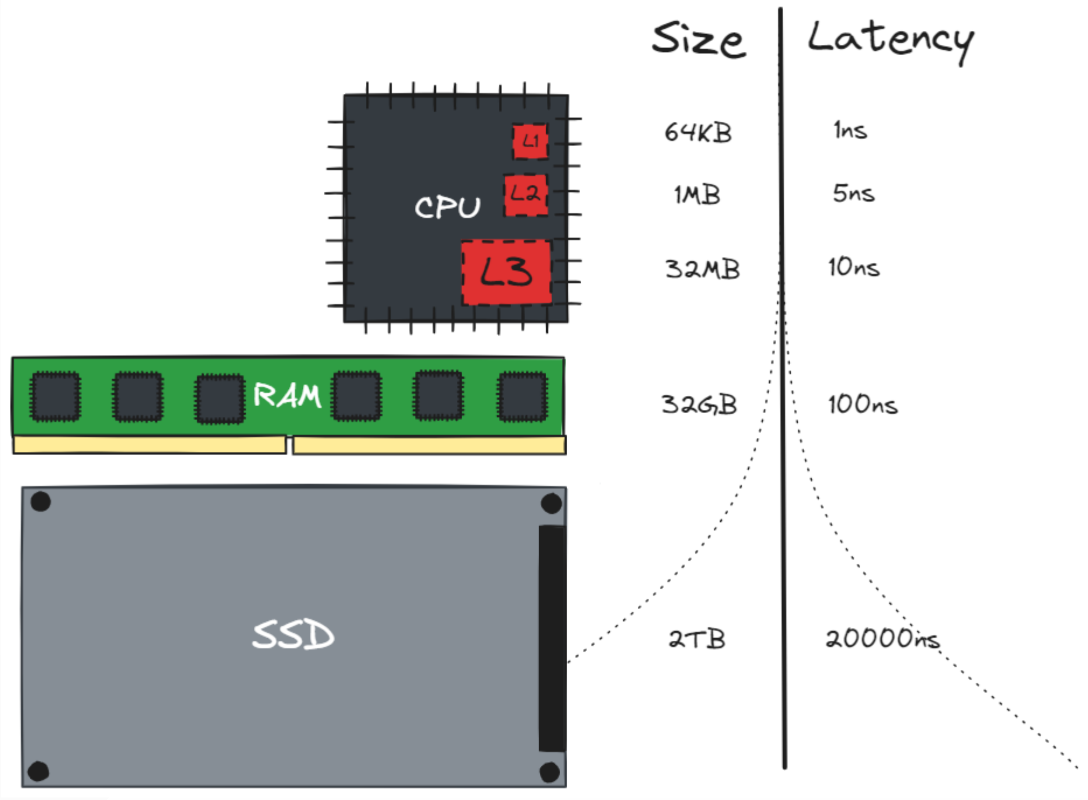
Module 1

Storing Data Safely

Numbers any engineer should know



Pros and cons of disks

👍 They have a bigger capacity than volatile memory or caches

👍 They are **persistent**

😔 They are **slow**

How do this?

🙋 Any guess?

Using the OS

`mmap` allows for mapping in virtual memory a physical file

But this is problematic. Why? 🙋

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`mmap` allows for mapping in virtual memory a physical file

But this is problematic. Why? 🙋

For **performance** reasons mostly. Pages can be evicted at any time, which could stall processes

Buffer Pool

Most DBMS choose instead to, implement their own layer, sitting **between** the database process and the filesystem.

