We previously introduced the role of the server: to provide persistence, a means for communicating between users and a secure environment (controlled by you) for operations that could/should not be performed by the untrusted client. Today we will focus of the first of those roles – persistence, that is saving data for future use. Although in doing so we will also touch on data integrity and other issues.
Our memory backed server worked (and was nice and simple) but had a major limitation, all modifications were lost when we reloaded the server. That is obviously not something we can tolerate in a real application. But the in-memory approach also has many other limitations that make it a poor choice for any real application.

What are those limitations, or perhaps from a more optimistic perspective, what are benefits of using a real database system as the persistence tier for our application (other than that when restart out server/the database the data is still there!)

Why a database?

What are the limitations of the memory-backed server (or what missing features do we want)?

```javascript
app.get('/api/films/:id', (request, response) => {
  response.send(films[request.params.id]);
});
```

- Efficient random access when total dataset is too large to fit in memory
- Fast and complex queries (not fast or complex)
- Model relationships within the data
- Transactions and other forms of fault tolerance
- Security (and management tools)
In the typical approach the database is own server, and our application server (i.e. running in with Node) communicates with the database server via TCP/IP or some other message-based protocol. That interaction occurs via SQL (a standardized language for querying relation databases) or a custom domain-specific language.

Although I should note that one of the databases we will use extensively, SQLite, is not a server. It is a library that runs inside the “client” process, accessing a database stored entirely within a single file. As an aside, SQLite is one of the most widely-used pieces of SW ever. It is embedded in many tools, e.g web browsers, iOS, etc.,..
I just mentioned the term “relational database”. That is a term for particular class of database management, it also sometimes referred to via “SQL”, which is really the name of the query language used by relational DBs. The alternative is often called “NoSQL”, or more appropriately “non-relational” databases. We will encounter both.

One of the decisions we will need to make in our project is what kind of database to use. Like many decisions we encounter in class there is no right answer – although the entire Internet will have an opinion – just tradeoffs. From my perspective, NoSQL is more flexible, and perhaps easier to get started, but the flexibility begets challenges in managing your data. In contrast, relational databases have a steeper learning curve but force us to organize our data in helpful ways. A relevant analogy might be a statically-typed languages like Java (relational) vs. dynamic languages like Python (non-relational). The latter is quick to get going but is susceptible to type errors that are not possible in Java...

Before we can pick a database, we need to figure out how the data in our application I structured (i.e. determine the data model as discussed previously) and only then can we pick a database that make sense for our particular application.

Glossary:
SQL: Structured Query Language
ACID: ACID (Atomicity, Consistency, Isolation, Durability) is a set of properties of
database transactions intended to guarantee validity even in the event of errors, power failures, etc.
CAP: Two of consistency (most recent data), availability, and partition tolerance.
CRC cards are like user stories, but for classes. Each index card contains:

- On top of the card, the class name
- On the left, the responsibilities of the class, i.e. what this class "knows" and "does". For example, a "car" class may know how many seats and doors it has, and could "do" things like stop and go.
- On the right, the collaborators (other classes) with which this class interacts to fulfill its responsibilities

Like User Stories, using an index card limits complexity and helps designers focus on the essentials of the system. The CRC cards guide the design of our models and database schema.

The knows are going to become the fields that we store in our database for each model and the knows/collaborators define the relationships or associations between those models. Recall that:
- A film has a one-to-many relationship with genres (i.e. film “has many” genres)
- There is a many-to-many relationship between Users and Films via the ratings. Often called a “has many-through” association.

These terms are semi-formal (note different tools use slightly different names, but the concepts are the same), that is they map directly to the design of the database.
schema. We are effectively designing database tables as we work out these relations. That said, I encourage you to approach the data modeling from this “direction”, that is start by modeling the nouns in your application (and their relationships) then choose and design your database instead of starting with the database design (and not try to go the other way, that is start with the database, then develop the data model).

Adapted from Armando Fox and David Patterson (Berkeley cs169) under CC-BY-SA-NC license.
The relations/associations you will typically encounter are listed here (again a quick reminder that different tools will use slightly different terminology, but the concepts are the same). We can think of these associations as design patterns that will enable us to utilize libraries/frameworks for the “parts that are the same every time”, i.e. automatic validations, optimized queries and more.

A note: the “through” modifier can be applied to “HasMany” as well, and typically implies that you might want to work with the “through” noun independently of the two sides of the relationship. We still would want to identify the relationship as one-to-many to take advantage of built-in validations.

Thinking in relations/associations

- “HasOne” / “BelongsToOne”  
  One-to-one relationship, e.g. Supplier and Account
- “HasMany” / “BelongsToOne”  
  One-to-many relationship, e.g. Film and Genre
- “ManyToMany”  
  Many-to-many relationship (often called “has many through”), e.g. User and Film through Rating
You are developing an application for a veterinarian’s office. How would you model the relation between Customer and Animal?

