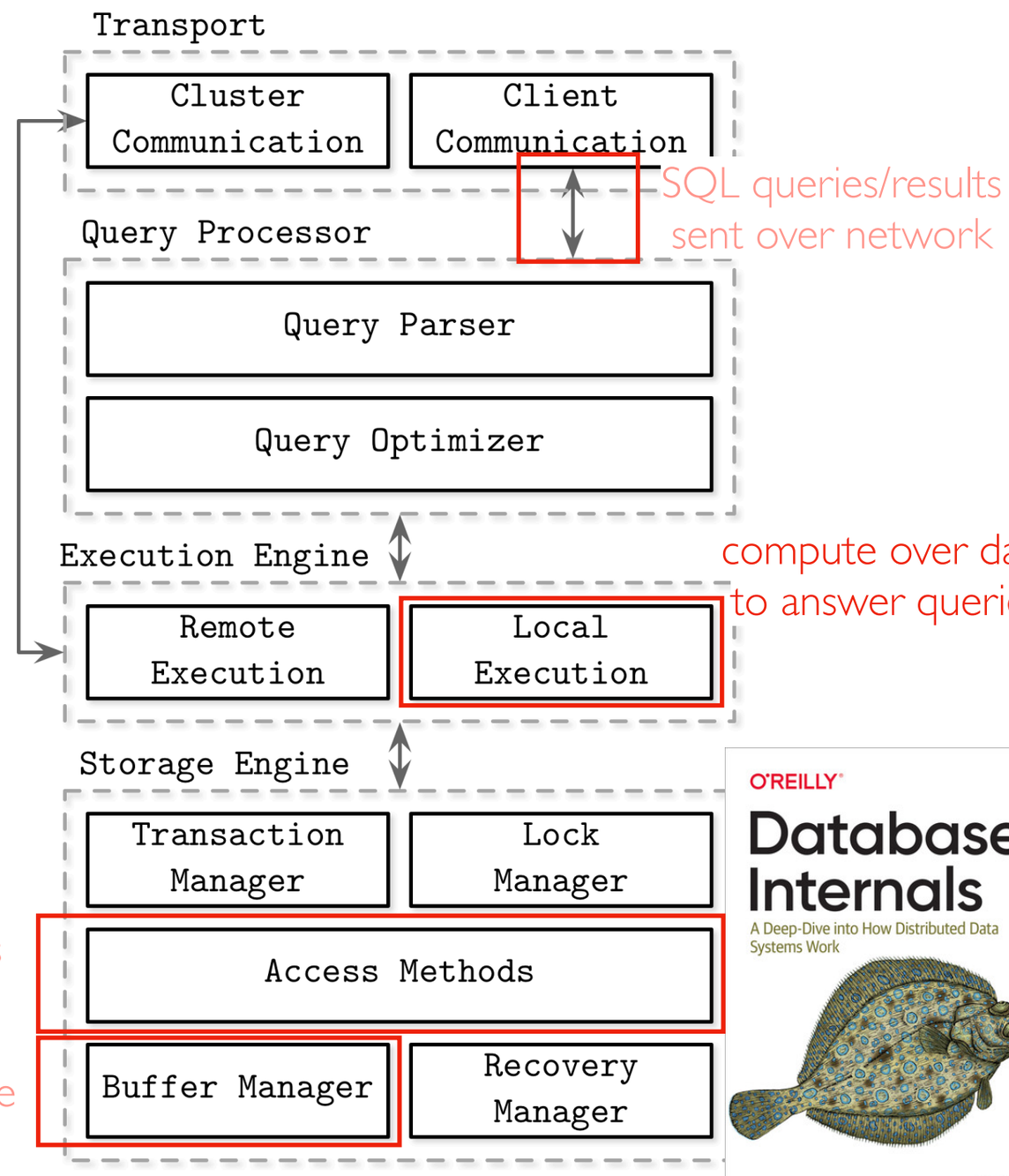

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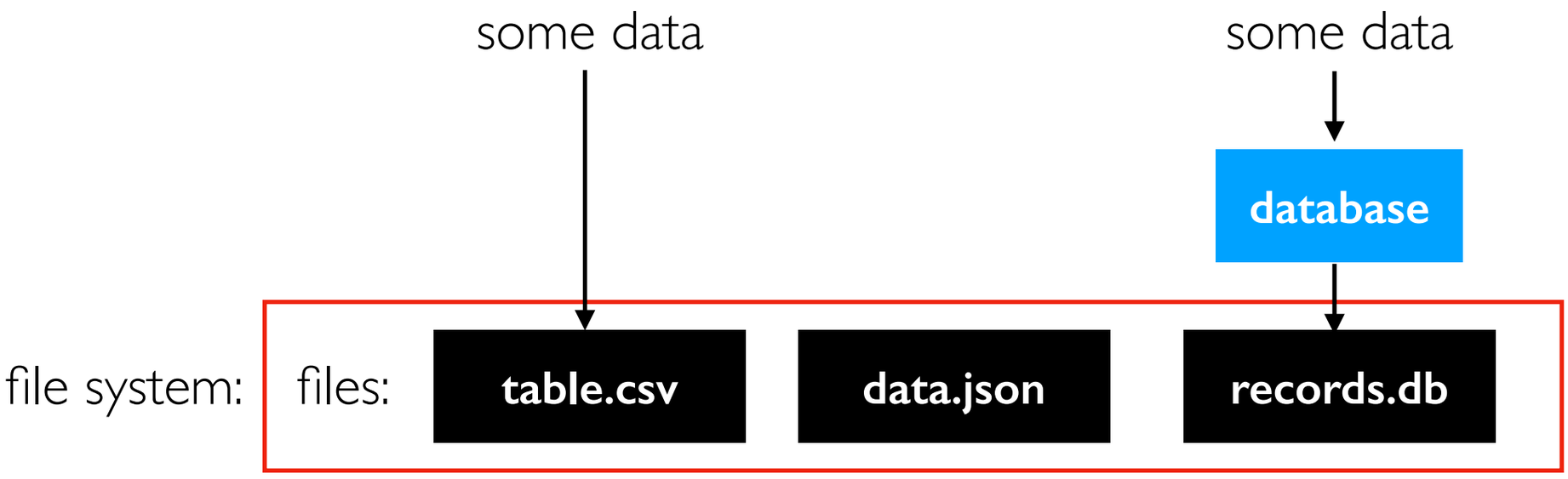
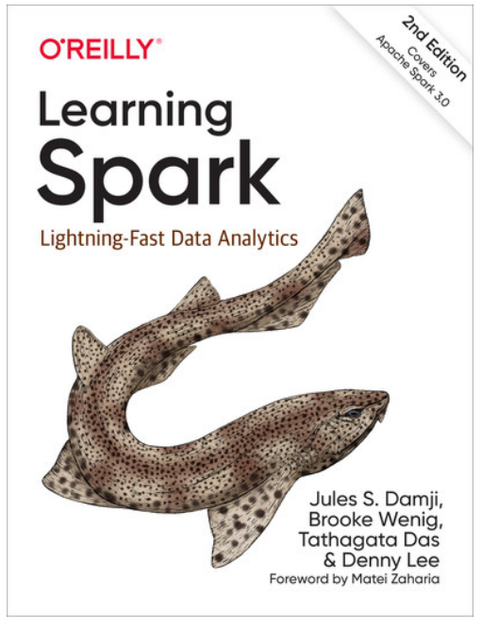
Files vs. Databases (storage+compute coupling)



Databases pros/cons (relative to files):

- "*[databases] tightly couple their internal layout of the data and indexes in on-disk files with their highly optimized query processing engines, thus providing very fast computations on the stored data...*"
- "*Databases store data in complex (often proprietary) formats that are typically highly optimized for only that database's SQL processing engine to read. This means other processing tools, like machine learning and deep learning systems, cannot efficiently access the data (except by inefficiently reading all the data from the database).*"



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analytics (calculate over many/all rows, few colums)

```
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INSERT INTO tbl_loan (...) VALUES (...);
```

transactions (working with whole row or few rows at a time)

SQL (as a language) works great for both transactions and analytics.

Problem: it's hard for a single database (SQL or otherwise) to be efficient at both.

Main database types:

- OL**T**P (online transactions processing)
- OL**A**P (online analytics processing)

"The meaning of online in OLAP is *unclear*; it probably refers to the fact that queries are not just for predefined reports, but that analysts use the OLAP system interactively for explorative queries." ~ Kleppmann.

