Intro to Database Systems (15-445/645)

23 Distributed OLAP Databases

Carnegie Mellon University

SPRING 2023

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ADMINISTRIVIA

Homework 5 ongoing
→ Due Friday, April 21st at 11:59 p.m.

Project 4 ongoing
→ Due Friday, April 28th at 11:59 p.m.

Interested in TAing this course?
→ https://forms.gle/AvjfUtSaWtrNiJMXA

Final exam Monday, May 1st, 8:30 – 11:30 a.m.

LAST TIME

Distributed commit protocols
→ Two-phase commit (2PC)

Distributed consensus protocols
→ Paxos

Other topics
→ Replication
~~→ CAP theorem~~
→ Google Spanner

CAP THEOREM

Proposed by Eric Brewer that it is impossible for a distributed system to always be:

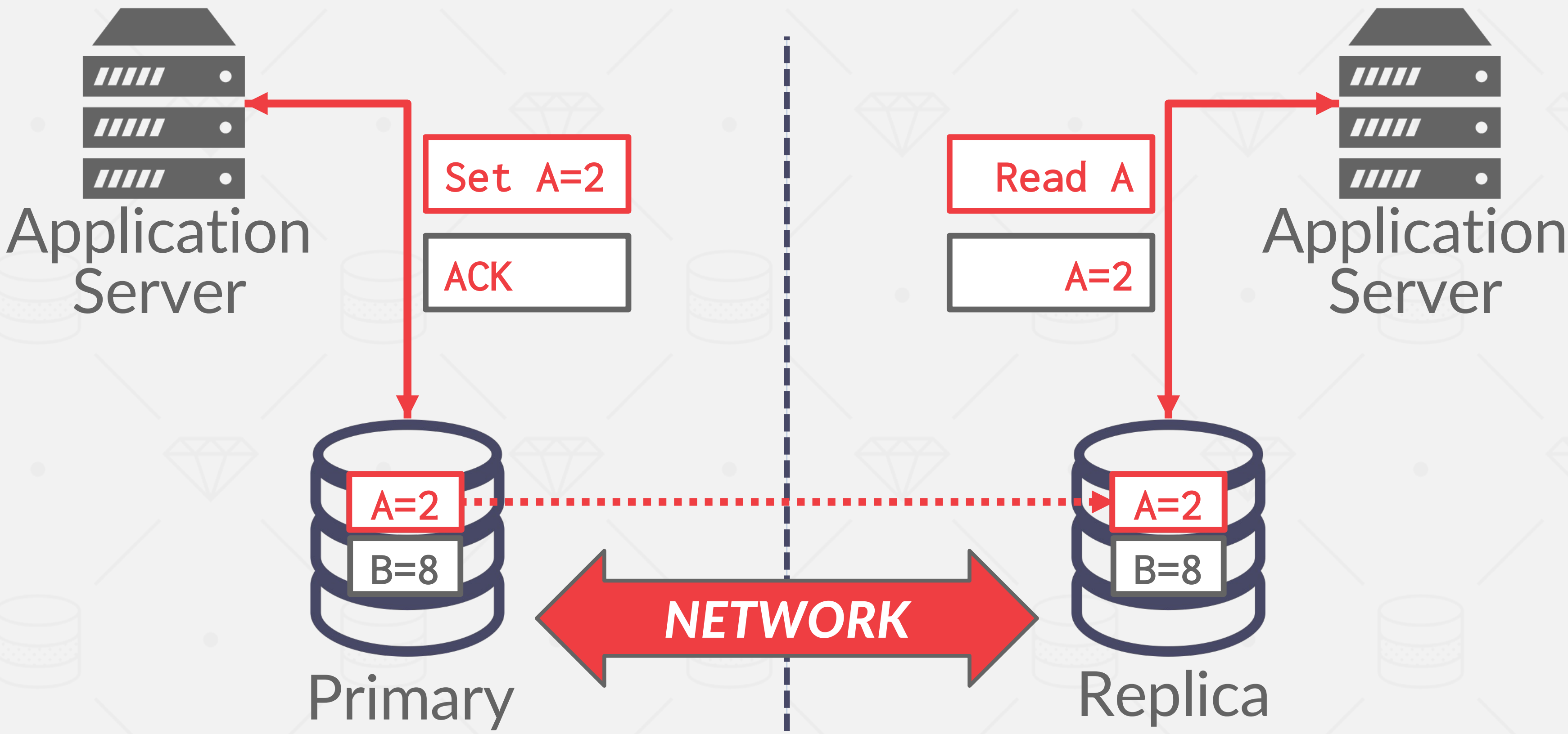
- → **C**onsistent
- → **A**lways Available
- → Network **P**artition Tolerant

One flaw is that it ignores consistency vs. latency trade-offs.

