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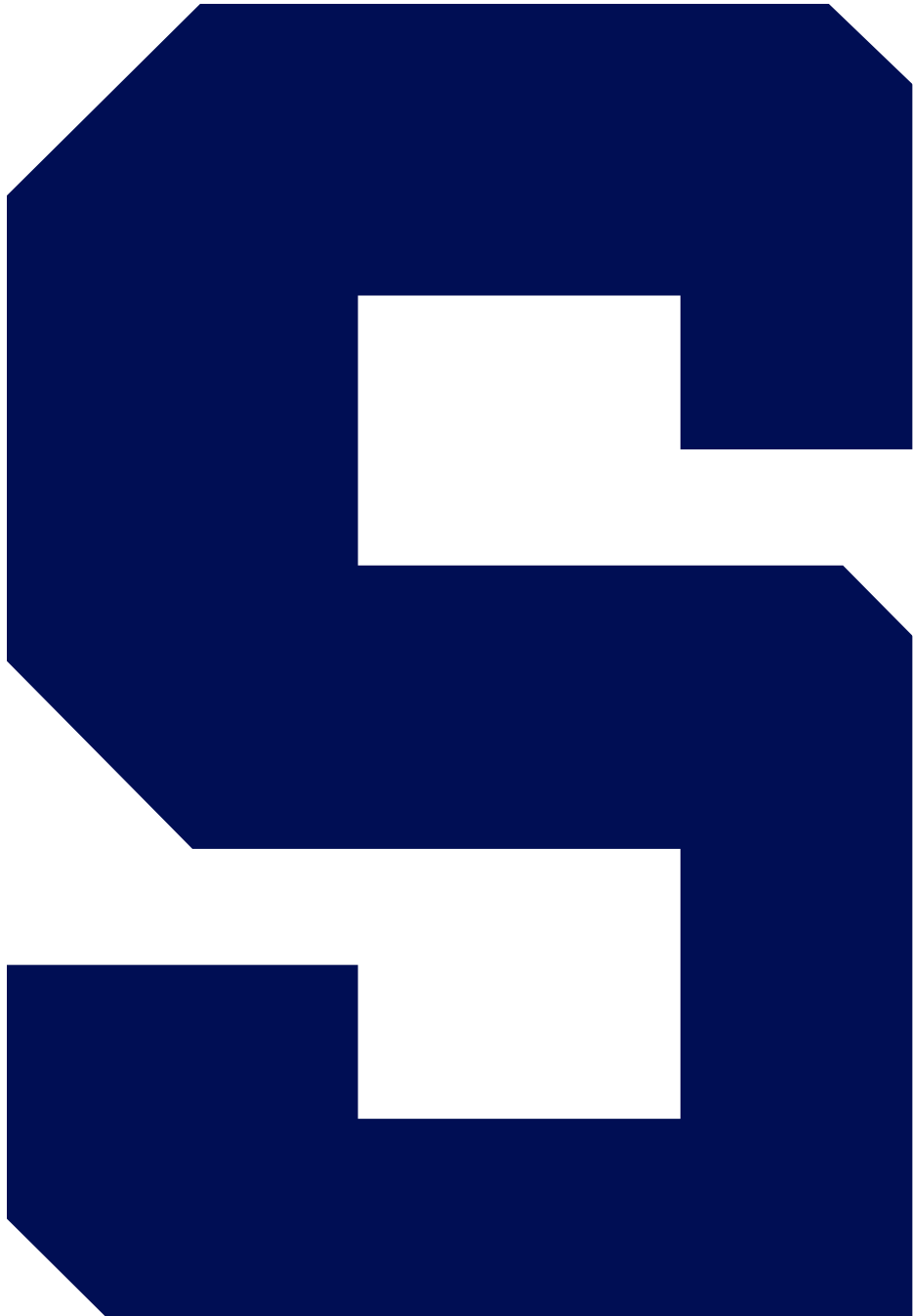


The Physical Model, Performance, and Indexing

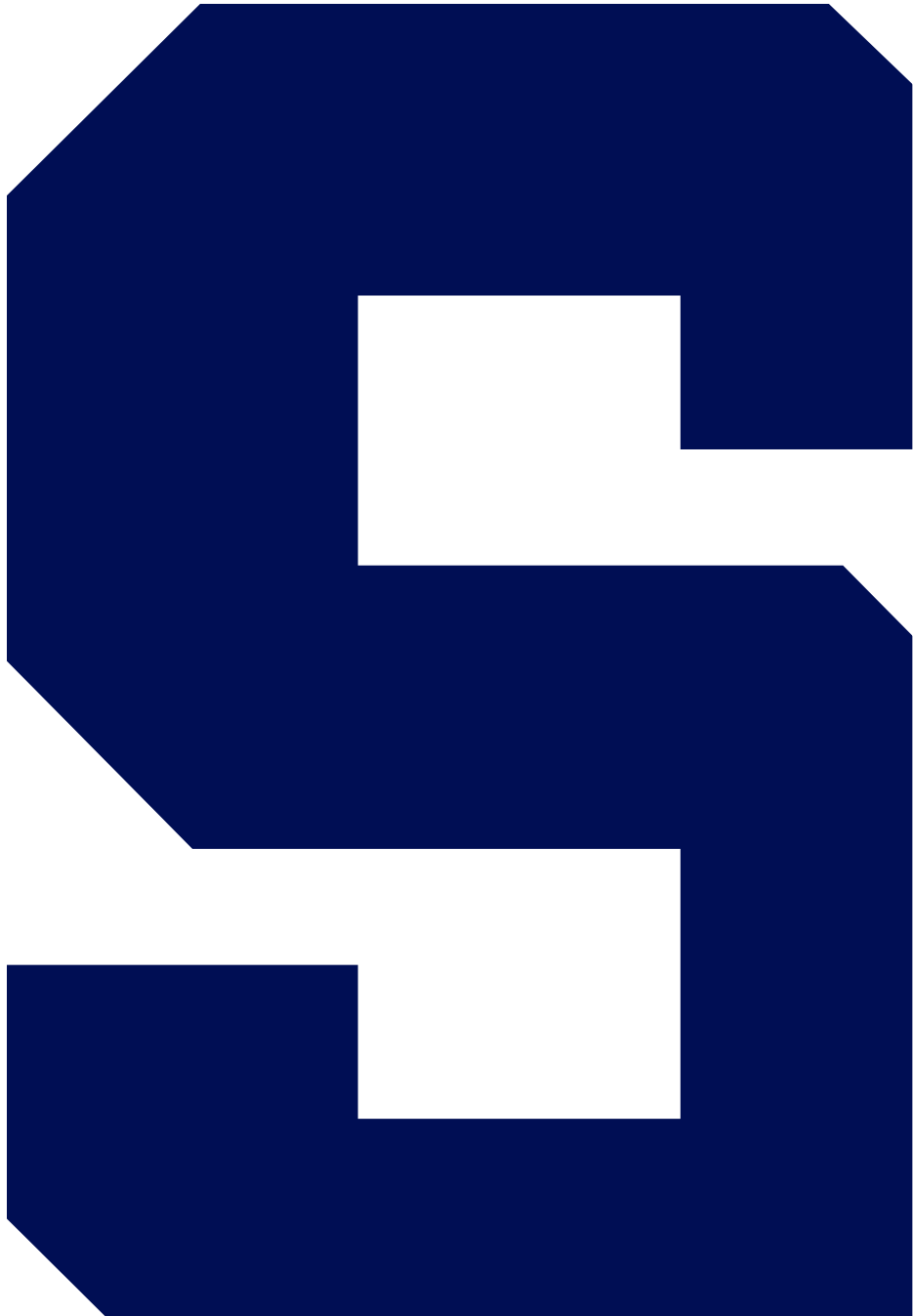
Agenda

- What is the physical data model?
- The details of the SQL Server physical model: pages, files, and filegroups
- Clustered and nonclustered indexes
- Understanding query plans
- Correcting page fragmentation in indexes
- Column store indexes and indexed queries

The Physical Model,
Performance, and Indexing

The End

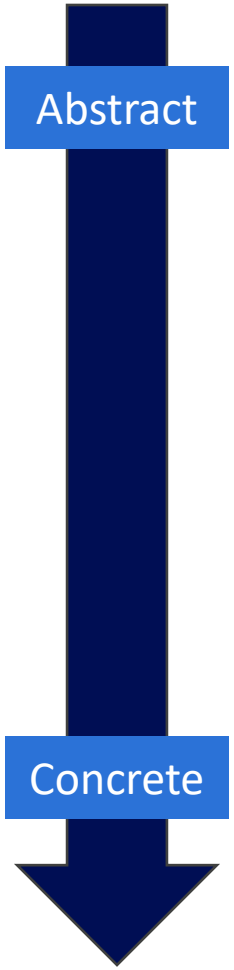
Physical Data Model



Physical Data Model

- Implementation of the logical data model
- Dependent on the selected implementation model (relational, etc.) and the specific DBMS (SQL Server, MySQL, etc.)
- The physical data model is concerned with performance and should consider the DBMS architecture

Recall: Data Models



Conceptual data model

- An abstract representation of the data requirements
- No implementation of the database itself; no implementation model selected

Logical data model

- Mapping of the conceptual model to an implementation model
- No implementation of the database; model selected

Internal data model

- The internalized implementation of the database application
- A DBMS and implementation model selected

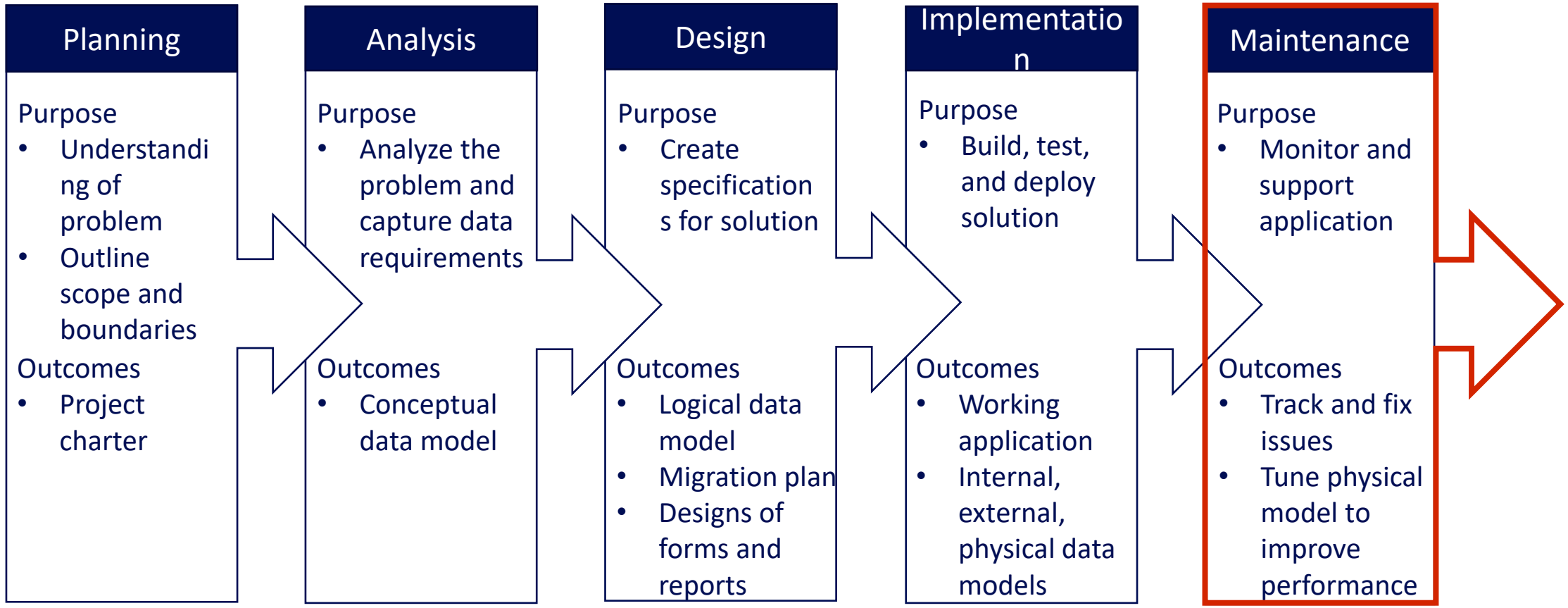
External data model

- User's view of the database application
- DBMS and implementation model selected, internal model implemented

Physical data model

- How the internal/external model is stored by the DBMS and operating system
- All aspects of the database are an implementation

Recall: DBLC


Planning
Purpose
• Understanding of problem
• Outline scope and boundaries
Outcomes
• Project charter
Analysis
Purpose
• Analyze the problem and capture data requirements
Outcomes
• Conceptual data model
Design
Purpose
• Create specifications for solution
Outcomes
• Logical data model
• Migration plan
• Designs of forms and reports
Implementation
Purpose
• Build, test, and deploy solution
Outcomes
• Working application
• Internal, external, physical data models
Maintenance
Purpose
• Monitor and support application
Outcomes
• Track and fix issues
• Tune physical model to improve performance

Physical Database Design

Does it matter?

It does if you care about performance!

Caveats of Physical Design

- We will explain the physical design of Microsoft SQL Server.
- Other databases have similar concepts.
- Every DBMS has a different means of implementing physical design.
- You can improve performance without knowledge of physical design but will be limited.
- Ultimately, to get the best performance, you must understand the physical design of the database you are using.