Transactions vs. Analytics

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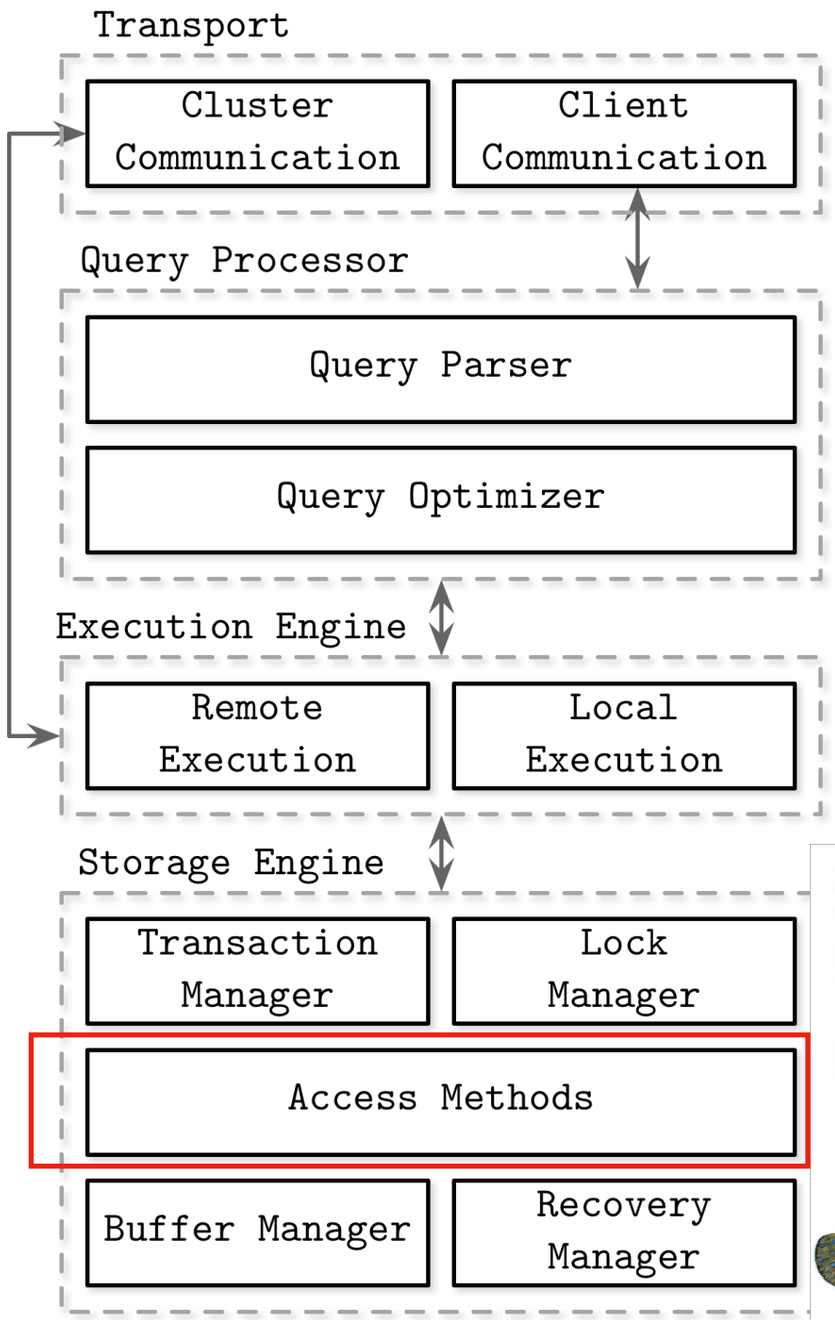

