

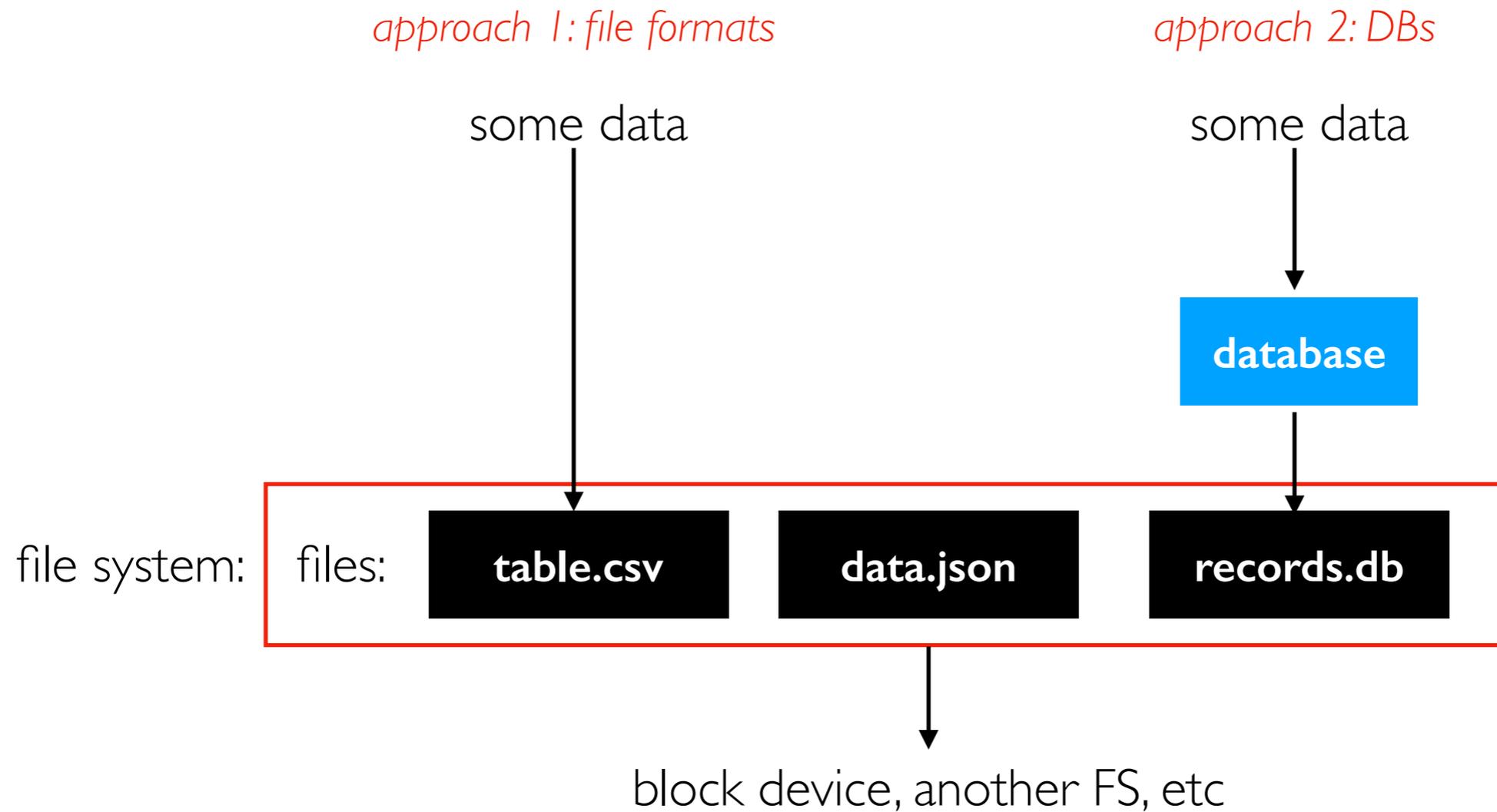
[544] File Formats

Meenakshi Syamkumar

Learning Objectives

- describe different file formats in terms of orientation, encoding, compression, and schemas
- write code to use parquet files
- differentiate between transactions workloads and analytics workloads
- explain the motivation for using an ETL (extract transform load) process to copy data from an transactions processing system to an analytics processing system

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

	CSV	Parquet
orientation	row	column
encoding	text	binary
compression	none	snappy
schemas	inferred	explicit

Demos

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

good: just read the one block containing the row

bad: need to read everything to access any one column

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?)

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:

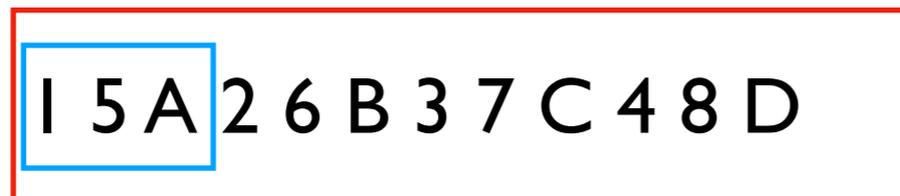
1 2 3 4 5 6 7 8 A B C D

position in file

Row-Oriented vs. Column-Oriented Layout

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

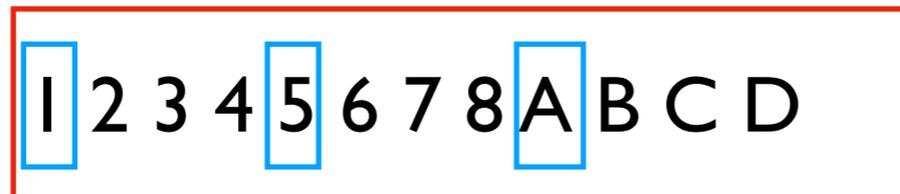
row-oriented file:



fast

transactional access pattern

col-oriented file:



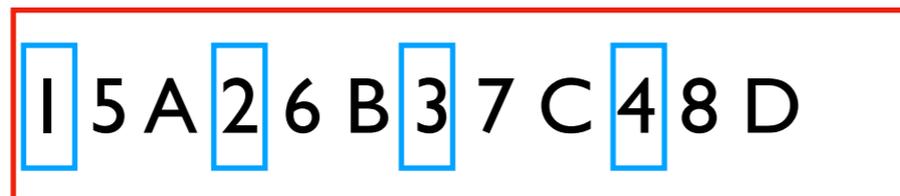
slow

position in file →

Row-Oriented vs. Column-Oriented Layout

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

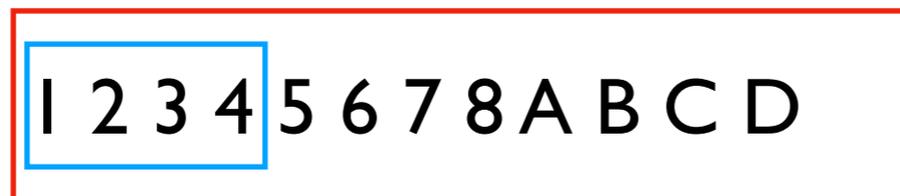
row-oriented file:



slow

analytics access pattern

col-oriented file:



fast

position in file

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

col-oriented file:

