Course Review

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What Are
Data-Intensive Systems?

Relational databases: most popular type of data-intensive system (MySQL, Oracle, etc)

Many systems facing similar concerns: message queues, key-value stores, streaming systems, ML frameworks, your custom app?

Goal: learn the main issues and principles that span all data-intensive systems

Typical System Challenges

Reliability in the face of hardware crashes, bugs, bad user input, etc

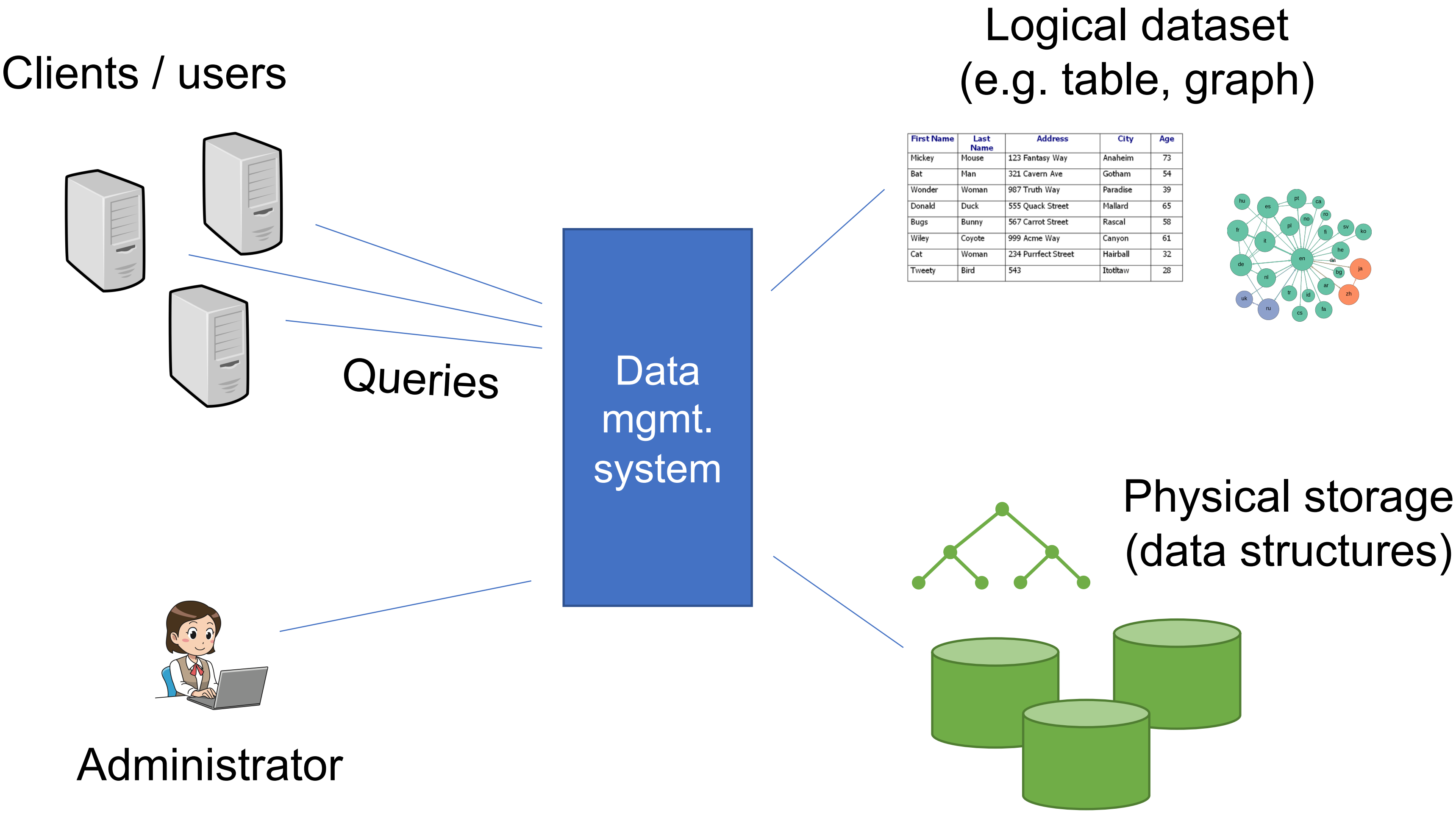
Concurrency: access by multiple users

Performance: throughput, latency, etc

Access interface from many, changing apps

Security and data privacy

Basic Components



First Name	Last Name	Address	City	Age
