Using a DBMS

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DBMS ≠ Database

- A database is a collection of your data stored in a computer
- A DBMS (DataBase Management System) is a software that manages databases

Outline

- Main Features of a DBMS
- Data Models
- SQL Queries

Why not file systems?

Advantages of a Database System

- It answers ***queries*** fast
  - E.g., among all posts, find those written by Bob and contain word “db”
- Groups modifications into ***transactions*** such that either all or nothing happens
  - E.g., money transfer
- Recovers from crash
  - Modifications are logged
  - No corrupt data after recovery

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Queries

Q: find ID and text of all pages written by Bob and containing word “db”

Step1: structure data using ***tables***

users

id	name	karma
729	Bob	35
730	John	0

Column/field

posts

id	text	ts	authorId
33981	‘Hello DB!’	1493897351	729
33982	‘Show me code’	1493854323	812

Row/record

Queries

Q: find ID and text of all pages written by Bob and containing word “db”

Step2:

```
SELECT p.id, p.text
FROM posts AS p, users AS u
WHERE u.id = p.authorId
      AND u.name='Bob'
      AND p.text ILIKE '%db%';
```

users

id	name	karma
729	Bob	35
730	John	0

posts

id	text	ts	authorId
33981	‘Hello DB!’	1493897351	729
33982	‘Show me code’	1493904323	812

How Is a Query Answered?

```
SELECT p.id, p.text
FROM posts AS p, users AS u
WHERE u.id = p.authorId
      AND u.name='Bob'
      AND p.text ILIKE '%db%';
```

(p, u)

p.id	p.text	p.ts	p.authorId	u.id	u.name	u.karma
33981	'Hello DB!'	…	729	729	Bob	35
33981	'Hello DB!'	…	729	730	John	0
33982	'Show me code'	…	812	729	Bob	35
33982	'Show me code'	…	812	730	John	0

p

id	text	ts	authorId
33981	'Hello DB!'	…	729
33982	'Show me code'	…	812

u

id	name	karma
729	Bob	35
730	John	0

How Is a Query Answered?

```
SELECT p.id, p.text
FROM posts AS p, users AS u
WHERE u.id = p.authorId
      AND u.name='Bob'
      AND p.text ILIKE '%db%';
```

where(p, u)

p.id	p.text	p.ts	p.authorId	u.id	u.name	u.karma
33981	'Hello DB!'	...	729	729	Bob	35

(p, u)

p.id	p.text	p.ts	p.authorId	u.id	u.name	u.karma
33981	'Hello DB!'	...	729	729	Bob	35
33981	'Hello DB!'	...	729	730	John	0
33982	'Show me code'	...	812	729	Bob	35
33982	'Show me code'	...	812	730	John	0

How Is a Query Answered?

```
SELECT p.id, p.text
FROM posts AS p, users AS u
WHERE u.id = p.authorId
      AND u.name='Bob'
      AND p.text ILIKE '%db%';
```

select(where(p, u))

p.id	p.text
33981	'Hello DB!'

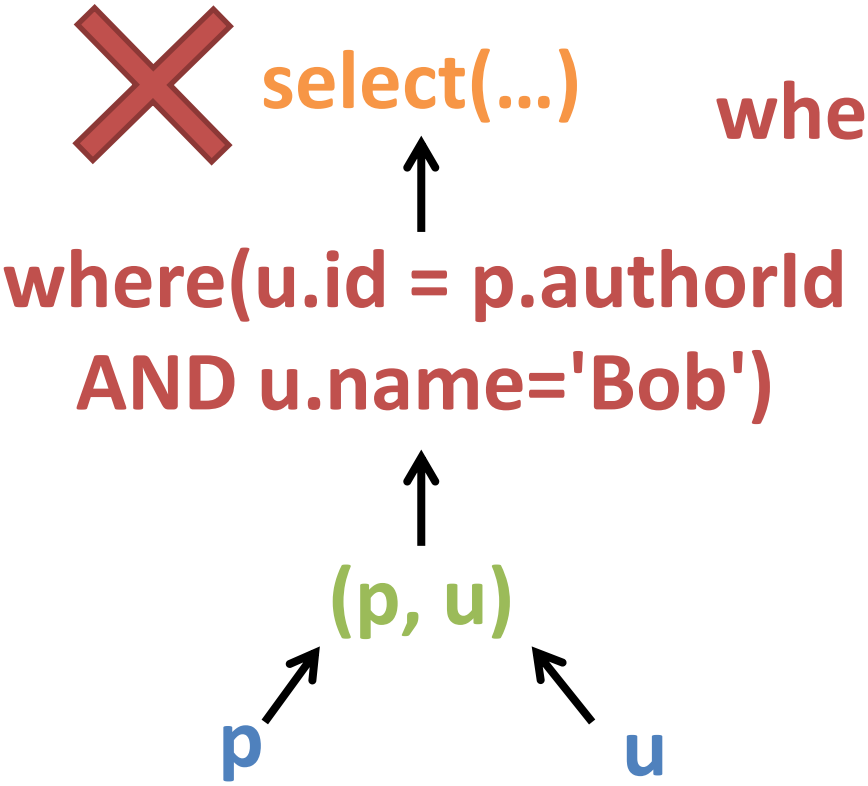
where(p, u)

