# Module 2

Querying data

# Relational Algebra

# Relational Algebra

## Basic Operations

| Operator | Description | SQL Translation |
| --- | --- | --- |
| Π | Project | `SELECT` + `FROM` |
| ρ | Rename | `AS` |
| σ | Select | `WHERE` |

# Relational Algebra

## Set Operations

| Operator | Description | SQL Translation |
|---|---|---|
| ∪ | Union | `UNION` |
| ∩ | Intersection | `INTERSECT` |
| - | Set Difference | `EXCEPT` |
| / | Division | ⚠ **Not implemented!** |

# Relational Algebra

## Join Operators

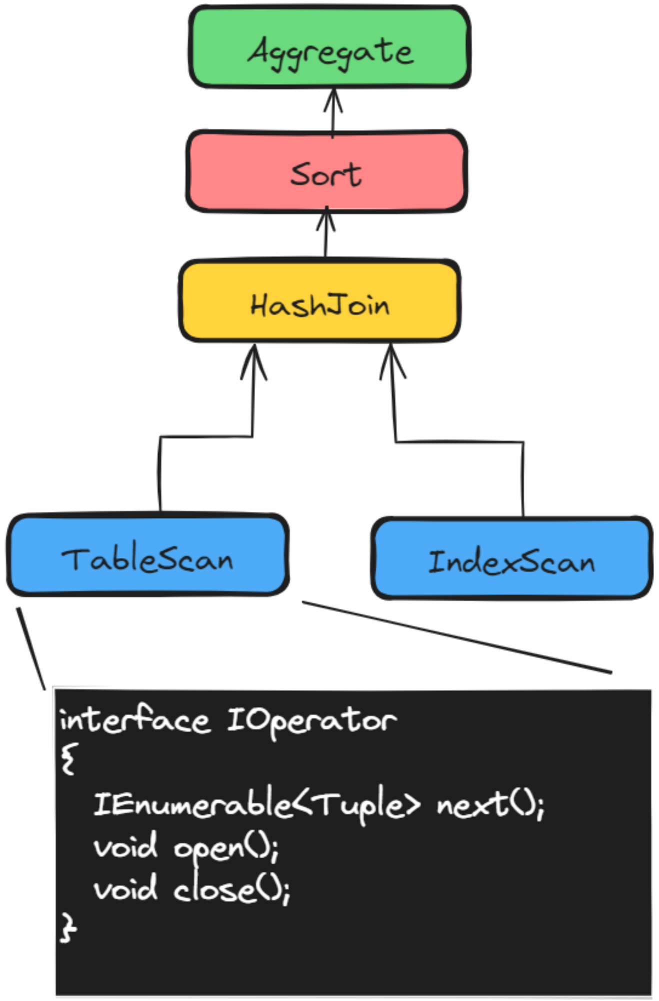
| Operator | Description | SQL Translation |
|---|---|---|
| ⋈ | Natural Join | `INNER JOIN` * |
| ⋉ | Left Semi Join | `WHERE EXISTS(...)` ** |
| ▷ | Left Anti Join | `WHERE NOT EXISTS(...)` ** |
| □ | Left Outer Join | `LEFT OUTER JOIN` |
| □ | Full Outer Join | `FULL OUTER JOIN` |