Physical Data Model

The End

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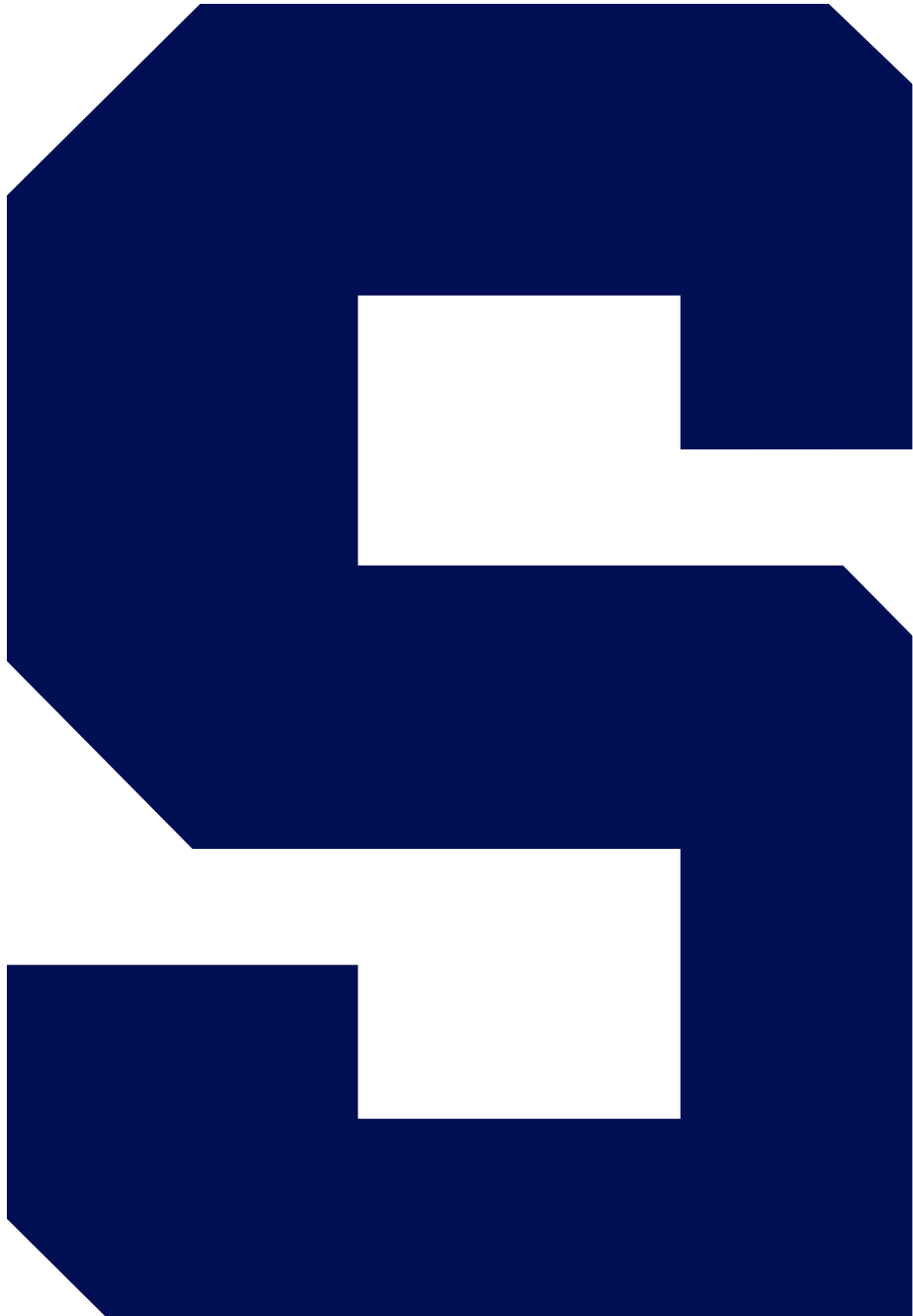
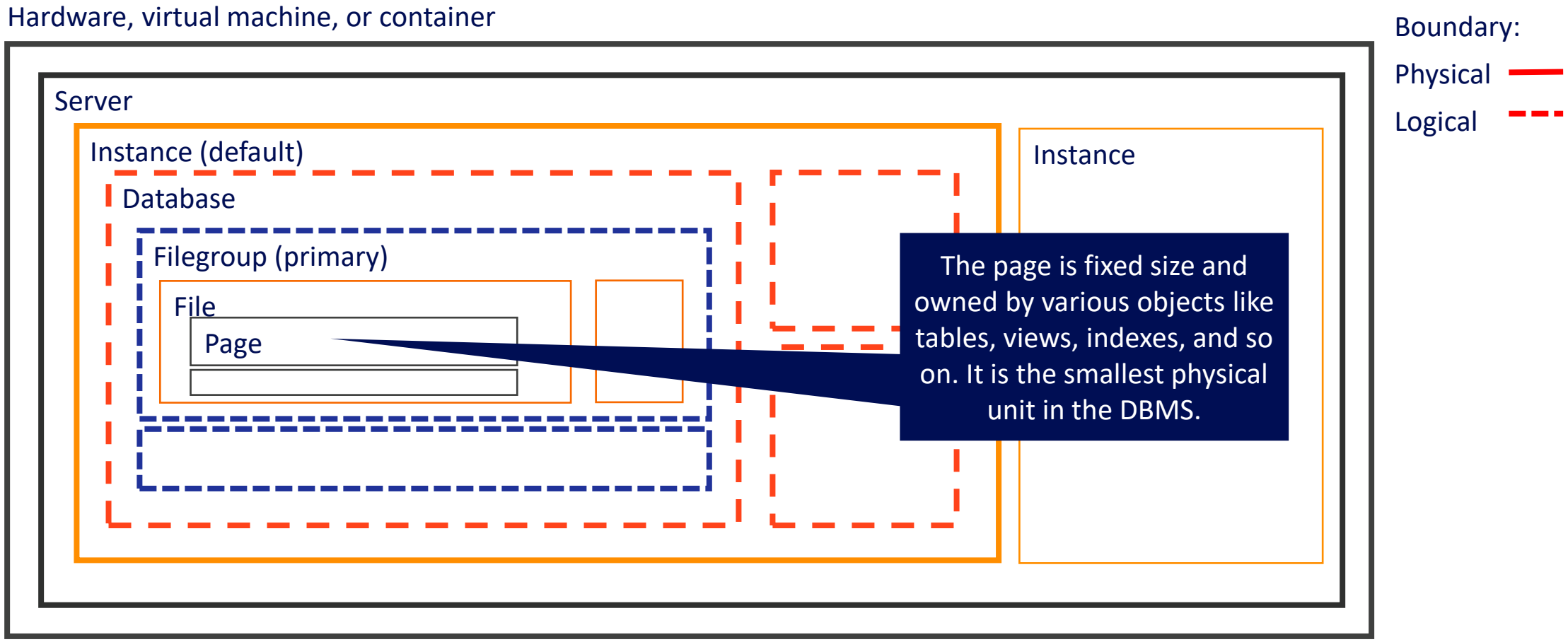


SQL Server
Physical Data Model

The Physical Abstraction of SQL Server

- Server: installed on an operating system or in a container
- Instance: one or more “setups” of SQL Server on the same physical server (test, production, development)
- Database: stored as one or more files
  - *databasename*.mdf → primary file, member of the PRIMARY filegroup
  - Othername.ndf → secondary files used to spread data across physical partitions/disks
  - *databbasename*_log.ldf → transaction log file holds transactions/recovery information
- Filegroup (tablespace): a logical name for one or more physical files; all database objects are written to a filegroup
- Page: set of continuous table rows inside a physical file

SQL Server Physical Model Visualized



SQL Server and Physical Data Model

The End

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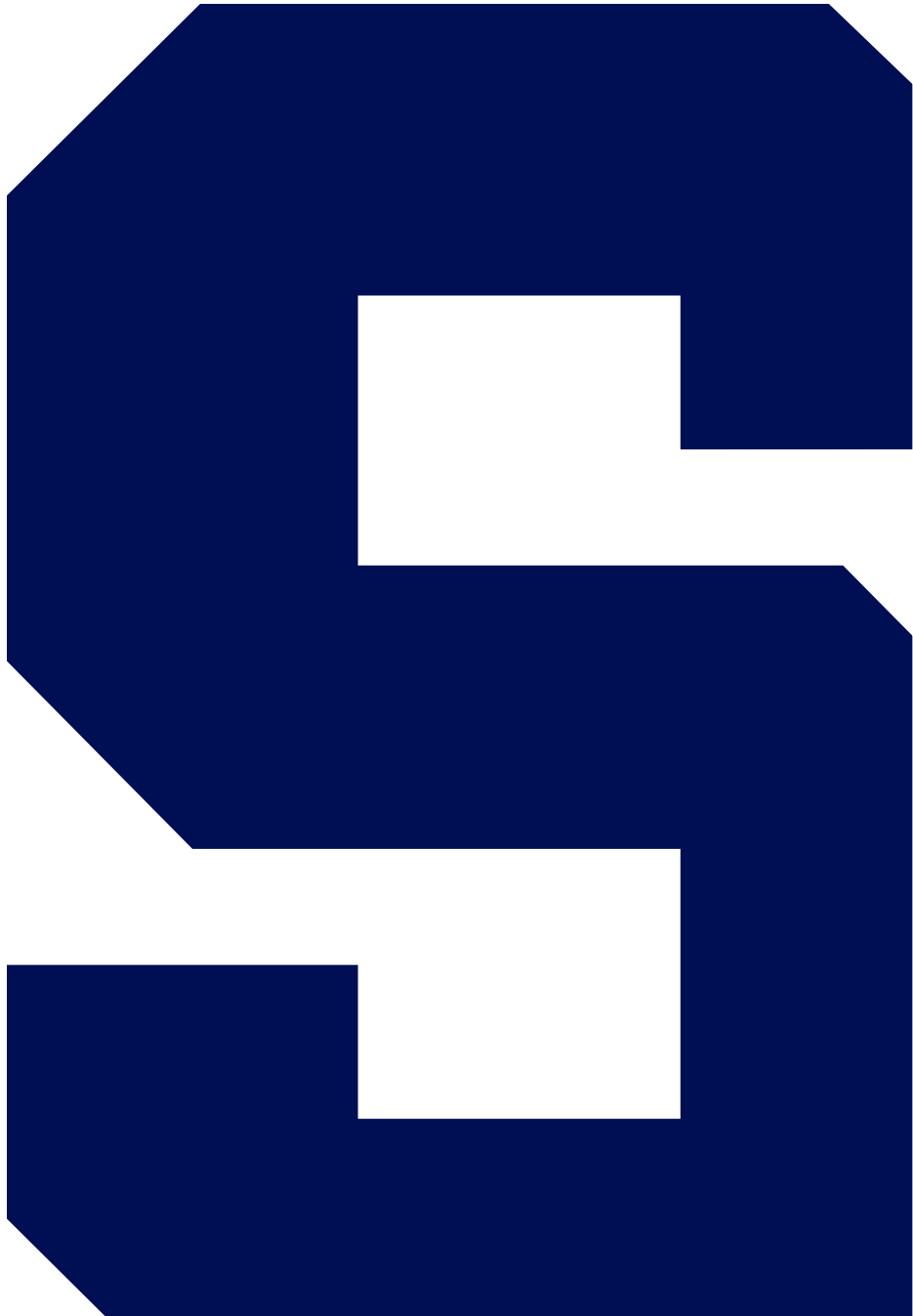
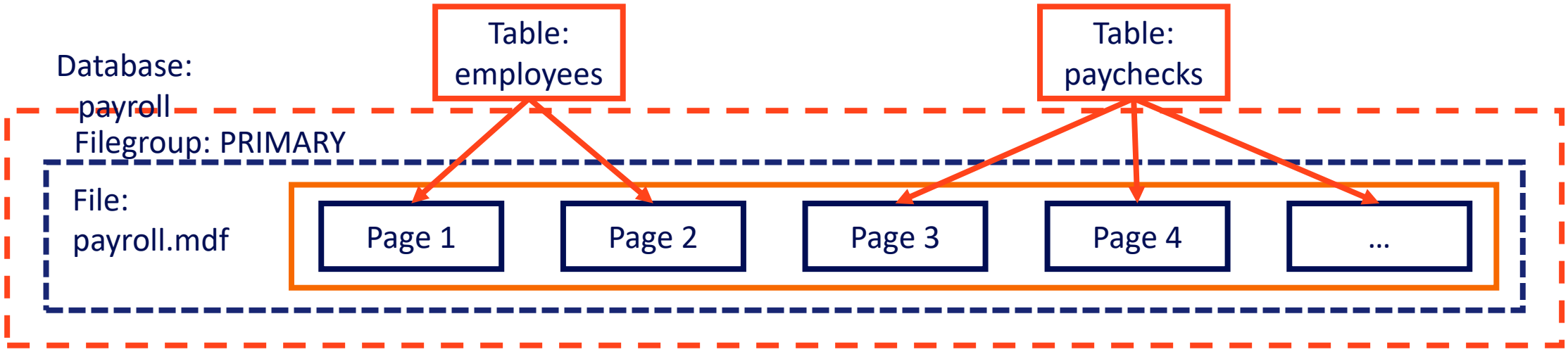