Buffer Pool

Database files are split in **pages** of a few KBs

A page is the **smallest** unit of storage the DBMS can interact with

➡️ Postgres uses 8KB pages by default (same for Microsoft SQL Server)

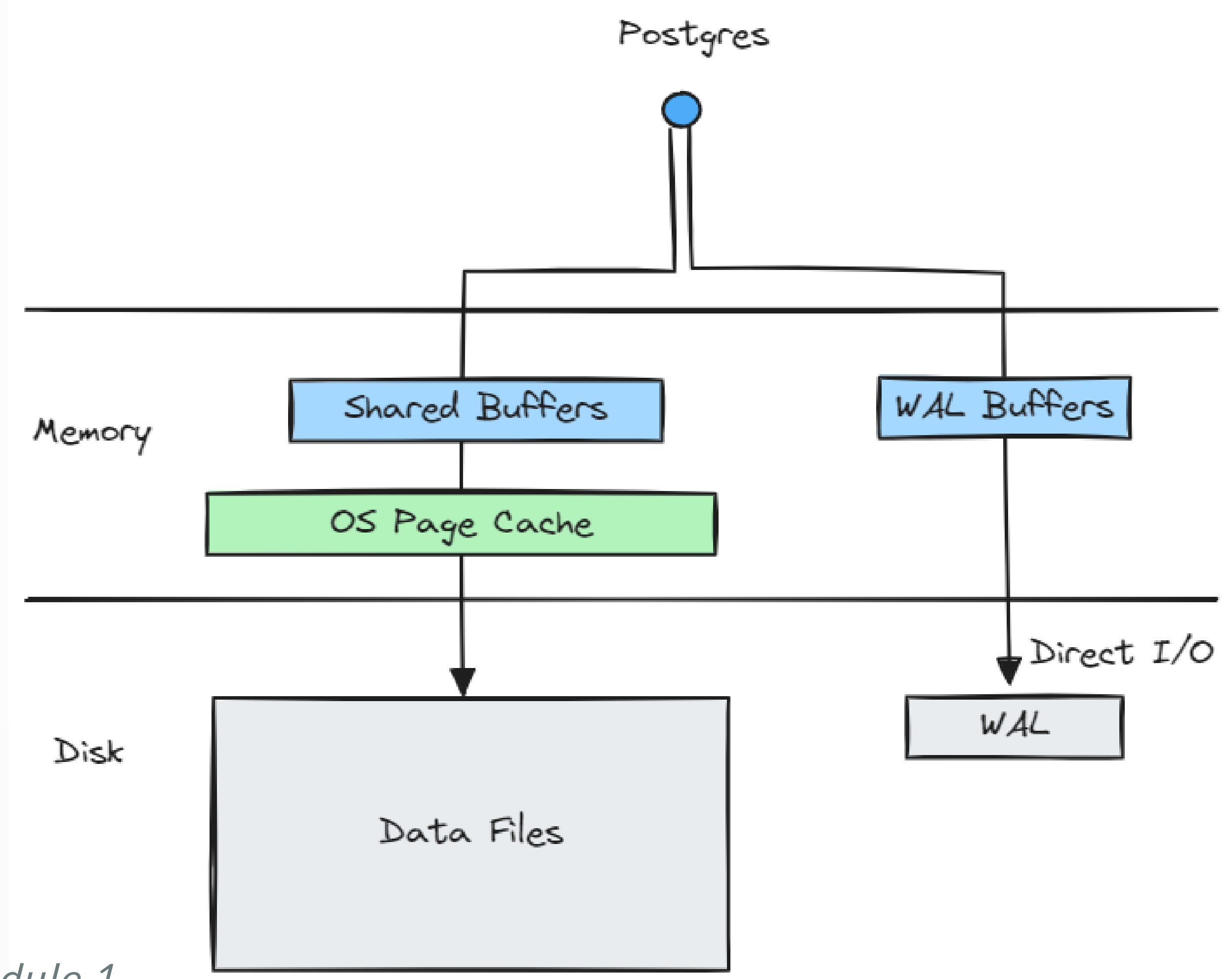
The **Buffer Pool** is a cache of pages, organized as an in-memory array

Buffer Pool

The Buffer decides **when** data is read from disk to memory, and **when** pages are persisted to disk

The Buffer Pool generally does `O_DIRECT`, but Posgres does not.

Anatomy of Postgres storage



😱 Postgres uses Buffered I/O ?