Mickey	Mouse	123 Fantasy Way	Anaheim	73
Bat	Man	321 Cavern Ave	Gotham	54
Wonder	Woman	987 Truth Way	Paradise	39
Donald	Duck	555 Quack Street	Mallard	65
Bugs	Bunny	567 Carrot Street	Rascal	58
Wiley	Coyote	999 Acme Way	Canyon	61
Cat	Woman	234 Purrfect Street	Hairball	32
Tweety	Bird	543	Itotltaw	28

Two Big Ideas

Declarative interfaces

- Apps specify *what* they want, not *how* to do it
- Example: “store a table with 2 integer columns”, but not how to encode it on disk
- Example: “count records where column1 = 5”

Transactions

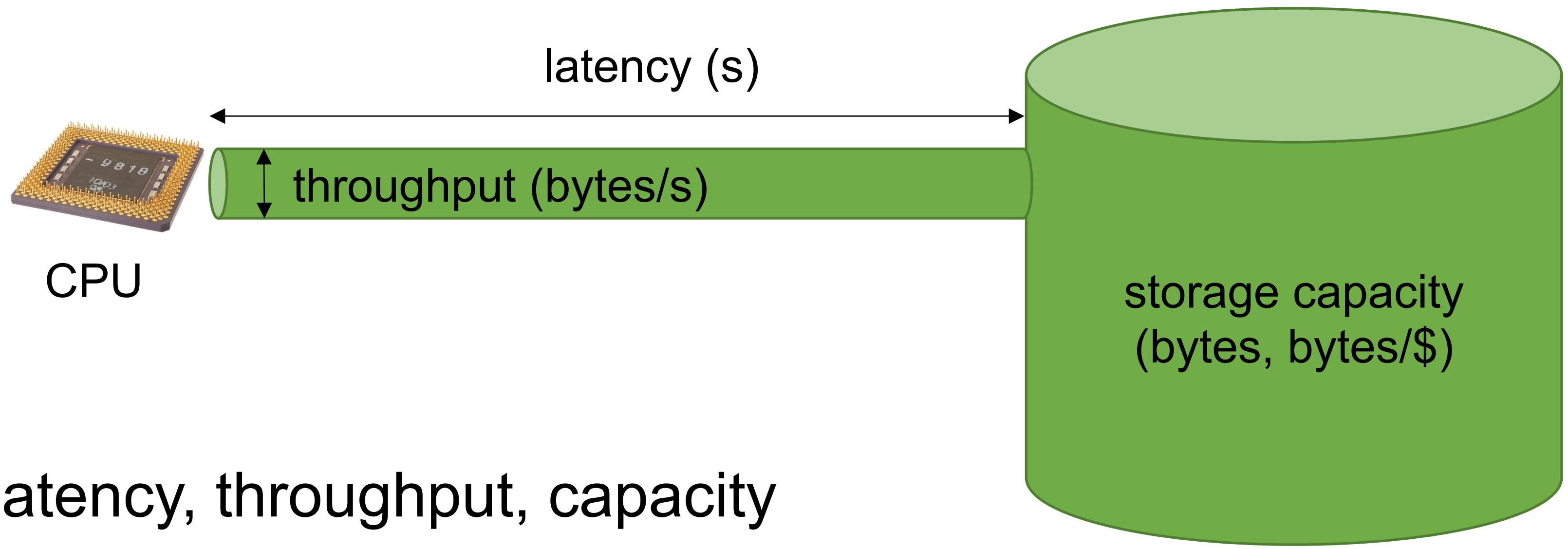
- Encapsulate multiple app actions into one *atomic* request (fails or succeeds as a whole)
- Concurrency models for multiple users
- Clear interactions with failure recovery