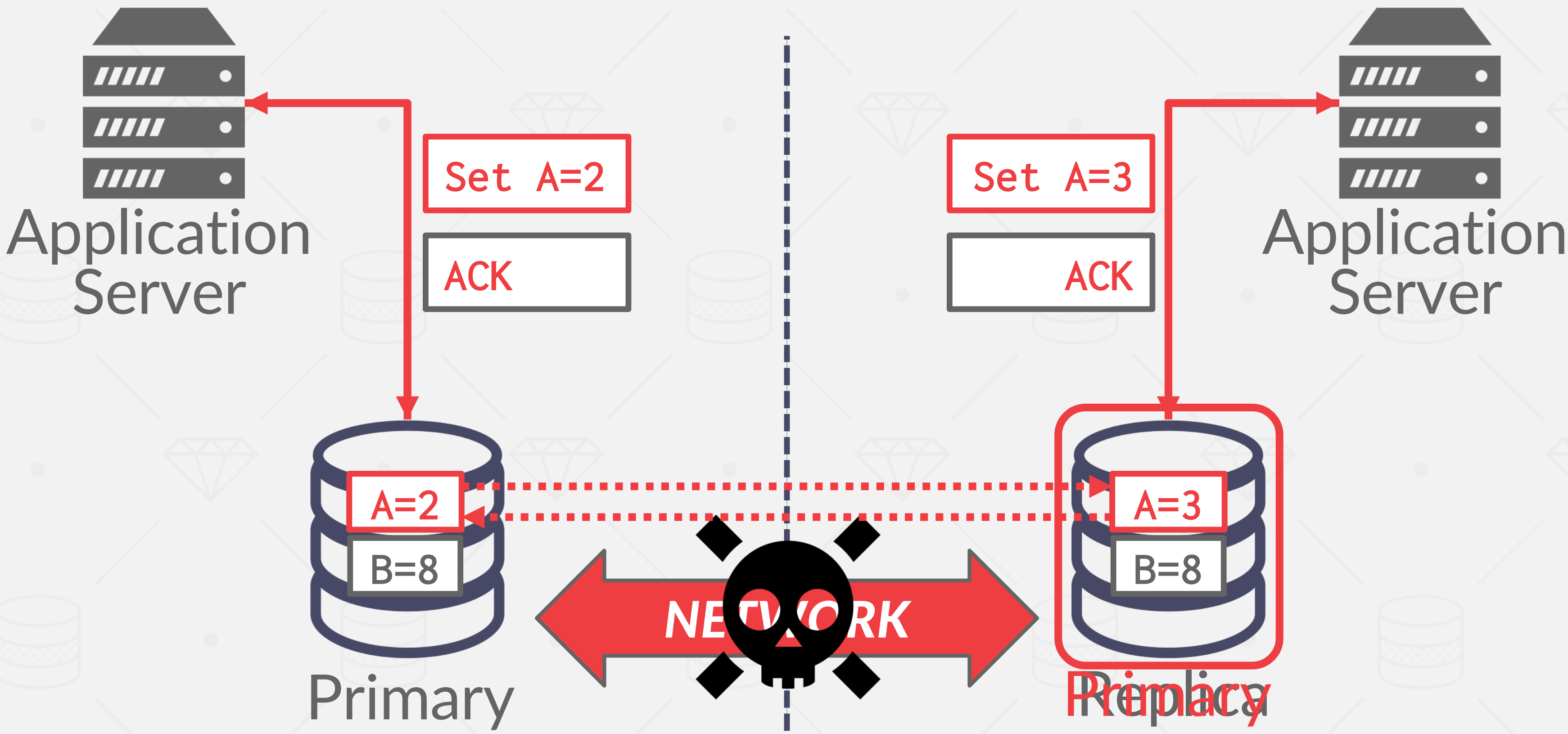
- → See PACELC Theorem

Brewer

CAP – CONSISTENCY



CAP – PARTITION TOLERANCE



CAP FOR OLTP DBMSs

How a DBMS handles failures determines which elements of the CAP theorem they support.

Traditional/Distributed Relational DBMSs

→ Stop allowing updates until a majority of nodes are reconnected.

NoSQL DBMSs

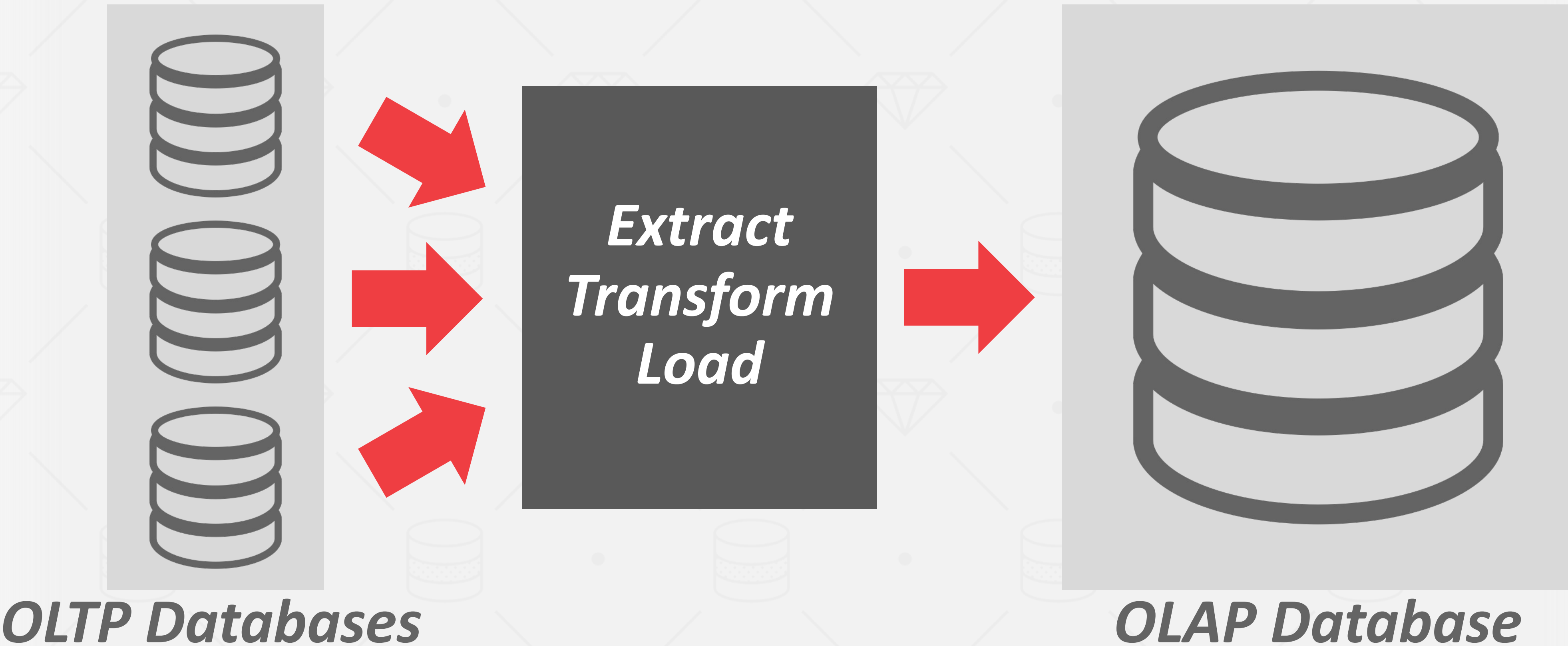
→ Provide mechanisms to resolve conflicts after nodes are reconnected.

DISTRIBUTED TRANSACTIONS CONCLUSION

Maintaining transactional consistency across multiple nodes is hard. Bad things happen.