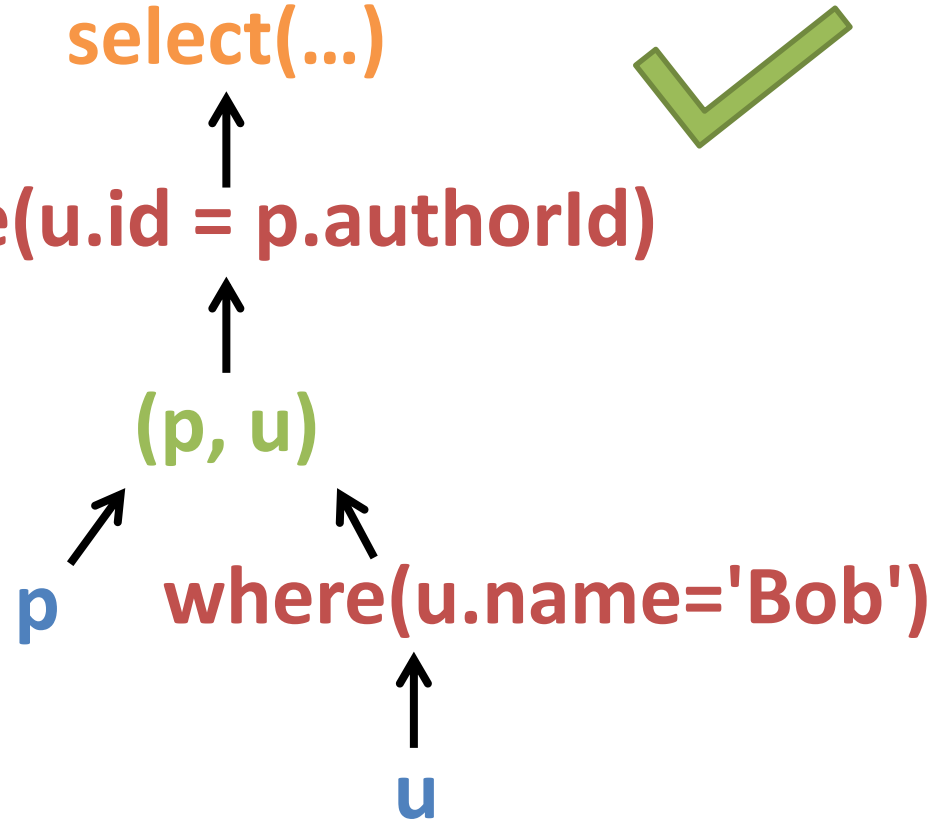
p.id	p.text	p.ts	p.authorId	u.id	u.name	u.karma
33981	'Hello DB!'	...	729	729	Bob	35

Why fast?

Query Optimization

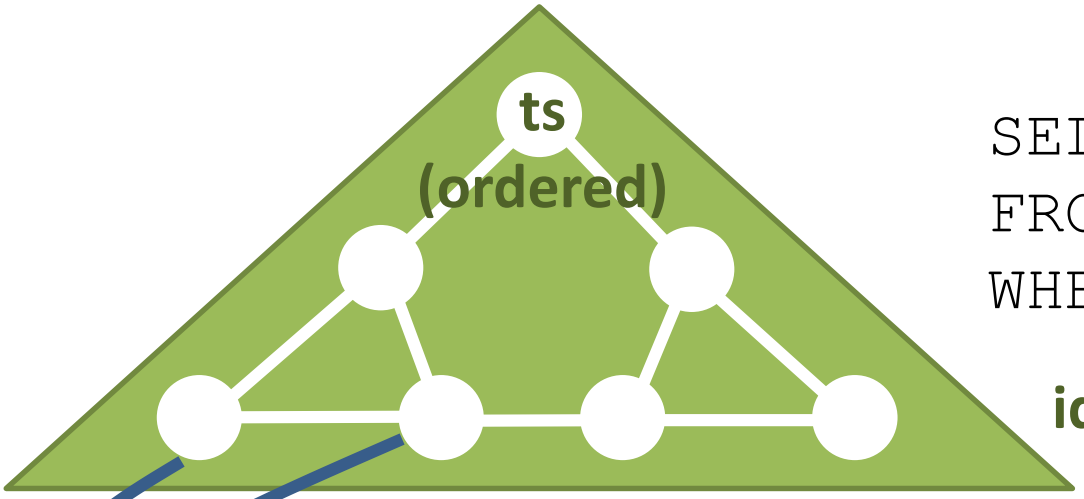
- ***Planning***: DBMS finds the best ***plan tree*** for each query





Query Optimization

- ***Indexing***: creates a search tree for column(s)




```
SELECT text
FROM posts
WHERE ts > 1493897220;
```

idx_ts

posts

id	text	ts	authorId
1	‘Good day’	1493880220	664
…	…	…	…
33981	‘Hello DB!’	1493897351	729
33982	‘Show me code’	1493904323	812

Advantages of a Database System

- It answers ***queries*** fast
  - E.g., among all posts, find those written by Bob and contain word “db”
- Groups modifications into ***transactions*** such that either all or nothing happens
  - E.g., money transfer
- Recovers from crash
  - Modifications are logged
  - No corrupt data after recovery

Transactions I

- Each query, by default, is placed in a ***transaction*** (***tx*** for short) automatically

```
BEGIN;
  SELECT ...; -- query
COMMIT;
```

Transactions II

- Can group multiple queries in a tx
  - ***All or nothing*** takes effect
- E.g., karma transfer

users

id	name	karma
729	Bob	35
730	John	0

```
BEGIN;
  UPDATE users
  SET karma = karma - 10
  WHERE name='Bob';

  UPDATE users
  SET karma = karma + 10
  WHERE name='John';
COMMIT;
```

