Announcements

Waitlist

Participation

HW1

- Due Tue 2/8

Grading infrastructure

- https://mugrade.datasciencecourse.org/
- Create new account with <andrewid>@andrew.cmu.edu
- More instructions in hw1_get_started

Announcements

HW 1 tip

- Number of pages
- Inspecting

15-388/688 - Practical Data Science: Relational Data

Pat Virtue
Carnegie Mellon University
Spring 2022

Slide credits: CMU AI, Zico Kolter

Outline

Overview of relational data

Entity relationships

Pandas and SQLite

$\rightarrow$ Joins

Outline

Overview of relational data

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Joins

The basic relation (i.e. the table)

The term technical term "relation" can be interchanged with the standard notion we have of "tabular data," say an instance of a "Person" relation

ID	Last Name	First Name	Role
1	Virtue	Pat	Instructor
2	Koppol	Pallavi	TA
3	Cordwell	Katherine	TA
4	Vajiac	Cat	TA
5	Veloso	Manuela	Student
6	Resnik	Judy	Student

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6	Resnik	Judy	Student

Rows are called *tuples (or records),* represent a single instance of this relation, and *must be unique*

The basic relation (i.e. the table)

The term technical term “relation” can be interchanged with the standard notion we have of “tabular data,” say an instance of a “Person” relation

ID	Last Name	First Name	Role
1	Virtue	Pat	Instructor
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3	Cordwell	Katherine	TA
4	Vajiac	Cat	TA
5	Veloso	Manuela	Student
6	Resnik	Judy	Student

Columns are called *attributes*, specify some element contained by each of the tuples

Multiple tables and relations

Person

ID	Last Name	First Name	Role ID
1	Virtue	Pat	1
2	Koppol	Pallavi	2
3	Cordwell	Katherine	2
4	Vajiac	Cat	2
5	Veloso	Manuela	3
6	Resnik	Judy	3

Role

ID	Name
1	Instructor
2	TA
3	Student

Primary keys

Person

ID	Last Name	First Name	Role ID
1	Virtue	Pat	1
2	Koppol	Pallavi	2
3	Cordwell	Katherine	2
4	Vajiac	Cat	2
5	Veloso	Manuela	3
6	Resnik	Judy	3

Role

ID	Name
1	Instructor
2	TA
3	Student

Primary key: *unique* ID for every tuple in a relation (i.e. every row in the table), each relation must have exactly one primary key

Foreign keys

Person

ID	Last Name	First Name	Role ID
1	Virtue	Pat	1
2	Koppol	Pallavi	2
3	Cordwell	Katherine	2
4	Vajiac	Cat	2
5	Veloso	Manuela	3
6	Resnik	Judy	3

Role

ID	Name
1	Instructor
2	TA
3	Student

A **foreign key** is an attribute that points to the primary key of *another* relation

If you delete a primary key, need to delete all foreign keys pointing to it

Reminder: Computational Complexity

Poll 1

I’m thinking of a number between 1 and 64. After each guess, I’ll tell you if you’re correct or if my number is higher or lower.

What is the maximum number of guesses you’ll need to win this game?

[✓ A: 6]

[✓ B: 7]

C: 32

D: 64

Poll 1

I'm thinking of a number between 1 and 64. After each guess, I'll tell you if you're correct or if my number is higher or lower.

What is the maximum number of guesses you'll need to win this game?

N	10	100	1000	10K	100K	1M	10M	100M
$\log_2 N$	3.3	6.6	10.0	13.3	16.6	19.9	23.3	26.6
$\lfloor \log_2 N \rfloor + 1$	4	7	11	14	17	20	24	27

Reminder: Computational Complexity

$O(1)$	Constant	array indexing
$O(\log N)$	log	search ordered array
$O(N)$	linear	search unorder array
$O(N^2)$	quadratic	
$O(2^N)$	exponential	

Indexes (not indices)

Indexes are created as ways to "quickly" access elements of a table

For example, consider finding people with last name "Gates": no option but just scan through the whole dataset: $O(n)$ operation

ID	Last Name	First Name	Role ID
1	Virtue	Pat	1
2	Koppol	Pallavi	2
3	Cordwell	Katherine	2
4	Vajiac	Cat	2
5	Veloso	Manuela	3
6	Resnik	Judy	3

