Carnegie Mellon University

Advanced SQL

Lecture #02

Database Systems
15-445/15-645
Fall 2018

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RELATIONAL LANGUAGES

User only needs to specify the answer that they want, not how to compute it.

The DBMS is responsible for efficient evaluation of the query.

→ Query optimizer: re-orders operations and generates query plan

SQL HISTORY

Originally "SEQUEL" from IBM's **System R** prototype.
→ Structured English Query Language
→ Adopted by Oracle in the 1970s.

IBM releases DB2 in 1983.

ANSI Standard in 1986. ISO in 1987
→ Structured Query Language

SQL HISTORY

Current standard is **SQL:2016**

→ **SQL:2016** → JSON, Polymorphic tables
→ **SQL:2011** → Temporal DBs, Pipelined DML
→ **SQL:2008** → TRUNCATE, Fancy ORDER
→ **SQL:2003** → XML, windows, sequences, auto-generated IDs.
→ **SQL:1999** → Regex, triggers, OO

Most DBMSs at least support **SQL-92**

→ System Comparison: http://troels.arvin.dk/db/rdbms/

RELATIONAL LANGUAGES

Data Manipulation Language (DML)

Data Definition Language (DDL)

Data Control Language (DCL)

Also includes:

→ View definition
→ Integrity & Referential Constraints
→ Transactions

Important: SQL is based on **bags** (duplicates) not **sets** (no duplicates).

TODAY'S AGENDA

Aggregations + Group By
String / Date / Time Operations
Output Control + Redirection
Nested Queries
Common Table Expressions
Window Functions

EXAMPLE DATABASE

student(sid,name,login,gpa)

sid	name	login	age	gpa
53666	Kanye	kayne@cs	39	4.0
53688	Bieber	jbieber@cs	22	3.9
53655	Tupac	shakur@cs	26	3.5

course(cid,name)

cid	name
15-445	Database Systems
15-721	Advanced Database Systems
15-826	Data Mining
15-823	Advanced Topics in Databases

enrolled(sid,cid,grade)

sid	cid	grade
53666	15-445	C
53688	15-721	A
53688	15-826	B
53655	15-445	B
53666	15-721	C

AGGREGATES

Functions that return a single value from a bag of tuples:

→ `AVG(col)` → Return the average col value.
→ `MIN(col)` → Return minimum col value.
→ `MAX(col)` → Return maximum col value.
→ `SUM(col)` → Return sum of values in col.
→ `COUNT(col)` → Return # of values for col.

AGGREGATES

Aggregate functions can only be used in the **SELECT** output list.

Get # of students with a "@cs" login:

```
SELECT COUNT(login) AS cnt
  FROM student WHERE login LIKE '%@cs'
```

```
SELECT COUNT(*) AS cnt
  FROM student WHERE login LIKE '%@cs'
```

```
SELECT COUNT(1) AS cnt
  FROM student WHERE login LIKE '%@cs'
```

MULTIPLE AGGREGATES

Get the number of students and their average GPA that have a "@cs" login.

```
SELECT AVG(gpa), COUNT(sid)
  FROM student WHERE login LIKE '%@cs'
```

AVG(gpa)	COUNT(sid)
3.25	12

DISTINCT AGGREGATES

COUNT, **SUM**, **AVG** support **DISTINCT**

Get the number of unique students that have an "@cs" login.

```
SELECT COUNT(DISTINCT login)
  FROM student WHERE login LIKE '%@cs'
```

COUNT(DISTINCT login)
10

AGGREGATES

Output of other columns outside of an aggregate is undefined.

Get the average GPA of students enrolled in each course.

```
SELECT AVG(s.gpa), e.cid
  FROM enrolled AS e, student AS s
 WHERE e.sid = s.sid
```

AVG(s.gpa)	e.cid
3.5	???