ACID Guarantees

- ***Atomicity***
  - Operation are all or none in effect
- ***Consistency***
  - Data are correct after each tx commits
  - E.g., `posts.authorId` must be a valid `users.id`
- ***Isolation***
  - Concurrent txs = serial txs (in some order)
- ***Durability***
  - Changes will not be lost after a tx commits (even after crashes)

Why model data as ***tables***?

users

id	name	karma
729	Bob	35
730	John	0

posts

id	text	ts	authorId
33981	‘Hello DB!’	1493897351	729
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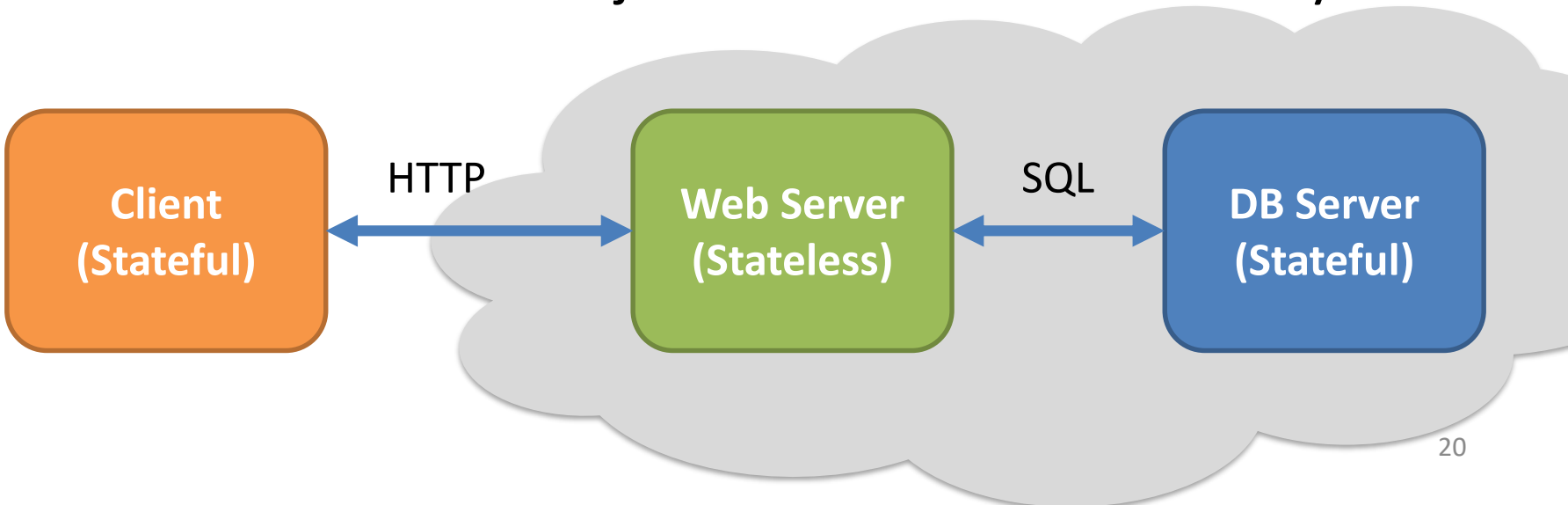
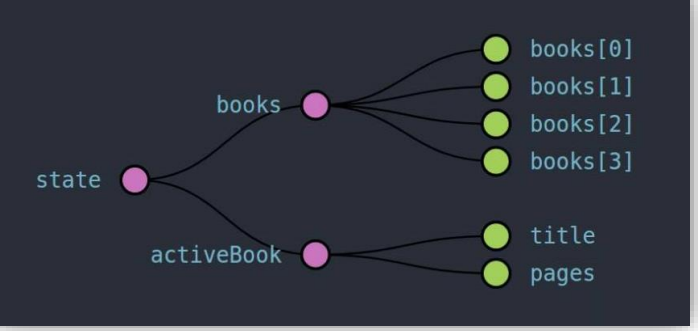
Storing Data

- Let's say, you have data/states in memory to store
- What do states look like?
  - Objects
  - References to objects
- Objects formatted by classes you defined
- Can we store these objects and references directly?



Data Models

- Definition: A ***data model*** is a framework for describing the structure of databases in a DBMS
- Common data models at client side:
  - Tree model
- Common data models at server side:
  - ***ER model*** and ***relational model***
- A DBMS supporting the relational model is called the relational DBMS



Tree Model

- At client side, data are usually stored as ***trees***

```
{ // state of client 1
  name: 'Bob',
  karma: 32,
  posts: [...],
  friends: [{
    name: 'Alice',
    karma: 10
  }, {
    name: 'John',
    karma: 17
  }, ...],
  ...
}
```

```
{ // state of client 2
  name: 'Alice',
  karma: 10,
  posts: [...],
  friends: [{
    name: 'Bob',
    karma: 32
  }, {
    name: 'John',
    karma: 17
  }, ...],
  ...
}
```