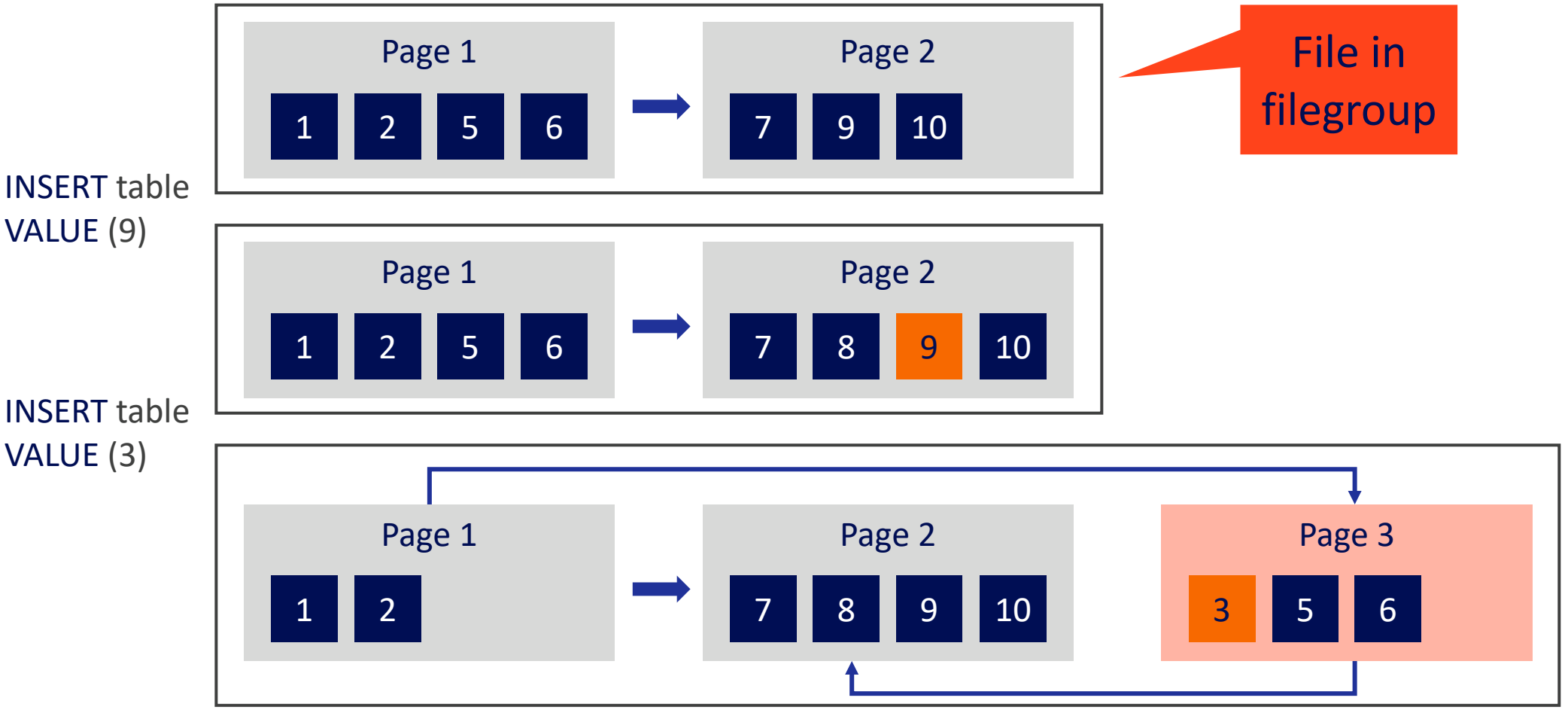
SQL Server Pages

What Is a Page Exactly?

- In the DBMS, rows of data are written to physical blocks inside the file called pages.
- The page size in SQL Server is 8 KB (kilobytes).
- This is the smallest unit of storage in the database. For example, even if you update just one column in a table, an entire page is written.
- The table boundary is the page.



How Data Are Inserted Into Pages



SQL Server Pages

The End

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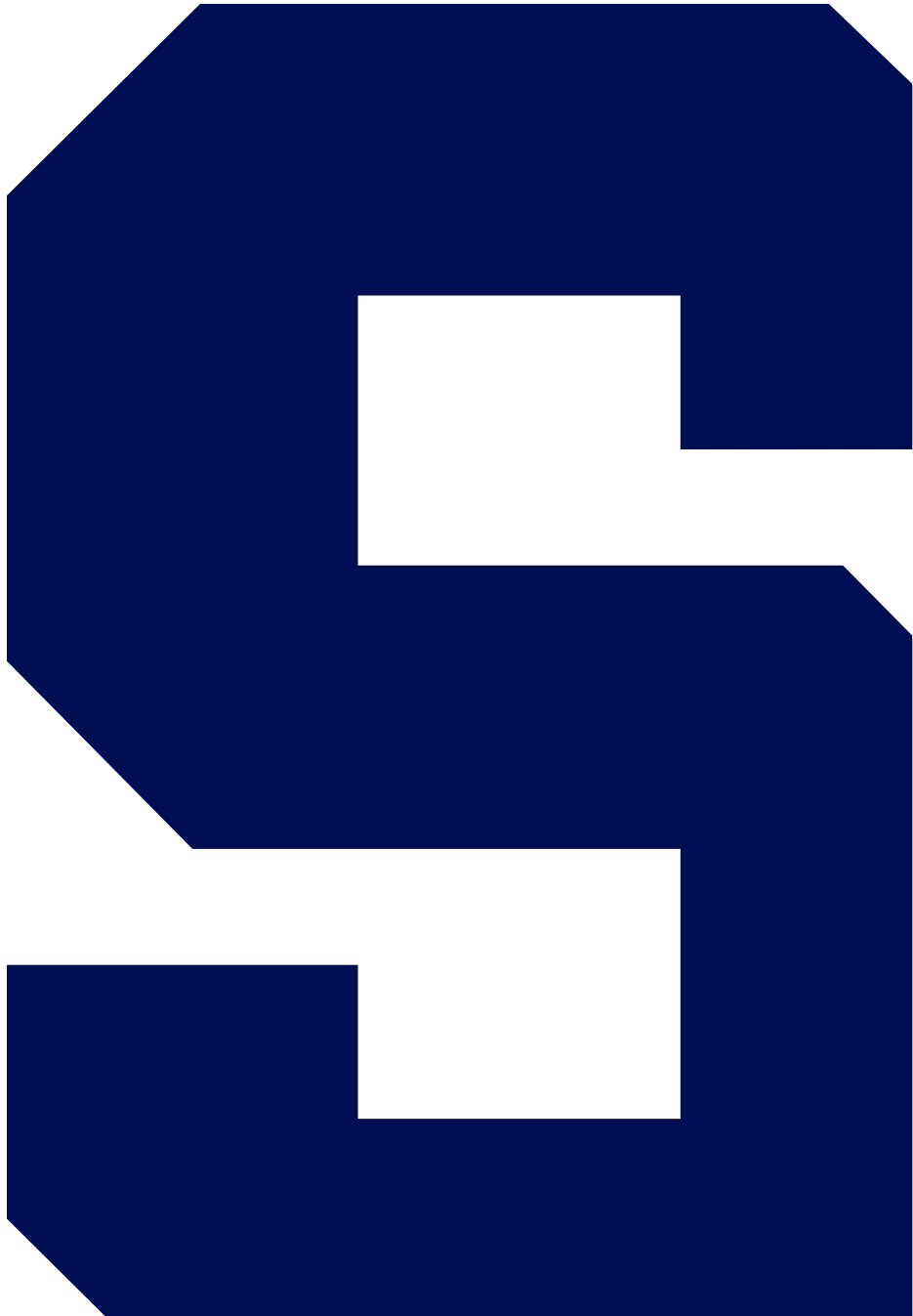

SQL Server
Filegroups and Files

SQL: Filegroups

- Logical storage for database object like tables
- Cannot exist outside a database
- Every SQL Server database as a default filegroup called PRIMARY

```
ALTER DATABASE database_name
    ADD FILEGROUP file_group_name
```

- View the filegroups in a database

```
SELECT *    FROM sys.filegroups
```

SQL: Files in Filegroups

- Filegroups require one or more physical files on disk
- Filegroup is a logical structure; the file is where data are actually stored
- Every SQL Server database as a file database_name.mdf in the default filegroup PRIMARY

```
ALTER DATABASE database_name ADD FILE (
    NAME = logical_name,
    FILENAME = path_to_file
) TO FILEGROUP file_group_name
```

SQL: File/Filegroup Inspection

- View the filegroups in a database.
  `SELECT * FROM sys.filegroups`
- View the filegroups in a database.
  `SELECT * FROM sys.database_files`
- Show the objects in a filegroup. This is tricky.

```
SELECT o.[name] as object_name,  i.[name] as index_name,  f.[name] as filegroup_name
    FROM sys.indexes i
        JOIN sys.filegroups f ON i.data_space_id = f.data_space_id
        JOIN sys.all_objects o ON i.[object_id] = o.[object_id]
    WHERE i.data_space_id = f.data_space_id AND o.type = 'U' -- User Created Tables
```

SQL Server Filegroups and Files

The End

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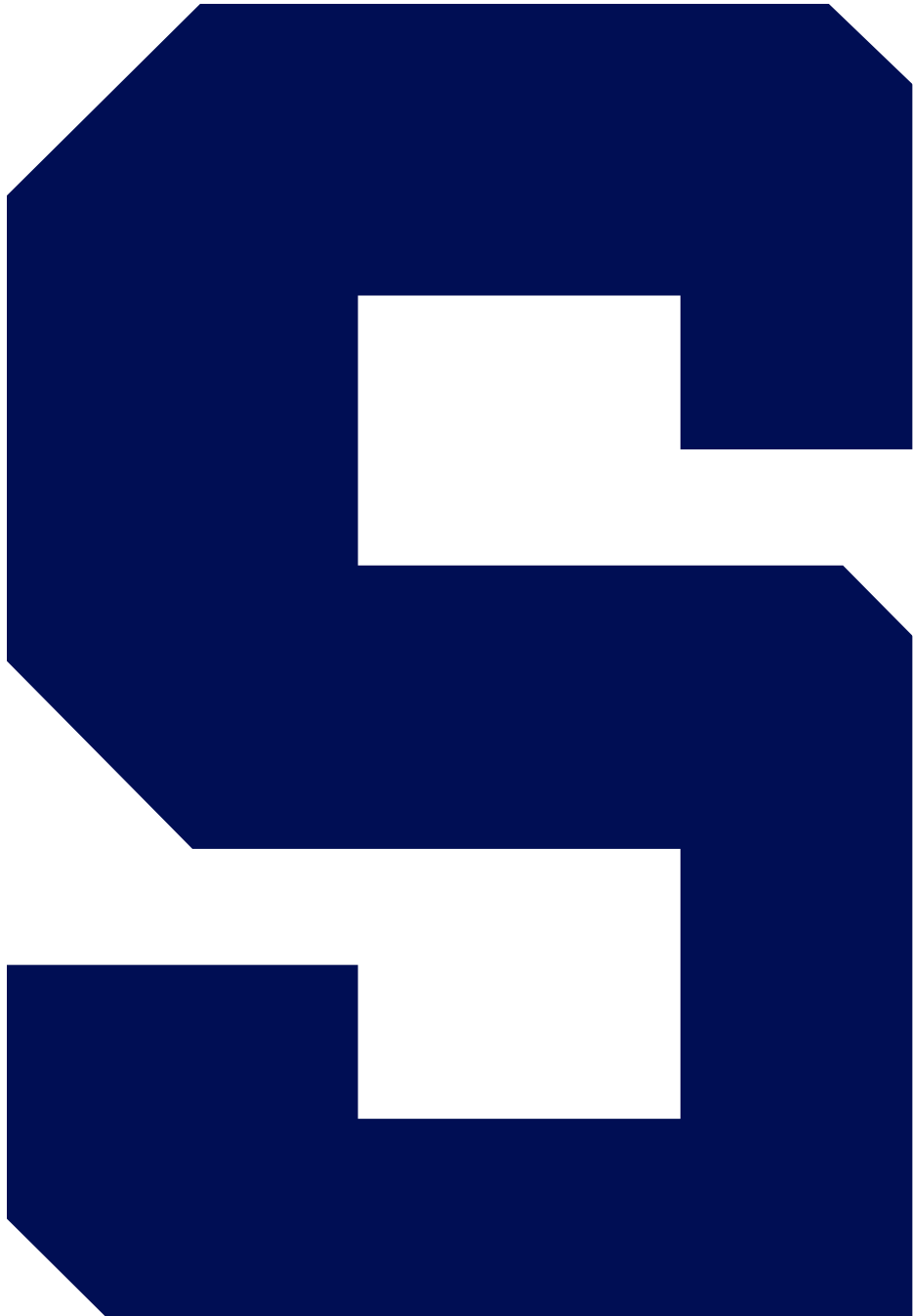

Demo

Database, Filegroups, and Files

Demo: Database, Filegroups, and Files

- We will use the Azure Data Studio application
- We will use the demo database
- Add filegroup to demo
- Show filegroups
- Create table but cannot insert, as there is no file
- Add file to filegroup on demo
- Insert and show it now works
- Show files in filegroups, objects in filegroup
- Move object to another filegroup
- Show physical files on server instance