A. One-to-one, e.g. “HasOne”
B. One-to-many, e.g. “HasMany”
C. Many-to-many, e.g. “HasManyThrough”

Answer: B

A customer can have many animals (pets), but each animal is presumably owned by a single customer. Although we could imagine situations though where C might be needed... What would such an example be? Multiple customers were owners/responsible parties for a pet.

We could imagine there is data associated with the specific Customer-Animal relation (e.g. insurance), however that each association may be its own entity doesn’t itself change that it is a one-to-many relation.
True or False? Two models can only have one relation.

A. True
B. False

Answer: False

Consider an application where a user can make and like comments. A user has many comments via posting (a has-many relation), and user also has many comments via liking (a many-to-many or has-many-through relation).
The associations can be directly translated to URLs. Here the nesting implies genres associated with a specific film. In theory we can go infinitely deep, in practice we shouldn’t go more than one or two levels, otherwise it gets unwieldy.
With our CRC cards we focused on modeling our data independent of how it is stored. We will now implement those models using a relational database. Our mental model is table (e.g. a spreadsheet table). The attributes/columns are typically the “knows” in your CRC cards, that is the schema is nearly direct translation of the CRC card.

Primary key is a unique identifier for a record (that should be not be reused). Often it is an arbitrary (auto-incrementing) integer, e.g. the “id” in Simplepedia. Schema includes type (storage size), and can further include indexes (think hash tables or trees) to speed up queries and other constraints, like not null.
# RDBMS vocabulary

<table>
<thead>
<tr>
<th>DB instance (e.g. PostreSQL)</th>
<th>Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Has 0+</td>
<td>Optimized lookup tables (e.g. tree) for specific columns</td>
</tr>
</tbody>
</table>

## Databases

<table>
<thead>
<tr>
<th>Has 0+</th>
</tr>
</thead>
</table>

## Tables

<table>
<thead>
<tr>
<th>Contains 0+</th>
</tr>
</thead>
</table>

Each table has a schema with types, optional primary key, optional constraints

## Rows

<table>
<thead>
<tr>
<th>With 1+</th>
</tr>
</thead>
</table>

## Attributes/Columns

Cursor

Iterator into the result set that can obtain a few documents at a time
We generally won’t write “raw” queries, instead we will use the knex.js query builder to abstract DB-specific differences, handle “safe” parameters substitution, etc.. We will further wrap knex with an ORM library (Object Relational Mapping) that provides an object-oriented interface to our database (stay tuned).
Migrations are the answer to how we smartly evolve our database schema at all stages in our application lifecycle, from creating the initial database schema to safely evolving the database to add features to our production application (which presumably has customer data in it). While we could modify our database manually, we won’t. Instead we define a series of migrations scripts that evolve the schema from an empty database to the desired state.

Each migration has two parts, an “up” function that makes the desired changes, e.g. creating a table, adding column, etc. and the a “down” function that reverts those changes. Performing the up function and then the down function should return the database to its prior state. Each migration is incremental, that is makes the “next” set of changes to the prior database/schema data. For example, if you add a feature that needs a new column in an existing table, we create a migration that adds that column (and sets an appropriate value for existing entries).

Migrations are a key part of our “overall” DevOps approach.

Adapted from Armando Fox and David Patterson (Berkeley cs169) under CC-BY-SA-NC license.
Specific schema is needed to implement associations

<table>
<thead>
<tr>
<th>User</th>
<th>Film</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Responsibility</strong></td>
<td><strong>Collaborator</strong></td>
</tr>
<tr>
<td>Knows user’s name</td>
<td></td>
</tr>
<tr>
<td>...</td>
<td></td>
</tr>
<tr>
<td>Knows movies I rated</td>
<td>Rating</td>
</tr>
<tr>
<td>Knows its title</td>
<td>Knows its plot overview</td>
</tr>
<tr>
<td>Know which genres it is</td>
<td>Genre</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rating</th>
<th>Genre</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Responsibility</strong></td>
<td><strong>Collaborator</strong></td>
</tr>
<tr>
<td>Knows rating</td>
<td></td>
</tr>
<tr>
<td>Knows its owner</td>
<td>User</td>
</tr>
<tr>
<td>Knows its film</td>
<td>Film</td>
</tr>
<tr>
<td>Knows its descriptor</td>
<td></td>
</tr>
</tbody>
</table>

*“many to many”  “has many”*

*Kent Beck & Ward Cunningham, OOPSLA 1989*

These associations have specific schema associated with them. That is the association will determine what columns we need in our database. Specifically ...

Adapted from Armando Fox and David Patterson (Berkeley cs169) under CC-BY-SA-NC license.
The first approach is essentially what was implemented in our memory backed server. All the data for film, including its one or more genres are packed together in a single, albeit variable sized, object. No additional data is required. In contrast a normalized approach breaks the film into two fixed size parts, the film itself and separate genre entries, that are linked together via foreign keys, that is we need to include additional columns/attributes - the `filmId` column - to create the connection between the two tables.