Indexes

$\downarrow$

Person

Location	ID	Last Name	First Name	Role ID
0	1	Virtue	Pat	1
100	2	Koppol	Pallavi	2
200	3	Cordwell	Katherine	2
300	4	Vajiac	Cat	2
400	5	Veloso	Manuela	3
500	6	Resnik	Judy	3

$O(1) \longrightarrow$

Last Name Index

log N search

Last Name	Location
Cordwell	200
Koppol	100
Resnik	500 $\leftarrow$
Vajiac	300
Veloso	400
Virtue	0

Think of an index as a separate *sorted* table containing the indexed column and the tuple location: searching for value takes $\underline{O(\log n)}$ time

In practice, use data structure like a <u>B-tree</u> or several others

Indexes

The primary key always has an index associated with it (so you can think of primary keys themselves as always being a fast way to access data)

Indexes don’t have to be on a single column, can have an index over multiple columns (with some ordering)

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Entity relationships

Several types of inter-table relationships

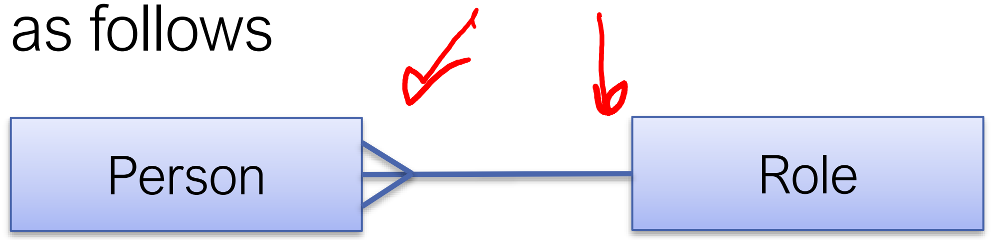
1. One-to-one
2. (One-to-zero/one)
3. One-to-many (and many-to-one)
4. Many-to-many

These relate one (or more) rows in a table with one (or more) rows in another table, via a foreign key

Note that these relationships are really between the "entities" that the tables represent, but we won't formalize this beyond the basic intuition

One-to-many relationship

We have already seen a one-to-many relationship: one **role** can be shared by many **people**, denoted as follows



Person

ID	Last Name	First Name	Role ID
1	Virtue	Pat	1
2	Koppol	Pallavi	2
3	Cordwell	Katherine	2
4	Vajiac	Cat	2
5	Veloso	Manuela	3
6	Resnik	Judy	3

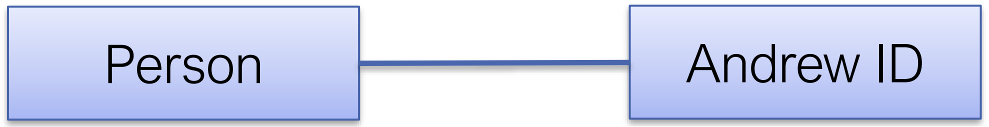
Role

ID	Name
1	Instructor
2	TA
3	Student

One-to-one relationships

In a true one-to-one relationship spanning multiple tables, each row in a table has *exactly* one row in another table

Not very common to break these across multiple tables, as you may as well just add another attribute to an existing table, but it is possible



Person

ID	Last Name	First Name	Role ID
1	Virtue	Pat	1
2	Koppol	Pallavi	2

⋮

Andrew ID

Person ID	Andrew ID
1	pvirtue
2	pkoppol

⋮

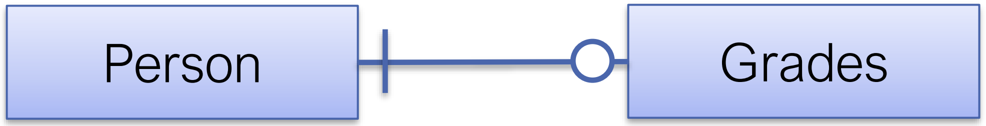
One-to-zero/one relationships

More common in databases is to find “one-to-zero/one” relationships broken across multiple tables

Consider adding a “Grades” table to our database: each person can have at most one tuple in the grades table

Person

1
2
3
4
5
6



Grades

Person ID	HW1 Grade	HW2 Grade
5	100	80
6	60	80

stud
stud

Bars and circles denote “mandatory” versus “optional” relationships (we won’t worry about these, just know that there is notation for them)

Many-to-many relationships

Creating a grades table as done before is a bit cumbersome, because we need to keep adding columns to the table, null entries if someone doesn't do the homework

Alternatively, consider adding two tables, a "homework" table that represents information about each homework, and an associative table that links homeworks to people

Homework

ID	Name	388 Points	688 Points
1	HW 1	65	35
2	HW 2	75	25

Person Homework

Person ID	HW ID	Score
5	1	100
5	2	80
6	1	60
6	2	80

Poll 2: Associative tables

What is the primary key of this table?