More info (and humiliation):
→ Kyle Kingsbury's Jepsen Project

BIFURCATED ENVIRONMENT

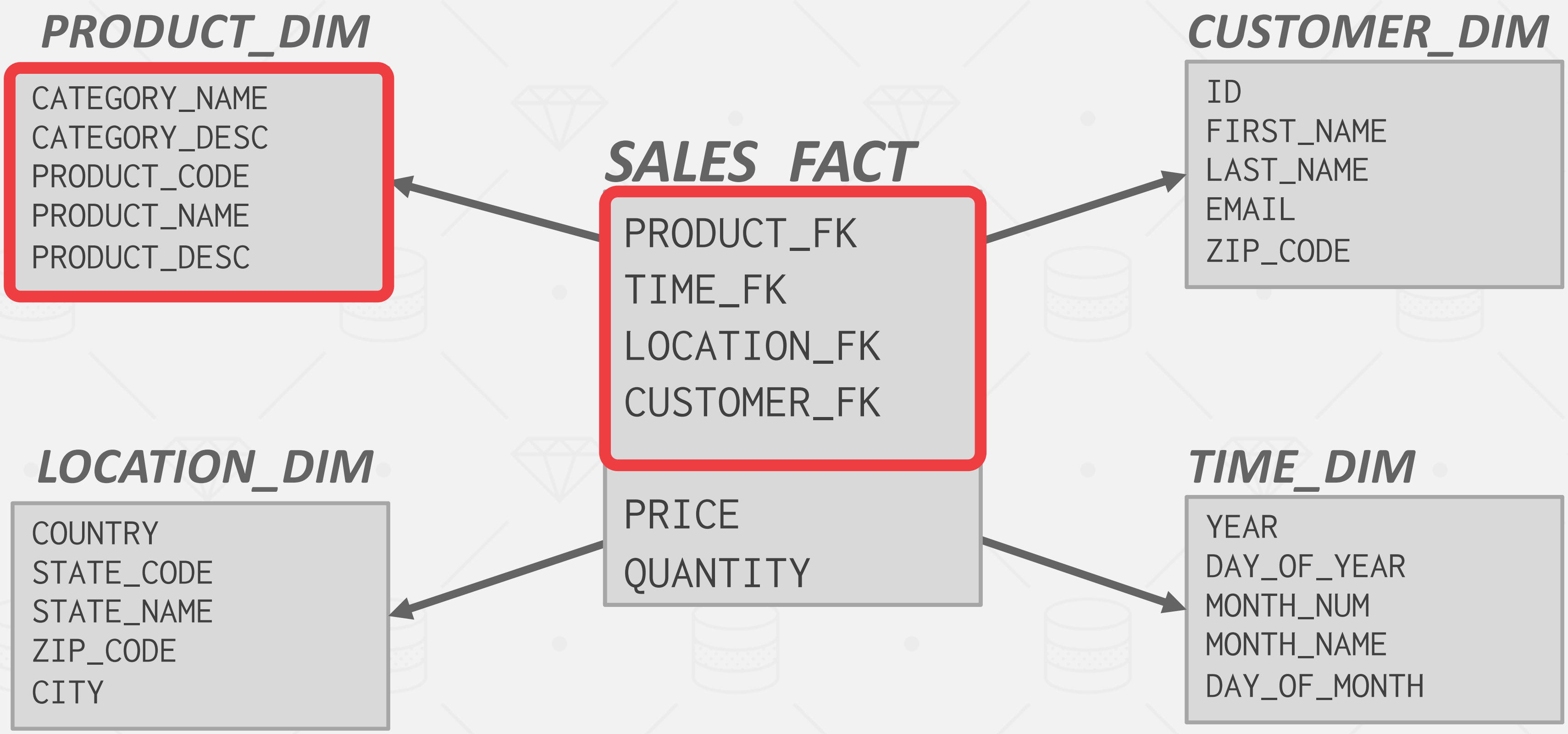


DECISION SUPPORT SYSTEMS

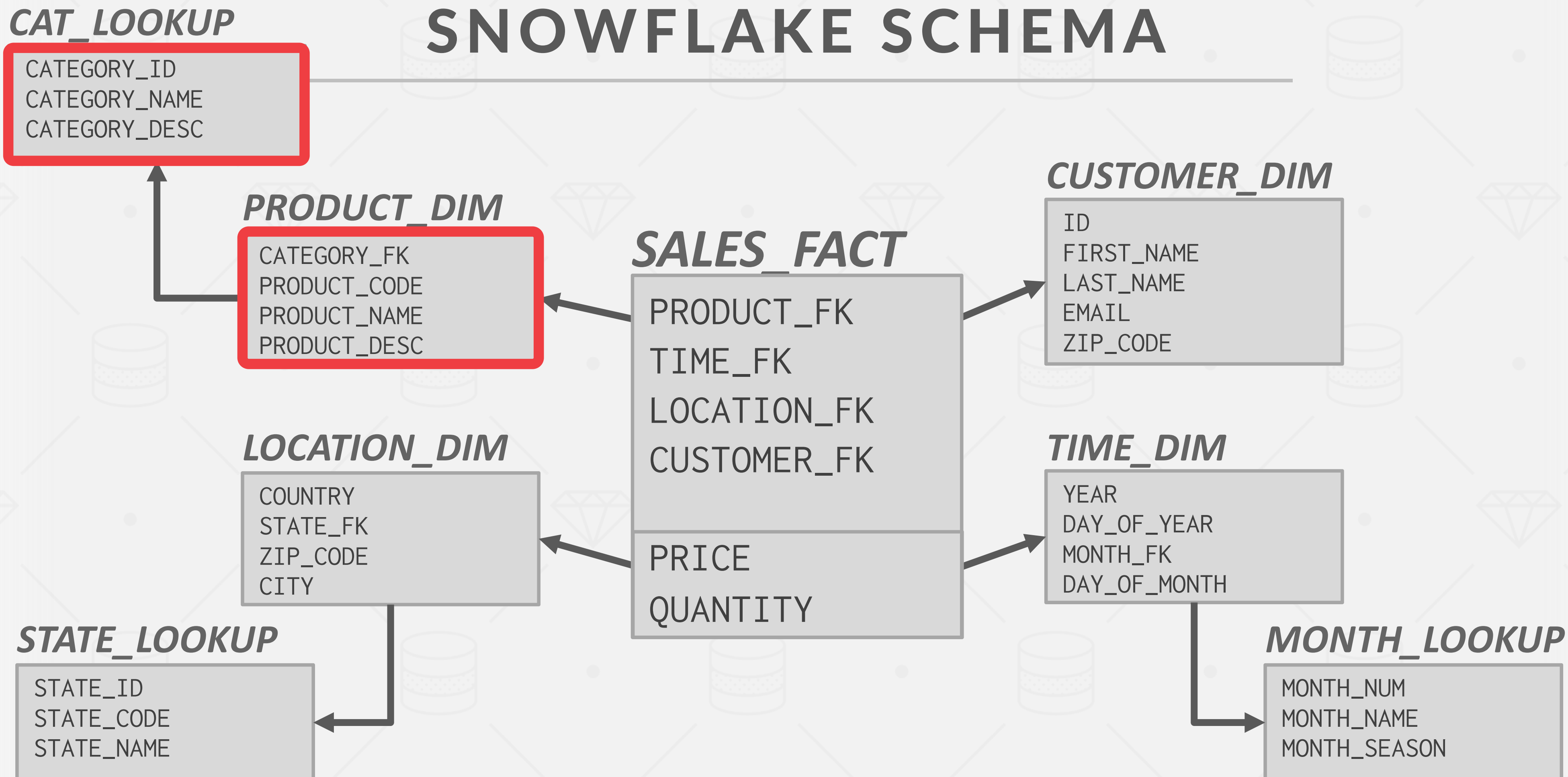
Applications that serve the management, operations, and planning levels of an organization to help people make decisions about future issues and problems by analyzing historical data.

Star Schema vs. Snowflake Schema

STAR SCHEMA


PRODUCT_DIM
CATEGORY_NAME
CATEGORY_DESC
PRODUCT_CODE
PRODUCT_NAME
PRODUCT_DESC
SALES_FACT
PRODUCT_FK
TIME_FK
LOCATION_FK
CUSTOMER_FK
PRICE
QUANTITY
CUSTOMER_DIM
ID
FIRST_NAME
LAST_NAME
EMAIL
ZIP_CODE
LOCATION_DIM
COUNTRY
STATE_CODE
STATE_NAME
ZIP_CODE
CITY
TIME_DIM
YEAR
DAY_OF_YEAR
MONTH_NUM
MONTH_NAME
DAY_OF_MONTH