GROUP BY

Project tuples into subsets and calculate aggregates against each subset.

```
SELECT AVG(s.gpa), e.cid
  FROM enrolled AS e, student AS s
 WHERE e.sid = s.sid
 GROUP BY e.cid
```

e.sid	s.sid	s.gpa	e.cid
53435	53435	2.25	15-721
53439	53439	2.70	15-721
56023	56023	2.75	15-826
59439	59439	3.90	15-826
53961	53961	3.50	15-826
58345	58345	1.89	15-445

GROUP BY

Project tuples into subsets and calculate aggregates against each subset.

```
SELECT AVG(s.gpa), e.cid
  FROM enrolled AS e, student AS s
 WHERE e.sid = s.sid
 GROUP BY e.cid
```

e.sid	s.sid	s.gpa	e.cid
53435	53435	2.25	15-721
53439	53439	2.70	15-721
56023	56023	2.75	15-826
59439	59439	3.90	15-826
53961	53961	3.50	15-826
58345	58345	1.89	15-445

GROUP BY

Project tuples into subsets and calculate aggregates against each subset.

```
SELECT AVG(s.gpa), e.cid
  FROM enrolled AS e, student AS s
 WHERE e.sid = s.sid
 GROUP BY e.cid
```

e.sid	s.sid	s.gpa	e.cid
53435	53435	2.25	15-721
53439	53439	2.70	15-721
56023	56023	2.75	15-826
59439	59439	3.90	15-826
53961	53961	3.50	15-826
58345	58345	1.89	15-445

AVG(s.gpa)	e.cid
2.46	15-721
3.39	15-826
1.89	15-445

GROUP BY

Non-aggregated values in **SELECT** output clause must appear in **GROUP BY** clause.

```
SELECT AVG(s.gpa), e.cid, s.name
  FROM enrolled AS e, student AS s
 WHERE e.sid = s.sid
 GROUP BY e.cid
```

GROUP BY

Non-aggregated values in **SELECT** output clause must appear in **GROUP BY** clause.

```
SELECT AVG(s.gpa), e.cid, s.name
  FROM enrolled AS e, student AS s
 WHERE e.sid = s.sid
 GROUP BY e.cid, s.name
```

HAVING

Filters results based on aggregation computation.

Like a **WHERE** clause for a **GROUP BY**

```
SELECT AVG(s.gpa) AS avg_gpa, e.cid
  FROM enrolled AS e, student AS s
 WHERE e.sid = s.sid
   AND avg_gpa > 3.9
 GROUP BY e.cid
```

HAVING

Filters results based on aggregation computation.

Like a **WHERE** clause for a **GROUP BY**

```
SELECT AVG(s.gpa) AS avg_gpa, e.cid
  FROM enrolled AS e, student AS s
 WHERE e.sid = s.sid
 GROUP BY e.cid
 HAVING avg_gpa > 3.9;
```

AVG(s.gpa)	e.cid
3.75	15-415
3.950000	15-721
3.900000	15-826

avg_gpa	e.cid
3.950000	15-721

STRING OPERATIONS

	String Case	String Quotes
SQL-92	Sensitive	Single Only
Postgres	Sensitive	Single Only
MySQL	Insensitive	Single/Double
SQLite	Sensitive	Single/Double
DB2	Sensitive	Single Only
Oracle	Sensitive	Single Only

```
WHERE UPPER(name) = UPPER('KaNyE')
```
SQL-92

```
WHERE name = "KaNyE"
```
MySQL

STRING OPERATIONS

LIKE is used for string matching.

String-matching operators

→ **"%"** Matches any substring (including empty strings).

→ **"_"** Match any one character

```
SELECT * FROM enrolled AS e
 WHERE e.cid LIKE '15-%'
```

```
SELECT * FROM student AS s
 WHERE s.login LIKE '%@c_'
```

STRING OPERATIONS

SQL-92 defines string functions.

→ Many DBMSs also have their own unique functions

Can be used in either output and predicates:

```
SELECT SUBSTRING(name,0,5) AS abbrv_name
  FROM student WHERE sid = 53688
```

```
SELECT * FROM student AS s
 WHERE UPPER(e.name) LIKE 'KAN%'
```

STRING OPERATIONS

SQL standard says to use || operator to concatenate two or more strings together.

SQL-92

```
SELECT name FROM student
 WHERE login = LOWER(name) || '@cs'
```

MSSQL

```
SELECT name FROM student
 WHERE login = LOWER(name) + '@cs'
```

MySQL

```
SELECT name FROM student
 WHERE login = CONCAT(LOWER(name), '@cs')
```

DATE/TIME OPERATIONS

Operations to manipulate and modify `DATE`/`TIME` attributes.

Can be used in either output and predicates.

Support/syntax varies wildly…

Demo: Get the # of days since the beginning of the year.