Demo: Database, Filegroups, and Files

The End

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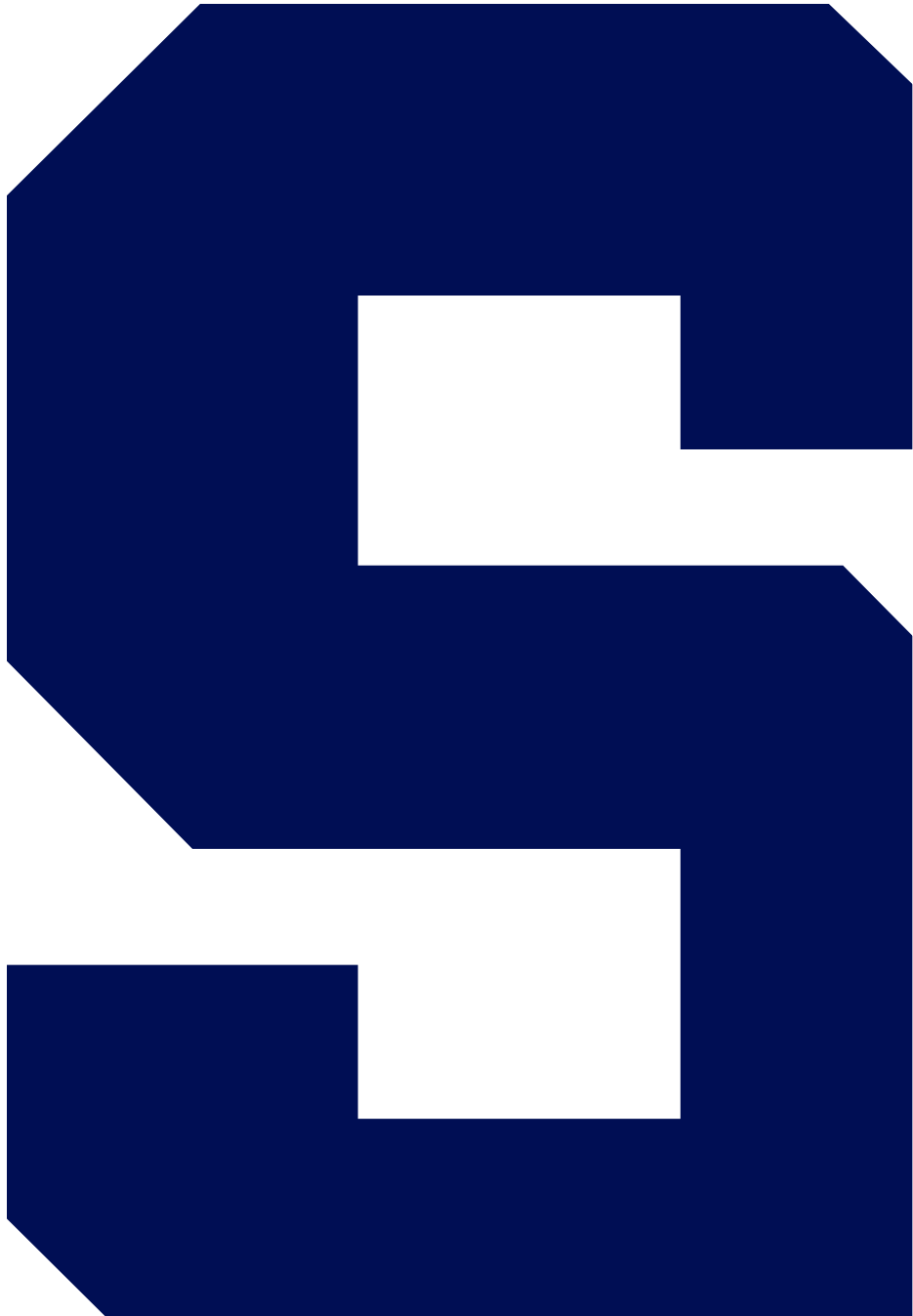


Clustered Indexes

Database Index

- Improves the searchability of our data, at the expense of maintaining multiple versions of it
- Just like the index in the back of a book, takes us to a page where that word occurs
- The database index takes us to the database page where the data for which we're searching can be found
- Scan traverses linearly, a page at a time
- Seek jumps to the page with the content

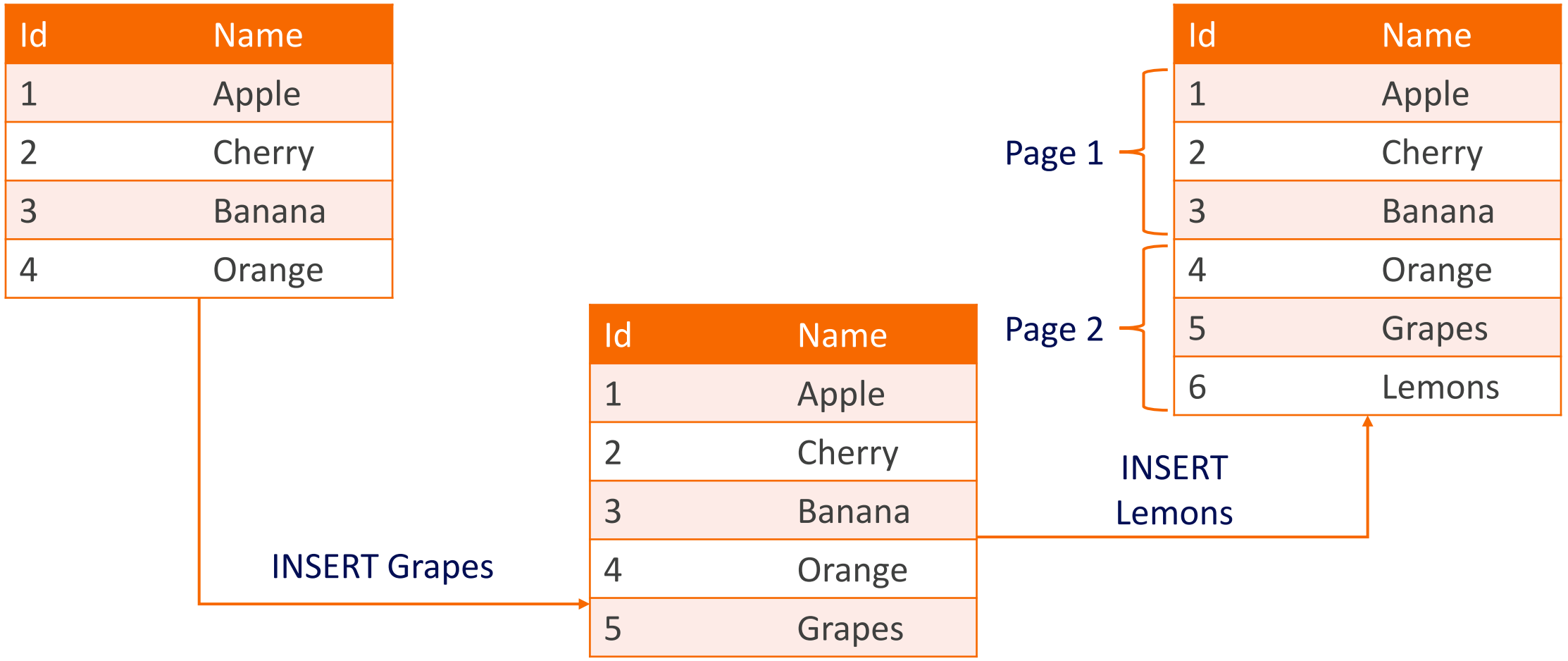
Clustered Index

- Sorts and stores the data in the order of the key values
- There can only be one clustered index per table since rows can only be stored in that order
- By default, the primary key contains a clustered index, but this is not a requirement
- The pages are organized by the clustered index

Primary Key as a Clustered Index

- This is why auto-incrementing values are good for clustered indexes—they avoid page fragmentation
  - Int identity
  - Date/time stamp
- Ideal key/clustered index
  - Narrow: not many bytes in size
  - Unique
  - Static: never changing
  - Ever-increasing

Clustered Index Visualized



CREATE TABLE Revisited

```
CREATE TABLE table_name (
    column,
    […],
    CONSTRAINT pk_name PRIMARY KEY CLUSTERED| NONCLUSTERED
        (columns) [ON filegroup_name]
) [ON filegroup_name]
```

- PK can be clustered or nonclustered.
- Separate filegroups can be specified for the table and the PK.
- A table can only have one clustered index!
- Nonclustered PKs make sense for natural keys.

Indexes

The End

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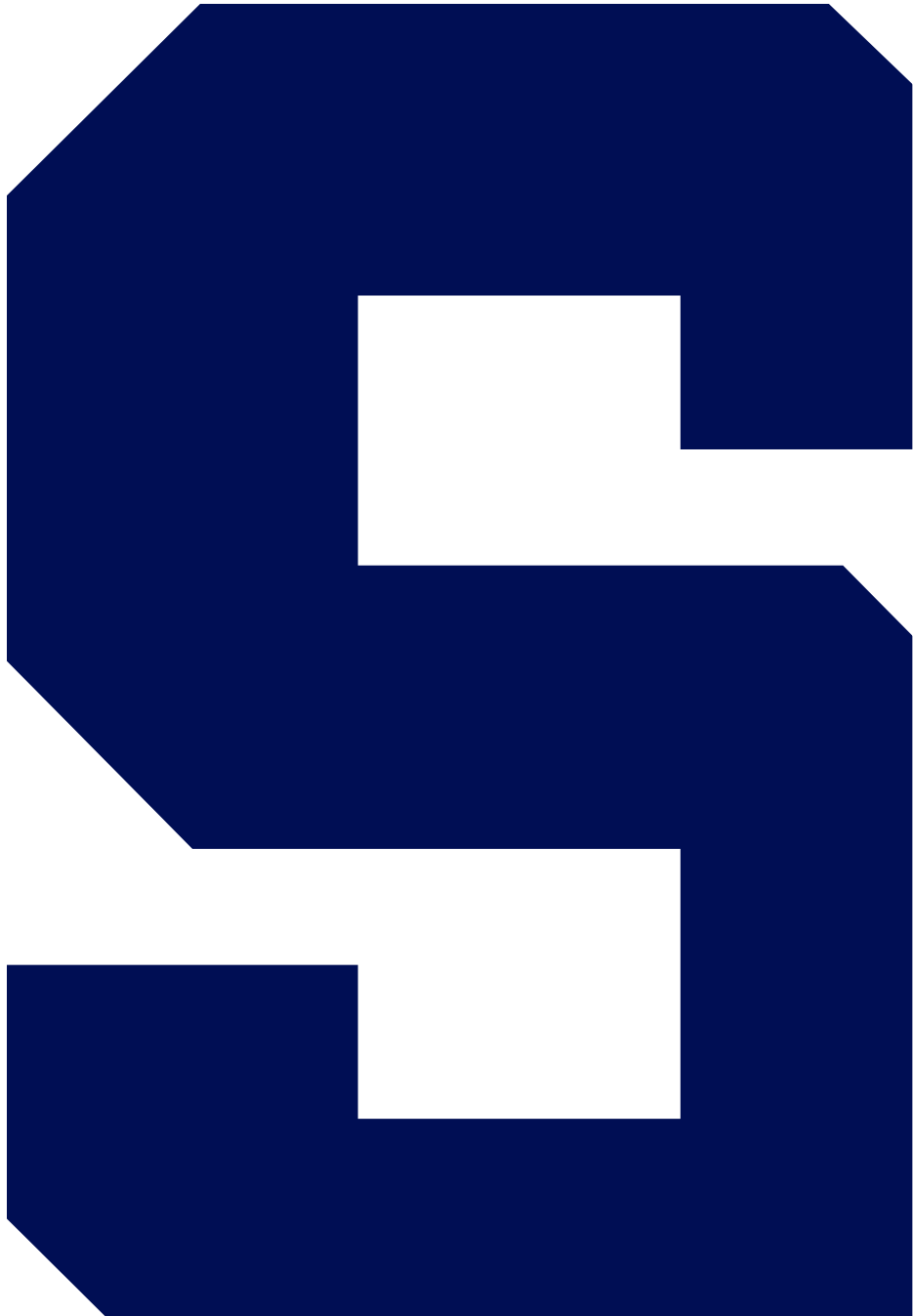


Demo

Tables and Primary Keys Revisited

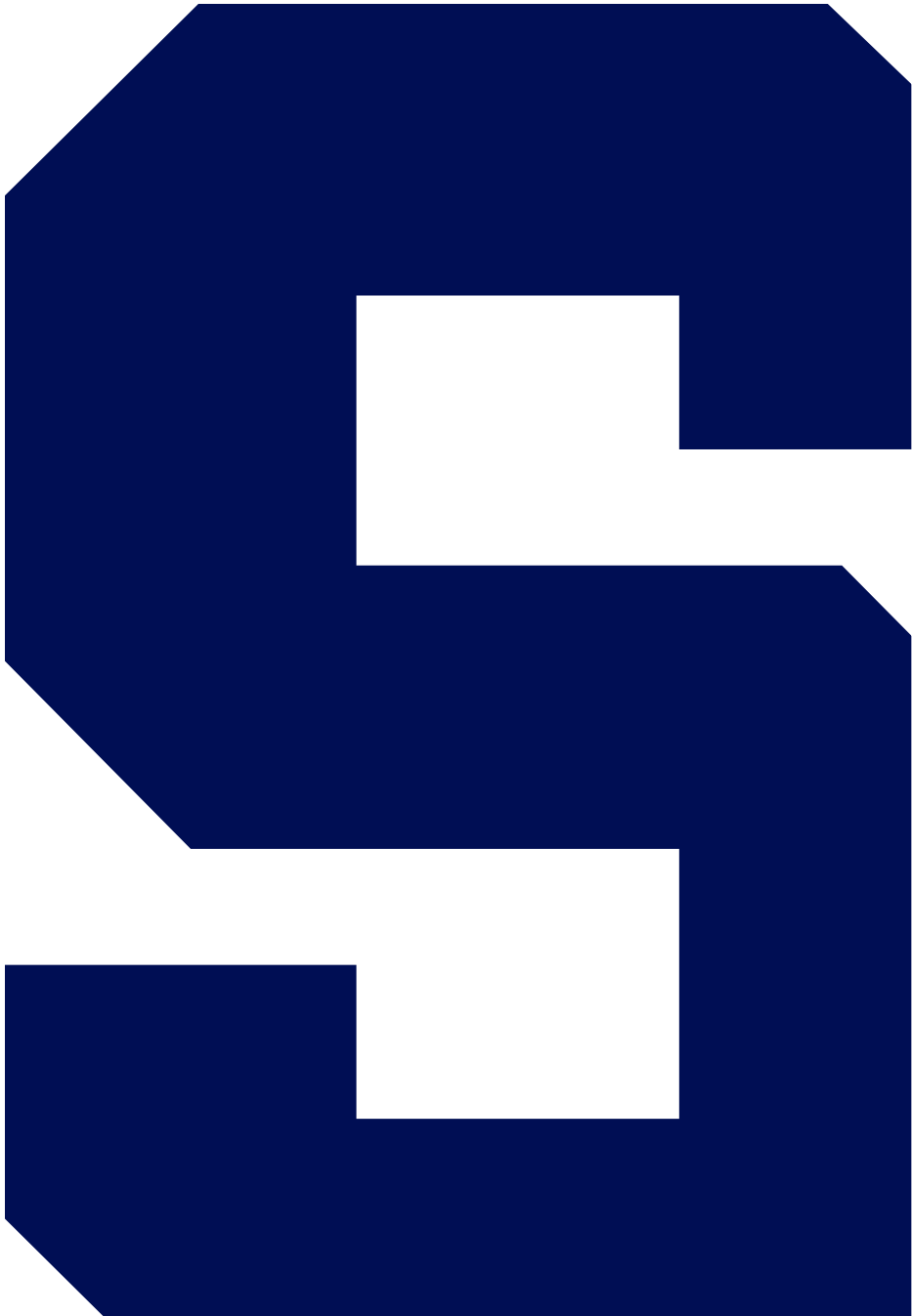
Demo: Tables and Primary Keys Revisited

- We will use the Azure Data Studio application
- We will use the demo database
- Primary key with nonclustered index
- Only can have one clustered index on a table
- Natural keys should be nonclustered
- Create table clustered/nonclustered
- You can store the index in the same filegroup or a different filegroup from the table

Demo: Tables and Primary Keys Revisited

The End

Nonclustered Indexes



Nonclustered Index

- Secondary indexes compared with the primary clustered index
- Use to improve the performance of queries
- You can create multiple nonclustered indexes on your table
- The cost is extra space and extra inserts
- Every index on a table must be updated when the data in a table are updated

Create Index

```
CREATE [UNIQUE] INDEX index_name
      ON table_name (column,[…])
      [INCLUDE (column, […])]
      [ON filegroup_name]
```

- The columns next to the table are the index keys.
- The index can be made unique—a constraint.
- The columns in the INCLUDE clause are not part of the index key, but included in the index.
- When these columns are in the projection of the SELECT statement, you get an index seek.