SNOWFLAKE SCHEMA



STAR VS. SNOWFLAKE SCHEMA

Issue #1: Normalization

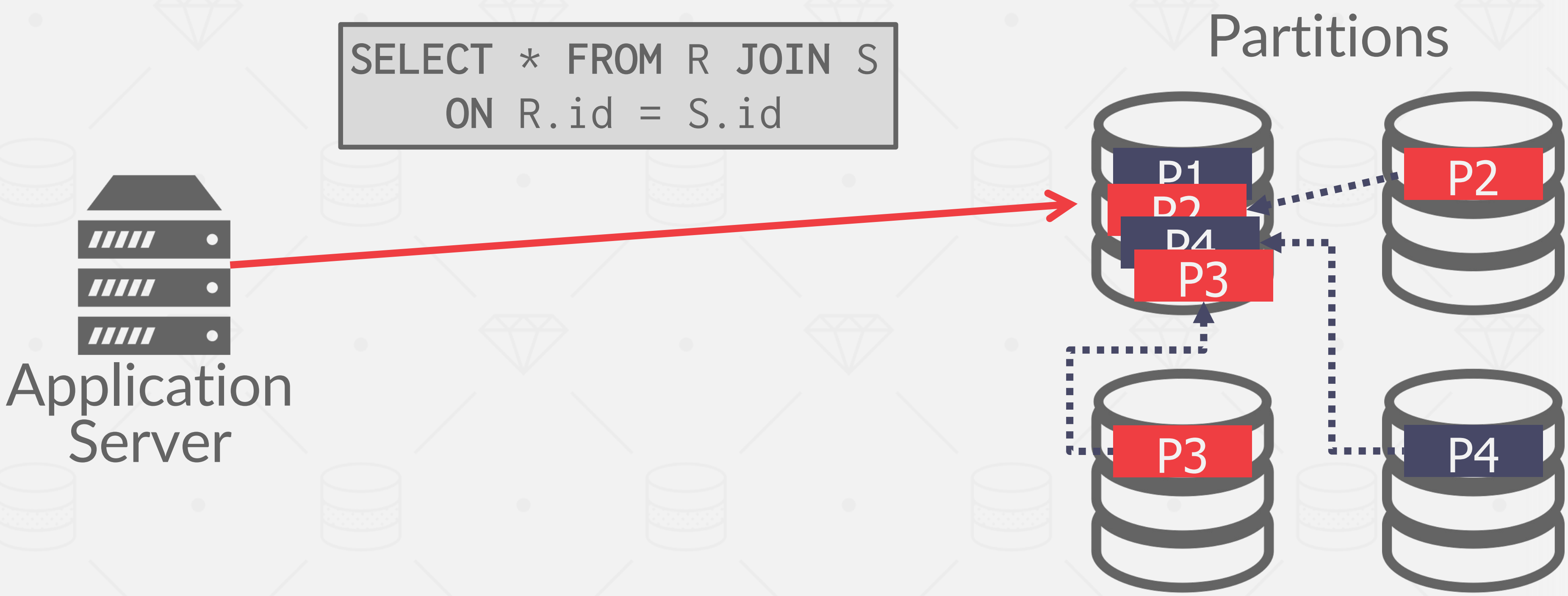
→ Snowflake schemas take up less storage space.
→ Denormalized data models may incur integrity and consistency violations.

Issue #2: Query Complexity

→ Snowflake schemas require more joins to get the data needed for a query.
→ Queries on star schemas will (usually) be faster.

PROBLEM SETUP

```
SELECT * FROM R JOIN S
ON R.id = S.id
```



TODAY'S AGENDA

Execution Models
Query Planning
Distributed Join Algorithms
Cloud Systems

Filtering and retrieving data using Amazon S3 Select

amazon

PDF | RSS

With Amazon S3 Select, you ...

...uery language (SQL) statements to filter the contents of an ...at you need. By using Amazon S3 Select to filter this data, you can ...ich reduces the cost and latency to retrieve this data.

...r Apache Parquet format. It also works with objects that are ... only), and server-side encrypted objects. You can specify the ...etermine how the records in the result are delimited.

...azon S3 Select supports a subset of SQL. For more information ...Select, see SQL reference for Amazon S3 Select.

...Object Content REST API, the AWS Command Line Interface ...e limits the amount of data returned to 40 MB. To retrieve

Microsoft

Query Blob Contents

Feedback

Article • 07/20/2021 • 10 minutes to read • 3 contributors

The `Query Blob Contents` API applies a simple Structured Query Language (SQL) statement on a blob's contents and returns only the queried subset of the data. You can also call `Query Blob Contents` to query the contents of a version or snapshot.

Request

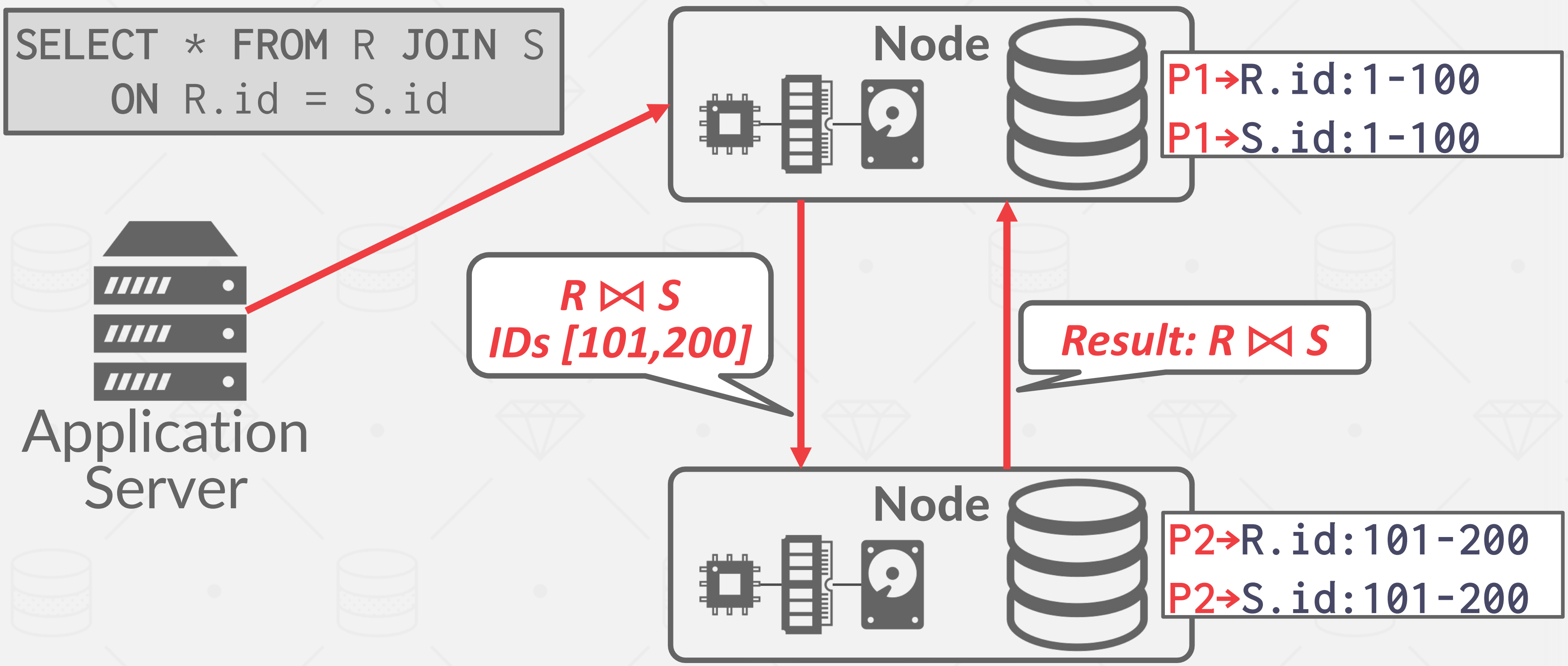
The `Query Blob Contents` request may be constructed as follows. HTTPS is recommended. Replace *myaccount* with the name of your storage account:

POST Method Request URI	HTTP Version
`https://myaccount.blob.core.windows.net/mycontainer/myblob?comp=query`	HTTP/1.0
`https://myaccount.blob.core.windows.net/mycontainer/myblob?comp=query&snapshot=<DateTime>`	HTTP/1.1
`https://myaccount.blob.core.windows.net/mycontainer/myblob?comp=query&versionid=<DateTime>`	

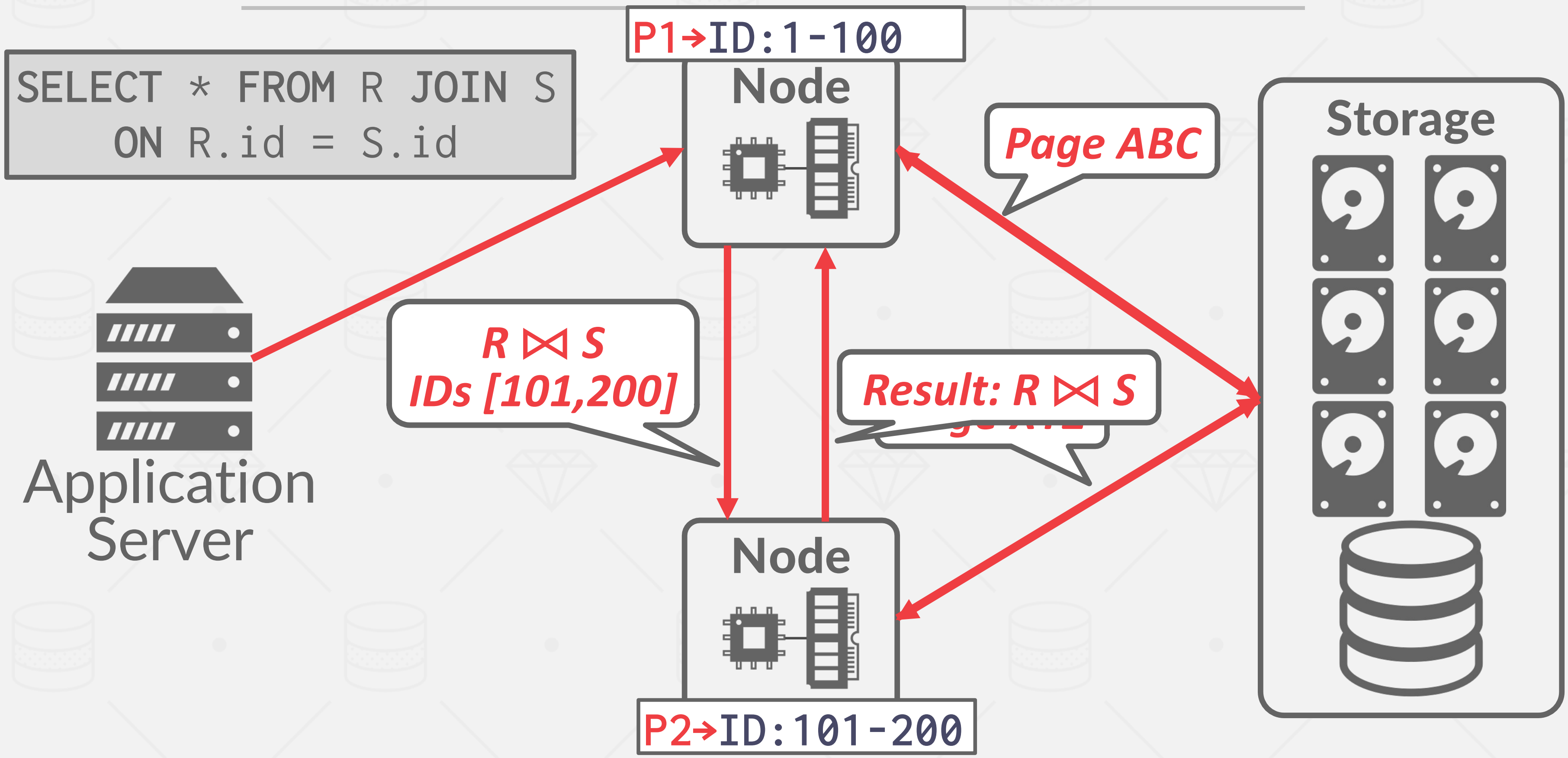
...cuting a query that

PUSH QUERY TO DATA

```
SELECT * FROM R JOIN S
ON R.id = S.id
```



PULL DATA TO QUERY



OBSERVATION

The data that a node receives from remote sources are cached in the buffer pool.

→ This allows the DBMS to support intermediate results that are large than the amount of memory available.
→ Ephemeral pages are not persisted after a restart.

What happens to a long-running OLAP query if a node crashes during execution?

QUERY FAULT TOLERANCE

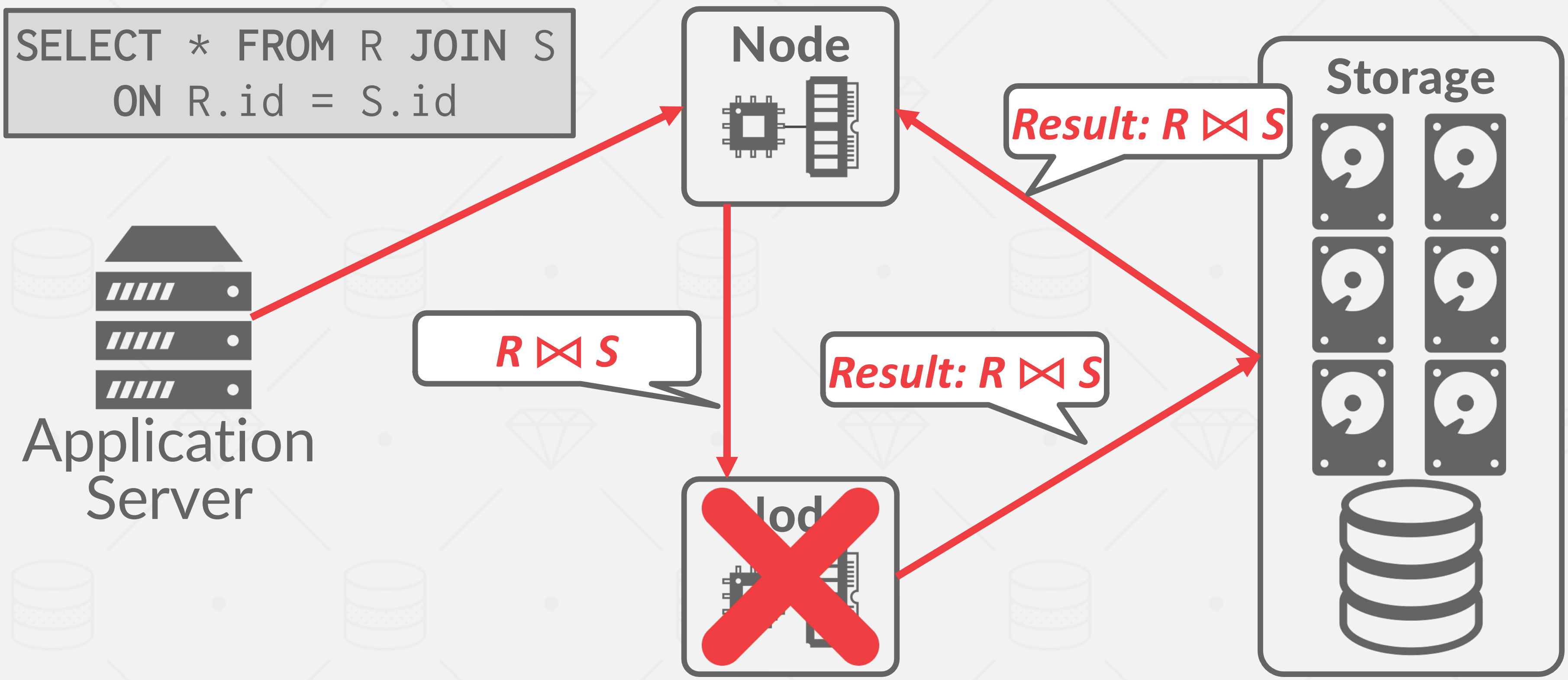
Most shared-nothing distributed OLAP DBMSs are designed to assume that nodes do not fail during query execution.