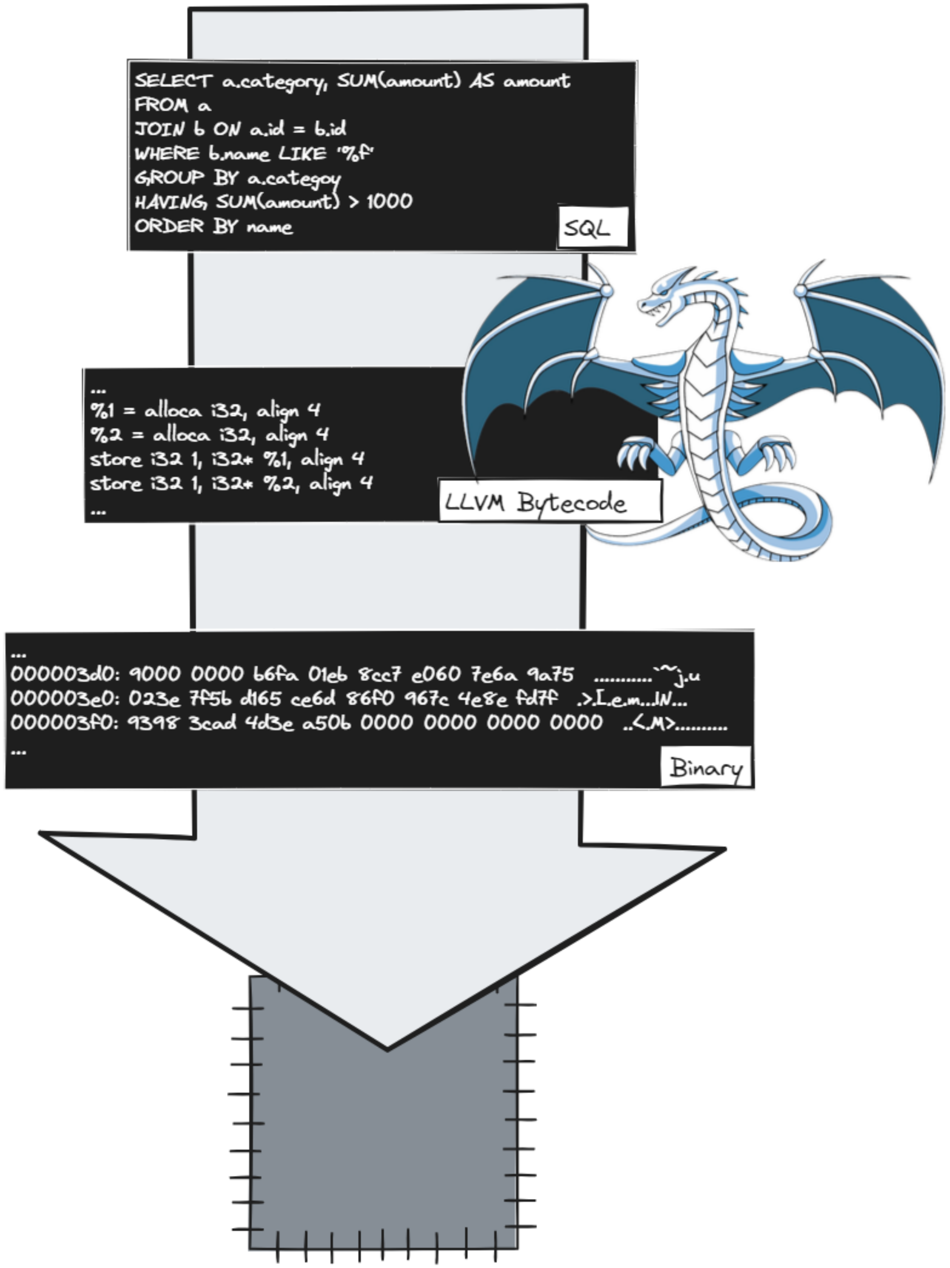
# Execution Strategies

# How are queries executed?

🙋 There are mainly two ways, can you find one?

# "Volcano" Model VS Query Compilation



# Volcano

👍 **Easy** to reason about, compose and enrich

👍 **Everyone** uses it

👎 Performance issues, mostly from instruction-cache misses

# Volcano with SIMD

**S**ingle **I**nstruction, **M**ultiple **D**ata

Modern CPUs - since the 1990s - can execute vectorized instructions

> Instructions operating on **vectors**

This limits the number of instruction **calls**

# Compilation

Compile SQL to some bytecode, and then to machine code

Only a handful of engines do it (SingleStore is a good example)

# Join Implementations

# Join Algorithms

- 🙋 What could be the simplest way to code an `INNER JOIN`?

# Join Algorithms

🙋 What could be the simplest way to code an `INNER JOIN`?