OUTPUT REDIRECTION

Store query results in another table:

→ Table must not already be defined.

→ Table will have the same # of columns with the same types as the input.

SQL-92

```
SELECT DISTINCT cid INTO CourseIds
  FROM enrolled;
```

MySQL

```
CREATE TABLE CourseIds (
SELECT DISTINCT cid FROM enrolled);
```

OUTPUT REDIRECTION

Insert tuples from query into another table:

→ Inner **SELECT** must generate the same columns as the target table.

→ DBMSs have different options/syntax on what to do with duplicates.

SQL-92

```
INSERT INTO CourseIds
(SELECT DISTINCT cid FROM enrolled);
```

OUTPUT CONTROL

ORDER BY <column*> [ASC|DESC]

→ Order the output tuples by the values in one or more of their columns.

```
SELECT sid, grade FROM enrolled
 WHERE cid = '15-721'
 ORDER BY grade
```

sid	grade
53123	A
53334	A
53650	B
53666	D

OUTPUT CONTROL

ORDER BY <column*> [ASC|DESC]

→ Order the output tuples by the values in one or more of their columns.

```
SELECT sid, grade FROM enrolled
 WHERE cid = '15-721'
 ORDER BY grade
```

sid	grade
53123	A
53334	A
53650	B
53666	D

```
SELECT sid FROM enrolled
 WHERE cid = '15-721'
 ORDER BY grade DESC, sid ASC
```

sid
53666
53650
53123
53334

OUTPUT CONTROL

LIMIT <count> [offset]

→ Limit the # of tuples returned in output.
→ Can set an offset to return a "range"

```
SELECT sid, name FROM student
 WHERE login LIKE '%@cs'
 LIMIT 10
```

```
SELECT sid, name FROM student
 WHERE login LIKE '%@cs'
 LIMIT 20 OFFSET 10
```

NESTED QUERIES

Queries containing other queries.

They are often difficult to optimize.

Inner queries can appear (almost) anywhere in query.

Outer Query →

```
SELECT name FROM student WHERE
 sid IN (SELECT sid FROM enrolled)
```

← Inner Query

NESTED QUERIES

Get the names of students in '15-445'

```
SELECT name FROM student
 WHERE ...
```

"sid in the set of people that take 15-445"

NESTED QUERIES

Get the names of students in '15-445'

```
SELECT name FROM student
 WHERE ...
   SELECT sid FROM enrolled
    WHERE cid = '15-445'
```

NESTED QUERIES

Get the names of students in '15-445'

```
SELECT name FROM student
 WHERE sid IN (
   SELECT sid FROM enrolled
    WHERE cid = '15-445'
 )
```

NESTED QUERIES

Get the names of students in '15-445'

```
SELECT name FROM student
 WHERE sid IN (
   SELECT sid FROM enrolled
    WHERE cid = '15-445'
 )
```

NESTED QUERIES

ALL → Must satisfy expression for all rows in sub-query

ANY → Must satisfy expression for at least one row in sub-query.

IN → Equivalent to '**=ANY()**' .

EXISTS → At least one row is returned.

NESTED QUERIES

Get the names of students in '15-445'

```
SELECT name FROM student
 WHERE sid = ANY(
   SELECT sid FROM enrolled
    WHERE cid = '15-445'
 )
```

NESTED QUERIES

Get the names of students in '15-445'

```
SELECT (SELECT S.name FROM student AS S
          WHERE S.sid = E.sid) AS sname
  FROM enrolled AS E
 WHERE cid = '15-445'
```

NESTED QUERIES

Find student record with the highest id that is enrolled in at least one course.

```
SELECT MAX(e.sid), s.name
  FROM enrolled AS e, student AS s
 WHERE e.sid = s.sid;
```

Won't work in SQL-92. This runs in SQLite, but not Postgres or MySQL (v5.7 with strict mode).