→ If one node fails during query execution, then the whole query fails.

The DBMS could take a snapshot of the intermediate results for a query during execution to allow it to recover if nodes fail.

QUERY FAULT TOLERANCE

```
SELECT * FROM R JOIN S
    ON R.id = S.id
```



QUERY PLANNING

All the optimizations that we talked about before are still applicable in a distributed environment.

- → Predicate Pushdown
- → Early Projections
- → Optimal Join Orderings

Distributed query optimization is even harder because it must consider the physical location of data and network transfer costs.

QUERY PLAN FRAGMENTS

Approach #1: Physical Operators

→ Generate a single query plan and then break it up into partition-specific fragments.
→ Most systems implement this approach.

Approach #2: SQL

→ Rewrite original query into partition-specific queries.
→ Allows for local optimization at each node.
→ SingleStore + Vitess are the only systems we know that use this approach.

N FRAGMENTS

Union the output of each join to produce the final result.

```
ROM R JOIN S
ON R.id = S.id
```

```
SELECT * FROM R JOIN S
    ON R.id = S.id
 WHERE R.id BETWEEN 1 AND 100
```

```
SELECT * FROM R JOIN S
    ON R.id = S.id
 WHERE R.id BETWEEN 101 AND 200
```

```
SELECT * FROM R JOIN S
    ON R.id = S.id
 WHERE R.id BETWEEN 201 AND 300
```

id:1-100

id:101-200

id:201-300

OBSERVATION

The efficiency of a distributed join depends on the target tables' partitioning schemes.

One approach is to put entire tables on a single node and then perform the join.

→ You lose the parallelism of a distributed DBMS.
→ Costly data transfer over the network.

DISTRIBUTED JOIN ALGORITHMS

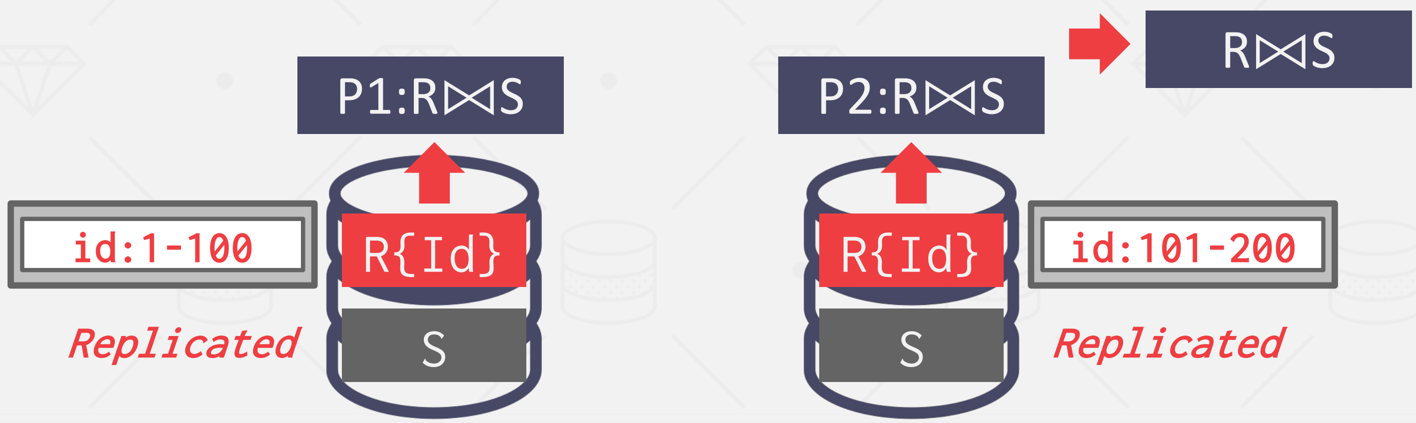
To join tables R and S, the DBMS needs to get the proper tuples on the same node.

Once the data is at the node, the DBMS then executes the same join algorithms that we discussed earlier in the semester.

SCENARIO #1

One table is replicated at every node. Each node joins its local data in parallel and then sends their results to a coordinating node.

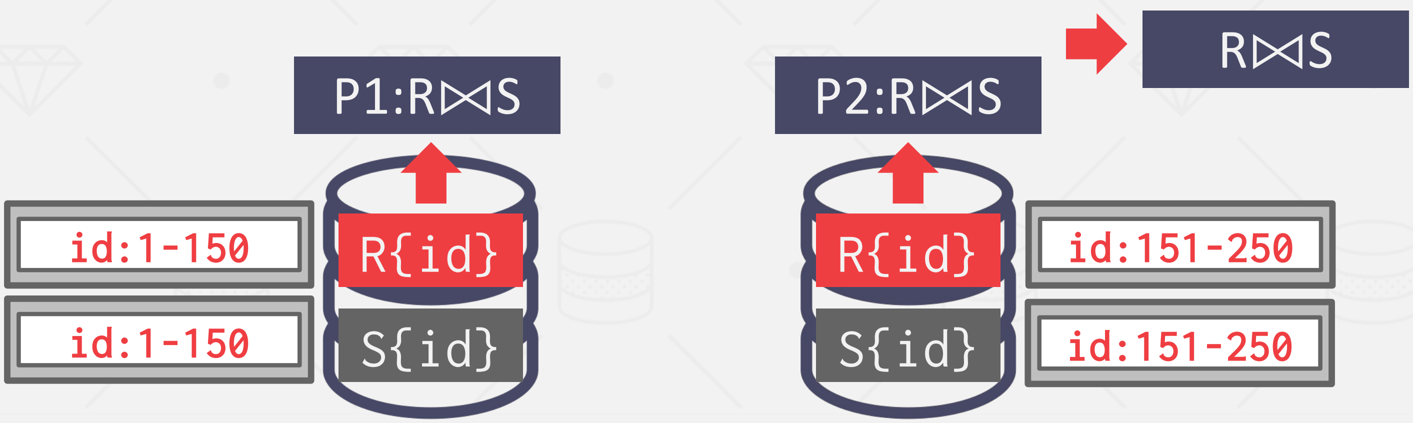
```
SELECT * FROM R JOIN S
ON R.id = S.id
```



SCENARIO #2

Tables are partitioned on the join attribute. Each node performs the join on local data and then sends to a coordinator node for coalescing.