Problems at Server Side

- Space complexity: large ***redundancy***

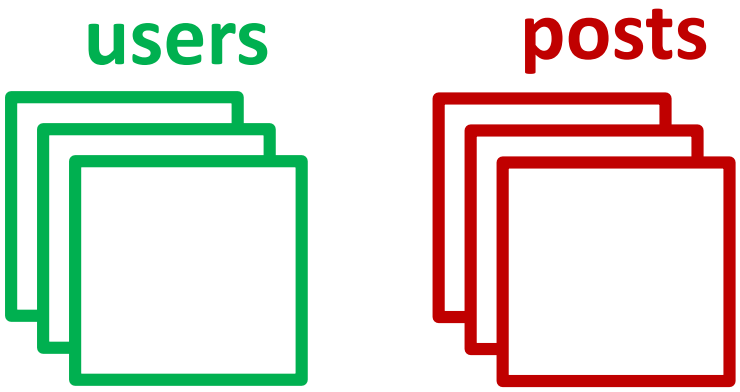
```
{ // state of a client 1
  name: 'Bob',
  karma: 35,
  posts: [...],
  friends: [
    name: 'Alice',
    karma: 10
  }, {
    name: 'John',
    karma: 17
  }, ...],
  ...
}
```

```
{ // state of a client 2
  name: 'Alice',
  karma: 10,
  posts: [...],
  friends: [{
    name: 'Bob',
    karma: 35
  }, {
    name: 'John',
    karma: 17
  }, ...],
  ...
}
```

Data Modeling at Server Side

1. Identify ***entity groups/classes***
   - Each class represents an "atomic" part of the data
2. Store entities of the same class in a ***table***
   - A rows/record denotes an entity
   - A column/field denote an attribute (e.g., "name")
3. Define ***primary keys*** for each table
   - Special column(s) that uniquely identifies an entity
   - E.g., "ID"

Identifying Entity Classes




```
{ // state of a client 1
  name: 'Bob',
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  posts: [...],
  friends: [{
    name: 'Alice',
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  }, {
    name: 'John'
    karma: 17
  }, ...],
  ...
}
```
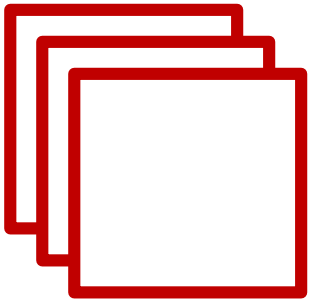

```
{ // state of a client 2
  name: 'Alice',
  karma: 10,
  posts: [...],
  friends: [{
    name: 'Bob',
    karma: 32
  }, {
    name: 'John'
    karma: 17
  }, ...],
  ...
}
```

One Table per Entity Class

id	name	karma
729	Bob	35
730	John	0



id	text
33981	‘Hello DB!’
33982	‘Show me code’

- No redundancy
- No repeated update

Wait, relationship is missing!

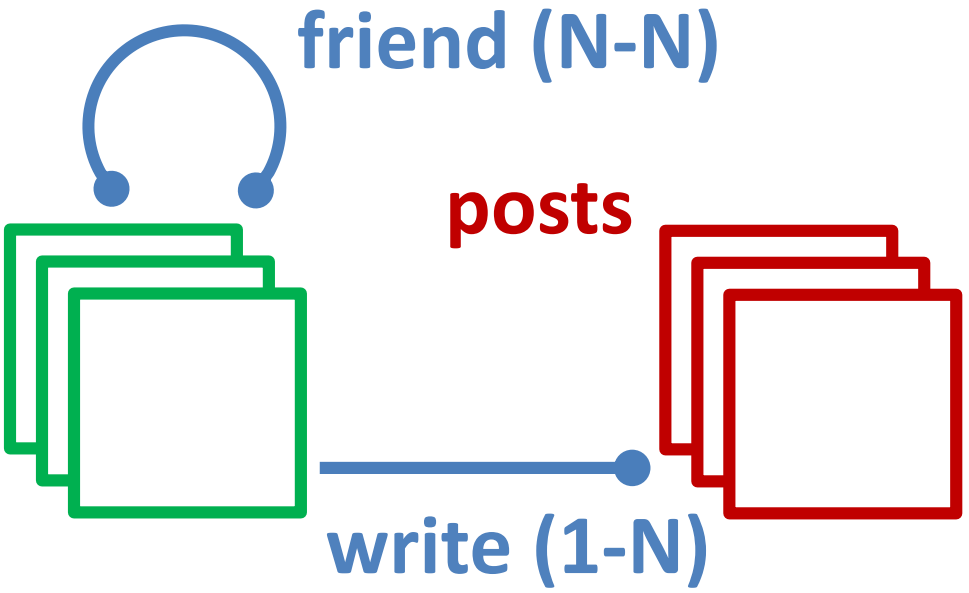
Step1 (ER Model)

```
{ // state of a client 1
  name: 'Bob',
  karma: 32,
  posts: [...],
  friends: [{
    name: 'Alice',
    karma: 10
  }, {
    name: 'John'
    karma: 17
  }, ...],
  ...
}
```

write

friend

- Identify relationships between entities



Step 2 (Relational Model)

- Relationships as ***foreign keys***

friend (N-N)

users

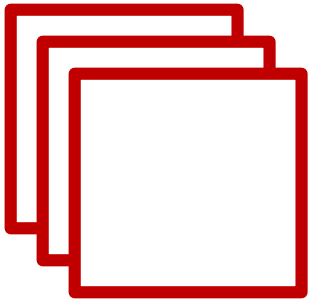
id	name	karma
729	Bob	35
730	John	0

friend

uId1	uId2	since
729	730	14928063
729	882	14827432

write (1-N)

foreign keys



posts

id	text	authorId	ts
33981	Hello DB!’	729	1493897351
33982	Show me code’	729	1493854323

write

Recap on Terminology

- Columns = fields = attributes
- Rows = records = tuples
- Tables = ***relations***

- Relational database: a collection of tables
  ≠ Relational DBMS
- ***Schema***: column definitions of tables in a database
  - Basically, the "look" of a database
  - Schema of a relation/table is fields and field types

Why ER Model?