NESTED QUERIES

Find student record with the highest id that is enrolled in at least one course.

```
SELECT sid, name FROM student
 WHERE ...
```

"Is greater than every other sid"

NESTED QUERIES

Find student record with the highest id that is enrolled in at least one course.

```
SELECT sid, name FROM student
 WHERE sid is greater than every
   SELECT sid FROM enrolled
```

NESTED QUERIES

Find student record with the highest id that is enrolled in at least one course.

```
SELECT sid, name FROM student
 WHERE sid => ALL(
   SELECT sid FROM enrolled
)
```

sid	name
53688	Bieber

NESTED QUERIES

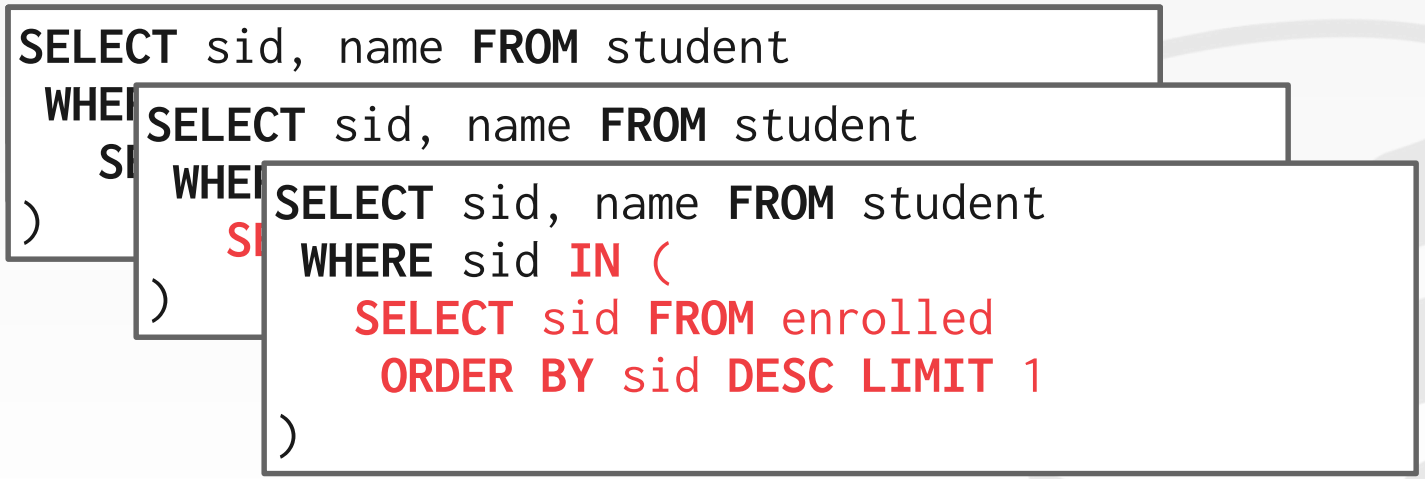
Find student record with the highest id that is enrolled in at least one course.

```
SELECT sid, name FROM student
 WHE
    SE
)
```

```
SELECT sid, name FROM student
 WHERE sid IN (
    SELECT MAX(sid) FROM enrolled
)
```

NESTED QUERIES

Find student record with the highest id that is enrolled in at least one course.



NESTED QUERIES

Find all courses that has no students enrolled in it.

```
SELECT * FROM course
 WHERE ...
```

"with no tuples in the 'enrolled' table"

cid	name
15-445	Database Systems
15-721	Advanced Database Systems
15-826	Data Mining
15-823	Advanced Topics in Databases

sid	cid	grade
53666	15-445	C
53688	15-721	A
53688	15-826	B
53655	15-445	B
53666	15-721	C

NESTED QUERIES

Find all courses that has no students enrolled in it.

```
SELECT * FROM course
 WHERE NOT EXISTS(
   tuples in the 'enrolled' table
)
```

NESTED QUERIES

Find all courses that has no students enrolled in it.

```
SELECT * FROM course
 WHERE NOT EXISTS(
   SELECT * FROM enrolled
    WHERE course.cid = enrolled.cid
)
```

cid	name
15-823	Advanced Topics in Databases

NESTED QUERIES

Find all courses that has no students enrolled in it.

```
SELECT * FROM course
 WHERE NOT EXISTS(
   SELECT * FROM enrolled
    WHERE course.cid = enrolled.cid
)
```

cid	name
15-823	Advanced Topics in Databases

WINDOW FUNCTIONS

Performs a calculation across a set of tuples that related to a single row.

Like an aggregation but tuples are not grouped into a single output tuples.

```
SELECT ... FUNC-NAME(...) OVER (...)
  FROM tableName
```

WINDOW FUNCTIONS

Performs a calculation across a set of tuples that related to a single row.