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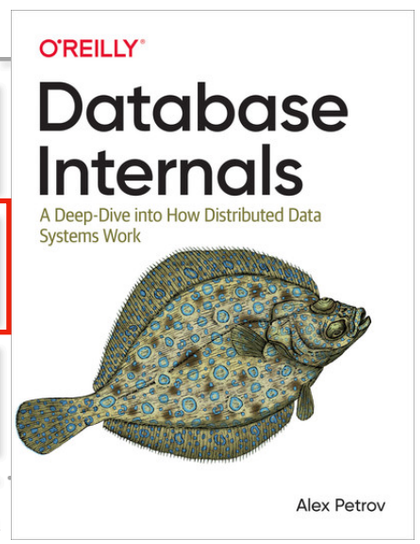
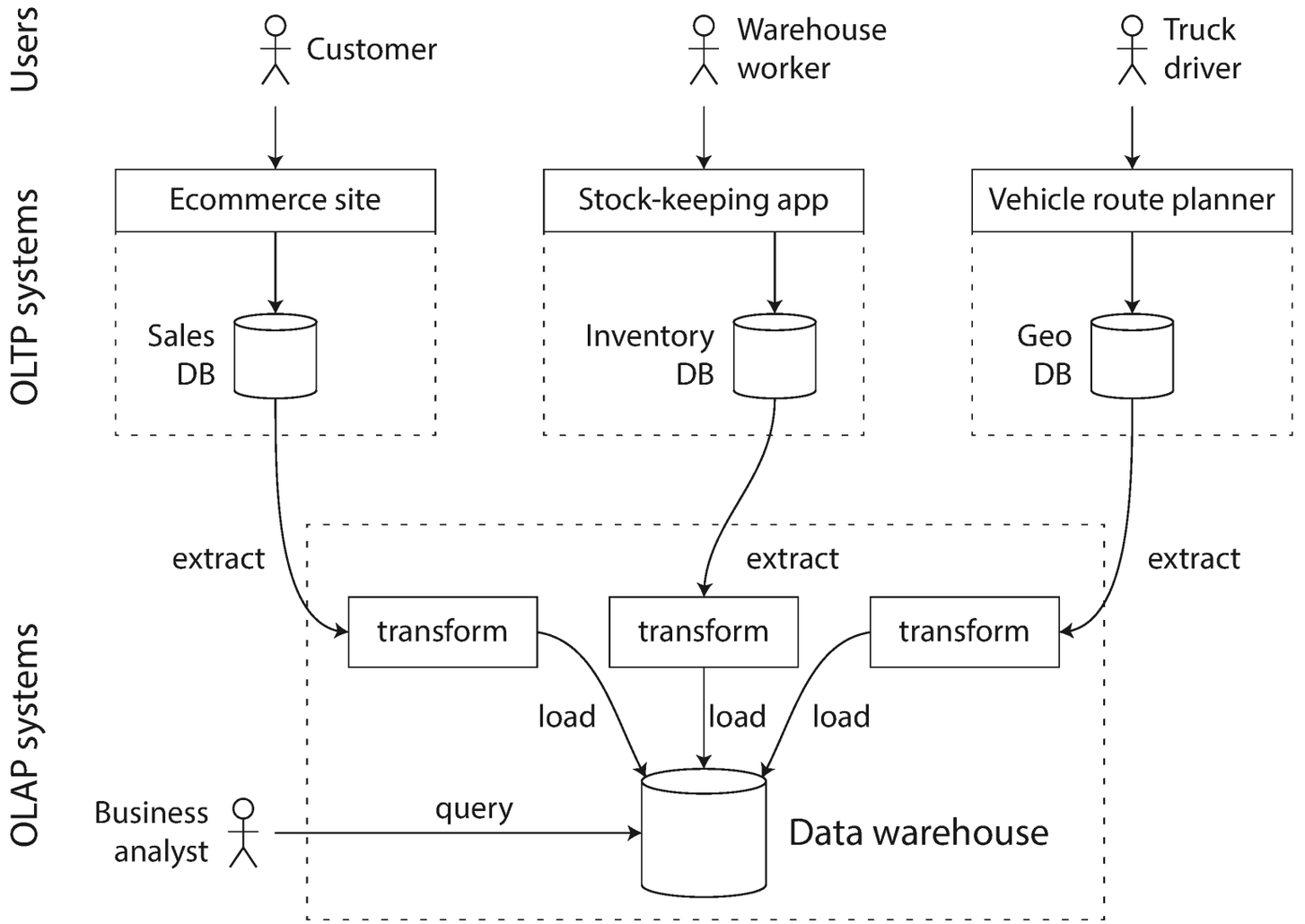


Typical storage design

OLTP: *row oriented data layout*

OLAP: *col oriented data layout*

What if you need transactions AND analytics?



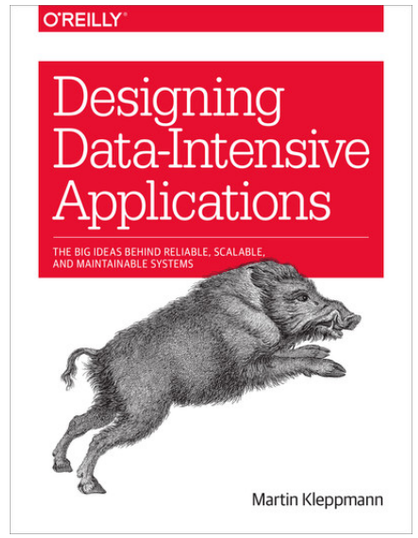


Figure 3-8. Simplified outline of ETL into a data warehouse.
(Chapter 3 of Data-Intensive Applications, by Kleppmann)

Vocab

- Data warehouse: *the OLAP database where we combine data from many sources*
- ETL: *extract-transform-load (process for getting data out of OLTP DBs and into OLAP DB)*