- Allows thinking your data in OOP way
- ***Entity***
  - An object (or instance of a class)
  - With attributes
- ***Entity group/class***
  - A class
  - Must define the ID attribute for each entity
- ***Relationship*** between entities
  - References (“has-a” relationship)
  - Could be 1-1, 1-N, or N-N

Why Relational Model?

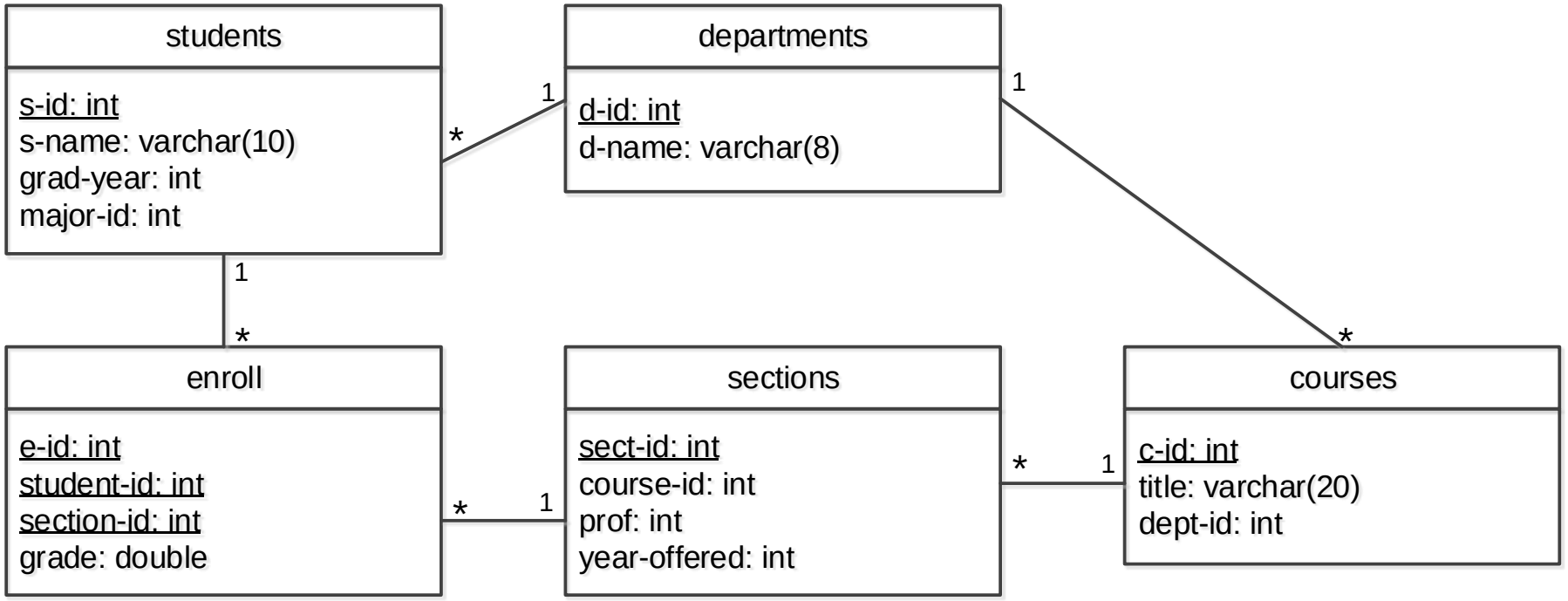
- Simplifies data management and query processing
- ***Table/relations*** for all kinds of entity classes
- ***Primary/foreign keys*** for all kinds of relationships between entities
- Relational schema is logical
  - ***Not*** how your data stored physically
  - Vs. physical schema

Exercise: Student DB

- Storing course-enrollment info in a school
  - Each department has many students and offers different courses
  - Each courses can have multiple sections (e.g., 2018 spring, 2019 fall, etc.)
  - Each students can enroll in different sections

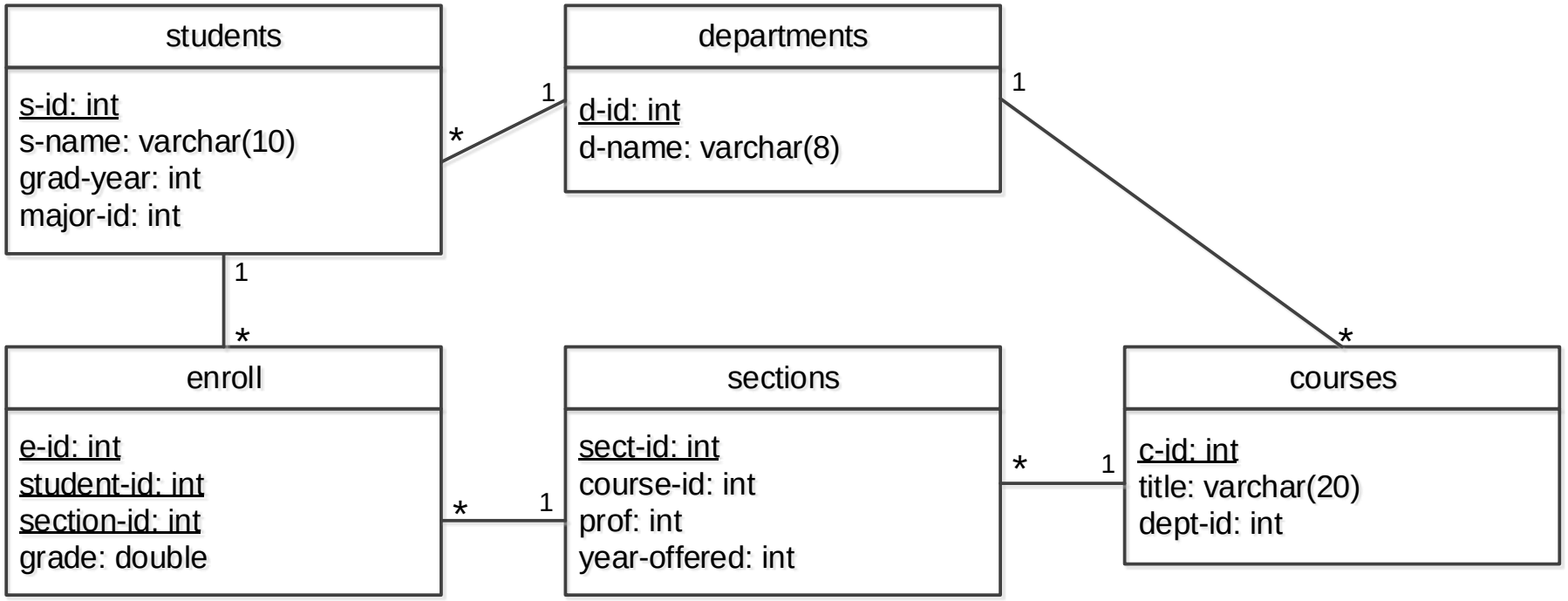
- Can you model data and draw a relational schema?