It started as a **research** project in the 1980s and only has still a few contributors

Main focus was on the **database engine** itself

A Direct I/O stack is **hard to implement**

Data Files

How are **standard** types stored?

🙋 How are `NULL` s stored?

For big enough values, store them in specific pages (**TOAST** pages in Postgres)

> **TOAST** = **T**he **O**versized-**A**ttribute **S**torage **T**echnique

Tuple Alignment

> Alignment: Making sure that tuples are stored on multiples of 64 bits.

Some systems reorganize columns in the tuple.
PostgreSQL will **pad** every type to make sure that everything is **64-bit** aligned

Holy grail of linearizability

Database systems would be **easier to write** if they were single process and single user

We would love transactions to appear as if they were executed in a **global order**, even if they are executed **concurrently**

This property is called **linearizability** and is often used in distributed systems

Dealing with concurrency

However in real life we will have **multiple users** running multiple concurrent queries

> How do we solve this?

Transaction

A sequence of **Read** and **Write** operations that has the four well known **ACID** properties
🙋 Remember what they stand for?

ACID

Atomicity: All changes commit or none
Consistency: They only tranistion from a valid state to another
Isolation: They execute isolated from each other
Durability: Committed transactions persist despite system failures

Atomicity & Durability

To provide **both**, the best way is to use a **log**

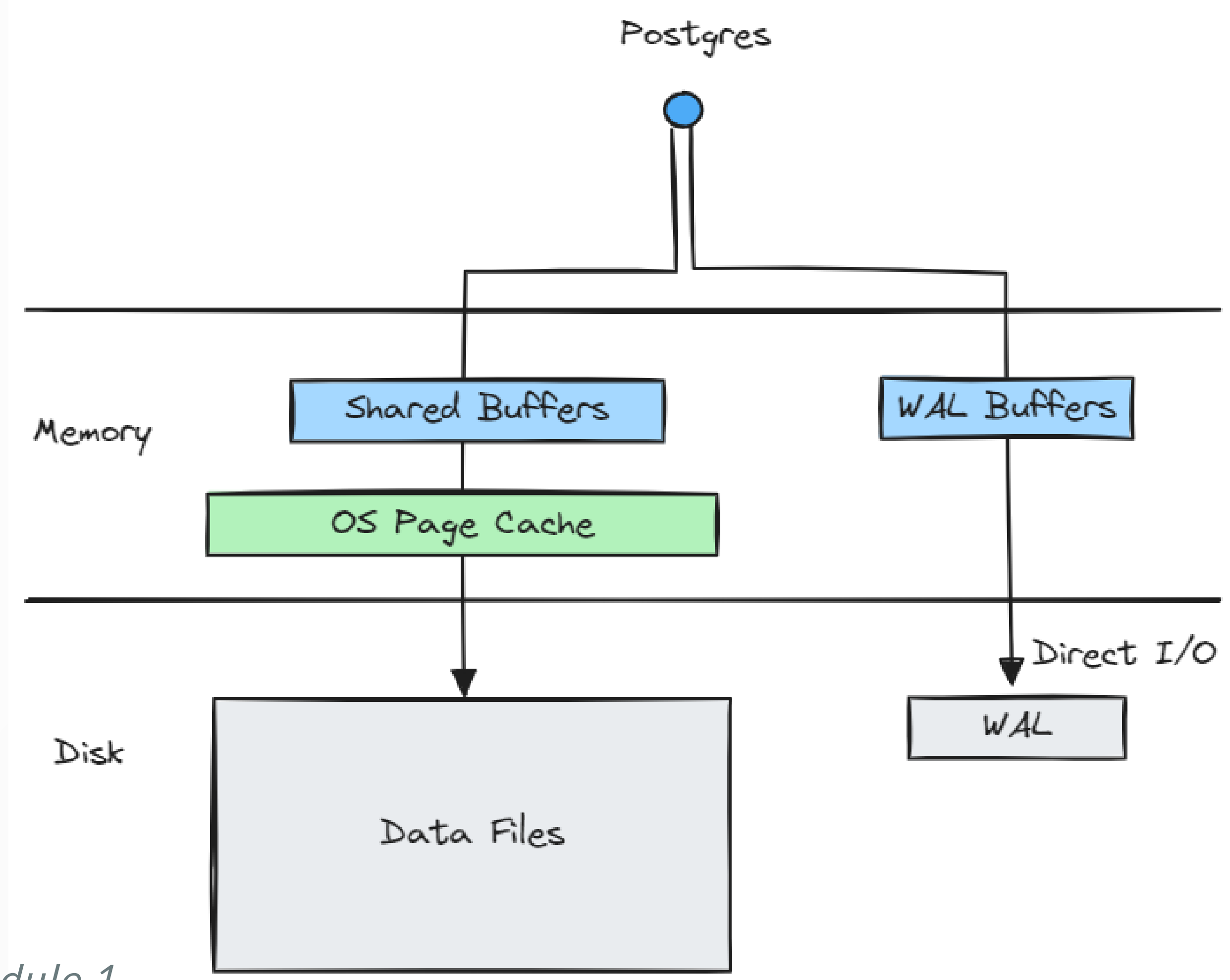
First write all operations in a queue, and apply them once committed