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

Parquet

position in file →

Outline

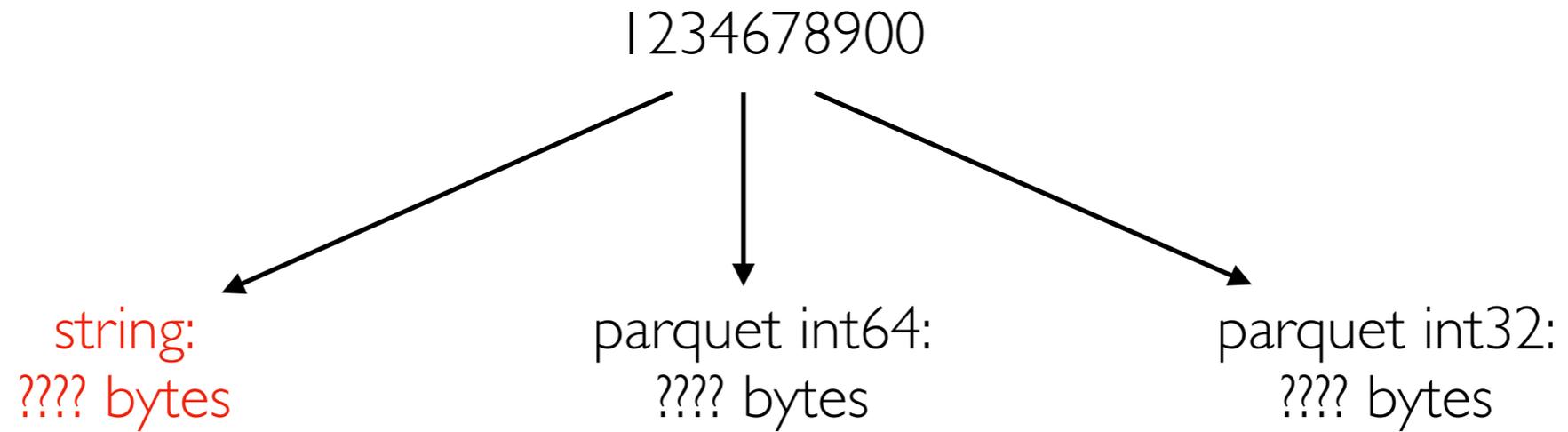
File Formats

	CSV	Parquet
orientation	row	column
encoding	text	binary
compression	none	snappy
schemas	inferred	explicit