Exercise: Student DB



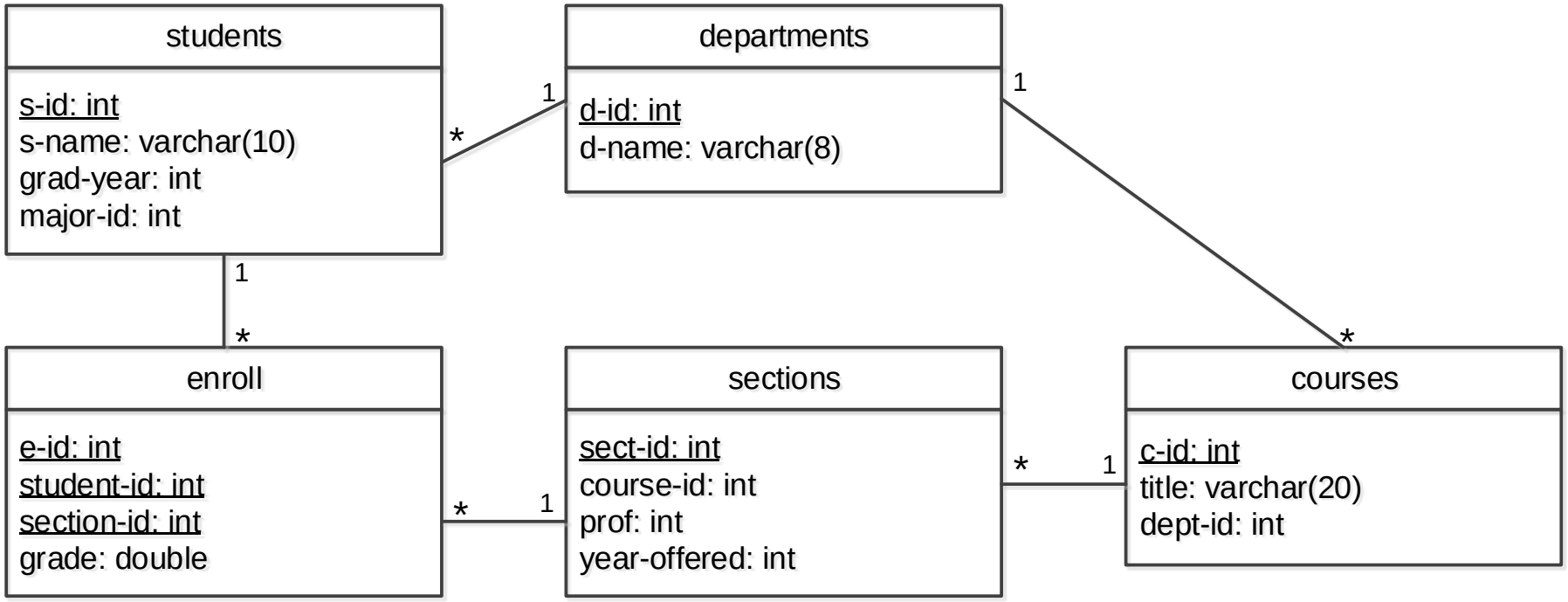
- Relation (table)
  - Realization of 1) an entity group via table; or 2) a relationship
  - ***Fields/attributes*** as columns
  - ***Records/tuples*** as rows

Exercise: Student DB

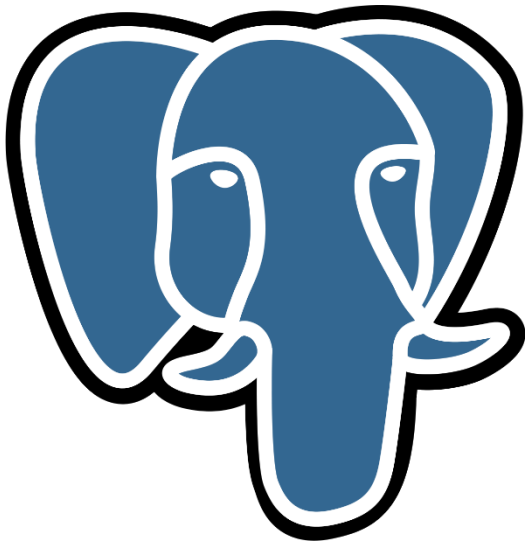


- ***Primary Key***
  - Realization of ID via a group of fields

Exercise: Student DB



- ***Foreign key***
  - Realization of relationship
  - A record can point to the primary key of the other record
  - Only 1-1 and 1-many
  - Intermediate relation is needed for many-many