Nonclustered Index Visualized

Id	Name	Type
1	Apple	Fruit
2	Carrot	Vegetable
3	Banana	Fruit
4	Orange	Fruit
5	Celery	Vegetable

Type	Name	Id
Fruit	Apple	1
	Banana	3
	Orange	5
Vegetable	Carrot	2
	Celery	4


```
CREATE INDEX ix_produce_type
      ON produce (Type) INCLUDE (Name)
```

Faster Reads

Id	Name	Type
1	Apple	Fruit
2	Carrot	Vegetable
3	Banana	Fruit
4	Orange	Fruit
5	Celery	Vegetable

Type	Name	Id
Fruit	Apple	1
	Banana	3
	Orange	5
Vegetable	Carrot	2
	Celery	4

```
SELECT Name FROM produce
WHERE Type='Fruit'
```

The index retrieves 1 row vs. scanning 5 rows that should be included in the query.

Slower Writes

Id	Name	Type
1	Apple	Fruit
2	Carrot	Vegetable
3	Banana	Fruit
4	Orange	Fruit
5	Celery	Vegetable
6	Tomato	Fruit

Type	Name	Id
Fruit	Apple	1
	Banana	3
	Orange	5
	Tomato	6
Vegetable	Carrot	2
	Celery	4

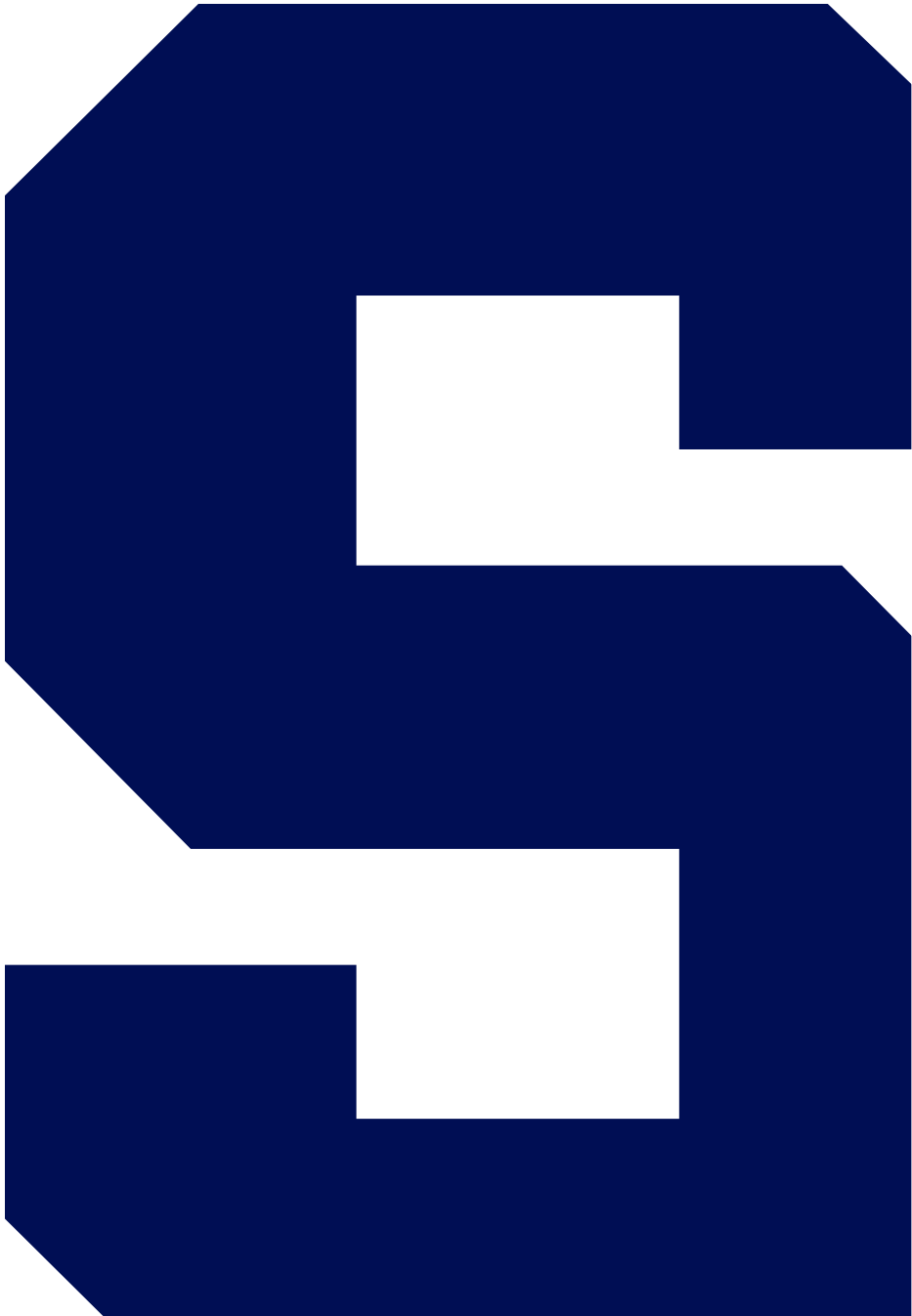
```
INSERT INTO produce
VALUES (6, 'Tomato','Fruit')
```

Every table write also forces a write to the index.

Nonclustered Indexes

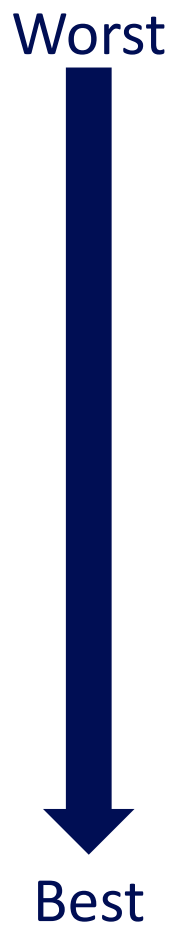
The End

Query Tuning



Scans and Seeks: Finding a Row of Data

- Table scan: search for—row by row—data in each column; worst-case scenario
- Clustered index scan: use the clustered index (primary key, usually) to search row by row
- Clustered index seek: jumps to the correct page using the clustered index
- Index scan: search the index row by row—better than scanning the clustered index, as it typically has fewer rows
- Index seek: use the index to jump to the correct page—Nirvana!



Query Plan Tool Shows Data Access

```
1   select student_firstname, student_lastname, student_gpa
2       from students
3       where student_year_name = 'Freshman'
4
```

Results Messages **Query Plan** Top Operations

Query 1

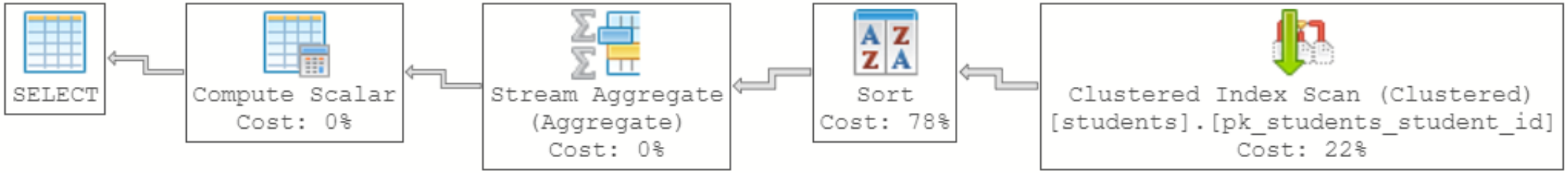
elect student_firstname, student_lastname, student_gpa from students where student_year_name = 'Freshman'

Still an Index Scan but Now Needs a Sort

```
6   select student_year_name, avg(student_gpa)
7       from students
8       group by student_year_name
9
```

Results Messages Query Plan Top Operations

Query 1
select student_year_name, avg(student_gpa) from students group by student_year_name



How to Cover Your Query With an Index

- Index key should be the column(s) in the:
  - WHERE
  - GROUP BY or
  - HAVING classes
- Included index columns are columns from the projection
  - SELECT line

```
drop index if exists  ix_students_by_year_name on students
go
create NONCLUSTERED index ix_students_by_year_name
    on students (student_year_name)
    include (student_firstname, student_lastname, student_gpa)
```

Query Plan: Before Index

```
1   select student_firstname, student_lastname, student_gpa
2       from students
3       where student_year_name = 'Freshman'
4
```

Results Messages Query Plan Top Operations

Query 1
elect student_firstname, student_lastname, student_gpa from students where student_year_name = 'Freshman'