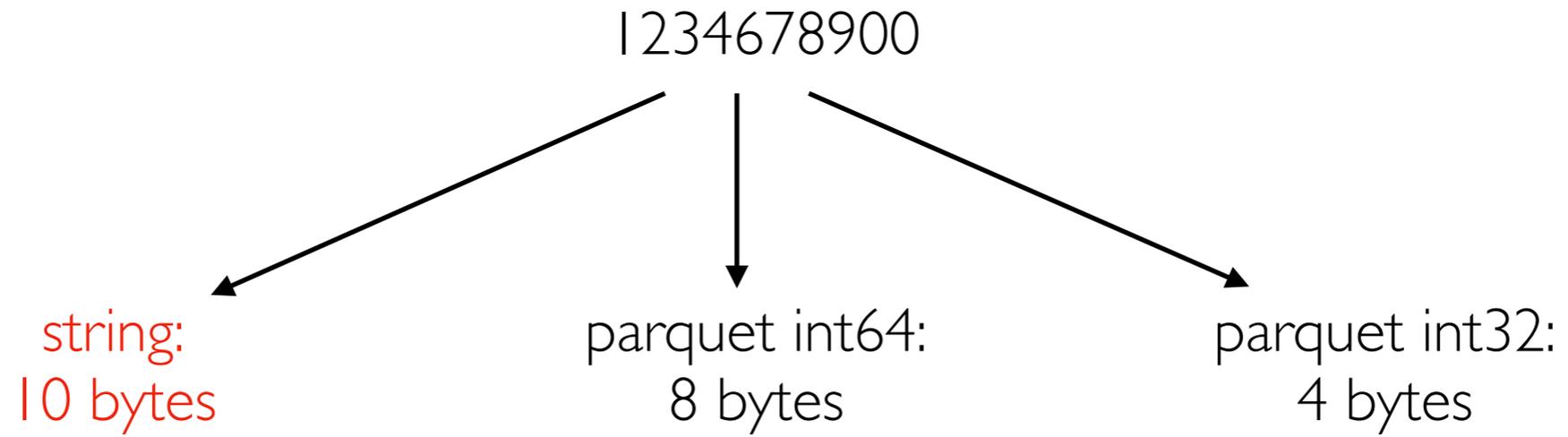
Demos

Databases

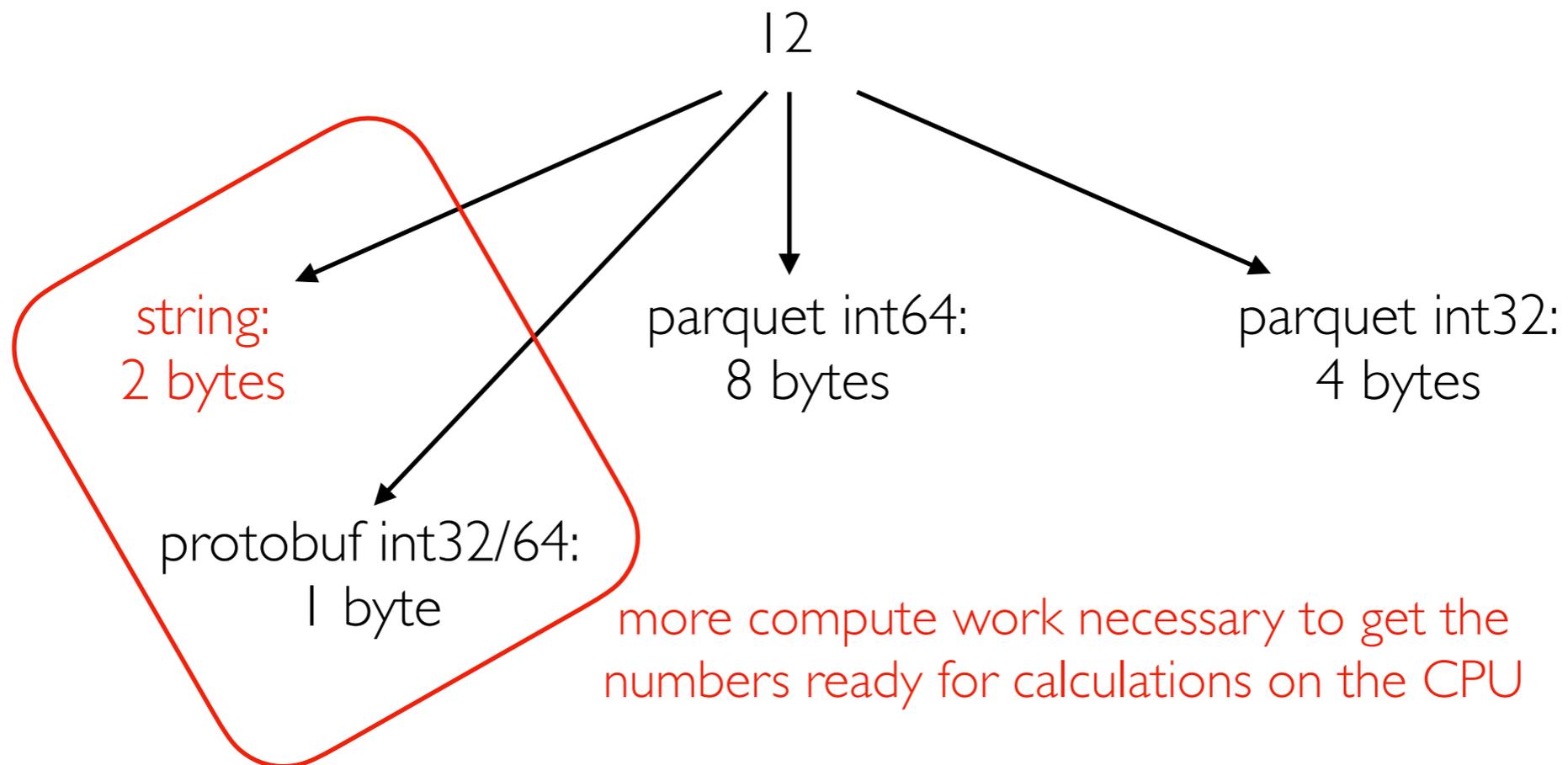
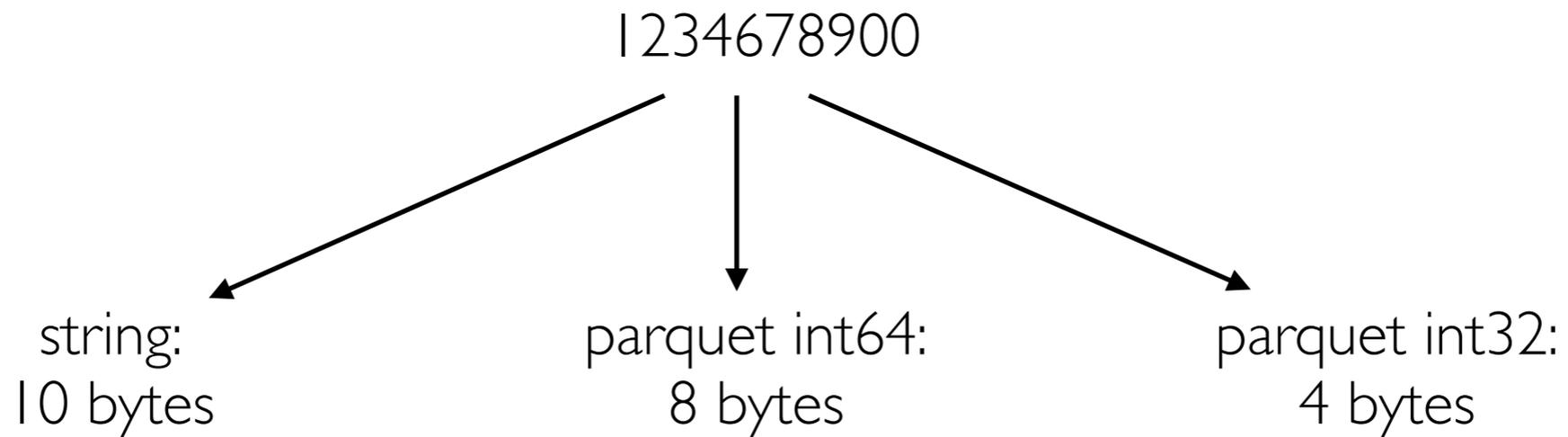
Text vs. Binary



Text vs. Binary



Text vs. Binary



Outline

File Formats

	CSV	Parquet
orientation	row	column
encoding	text	binary
compression	none	snappy
schemas	inferred	explicit

Demos

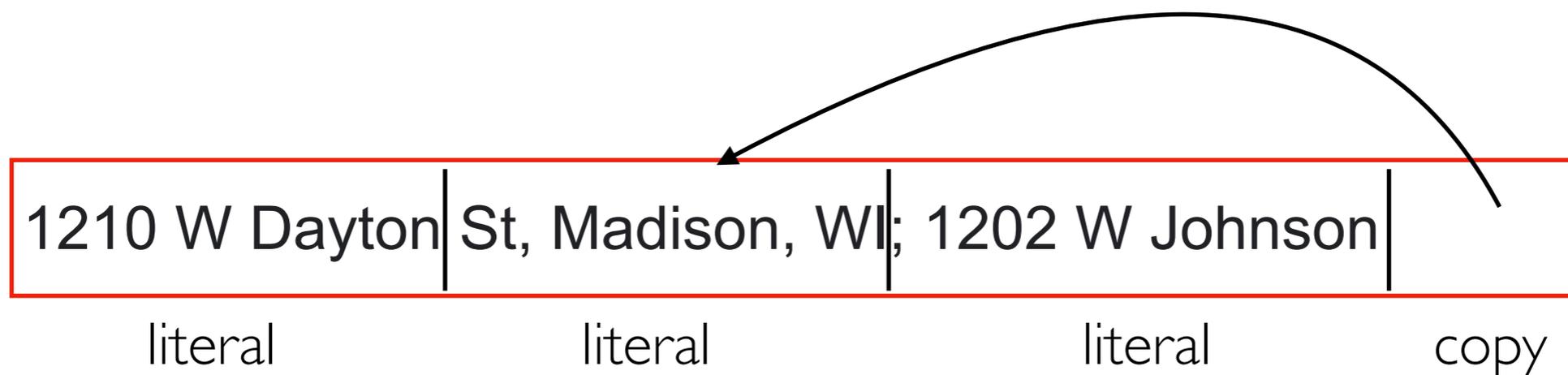
Databases

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):

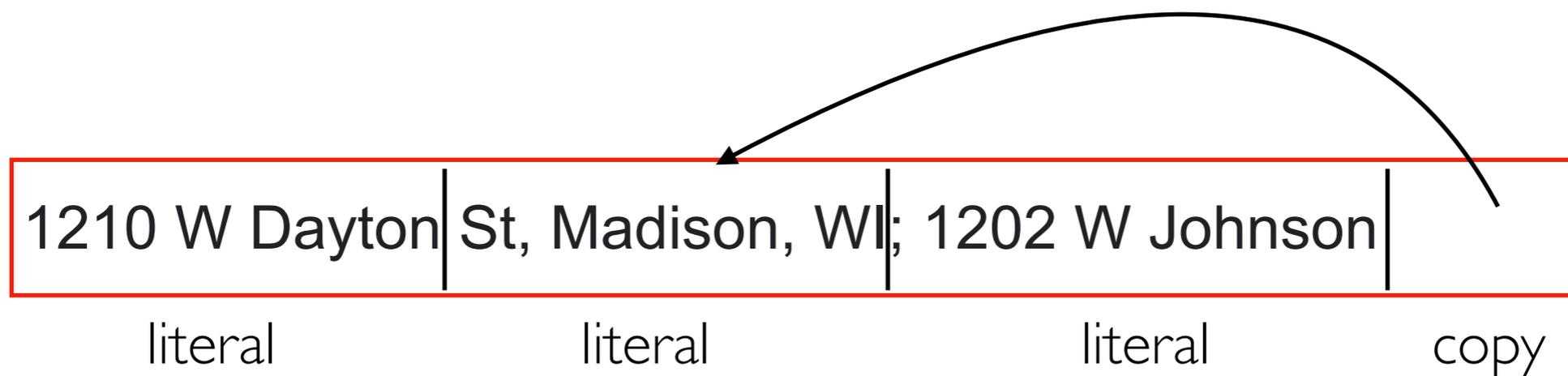


"[Snappy] does not aim for maximum compression, or compatibility with any other compression library; instead, it aims for **very high speeds** and **reasonable compression**."