Write-Ahead Log (WAL)

All **operations** are written in the log

`CHECKPOINT` is a special one

Recap



Postgres
Memory
Shared Buffers
WAL Buffers
OS Page Cache
Direct I/O
Disk
Data Files
WAL

Checkpoint

Happens automatically **every few minutes**

1. Get the current WAL **position**
2. Write data from Buffer Pool to **page cache**
3. Call `fsync` on **all modified files**
4. Mark the point of recovery, and clean the log

❓ Did you recently hear about **issues** there (think of `fsync`)?

Isolation Anomalies

Isolation is another story
We are trying to prevent the following to happen:

- **Dirty** reads: reading uncommitted changes
- **Non-repeatable** reads: reading a value has been changed by another committed transaction
- **Phantom Reads** reads: reading a value that has been inserted by another committed transaction

Isolation Levels

- **Read Uncommitted**: Allows dirty reads, non-repeatable reads, and phantom reads
- **Read Committed**: Prevents dirty reads but allows non-repeatable and phantom reads
- **Repeatable Read**: Prevents dirty and non-repeatable reads but allows phantom reads
- **Serializable**: Ensures the highest level of isolation, preventing all anomalies

How to guarantee this?

There are mainly two approaches.
🙋 Can you name one?

How to guarantee this?

There are mainly three approaches.
🙋 Can you name one?

MVCC, **Locks** and **Optimistic CC**

Optimistic Concurrency Control

Assume that everything *generally* goes fine

1. Record the transaction beginning timestamp
2. Prepare the values to write
3. If the destination has not changed since the beginning of the transaction, `COMMIT`, otherwise, `ROLLBACK`

Locks

A **Lock Manager** grants different kinds of locks on objects, such as **Exclusive** or **Shared** locks

Some locks are compatible with each other.

> in most DBMS, `SELECT` will acquire a S lock that is compatible with other S locks. However, modifying the table requires an X lock

Locks limit the **concurrency**

MVCC

Every operation operates on a **snapshot** of the database

> Reading never blocks writing and writing never blocks reading.

Tuples are not modified in **place**

Problems: outdated blocks need to be **cleaned up** and txid wraparound 💀

Isolation Levels in PostgreSQL

- `REPEATABLE_READ` is provided by taking a snapshot at the beginning of the transaction. Concurrent updates will lead to a so-called serialization error and a `ROLLBACK`
- `SERIALIZABLE` is the same with a stronger guarantee: if a table is **read** by two concurrent transactions, one is aborted
- `READ_COMMITTED` is the default
- `READ_UNCOMMITTED` does not really exist
  🙋 Why?

Recap

- We looked at how PostgreSQL **stores data on disk**
- We saw that it uses a **log** named the **WAL** to ensure atomicity and durability
- Isolation is provided by **transactions** that have different isolation levels