A. Person ID

B. HW ID

C. Score

✓ D. None of the above

Person Homework

Person ID	HW ID	Score
5	1	100
5	2	80
6	1	60
6	2	80

Poll 3: Associative tables

Which indexes would you want to create on this table? Select ALL that apply.

✓ A. Person ID

✓ B. HW ID

✓ C. Score

✓ D. HW ID and Score

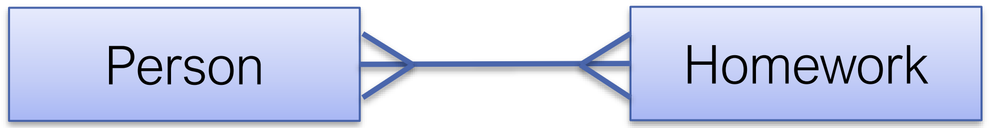
E. None of the above

Person Homework

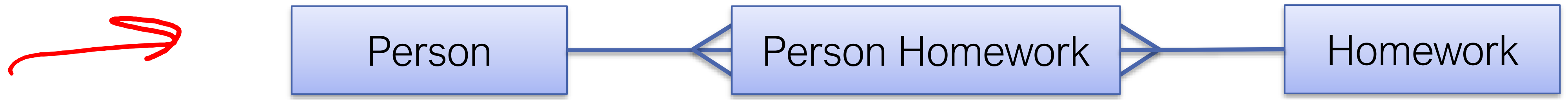
Person ID	HW ID	Score
5	1	100
5	2	80
6	1	60
6	2	80

Many-to-many relationships

Setups like this encode many-to-many relationships: each person can have multiple homeworks, and each homework can be done by multiple people



We could also write this in terms of relationships specified by the associative table, but this is not really correct, as it is mixing up the underlying relationships with how they are stored in a database



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Pandas

Pandas is a “Data Frame” library in Python, meant for manipulating in-memory data with row and column labels (as opposed to, e.g., matrices, that have no row or column labels)

Pandas is *not* a relational database system, but it contains functions that mirror some functionality of relational databases

We’re going to cover Pandas in more detail in other portions of the class, but just discuss basic functionality for now

Pandas examples

Create a DataFrame with our Person example:

```python
import pandas as pd

df = pd.DataFrame([(1, 'Virtue', 'Pat'),
                   (2, 'Koppol', 'Pallavi'),
                   (3, 'Cordwell', 'Katherine'),
                   (4, 'Vajiac', 'Cat'),
                   (5, 'Veloso', 'Manuela'),
                   (6, 'Resnik', 'Judy')],
                  columns=["id", "last_name", "first_name"])
```

	id	last_name	first_name
0	1	Virtue	Pat
1	2	Koppol	Pallavi
2	3	Cordwell	Katherine
3	4	Vajiac	Cat
4	5	Veloso	Manuela
5	6	Resnik	Judy

Some important notes

As mentioned, Pandas is *not* a relational data system, in particular it has no notion of primary keys (but it does have indexes)

Operations in Pandas are typically *not* in place (that is, they return a new modified DataFrame, rather than modifying an existing one)

    Use the “inplace” flag to make them done in place

If you select a single row or column in a Pandas DataFrame, this will return a “Series” object, which is like a one-dimensional DataFrame (it has only an index and corresponding values, not multiple columns)

Some common Pandas commands

```
# read CSV file into DataFrame
df = pd.read_csv(filename)

# get first five rows of DataFrame
df.head()

# index into a dataframe
# df.loc[rows, columns] and df.iloc[row numbers, column numbers]
df.loc[:, "Last Name"]                      # Series of all last names
df.loc[:, ["Last Name"]]                    # DataFrame with one column
df.loc[[1,2], :]                            # DataFrame with only ids 1,2
df.loc[1,"Last Name"] = "Vice"      # Set an entry in a DataFrame
df.loc[7,:] = (”Hebert", "Martial") # Add a new entry with index=7
df.iloc[0,0]                                # Index rows and columns by zero-index
```