Query Plan: After Index

```
1   select student_firstname, student_lastname, student_gpa
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3       where student_year_name = 'Freshman'
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```

Results Messages Query Plan Top Operations

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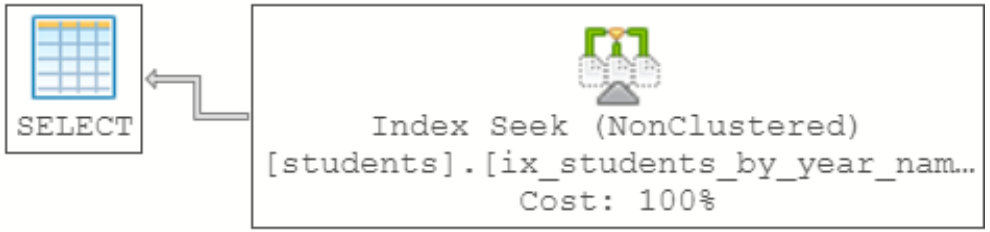

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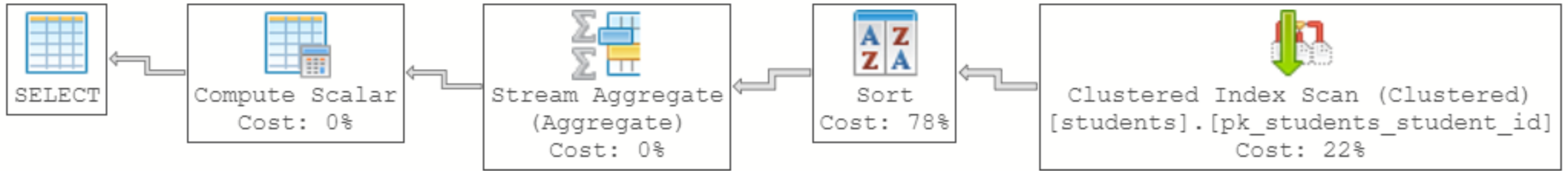

Query Plan: After Index

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Results Messages Query Plan Top Operations

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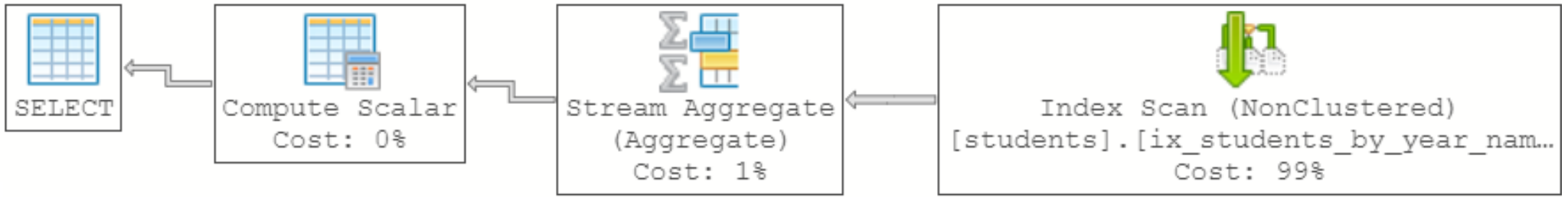
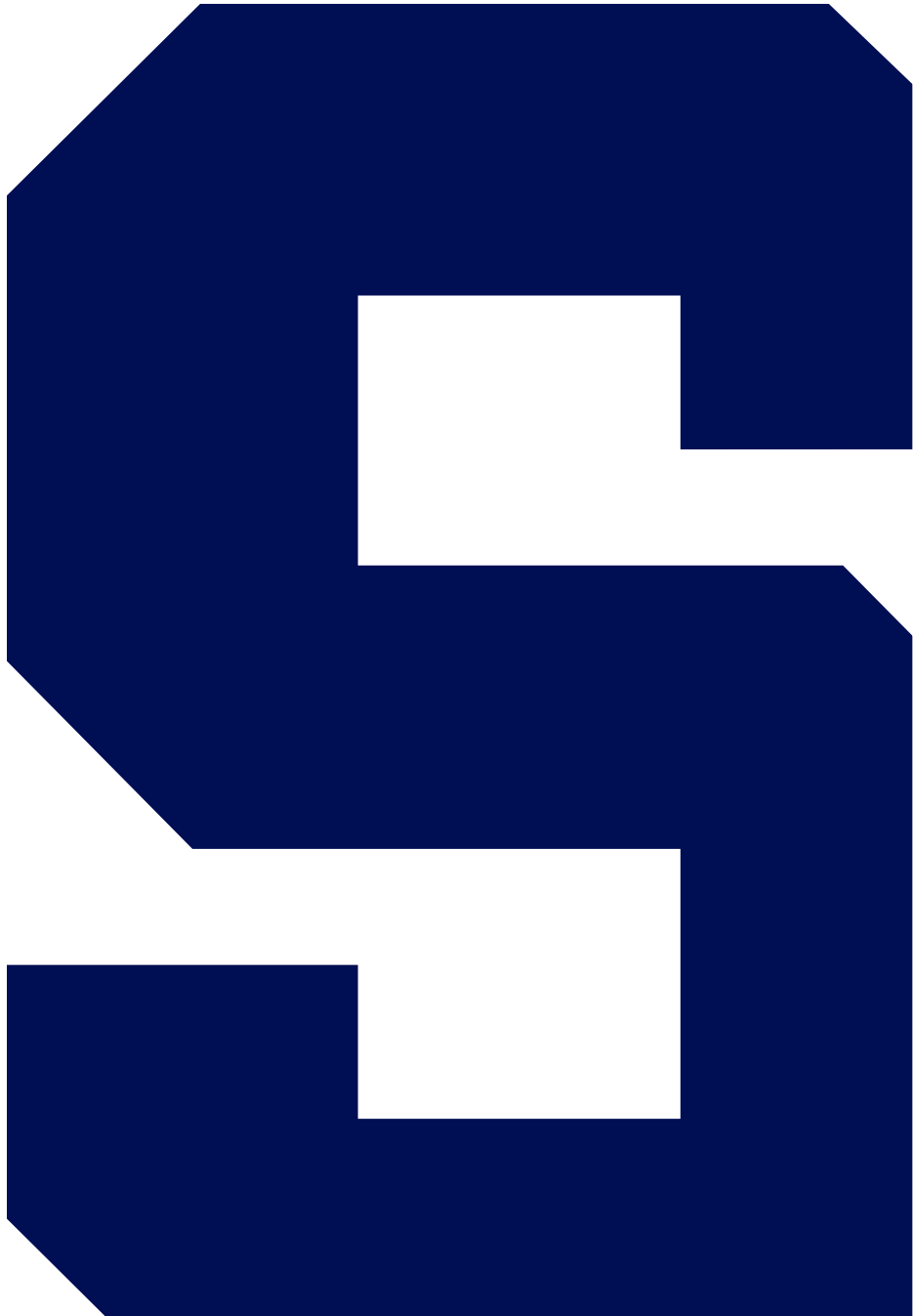


Query Tuning

The End



Demo

Understanding Query Plans

Demo: Understanding Query Plans

- We will use the Azure Data Studio application
- We will use the tinyu database
- Example of how to read query plans
- How window functions affects the query
- An adjustment to the window function improves performance
- Remove the sort operation with an index

Demo: Understanding Query Plans

The End

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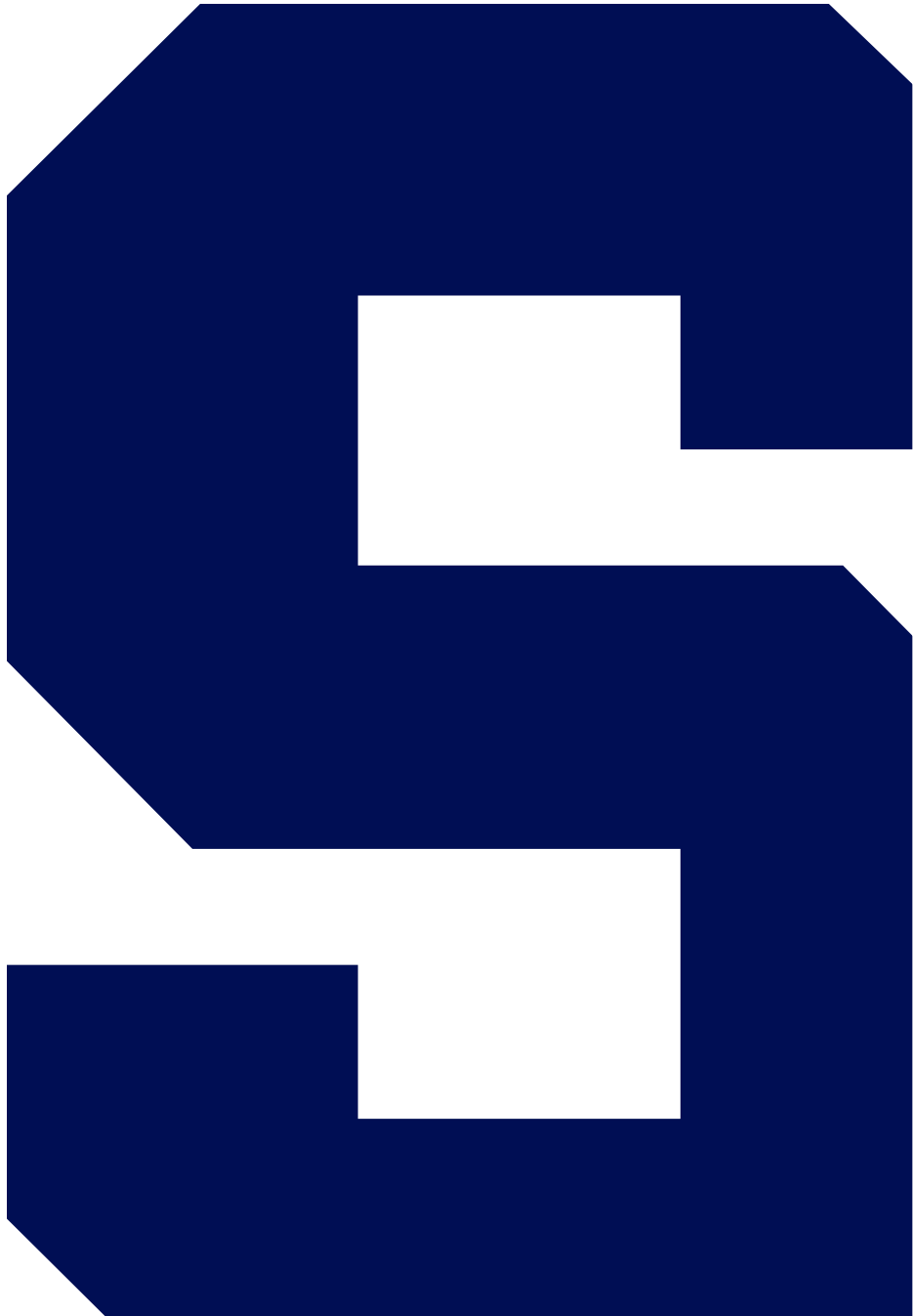


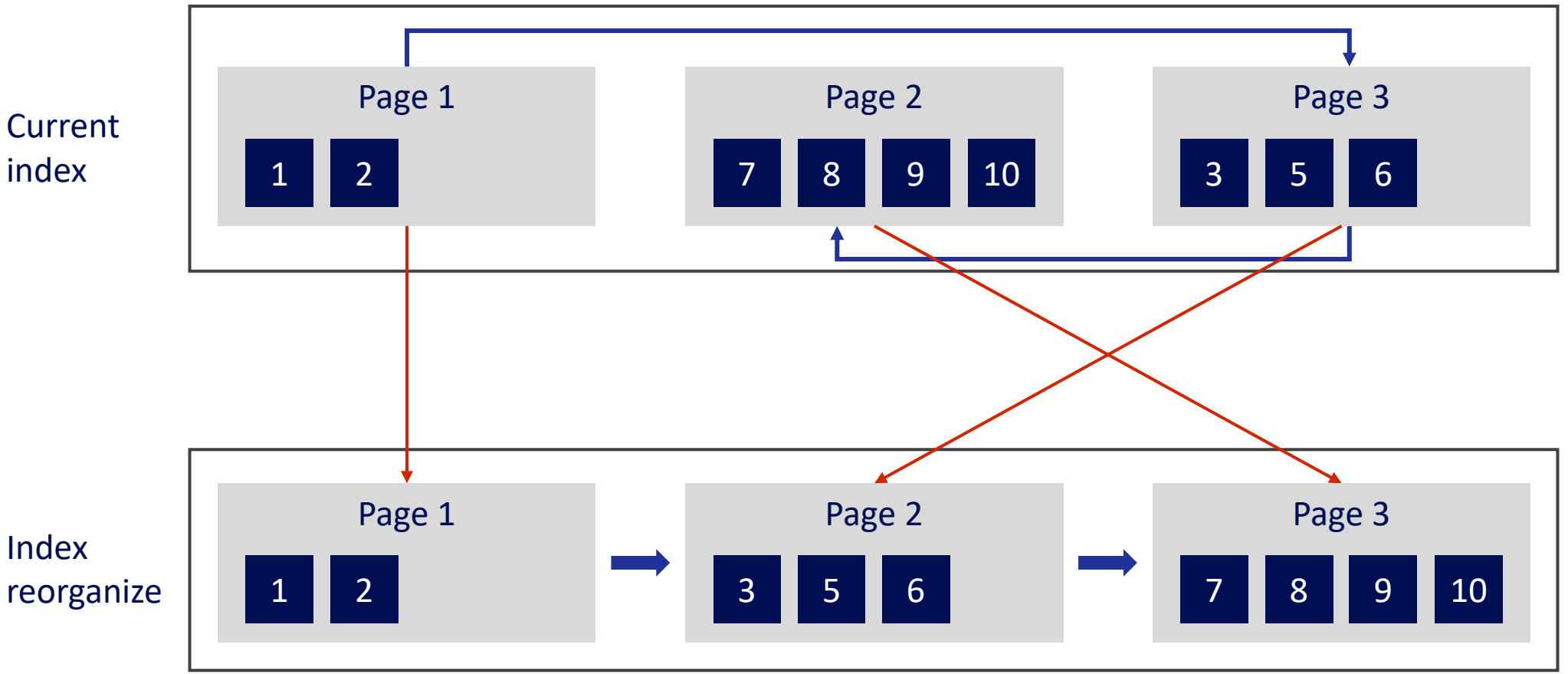
Index Fragmentation

Rebuilding Indexes

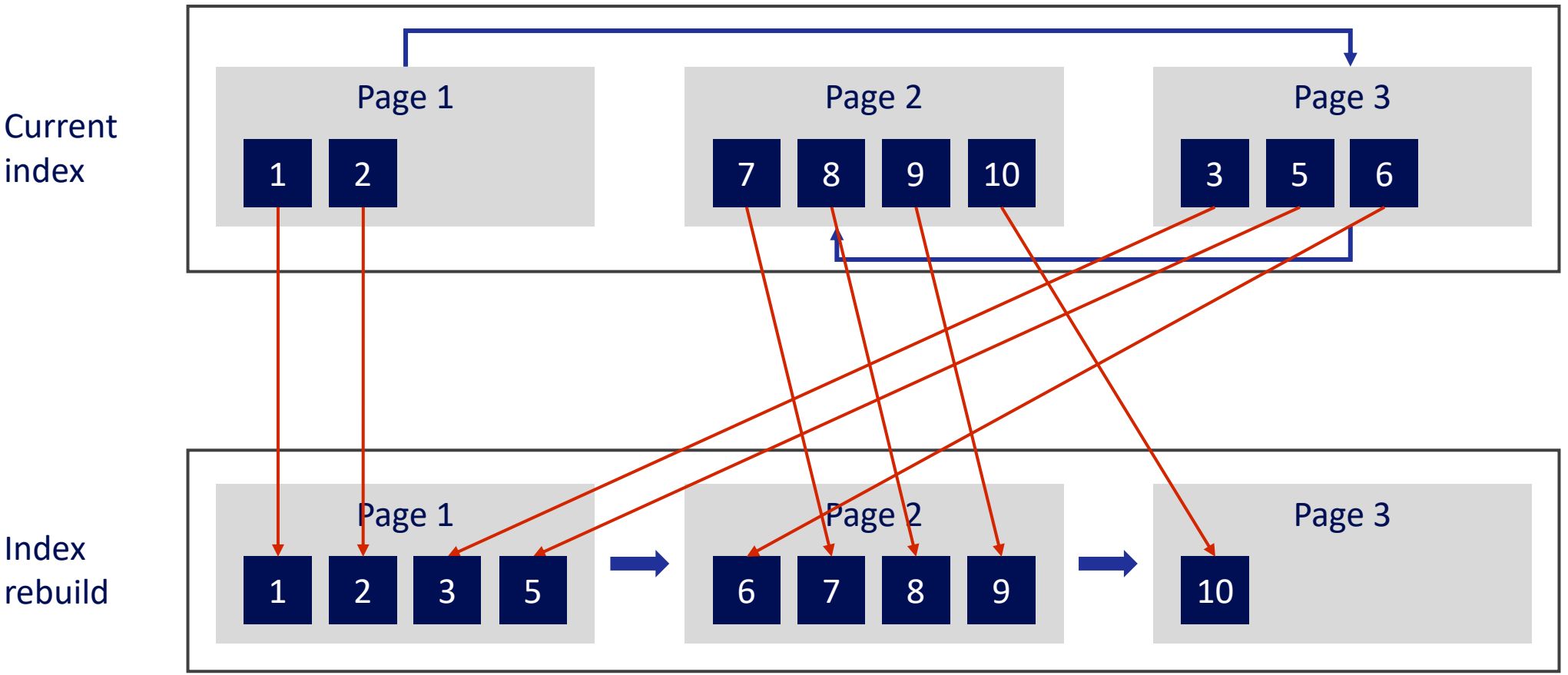
- As data are inserted, updated, and deleted into your tables, your indexes will no longer be optimal
- The pages will not be stored efficiently, and your indexes become fragmented
- Reorganize: move the pages around
- Rebuild: create the index from scratch, fill factor is percent of each page to fill