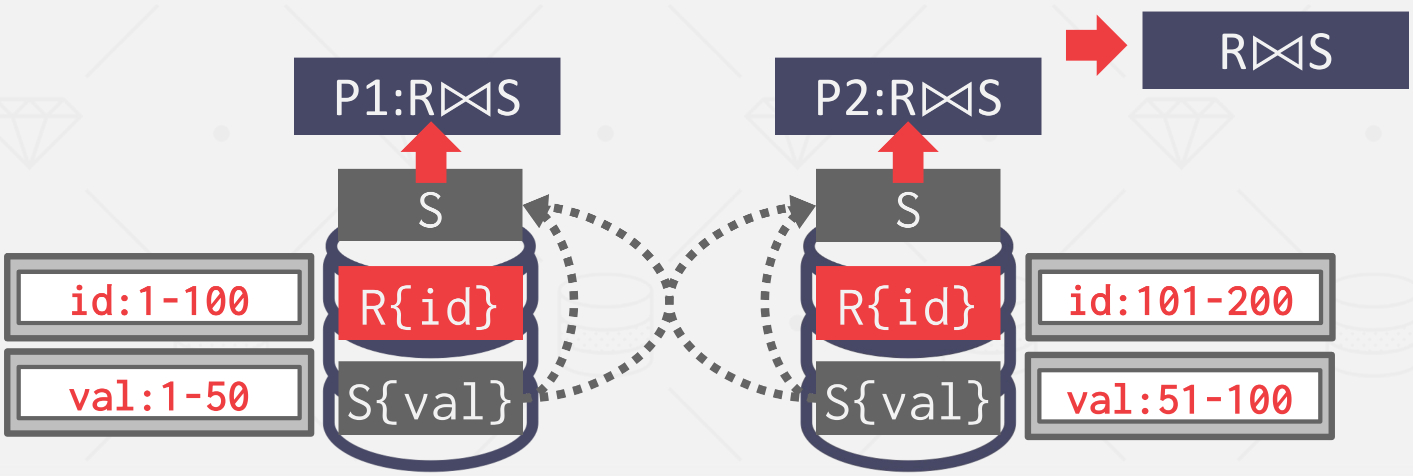
```
SELECT * FROM R JOIN S
    ON R.id = S.id
```



SCENARIO #3

Both tables are partitioned on different keys. If one of the tables is small, then the DBMS "broadcasts" that table to all nodes.

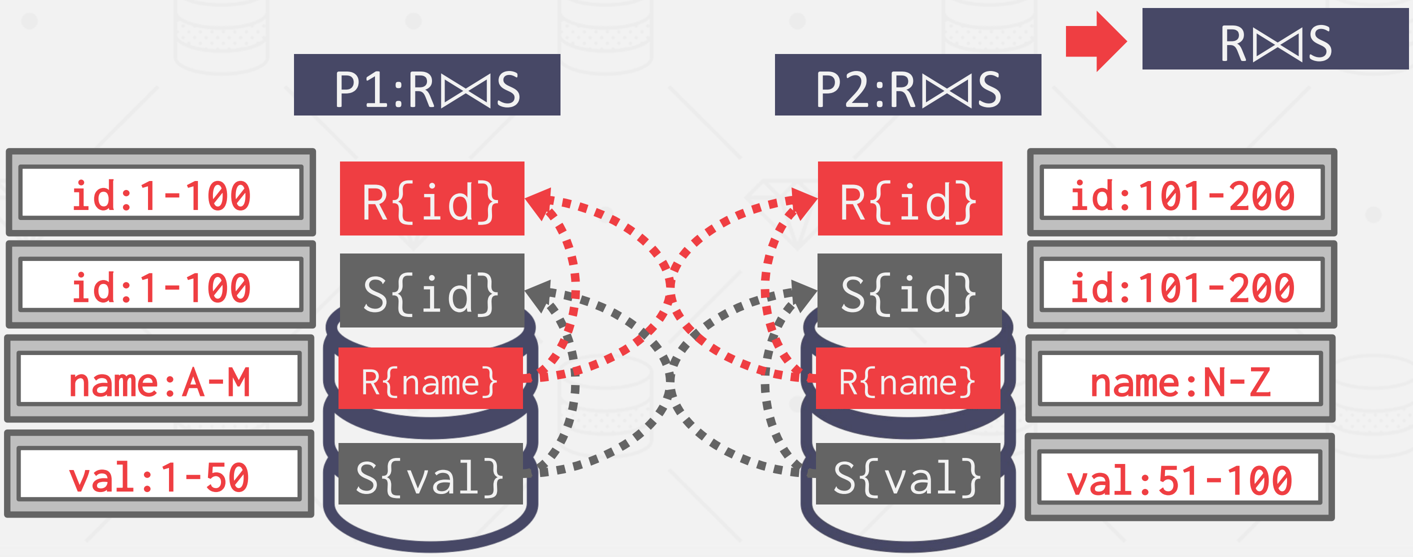
```
SELECT * FROM R JOIN S
ON R.id = S.id
```



SCENARIO #4

Both tables are not partitioned on the join key. The DBMS copies the tables by "shuffling" them across nodes.

```
SELECT * FROM R JOIN S
ON R.id = S.id
```



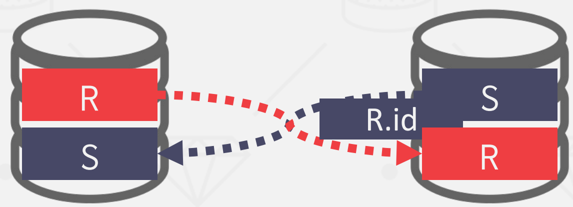
SEMI-JOIN

Join type where the result only contains columns from the left table.

Distributed DBMSs use semi-join to minimize the amount of data sent during joins.
→ This is like a projection pushdown.

Some DBMSs support **SEMI JOIN** SQL syntax. Otherwise you fake it with **EXISTS**.

```
SELECT R.id
  FROM R JOIN S
    ON R.id = S.id
 WHERE R.id IS NOT NULL
```




```
SELECT R.id FROM R
 WHERE EXISTS (
  SELECT 1 FROM S
   WHERE R.id = S.id)
```

CLOUD SYSTEMS

Vendors provide ***database-as-a-service*** (DBaaS) offerings that are managed DBMS environments.