Snappy documentation

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

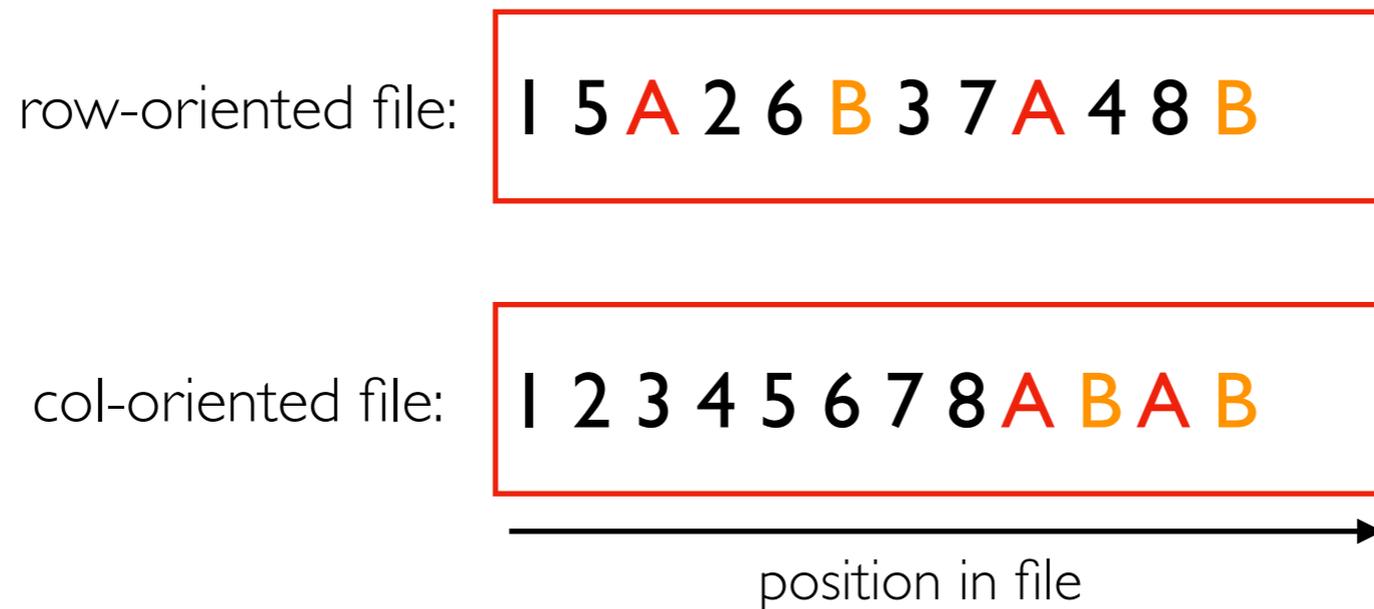
Challenge: Small Updates



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"



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

Outline

File Formats

	CSV	Parquet
orientation	row	column
encoding	text	binary
compression	none	snappy
schemas	inferred	explicit

Demos

Databases

Schemas

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



CSVs:

- in the file, everything is 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!)

schema specified as a dict



parquet files:

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

Outline

File Formats

Demos...

Databases

Outline

File Formats

Demos...

Databases

- tables and queries
- architecture
- transactions vs. analytics

Tables

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_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_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_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_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
...

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
...

Queries let us

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

SQL

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_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
...

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
...

Structure Query Language (SQL)

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

SQL

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_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
...

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
...

Structure Query Language (SQL)

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

```
SELECT AVG(rate) FROM tbl_loan;
```

```
SELECT amount, rate FROM tbl_loan WHERE id = 544;
```