We’re going to cover more next lecture in conjunction with visualization

SQLite

An actual relational database management system (RDBMS)

Unlike most systems, it is a *serverless* model, applications directly connect to a file

Allows for simultaneous connections from many applications to the same database file (but not quite as much concurrency as client-server systems)

All operations in SQLite will use SQL (Structured Query Language) command issued to the database object

You can enforce foreign keys in SQLite, but we won't bother

Creating a database and table

You can create a database and connect using this boilerplate code:

```
import sqlite3
conn = sqlite3.connect("people.db")
cursor = conn.cursor()

# do your stuff

conn.close()
```

cursor.execute
⋮
conn.commit()

Create a new table:

```
cursor.execute("""
CREATE TABLE role (
    id INTEGER PRIMARY KEY,
    name TEXT
)""")
```

Creating a new table and inserting data

Insert data into the table:

```
cursor.execute("INSERT INTO role VALUES (1, 'Instructor')")
cursor.execute("INSERT INTO role VALUES (2, 'TA')")
cursor.execute("INSERT INTO role VALUES (3, 'Student')")
conn.commit()
```

Delete items from a table:

```
cursor.execute("DELETE FROM role WHERE id == 3")
conn.commit()
```

Note: if you don't call commit, you can undo with `conn.rollback()`

Querying all data from a table

Read all the rows from a table:

```
for row in cursor.execute('SELECT * FROM role'):
    print(row)
```

Read table directly into a Pandas DataFrame:

```
pd.read_sql_query("SELECT * FROM role", conn, index_col="id")
```

	name
id	
1	Instructor
2	TA
3	Student

Outline

Joins

Join operations merge multiple tables into a single relation (can be then saved as a new table or just directly used)

Four typical types of joins:

1. Inner
2. Left
3. Right
4. Outer

You join two tables *on* columns from each table, where these columns specify which rows are kept

Example: joining Person and Grades

Consider joining two tables, Person and Grades, on ID / Person ID

Person

ID	Last Name	First Name	Role ID
1	Virtue	Pat	1
2	Koppol	Pallavi	2
3	Cordwell	Katherine	2
4	Vajiac	Cat	2
5	Veloso	Manuela	3
6	Resnik	Judy	3

Grades

Person ID	HW1 Grade	HW2 Grade
5	100	80
6	60	80
100	100	100

Inner join (usually what you want)

Join two tables where we only return the rows where the two joined columns contain the *same value*

ID	Last Name	First Name	Role ID	HW1 Grade	HW2 Grade
5	Veloso	Manuela	3	100	80
6	Resnik	Judy	3	60	80

Only these two rows have an entry in “Person” *and* an entry in “Grades”

Inner join in Pandas/SQLite

```
# Pandas way
df_person = pd.read_sql_query("SELECT * FROM person", conn)
df_grades = pd.read_sql_query("SELECT * FROM grades", conn)
df_person.merge(df_grades, how="inner",
                left_on="id", right_on="person_id")

# SQLite way
cursor.execute("SELECT * FROM person, grades WHERE
                person.id == grades.person_id")
```

In Pandas, you can also join on index using `right_index/left_index` parameters

There is also the join call in Pandas, which is a bit more limited (always assumes right is joined on index, left not on index)

Left joins

Keep all rows of the left table, add entries from right table that match the corresponding columns

Example: left join Person and Grades on ID, Person ID

ID	Last Name	First Name	Role ID	HW1 Grade	HW2 Grade
1	Virtue	Pat	1	NULL	NULL
2	Koppol	Pallavi	2	NULL	NULL
3	Cordwell	Katherine	2	NULL	NULL
4	Vajiac	Cat	2	NULL	NULL
5	Veloso	Manuela	3	100	80
6	Resnik	Judy	3	60	80

Left join in Pandas and SQLite

```
# Pandas way
df_person.merge(df_grades, how="left",
                left_on="id", right_on="person_id")

# SQLite way
cursor.execute("SELECT * FROM person LEFT JOIN grades ON
                person.id == grades.person_id")
```

	id	last_name	first_name	person_id	hw1_grade	hw2_grade
0	1	Virtue	Pat	NaN	NaN	NaN
1	2	Koppol	Pallavi	NaN	NaN	NaN
2	3	Cordwell	Katherine	NaN	NaN	NaN
3	4	Vajiac	Cat	NaN	NaN	NaN
4	5	Veloso	Manuela	5.0	100.0	80.0
5	6	Resnik	Judy	6.0	60.0	80.0