Like an aggregation but tuples are not grouped into a single output tuples.

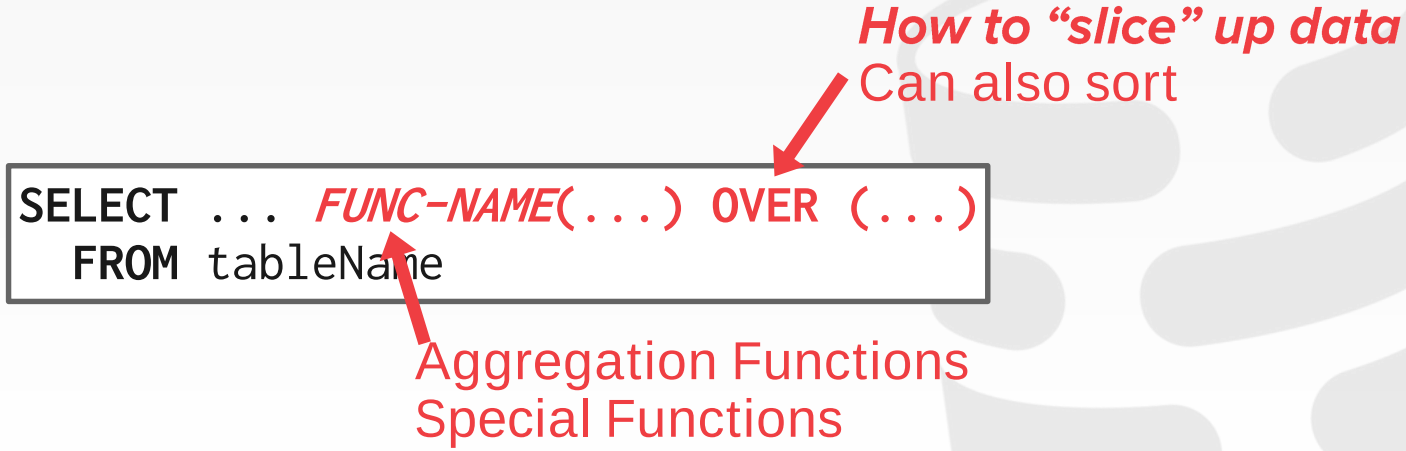
```
SELECT ... FUNC-NAME(...) OVER (...)
  FROM tableName
```

Aggregation Functions
Special Functions

WINDOW FUNCTIONS

Performs a calculation across a set of tuples that related to a single row.

Like an aggregation but tuples are not grouped into a single output tuples.



WINDOW FUNCTIONS

Aggregation functions:

→ Anything that we discussed earlier

Special window functions:

→ **ROW_NUMBER()** → # of the current row

→ **RANK()** → Order position of the current row.

```
SELECT *, ROW_NUMBER() OVER () AS row_num
  FROM enrolled
```

WINDOW FUNCTIONS

Aggregation functions:

→ Anything that we discussed earlier

Special window functions:

→ **ROW_NUMBER()** → # of the current row

→ **RANK()** → Order position of the current row.

sid	cid	grade	row_num
53666	15-445	C	1
53688	15-721	A	2
53688	15-826	B	3
53655	15-445	B	4
53666	15-721	C	5

```
SELECT *, ROW_NUMBER() OVER () AS row_num
  FROM enrolled
```

WINDOW FUNCTIONS

Aggregation functions:

→ Anything that we discussed earlier

Special window functions:

→ **ROW_NUMBER()** → # of the current row

→ **RANK()** → Order position of the current row.

sid	cid	grade	row_num
53666	15-445	C	1
53688	15-721	A	2
53688	15-826	B	3
53655	15-445	B	4
53666	15-721	C	5

```
SELECT *, ROW_NUMBER() OVER () AS row_num
  FROM enrolled
```

WINDOW FUNCTIONS

The **OVER** keyword specifies how to group together tuples when computing the window function.

Use **PARTITION BY** to specify group.

```
SELECT cid, sid,
    ROW_NUMBER() OVER (PARTITION BY cid)
  FROM enrolled
 ORDER BY cid
```

WINDOW FUNCTIONS

The **OVER** keyword specifies how to group together tuples when computing the window function.