Key Concepts: Architecture

Traditional RDBMS: self-contained end to end system

Data lake: separate storage from compute engines to let many engines use same data

Key Concepts: Hardware



Latency, throughput, capacity

Random vs sequential I/Os

Caching & 5-minute rule

Key Concepts: Data Storage

Field encoding

Record encoding: fixed/variable format, etc

Table encoding: row or column oriented

Data ordering

Indexes: dense, sparse, B+ trees, hashing, multi-dimensional

Key Concepts: Query Execution

Query representation
(e.g. SQL)

↓

Logical query plan
(e.g. relational algebra)

↓

Optimized logical plan

↓

Physical plan
(code/operators to run)

Many **execution methods:** per-record exec, vectorization, compilation

Key Concepts: Relational Algebra

$\cap$, $\cup$, $-$, $\times$, σ, Π, $\bowtie$, G

Algebraic rules involving these

Key Concepts: Optimization

Rule-based: systematically replace some expressions with other expressions

Cost-based: propose several execution plans and pick best based on a **cost model**

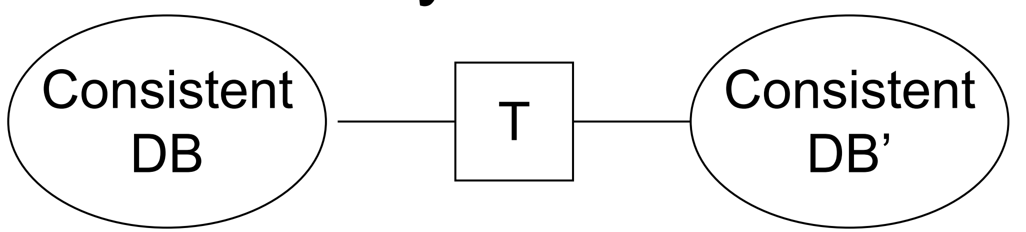
Adaptive: update execution plan at runtime

Data statistics: can be computed or estimated cheaply to guide decisions

Key Concepts: Correctness

Consistency constraints: generic way to define correctness with Boolean predicates

Transaction: collection of actions that preserve consistency



Transaction API: commit, abort, etc

Key Concepts: Recovery

Failure models

Undo, redo, and undo/redo logging

Recovery rules for various algorithms (including handling crashes during recovery)

Checkpointing and its effect on recovery

External actions → idempotence, 2PC

Key Concepts: Concurrency

Isolation levels, especially **serializability**

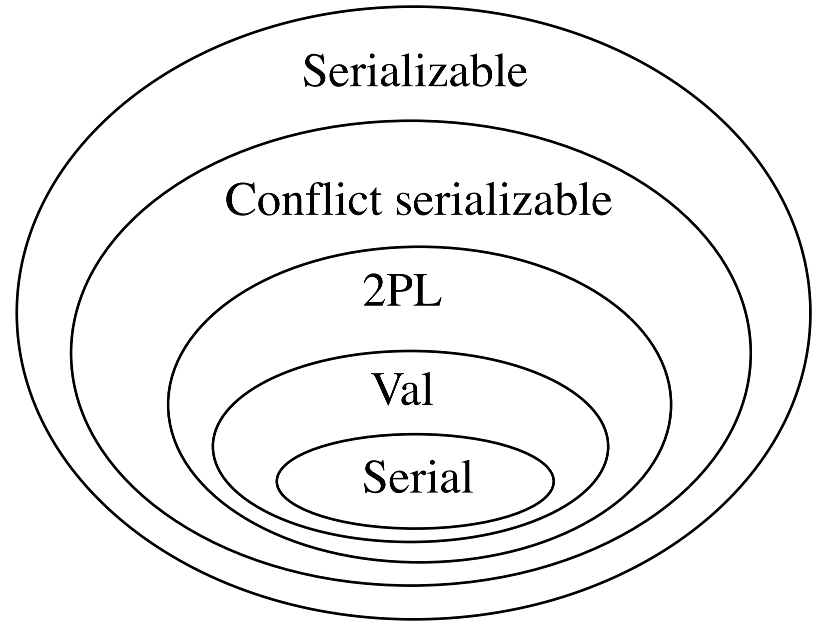
» Testing for serializability: conflict serializability, precedence graphs