PostgreSQL

- Download and install
- For Mac users, try PostgreSQL.app

Using PostgreSQL

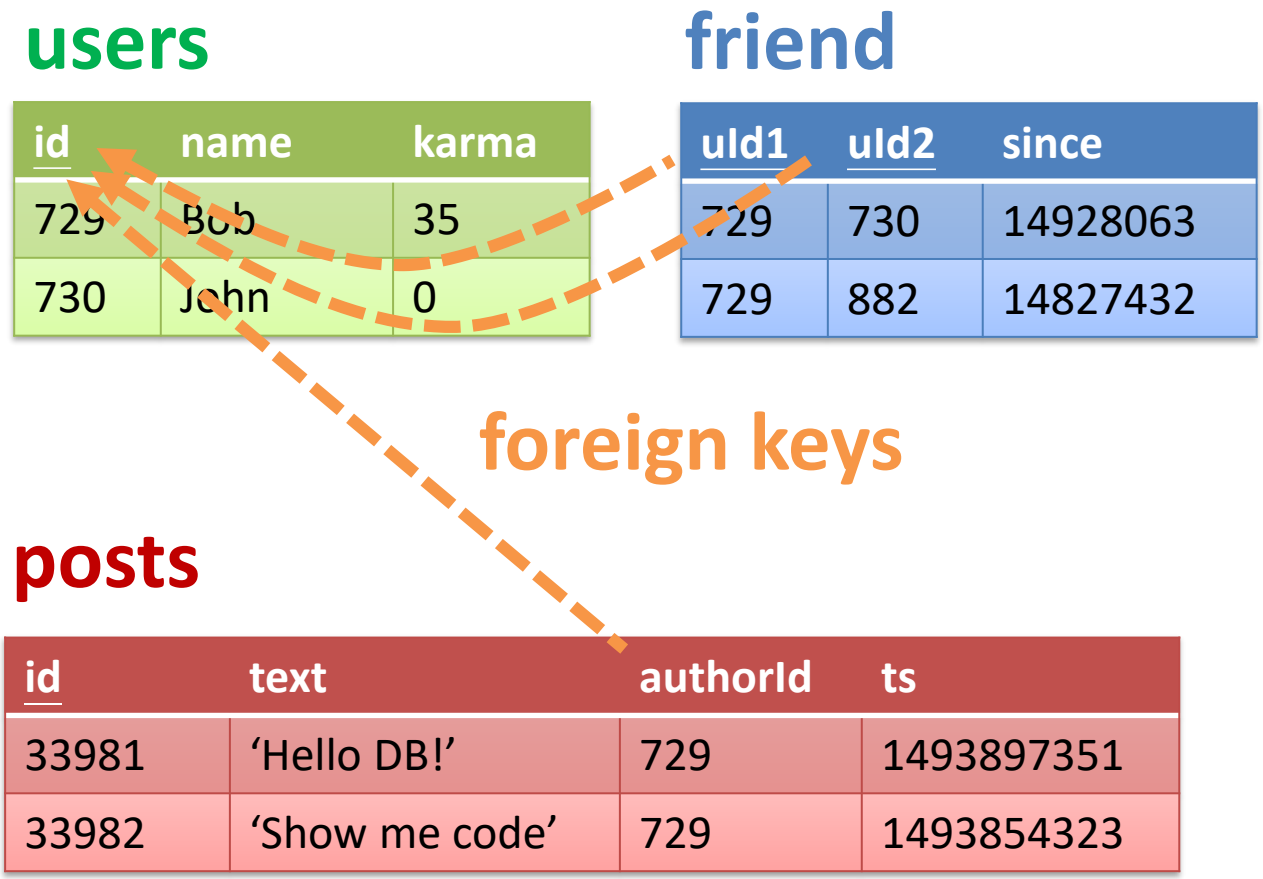
```
$ createdb <db>
$ psql <db> [user]
> \h or \?
> SELECT now(); -- SQL commands
```

- Default schema: `public`
  - `\dn` for listing all schemas
- Multiple lines until ';'
- '--' for comments
- ***Case insensitive***
  - Use "" to distinguish lower and upper cases
  - E.g., `SELECT "authorId" FROM posts;`

Structured Query Language (SQL)

- Data Definition Language (DDL) on schema
  - CREATE TABLE …
  - ALTER TABLE …
  - DROP TABLE …
- Data Manipulation Language (DML) on records
  - INSERT INTO … VALUES …
  - SELECT … FROM … WHERE …
  - UPDATE … SET … WHERE …
  - DELETE FROM … WHERE …

Schema


users
friend
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foreign keys
posts
id
text
authorId
ts
33981
'Hello DB!'
729
1493897351
33982
'Show me code'
729
1493854323

Creating Tables/Relations

```
CREATE TABLE posts (
  id            serial PRIMARY KEY NOT NULL,
  text          text NOT NULL,
  "authorId"    integer NOT NULL
                REFERENCES users ON DELETE CASCADE,
  ts            bigint NOT NULL
                DEFAULT (extract(epoch from now())),
  ...
);
```

- Column types:
  - Integer, bigint, real, double, etc.
  - varchar(10), text, etc.
- Non-null constraint
- Default values