A **Nested Loop Join**!

```
foreach Tuple r in R
    foreach Tuple s in S do
        if SatisfyJoinCondition(r,s)
            yield new Tuple(r,s)
```

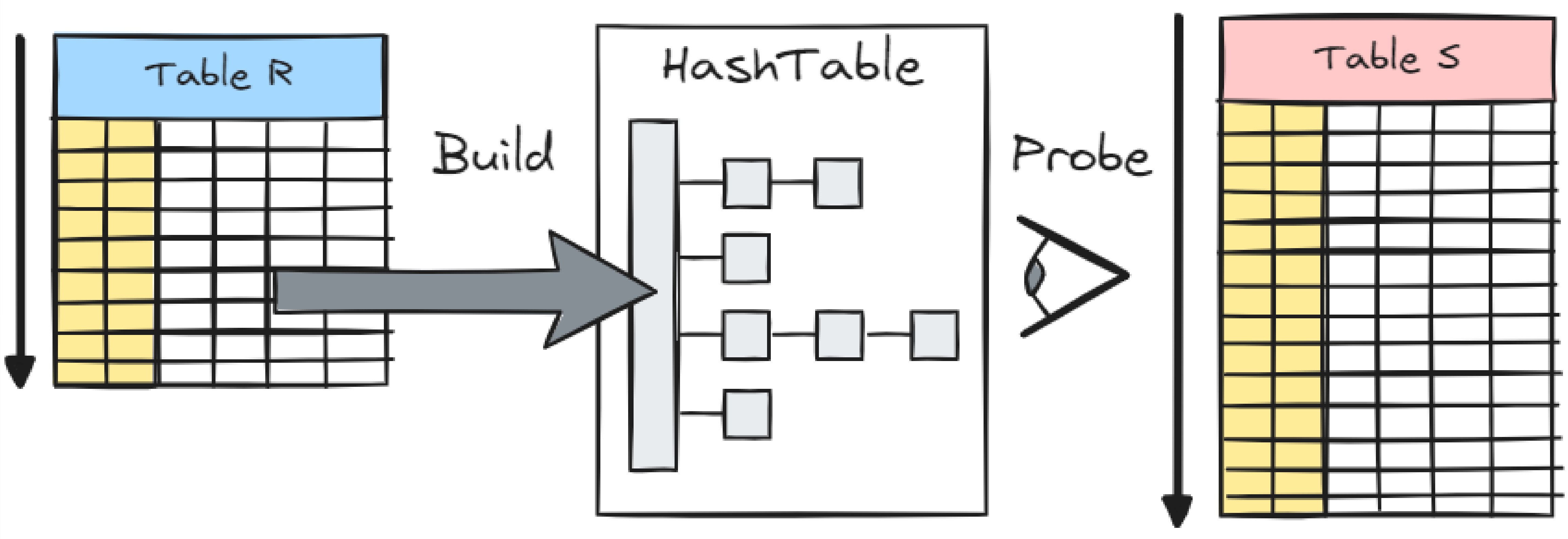
# Nested Loop Join

The complexity is O(m **x** n) with **m** and **n** the respective cardinality of both relations

Runs with **constant** memory

Supports **any matching condition** and early interruption (e.g. `LIMIT`)