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

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

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

Outline

File Formats

Demos

Databases

- tables and queries
- **architecture**
- transactions vs. analytics

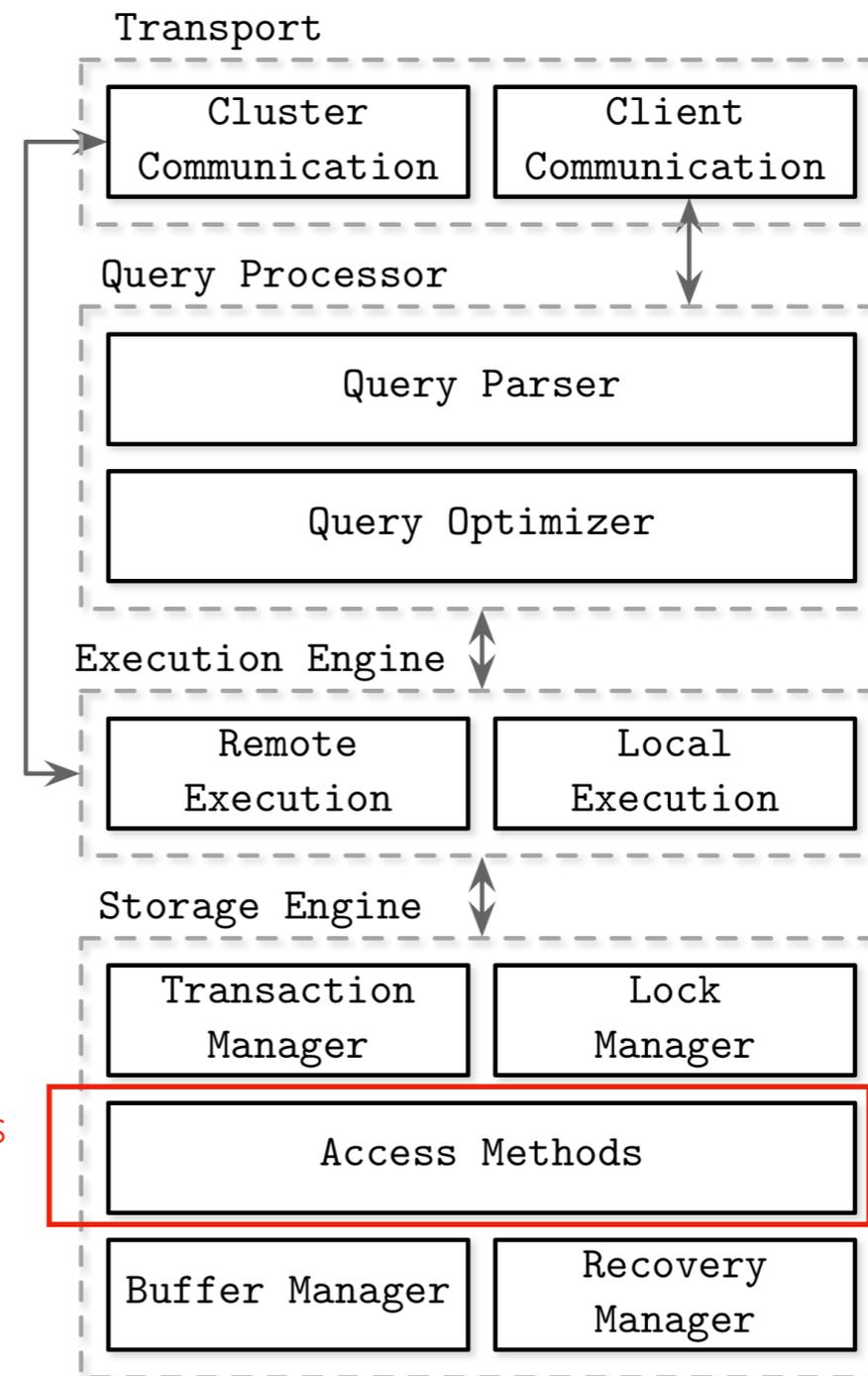
Data Base Management Systems

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

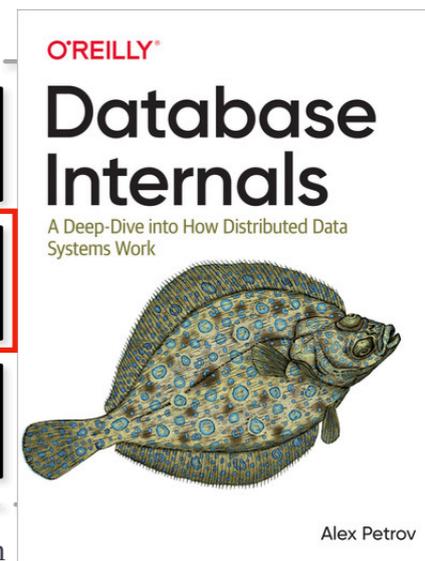


Figure 1-1. Architecture of a database management system (Chapter 1 of Database Internals, by Petrov)

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:

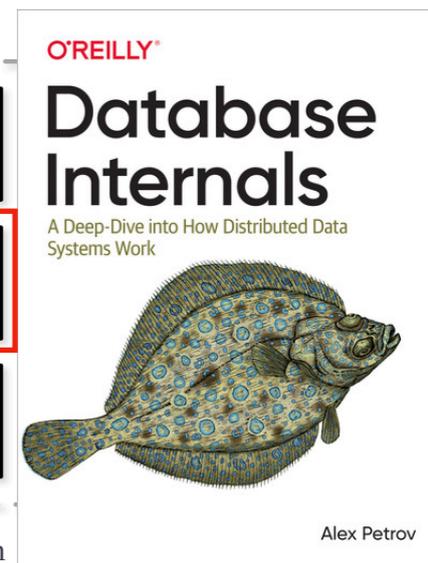
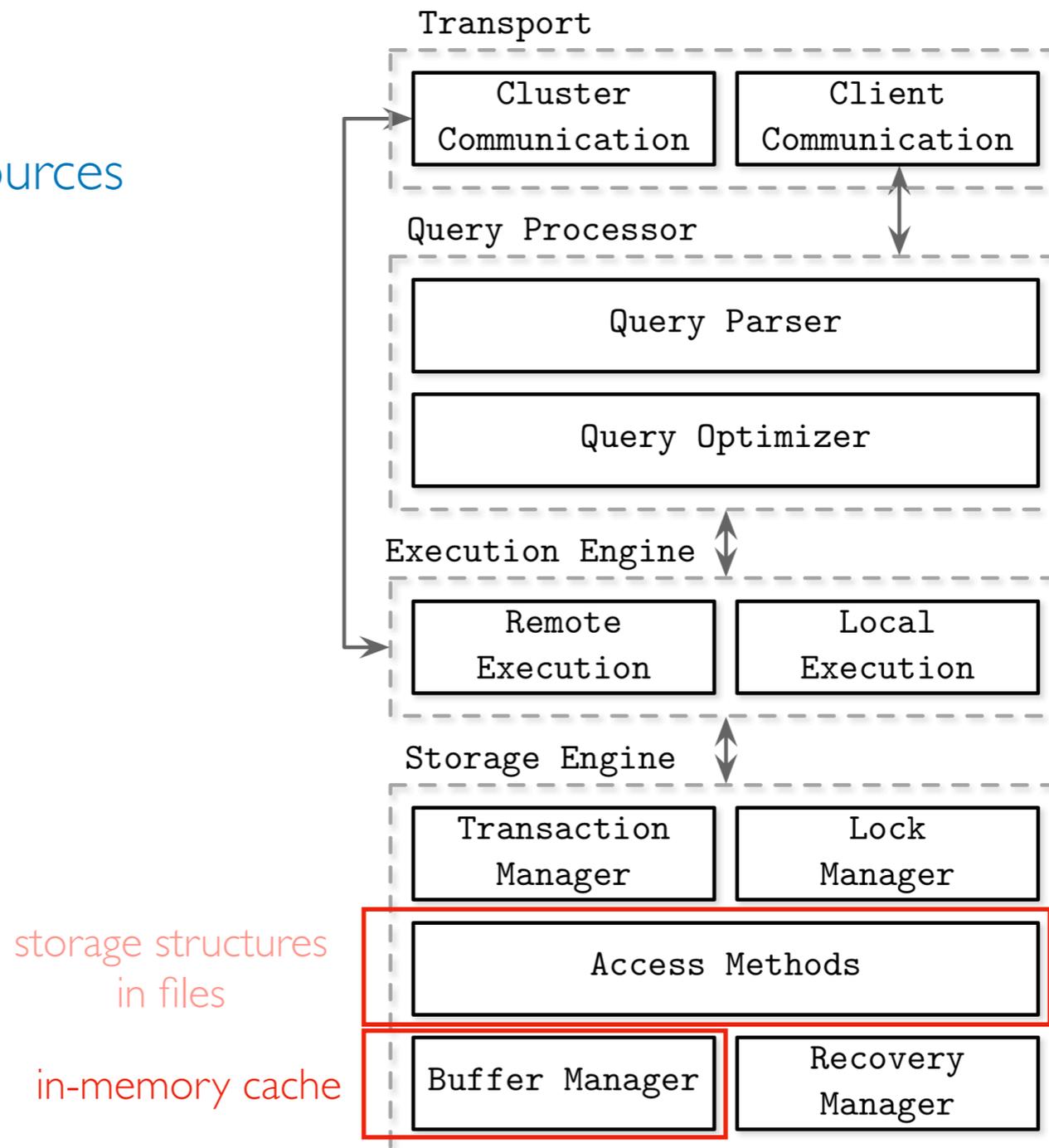


Figure 1-1. Architecture of a database management system (Chapter 1 of Database Internals, by Petrov)

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:

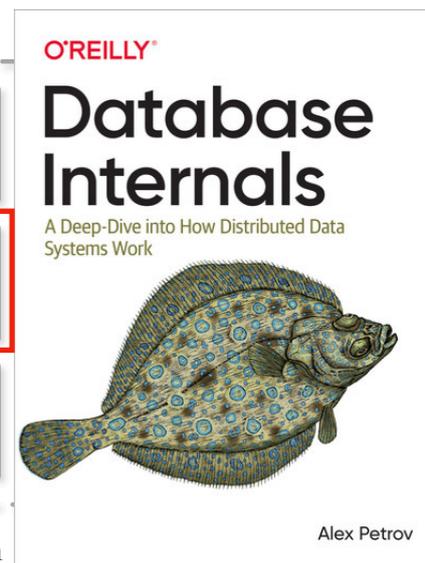
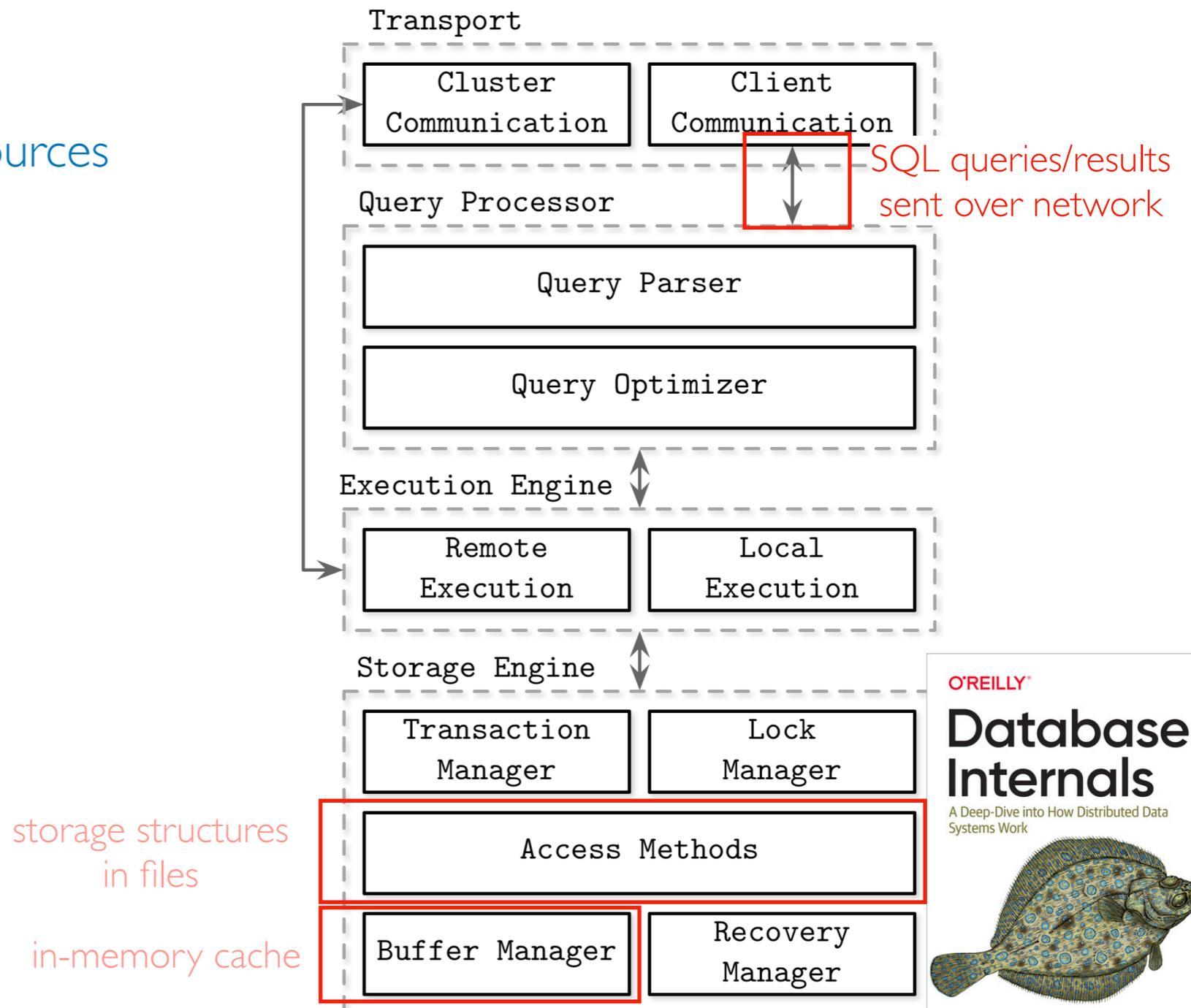


Figure 1-1. Architecture of a database management system (Chapter 1 of Database Internals, by Petrov)

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:

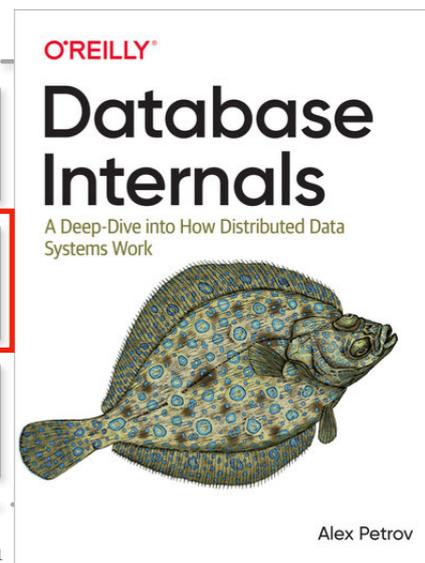
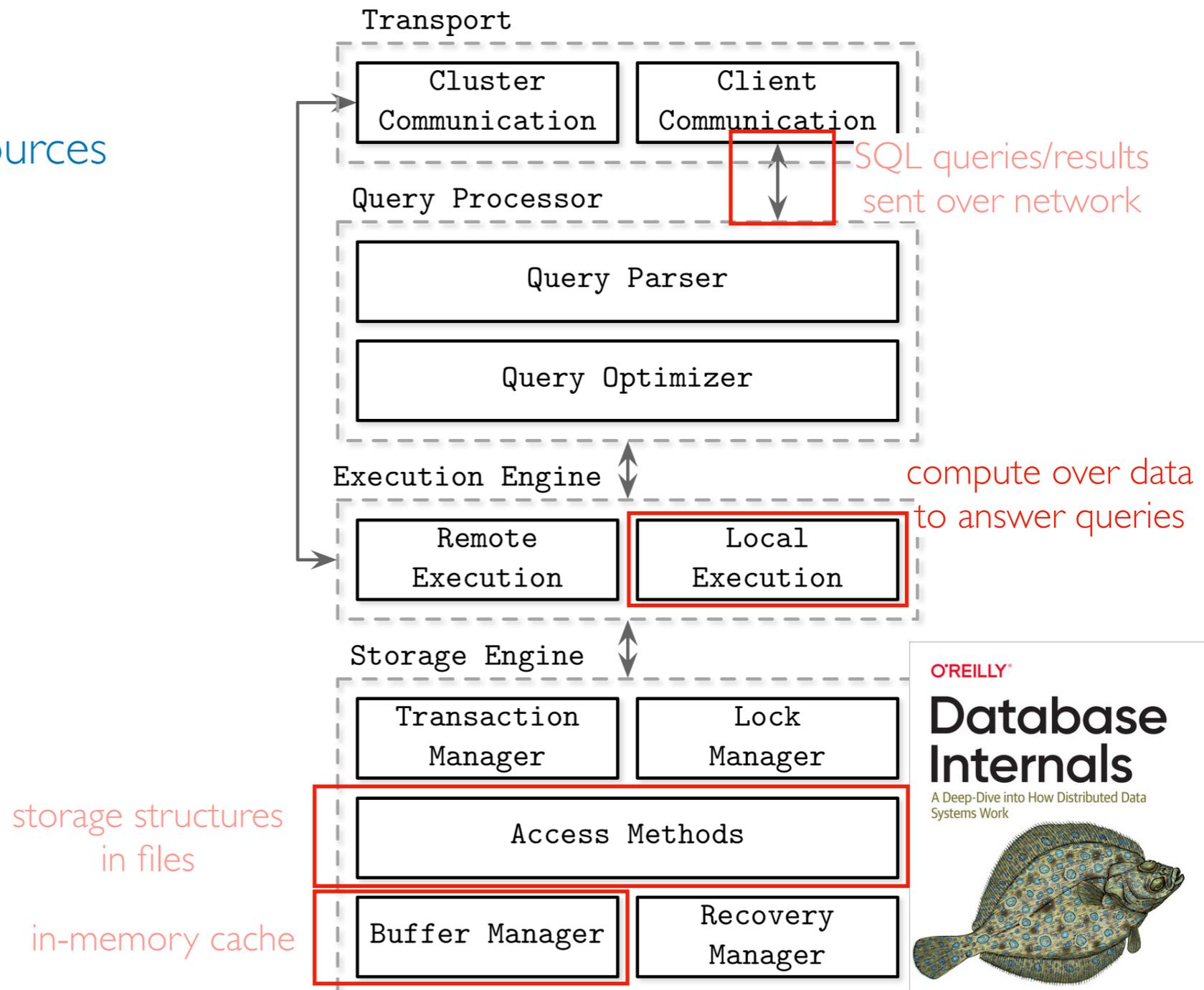
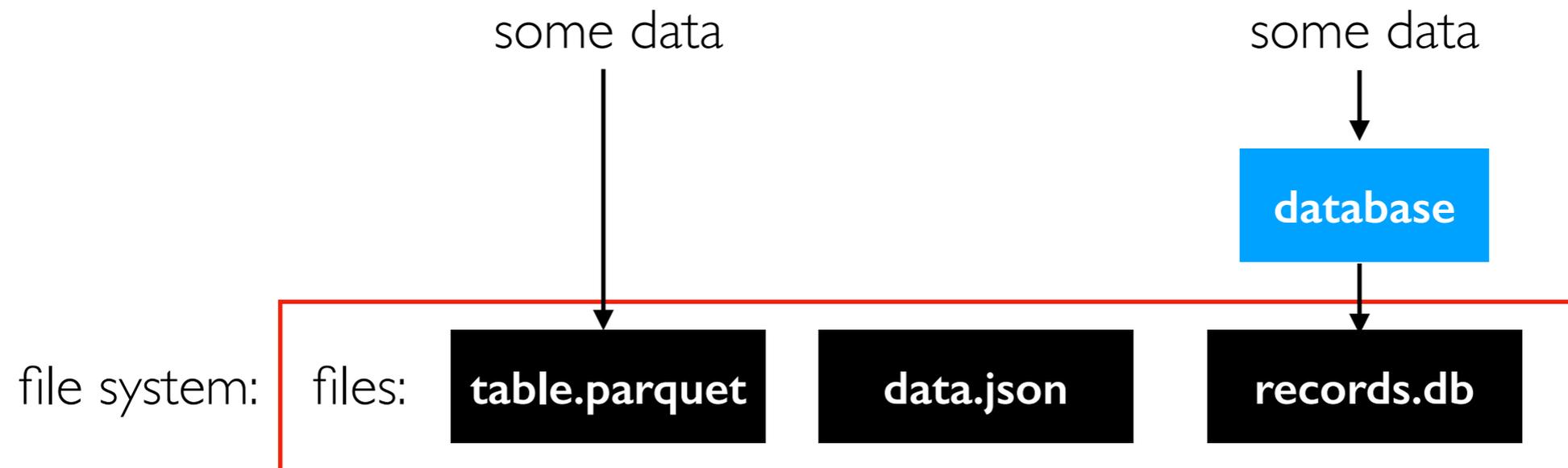