```
ALTER INDEX index_name ON table REORGANIZE
ALTER INDEX index_name ON table REBUILD
     [WITH FILLFACTOR=n)]
```

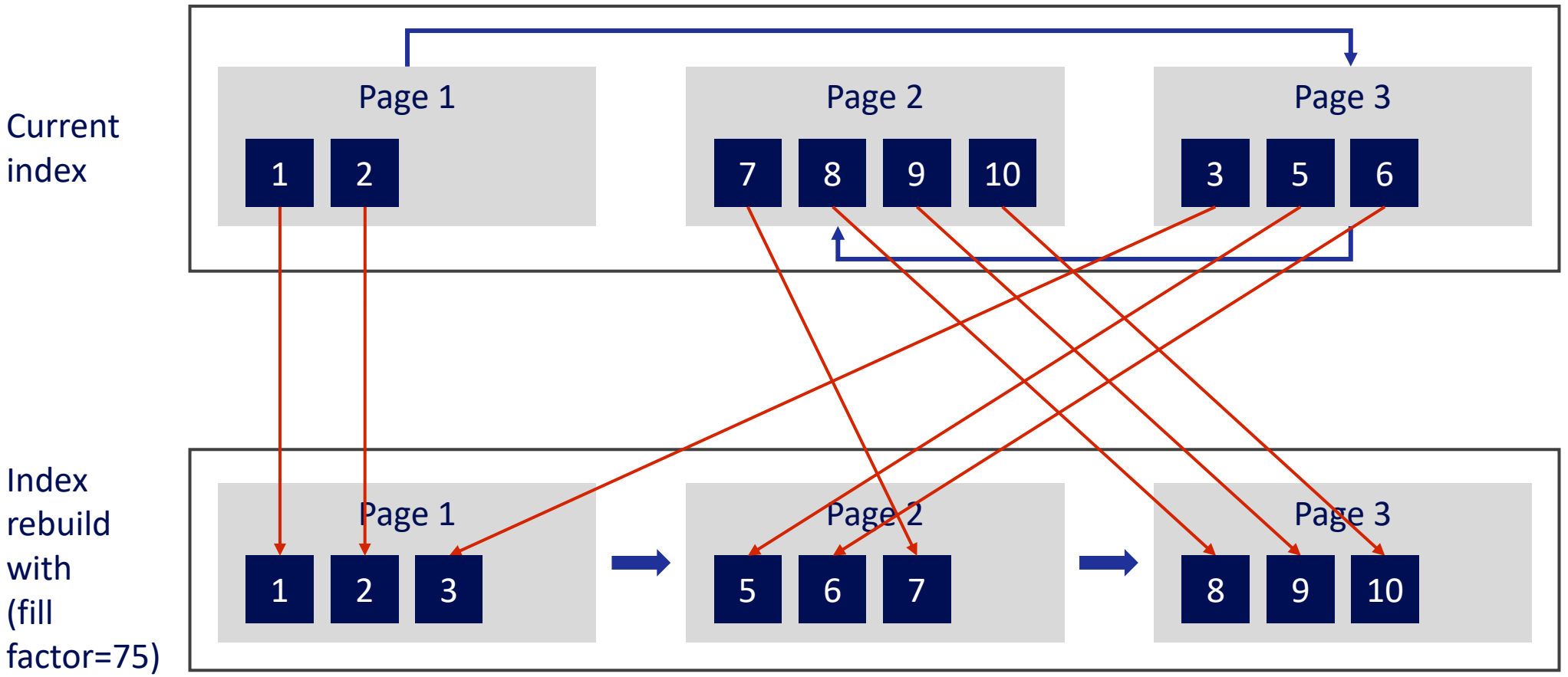
Index Page Fragmentation: Reorganize



Index Page Fragmentation: Rebuild

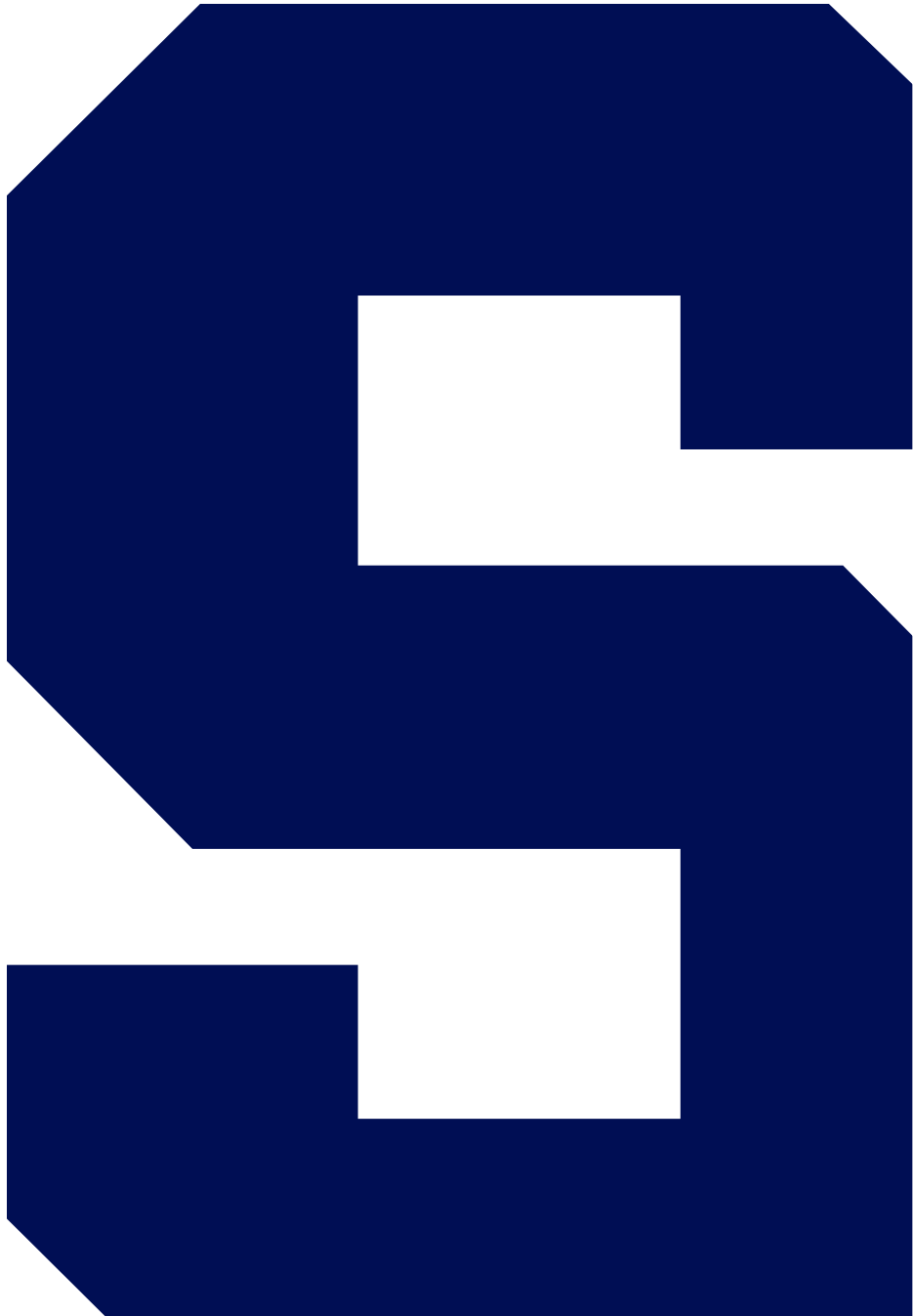


Index Page Fragmentation: Rebuild Fill Factor



Index Fragmentation

The End



Demo

Index Statistics

Demo: Index Statistics

- We will use the Azure Data Studio application.
- We will use the demo database.
- Create a table and index.
- Add data—not fragmented is on one page!
- Perform some random updates.
- Check index fragmentation.
- Rebuild and reorganize.

Demo: Index Statistics

The End

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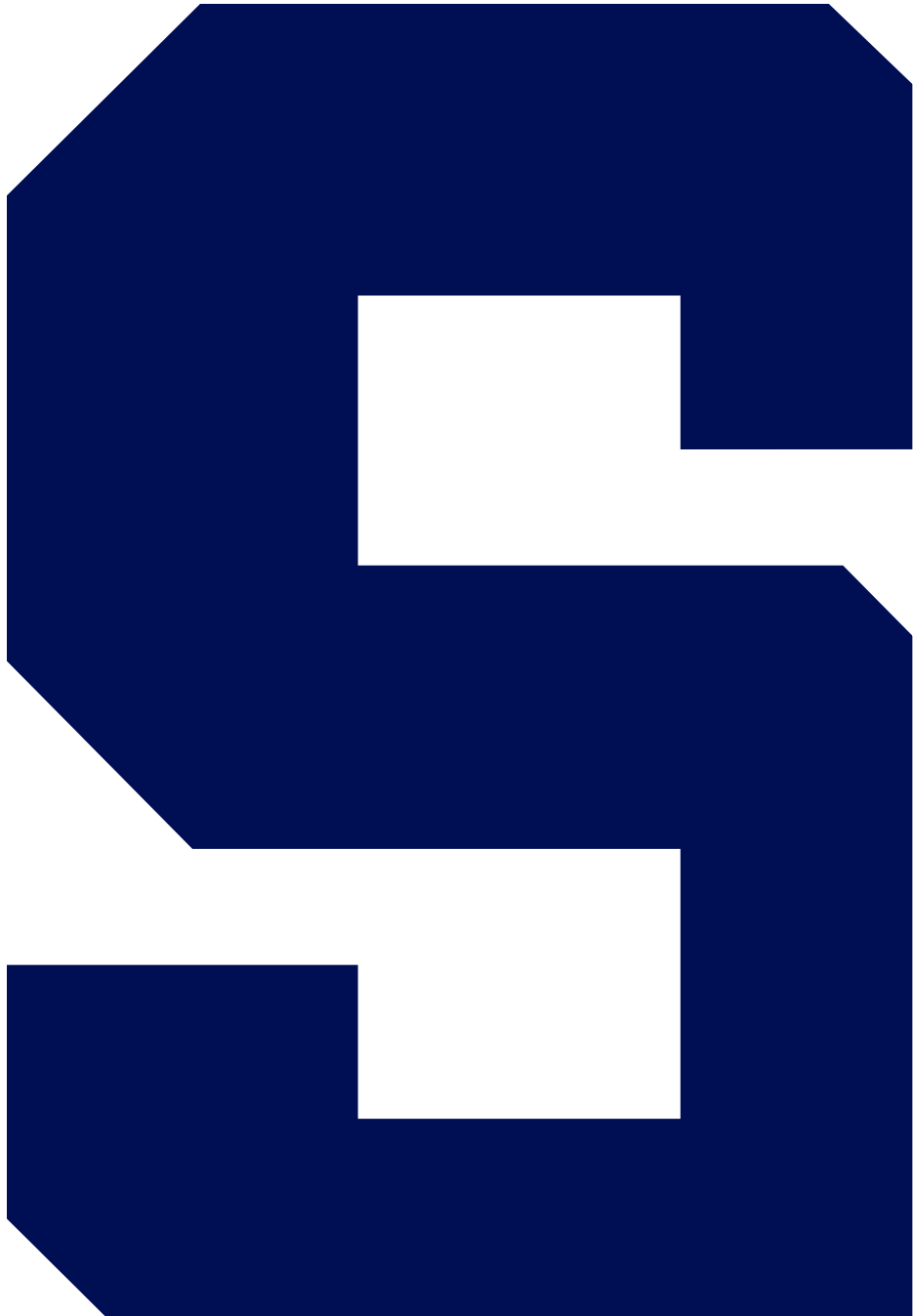


Columnstore Indexes

Columnstore Index

- The standard for storing and querying large tables with many columns
- Rather than storing the data in rows, the data are stored in columns
- Appropriate for tables with many columns (wide tables) and those with many similar values, as found in data warehouse fact tables
- Comes in clustered/nonclustered versions
- Data are compressed and cached in memory

Tangent: What Is a Columnstore?

Physical Rowstore

Row 1	US
	Alpha
	3,000
Row 2	US
	Beta
	1,250
Row 3	JP
	Alpha
	700
Row 4	UK
	Alpha
	450

Easier to retrieve a column

Easier to aggregate values or distinct values in a column

Used in analytics

Logical table

Country	Product	Sales
US	Alpha	3,000
US	Beta	1,250
JP	Alpha	700
UK	Alpha	450

Easier to add new rows

Simple to retrieve a row, update a row

Used for CRUD operations

Physical Columnstore

Country	US
	US
	JP
	UK
Product	Alpha
	Beta
	Alpha
	Alpha
Sales	3,000
	1,250
	700
	450
Country	US
	US
	JP
	UK

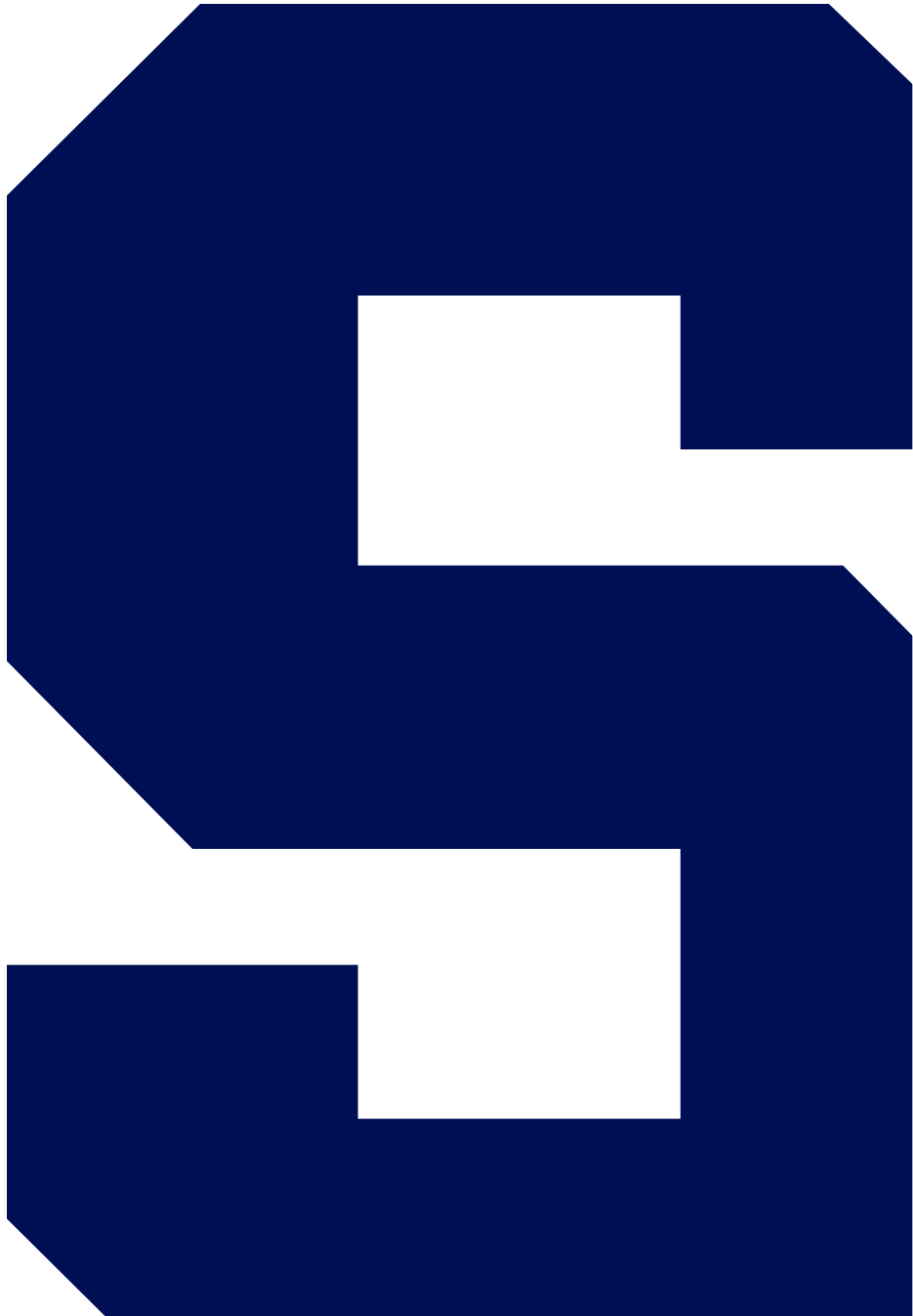
SQL: Create Columnstore