# Hash Join



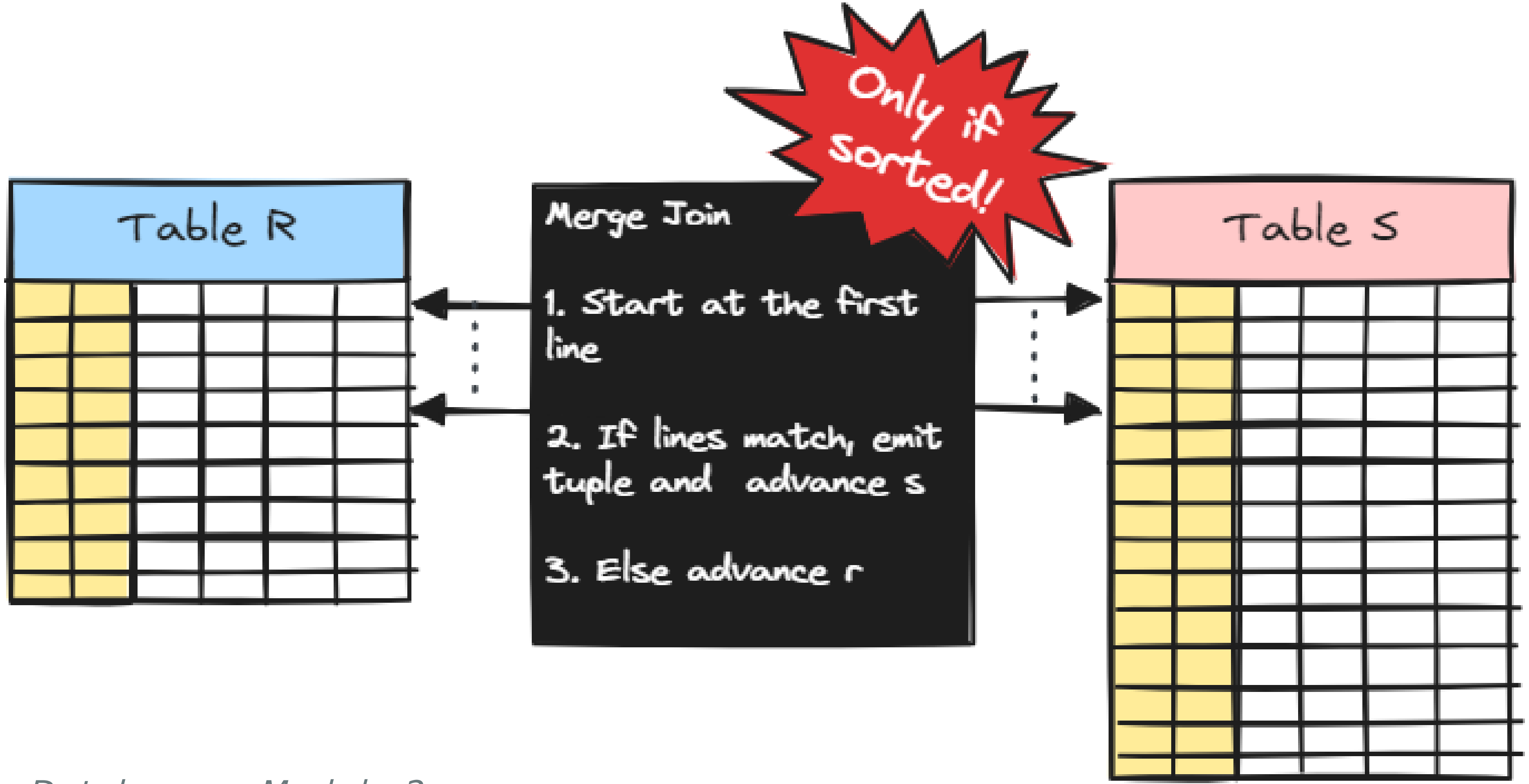
# Hash Join

The number of operations reduces to O(m **+** n) if we assume **O(1)** lookups

The memory requirements scale with the **build-side table size**

Supports **only equi-joins**

# Merge Join



Only if sorted!
Table R
Merge Join
1. Start at the first line
2. If lines match, emit tuple and advance s
3. Else advance r
Table S