Creating Tables/Relations

```
CREATE TABLE posts (
  id              serial PRIMARY KEY NOT NULL,
  text            text NOT NULL,
  "authorId"      integer NOT NULL
                  REFERENCES users ON DELETE CASCADE,
  ts              bigint NOT NULL
                  DEFAULT (extract(epoch from now())),
  ...
);
```

- Primary key:
  - Unique (no duplicate values among rows)
  - Usually of type “serial” (auto-filled integer)
  - Index automatically created

Creating Tables/Relations

```
CREATE TABLE posts (
  id              serial PRIMARY KEY NOT NULL,
  text            text NOT NULL,
  "authorId"      integer NOT NULL
                  REFERENCES users ON DELETE CASCADE,
  ts              bigint NOT NULL
                  DEFAULT (extract(epoch from now())),
  ...
);
```

- Foreign key: post.authorId must be a valid user.id
- When deleting a user (row):
  - NO ACTION (default): user not deleted, error raised
  - CASCADE: user ***and all referencing posts*** deleted

Inserting Rows

```
INSERT INTO posts(text, "authorId", ...)
VALUES ('Today is a good day!', 5, ...);
```

- String values should be ***single*** quoted
- Inserting dummy rows:

```
INSERT INTO posts(text, "authorId")
SELECT
  'Dummy word ' || i || '.',
  round(random() * 10) + 1
FROM generate_series(1, 20) AS s(i);
```

Queries

```
SELECT *
FROM posts
WHERE ts > 147988213 AND text ILIKE '%good%'
ORDER BY ts DESC, id ASC
LIMIT 2;
```

- To see how a query is processed:

```
EXPLAIN ANALYZE -- show plan tree
SELECT *
FROM posts
WHERE ts > 147988213 AND text ILIKE '%good%'
ORDER BY ts DESC, id ASC
LIMIT 2;
```

(Batch) Updating Rows

```
UPDATE post SET ts = ts + 3600 WHERE "authorId" = 10;
```

- ***All*** rows satisfying the WHERE clause will be updated
- ts + 3600 is an ***expression***
  - Can be evaluated to a single value

Handling “Big” Data

```
INSERT INTO posts(text, "authorId")
SELECT
  'Dummy word ' || i || '.',
  rount(random() * 10) + 1
FROM generate_series(1, 1000000) AS s(i);
```

- Some queries will be long:

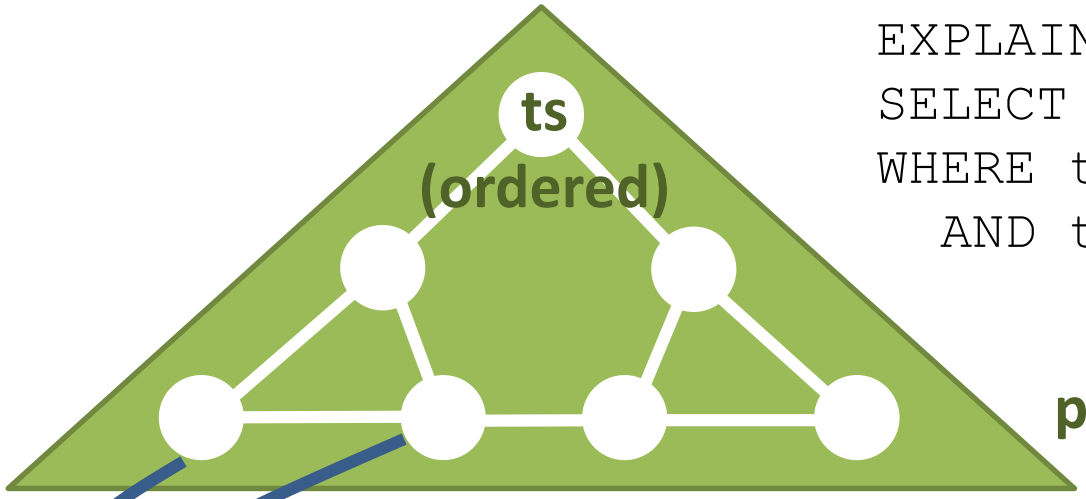
```
EXPLAIN ANALYZE SELECT * FROM posts
WHERE id > 500000 AND id < 501000; -- 1ms

EXPLAIN ANALYZE SELECT * FROM posts
WHERE ts > 1400000000 AND ts < 1403600000; -- 230ms
```

Using Index

```
CREATE INDEX posts_idx_ts
ON posts
USING btree(ts);
\di -- list indices

EXPLAIN ANALYZE
SELECT * FROM posts
WHERE ts > 1400000000
  AND ts < 1403600000; -- 2ms
```



posts_idx_ts

posts

id	text	ts
1	‘Good day’	1493880220
…	…	…
33981	‘Hello DB!’	1493897351
33982	‘Show me code’	1493904323

Index for `ILIKE`?

```
CREATE INDEX posts_idx_text ON posts
USING btree(text);

EXPLAIN ANALYZE SELECT * FROM posts
WHERE text ILIKE '% word 500000%'; -- 1.5s
```

- B-tree indices are ***not*** helpful for text searches
- Use GIN (generalized inverted index) instead:

```
CREATE EXTENSION pg_trgm;
\dx -- list extensions
CREATE INDEX posts_idx_text_trgm ON posts
USING gin(text gin_trgm_ops);

EXPLAIN ANALYZE SELECT * FROM posts
WHERE text ILIKE '%word 500000%'; -- 50ms
```

Assignment Reading

- A nice SQL Tutorial

- We will have a quiz on SQL next Mon!