```
CREATE [CLUSTERED|NONCLUSTERED]
    COLUMNSTORE INDEX index_name
    ON table_name (column,[…])
```

- Can be clustered or nonclustered; only one clustered index
- The columns specified are not keys, they are the columns included in the column store index; the keys are the names of the columns!

Columnstore Indexes

The End



Demo

Columnstore Indexes

Demo: Columnstore Index

- We will use the Azure Data Studio application
- We will use the fudgemart_v3 database
- Run query on orders table and look at live statistics
- Make a nonclustered index to improve this query
- But it doesn’t work for other queries—we’d need another index
- Columnstore to the rescue!

Demo: Columnstore Indexes

The End

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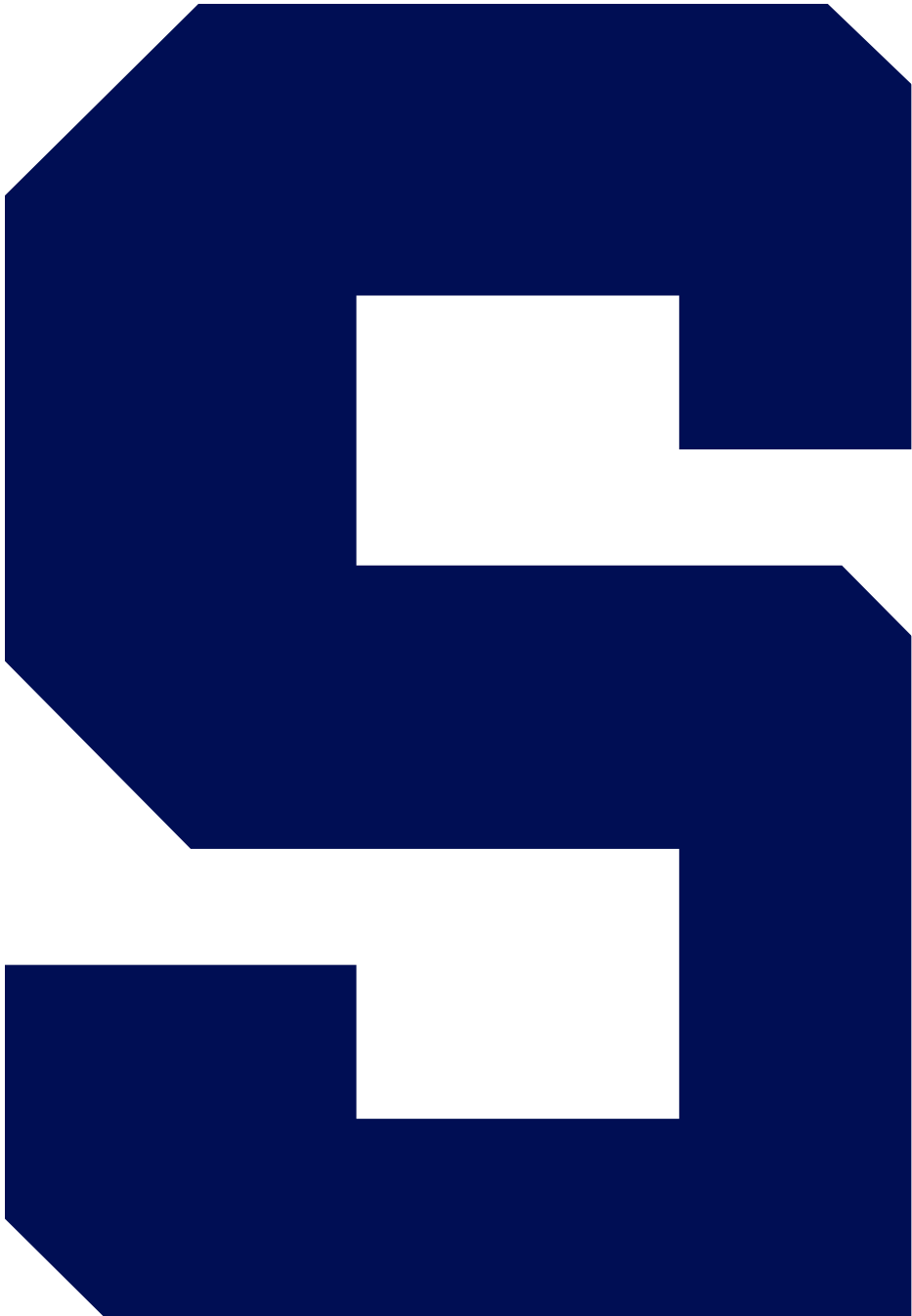

Indexed Views

Indexed Views

- Easy way to improve the performance of a view
- An indexed view is SQL Server's version of a materialized view
- The output of the view is saved into an index table to improve read performance of the view
- When the underlying data are updated, so is the view, just like an index!
- Must bind the schema of the underlying tables—cannot alter the underlying table schema without dropping the view first

Rules for Indexing a View

- Use WITH SCHEMABINDING in the CREATE VIEW statement
- The view must be deterministic—the same input yields the same output
- All columns must be specified; no wildcard columns
- Tables must be schema-qualified dbo
- Must be a unique clustered index (like setting a PK)

Indexed Views

The End

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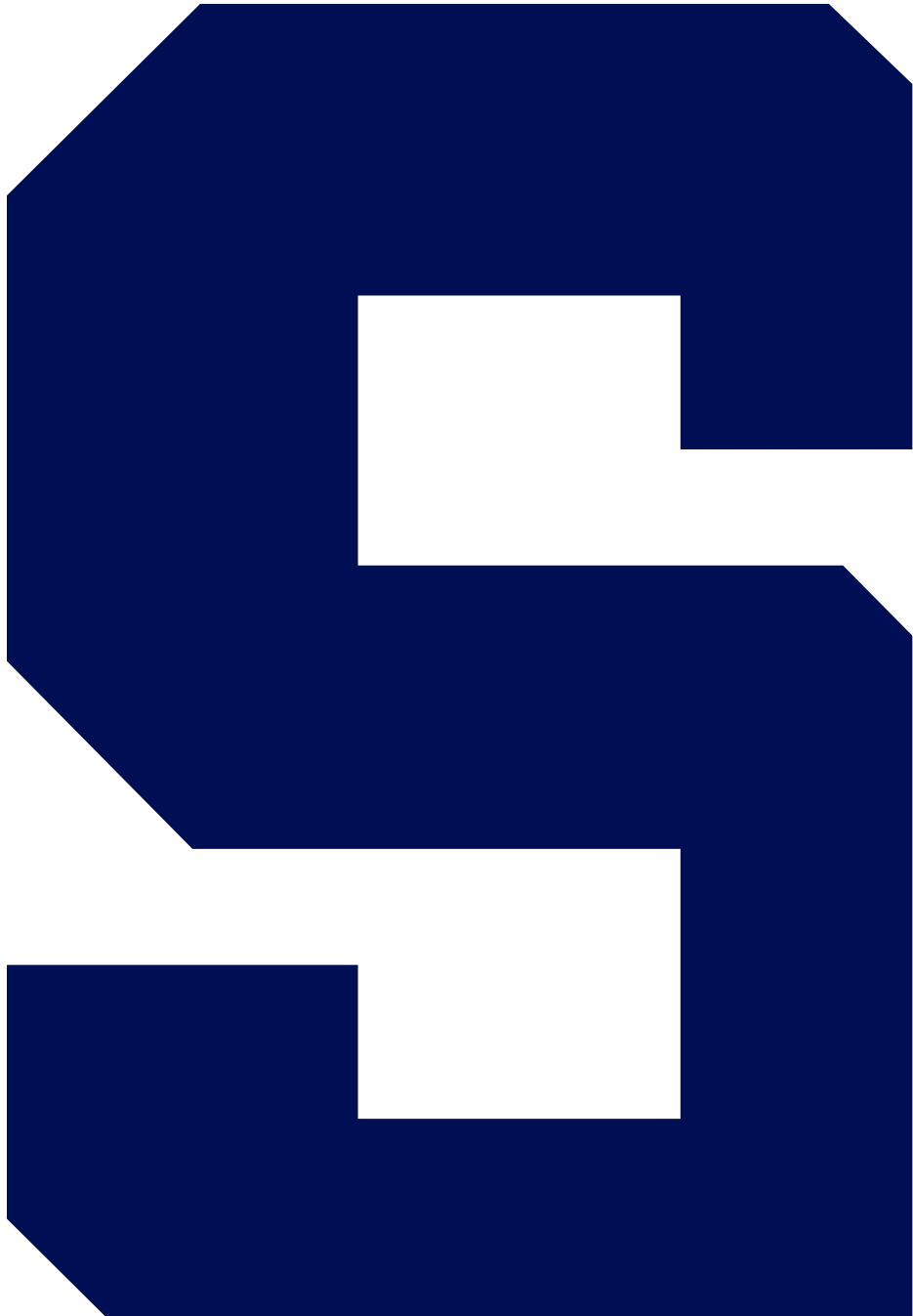

Demo

Indexed Views

Demo: Indexed Views

- We will use the Azure Data Studio application
- We will use the tinyu database
- Query plan of a view
- Add with schemabinding
- Then index
- Query plan is now like a table!

Demo: Indexed Views

The End

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Summary

Physical Performance Tricks and Tips

1

If your server has more than one disk, create one file per disk in the same filegroup to spread IO over the disks.

2

If your server has faster SSD (solid-state disks), create a filegroup on that disk to support high-velocity tables.

3

Do not store the database files on the same disk/partition as the operating system and SQL Server itself. Minimize your IO contention.

4

Put fast-growing time-series data and associative entities in their own filegroup.

Index Rules of Thumb

Use indexes

- The table contains over 100,000 rows.
- The searchable field (indexed column) has a wide range of values.
- The searchable field has a large number of null values.
- The searchable field is queried frequently.
- Queries retrieve less than 2–4% of the table's rows.

Avoid indexes

- There are relatively few rows in the table.
- The column is not used for searching.
- The majority of the queries retrieve more than 2–4% of the table's rows.
- There is high insert or update transaction volatility.

Summary

- The physical model is an implementation of the logical model on a DBMS.
- The SQL Server physical model consists of servers, instances, databases, filegroups, files, and pages.
- Indexes allow us to improve query performance at the expense of write performance.
- Columnstore indexes store table data in columns for faster retrieval.
- Views can be indexed to improve performance.

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Summary

The End