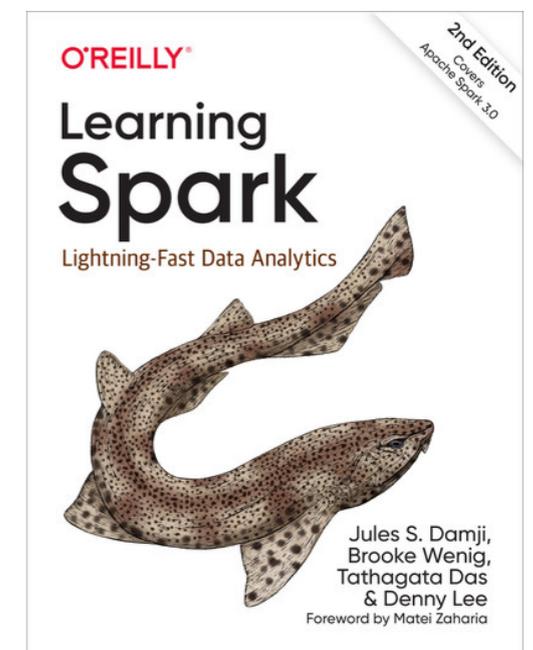
Figure 1-1. Architecture of a database management system (Chapter 1 of Database Internals, by Petrov)

Files vs. Databases (storage+compute coupling)



Databases pros/cons (relative to just using 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)."