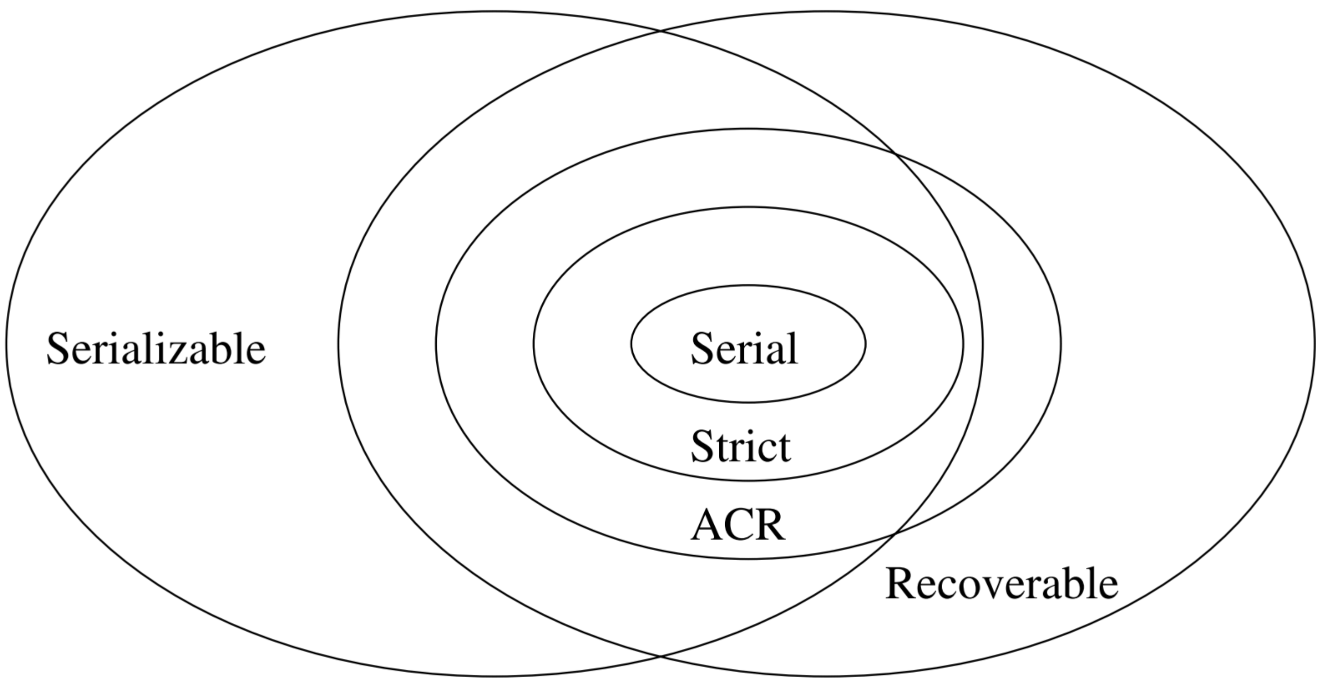
Locking: lock modes, hierarchical locks, and lock schedules (well formed, legal, 2PL)

Optimistic validation: rules and pros+cons

Recoverable, ACR & strict schedules

Categories of Schedules





Key Concepts: Distributed

Partitioning and **replication**

Consensus: nodes eventually agree on one value despite up to F failures

2-Phase commit: parties all agree to commit unless one aborts (no permanent failures)

Parallel queries: comm cost, load balance, faults

BASE and relaxing consistency

Key Concepts: Security and Data Privacy

Threat models

Security goals: authentication, authorization, auditing, confidentiality, integrity etc

Differential privacy: definitions, computing sensitivity & stability

Putting These Concepts Together

How can you integrate these different concepts into a coherent system design?

How to change system to meet various goals (performance, concurrency, security, etc)?