# Merge Join

Runs in **O(1)** memory, with O(m **+** n) operations

Works only on **sorted** tables

Supports **only equi-joins**

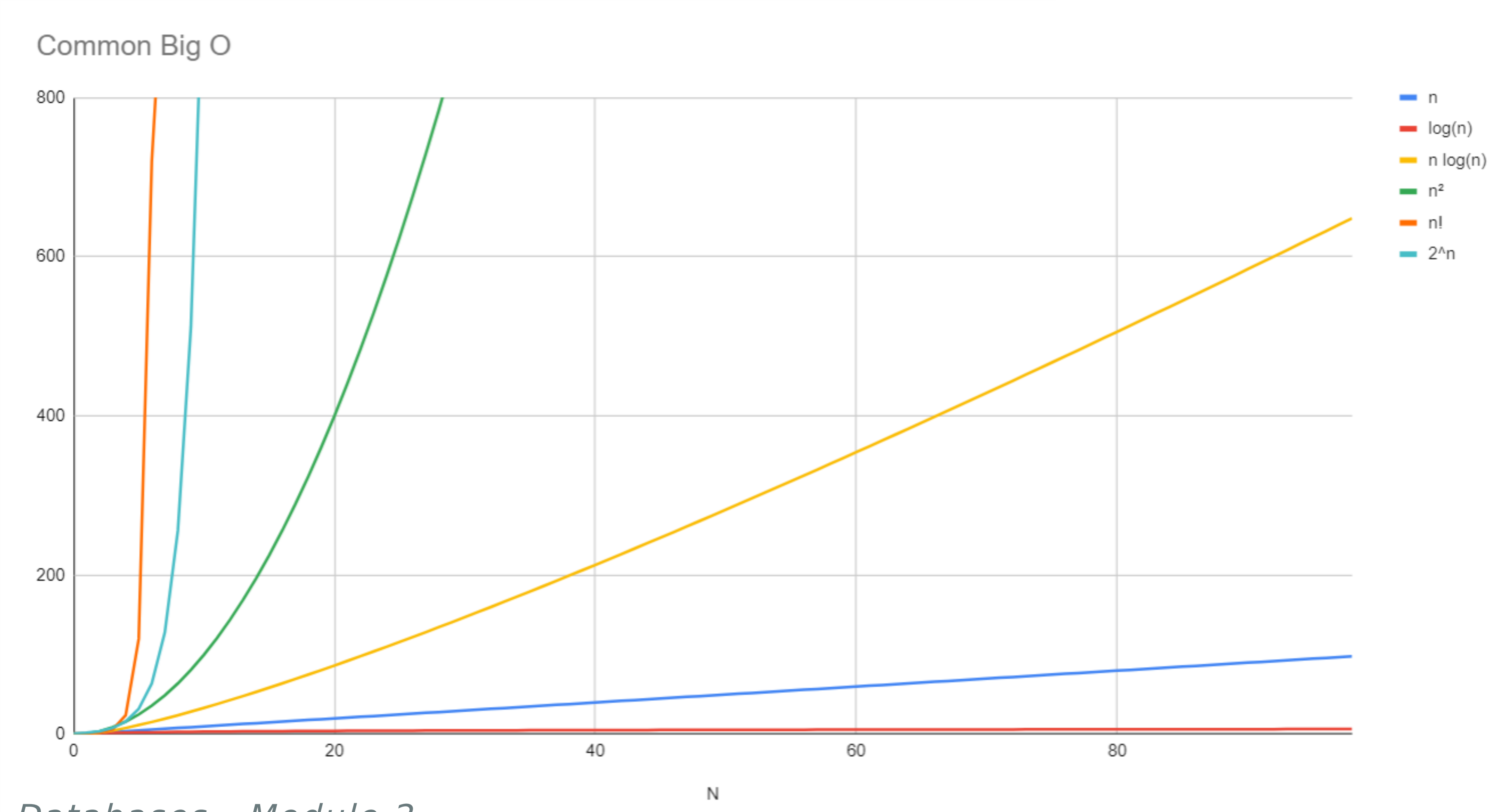
# Sort Merge Join

We can decide to **pay the cost of sorting** to perform a Merge Join

Sorting would be typically $O(n \log(n) + m \log(m))$, which makes the total complexity $O(m + m \log(m) + n + m \log(n))$

> We thus consider the complexity to be **$O(m \log(m) + n \log(n))$**

# As a reminder



# Recap on Joins

| Algorithm | Instructions | Memory | Constraints |
|---|---|---|---|
| Nested Loop | O(m*n) | 0(1) | None |
| Hash Join | O(m+n) | 0(n) | Equijoins |
| Merge Join | O(m+n) | 0(1) | Equijoins + Sorted |
| Sort-Merge Join | O(n log(n) + m log(n)) | 0(1) | EquiJoins |

# Indexes

# Full Table Scans

Without indexes, the only way to retrieve a particular value is to **scan the entire table**

> Think of a book with no table of contents

# B-Trees

Invented in the **1970s**

Generalization of a **Binary Search Tree** when each node can have up to *m* children

> **m** is usually called the B-Tree *order*

Used by pretty much every relational database

# B-Trees (continued)

Every node can have **up to m** children

Every leaf node is at the **same distance from the root**

When leaf nodes are chained, we call them **B+Trees** (allows for traversal)

> In databases, **leaf** nodes typically point to heap pages (data pages)

# B-Trees (continued)