Right join

Like a left join but with the roles of the tables reversed

ID	Last Name	First Name	Role ID	HW1 Grade	HW2 Grade
5	Veloso	Manuela	3	100	80
6	Resnik	Judy	3	60	80
100	NULL	NULL	NULL	100	100

```
# Pandas way
df_person.merge(df_grades, how="right",
                left_on="id", right_on="person_id")

# Not supported in SQLite
```

Outer join

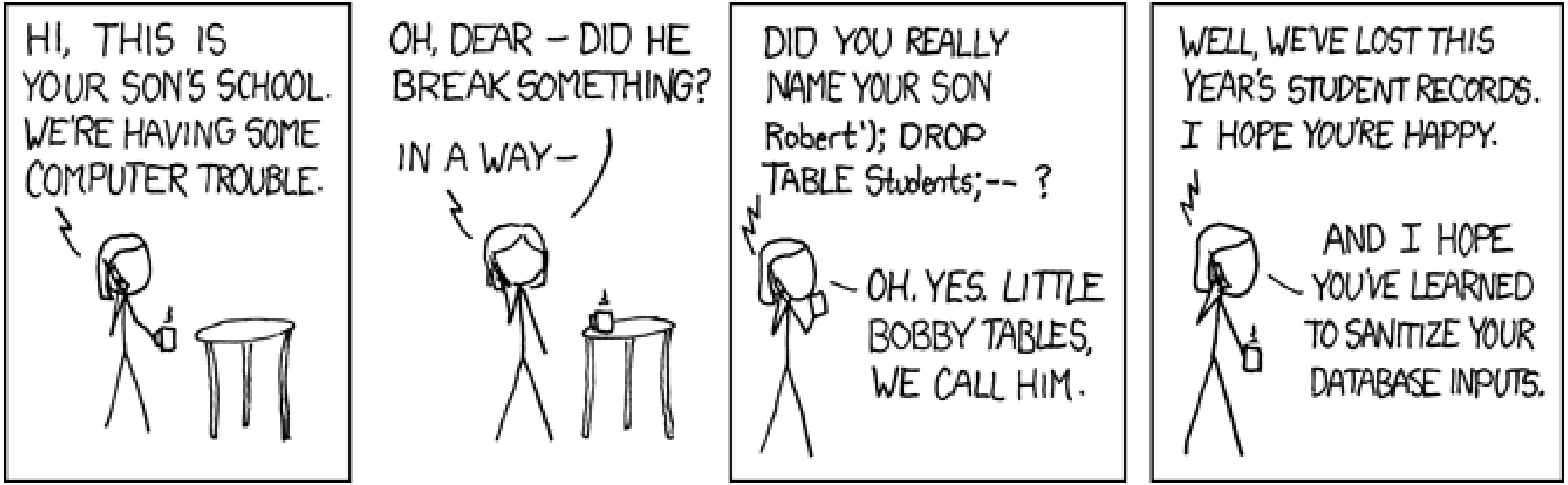
Return all rows from both left and right join

ID	Last Name	First Name	Role ID	HW1 Grade	HW2 Grade
1	Virtue	Pat	1	NULL	NULL
2	Koppol	Pallavi	2	NULL	NULL
3	Cordwell	Katherine	2	NULL	NULL
4	Vajiac	Cat	2	NULL	NULL
5	Veloso	Manuela	3	100	80
6	Resnik	Judy	3	60	80
100	NULL	NULL	NULL	100	100

```
# Pandas way
df_person.merge(df_grades, how=”outer",
                left_on="id", right_on="person_id")
```

Little Bobby Tables

https://xkcd.com/327/


HI, THIS IS YOUR SON'S SCHOOL. WE'RE HAVING SOME COMPUTER TROUBLE.
OH, DEAR – DID HE BREAK SOMETHING?
IN A WAY–
DID YOU REALLY NAME YOUR SON Robert'); DROP TABLE Students;-- ?
OH. YES. LITTLE BOBBY TABLES, WE CALL HIM.
WELL, WE'VE LOST THIS YEAR'S STUDENT RECORDS. I HOPE YOU'RE HAPPY.
AND I HOPE YOU'VE LEARNED TO SANITIZE YOUR DATABASE INPUTS.