Outline

File Formats

Demos

Databases

- tables and queries
- architecture
- transactions vs. analytics

Transactions vs. Analytics

```
SELECT AVG(rate) FROM tbl_loan;
```

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

```
SELECT amount, rate FROM tbl_loan WHERE id = 544;
```

```
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 good at both

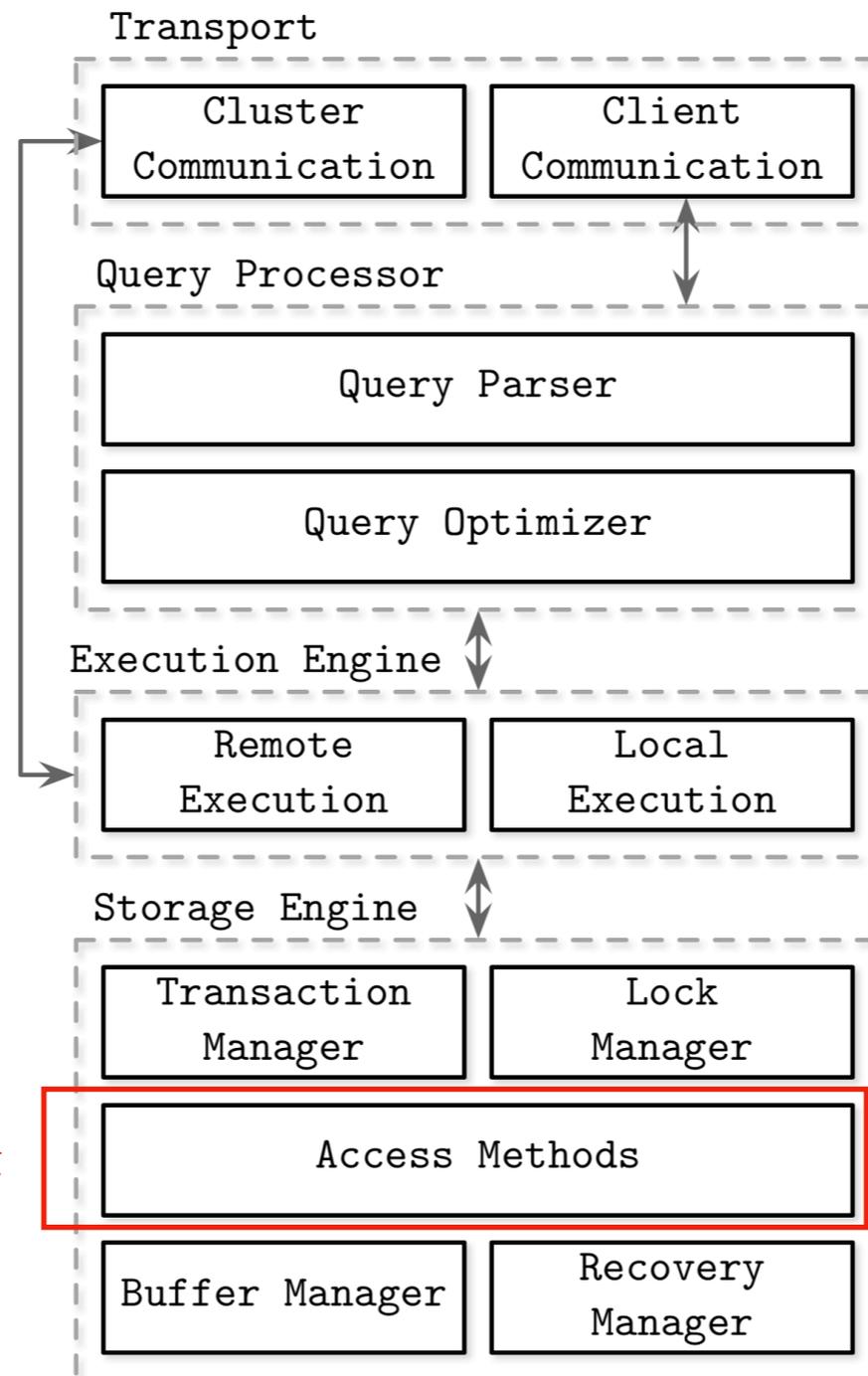
Main database types:

- OLTP (online **transactions** processing)
- OLAP (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

example database architecture:



Typical storage design

OLTP: row oriented data layout

OLAP: col oriented data layout

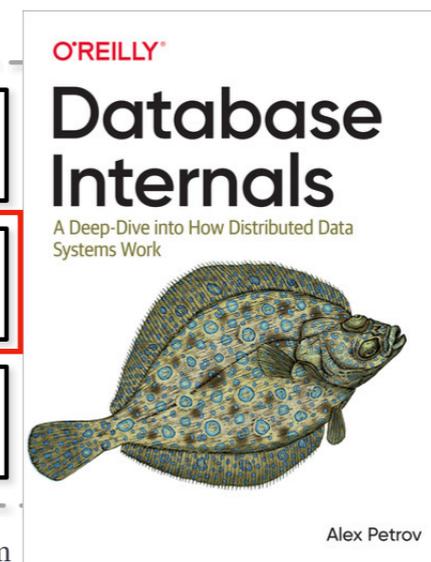


Figure 1-1. Architecture of a database management system (Chapter 1 of Database Internals, by Petrov)

What if you need transactions AND analytics?

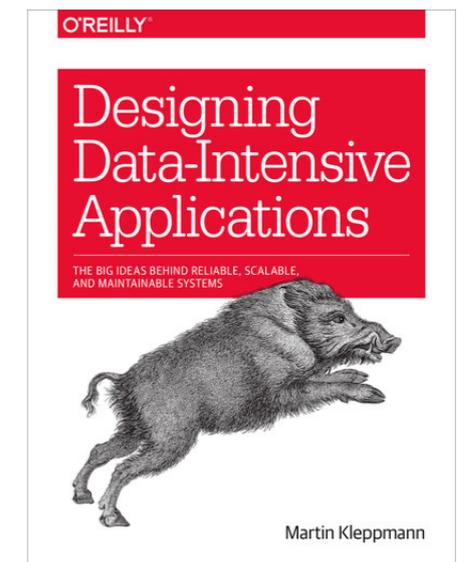
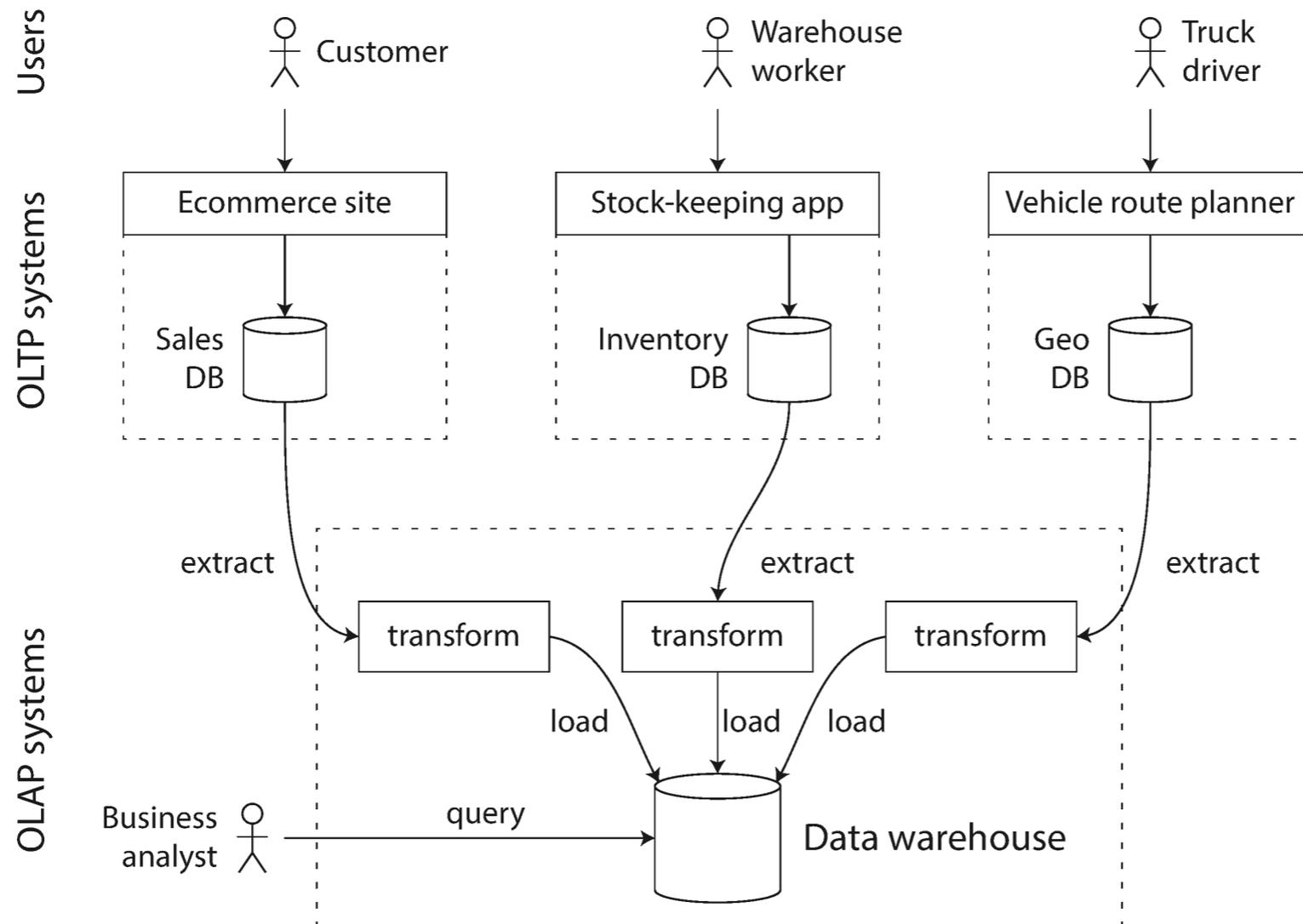


Figure 3-8. Simplified outline of ETL into a data warehouse.
(Chapter 3 of Data-Intensive Applications, by Kleppmann)

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)