Use **PARTITION BY** to specify group.

cid	sid	row_number
15-445	53666	1
15-445	53655	2
15-721	53688	1
15-721	53666	2
15-826	53688	1

```
SELECT cid, sid,
    ROW_NUMBER() OVER (PARTITION BY cid)
  FROM enrolled
 ORDER BY cid
```

WINDOW FUNCTIONS

The **OVER** keyword specifies how to group together tuples when computing the window function.

Use **PARTITION BY** to specify group.

cid	sid	row_number
15-445	53666	1
15-445	53655	2
15-721	53688	1
15-721	53666	2
15-826	53688	1

```
SELECT cid, sid,
    ROW_NUMBER() OVER (PARTITION BY cid)
  FROM enrolled
 ORDER BY cid
```

WINDOW FUNCTIONS

You can also include an **ORDER BY** in the window grouping to sort entries in each group.

```
SELECT *,
    ROW_NUMBER() OVER (ORDER BY cid)
  FROM enrolled
 ORDER BY cid
```

WINDOW FUNCTIONS

Find the student with the highest grade for each course.

Group tuples by cid
Then sort by grade

```
SELECT * FROM (
  SELECT *,
         RANK() OVER (PARTITION BY cid
                      ORDER BY grade ASC)
         AS rank
    FROM enrolled) AS ranking
 WHERE ranking.rank = 1
```

COMMON TABLE EXPRESSIONS

Provides a way to write auxiliary statements for use in a larger query.

→ Think of it like a temp table just for one query.

Alternative to nested queries and views.

```
WITH cteName AS (
    SELECT 1
)
SELECT * FROM cteName
```

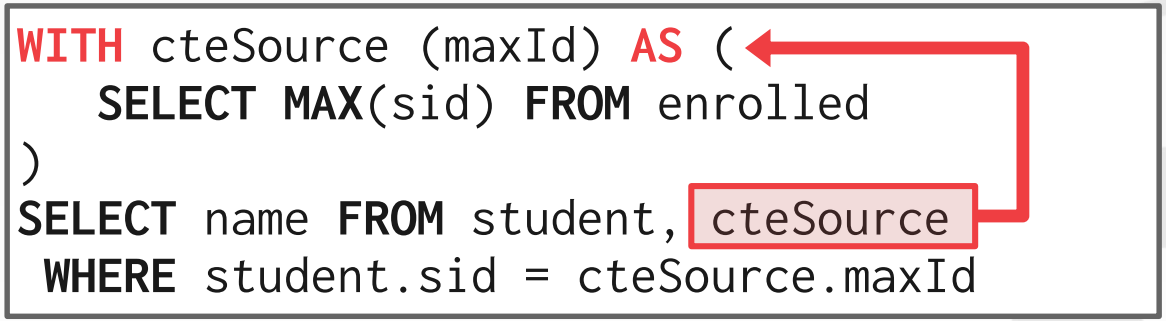
COMMON TABLE EXPRESSIONS

You can bind output columns to names before the **AS** keyword.

```
WITH cteName (col1, col2) AS (
   SELECT 1, 2
)
SELECT col1 + col2 FROM cteName
```

COMMON TABLE EXPRESSIONS

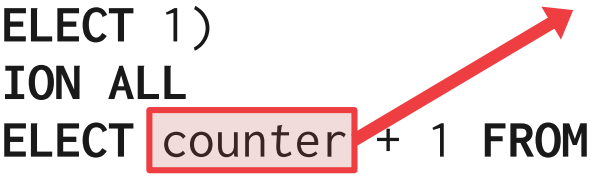
Find student record with the highest id that is enrolled in at least one course.



CTE – RECURSION

Print the sequence of numbers from 1 to 10.

```
WITH RECURSIVE cteSource (counter) AS (
    (SELECT 1)
    UNION ALL
    (SELECT counter + 1 FROM cteSource
      WHERE counter < 10)
)
SELECT * FROM cteSource
```



Demo: Postgres CTE!

CONCLUSION

SQL is not a dead language.

You should (almost) always strive to compute your answer as a single SQL statement.

HOMEWORK #1

Write SQL queries to perform basic data analysis on bike-sharing data from SFO.

→ Write the queries locally using SQLite.
→ Submit them to Gradescope
→ You can submit multiple times. We track your best score.

Due: Monday Sept 10th @ 11:59pm

https://15445.courses.cs.cmu.edu/fall2018/homework1/

NEXT CLASS

Storage Management