Newer systems are starting to blur the lines between shared-nothing and shared-disk.

→ Example: You can do simple filtering on Amazon S3 before copying data to compute nodes.

CLOUD SYSTEMS

Approach #1: Managed DBMSs

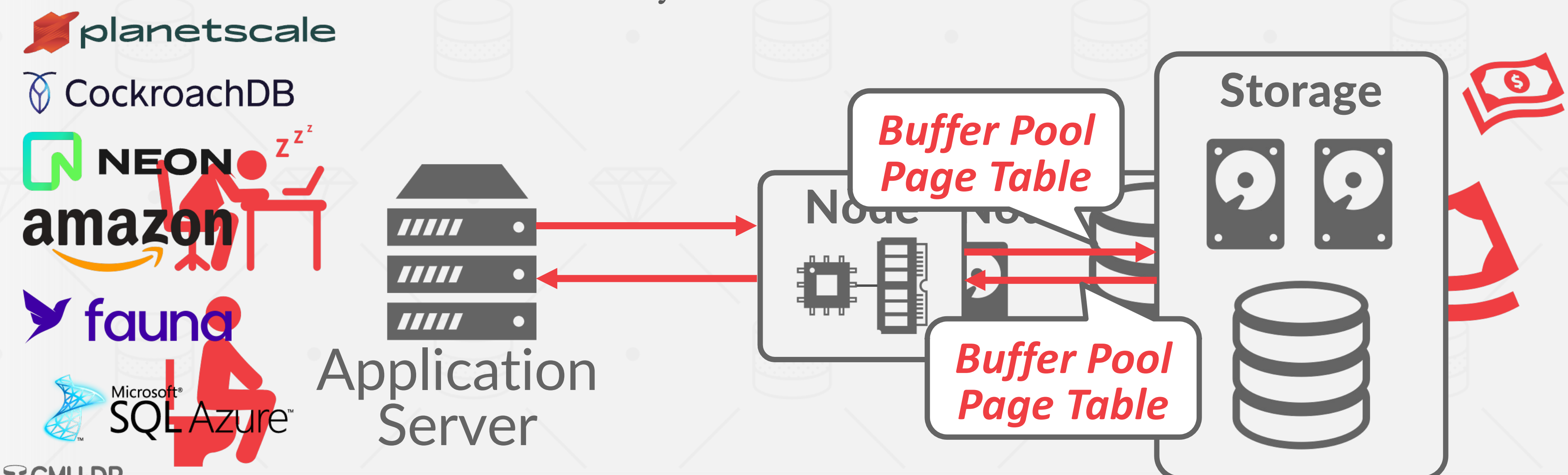
→ No significant modification to the DBMS to be "aware" that it is running in a cloud environment.
→ Examples: Most vendors

Approach #2: Cloud-Native DBMS

→ The system is designed explicitly to run in a cloud environment.
→ Usually based on a shared-disk architecture.
→ Examples: Snowflake, Google BigQuery, Amazon Redshift, Microsoft SQL Azure

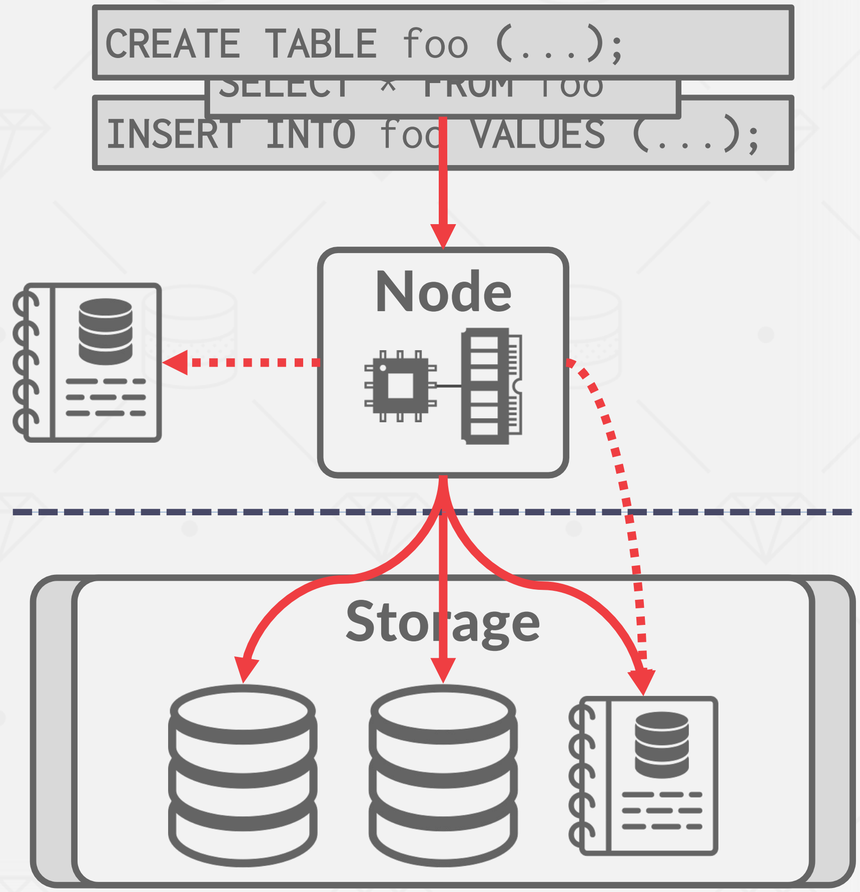
SERVERLESS DATABASES

Rather than always maintaining compute resources for each customer, a "serverless" DBMS evicts tenants when they become idle.



DATA LAKES

Repository for storing large amounts of structured, semi-structured, and unstructured data without having to define a schema or ingest the data into proprietary internal formats.



trino amazon REDSHIFT Google Big Query HIVE databricks snowflake presto

UNIVERSAL FORMATS

Most DBMSs use a proprietary on-disk binary file format for their databases.

→ Think of the BusTub page types…

The only way to share data between systems is to convert data into a common format

→ Examples: CSV, JSON, XML

There are new open-source binary file formats that make it easier to access data across systems.

UNIVERSAL FORMATS

Apache Parquet

→ Compressed columnar storage from Cloudera/Twitter

Apache ORC

→ Compressed columnar storage from Apache Hive.

Apache CarbonData

→ Compressed columnar storage with indexes from Huawei.

Apache Iceberg

→ Flexible data format that supports schema evolution from Netflix.

HDF5

→ Multi-dimensional arrays for scientific workloads.

Apache Arrow

→ In-memory compressed columnar storage from Pandas/Dremio.

DISAGGREGATED COMPONENTS

System Catalogs

→ HCatalog, Google Data Catalog, Amazon Glue Data Catalog

Node Management

→ Kubernetes, Apache YARN, Cloud Vendor Tools

Query Optimizers

→ Greenplum Orca, Apache Calcite

CONCLUSION

The cloud has made the distributed OLAP DBMS market flourish. Lots of vendors. Lots of money.

But more money, more data, more problems…

NEXT CLASS

Andy's potentially frivolous attempt to convince you to put as much application logic as you can into the DBMS but then you will go into the real world and find out that few people do these things.