Normalization: Eliminating repeated information in a table by decomposing repeating entries into separate linked tables. The data is reconstructed via join operations (to come…)

Specifically “first normal form” enforces these criteria: 1) Eliminate repeating groups in individual tables, 2) Create a separate table for each set of related data, 3) Identify each set of related data with a primary key

The second, normalized, approach is typically used with RDBMS (these are the relations in the name).

Foreign keys enforce the connection between two tables. A foreign key is a constraint not a type. To insert an entry into Genre, there must be a corresponding entry in the Film (it will fail if there is no Film).

---

**Two approaches to Film ↔ Genre**

<table>
<thead>
<tr>
<th>De-normalized Approach</th>
<th>Normalized Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Film table</strong></td>
<td><strong>Genre table</strong></td>
</tr>
<tr>
<td>id</td>
<td>genres</td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

-  + Fewer tables and joins
-  - Variable sized records
-  - Trickier to search

 Serialize multiple genres into attribute, e.g. “[63, 14]”

Foreign Key referencing

Film.id links tables
When we implement this route to on the film explorer server we want to obtain all the data for this film, including its array of genres. But now that data is separate. How do actually combine the data from the two tables?
Here we see two approaches to construct the entire object returned by this route:

1. The multiple queries approach first gets the film, then the associated genres.

2. The join approach conceptually builds a table with a row for each combination of movie and genre (with both sets of columns and duplicated movie entries) and then filters that table according to the join conditions and where clause, etc.

The former requires more queries (latency) but it is simpler to parse into tree of Objects. The latter is one (complex) query but parsing results into objects will be much trickier.

In practice we will not implement these queries directly. Instead we will use the Objection.js ORM to create the queries for us. Here we are telling Objection to eagerly, as opposed to lazily, fetch and populate the genres. The ORM uses the associations defined in the model class to generate the appropriate query and construct the final object.
Joins are such a key feature of an RDBMS I want to briefly expand on what is going on behind the scenes. Our mental model for joins is a filtered cartesian product. That is the database system is creating all combinations of entries from the Film table and the Genres table and then only keeping those where the join criteria, in this case that Film.id == Genre.filmId, is true (the actual implementation is more efficient than that though...).
Ratings: A “many-to-many” association

<table>
<thead>
<tr>
<th>filmId</th>
<th>userId</th>
<th>rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>int</td>
<td>int</td>
<td>int</td>
</tr>
<tr>
<td>12</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>53</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

Get a movie with its ratings?
GET /api/films/12
Film.query().findById(id).withGraphFetched('ratings')

Create a new rating for a movie?
POST /api/ratings
Rating.query().insert({...})
Or from a movie
POST /api/films/12/ratings
movie.$relatedQuery('ratings').insert({...})

The last assumes we have obtained the movie and the user already in the handler, e.g. via fetchById.
Where do the foreign keys go?

- “HasOne” / “BelongsToOne”  
  Foreign key typically in the “BelongsToOne” side (although could be reversed)
- “HasMany” / “BelongsToOne”  
  Foreign key in “BelongsToOne” side (the “many” model)
- “ManyToMany”  
  Foreign keys in join model, e.g. Rating in “User and Film through Rating”

These are established designs for these relations, that is once you define the relation we know where the keys need to go. We don’t need to figure that out every time.
Which of the following is the best migration (schema) for the Genre table in the Film Explorer? Note that `onDelete('CASCADE')` specifies that rows are deleted from the table if that corresponding row is deleted from the parent table.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>table.increments('id'); table.integer('filmId'); table.integer('genreId');</td>
</tr>
<tr>
<td>B.</td>
<td>table.integer('filmId'); table.integer('genreId'); table.primary([‘filmId’, ‘genreId’]);</td>
</tr>
<tr>
<td>C.</td>
<td>table.integer('filmId') .references('id') .inTable('Film'); table.integer('genreId'); table.primary([‘filmId’, ‘genreId’]);</td>
</tr>
<tr>
<td>D.</td>
<td>table.integer('filmId') .references('id') .inTable('Film') .onDelete('CASCADE'); table.integer('genreId'); table.primary([‘filmId’, ‘genreId’]);</td>
</tr>
</tbody>
</table>

Answer: D

Answers A/1 & B/2 are missing foreign key constraints and thus will not enforce that a genre entry must be associated with a valid film. When a Film is deleted, we want to delete all of its genre entries, onDelete('CASCADE') does that. Answer C/3 could work, but would leave orphan entries in the Genre table if a film is deleted.
In the Film Explorer application, the model is a Film. In our initial practicals, there is no explicit model class, just a plain old JavaScript object (POJO) representing the records in the table. Depending on the application we might not need much more. But as we saw already, Film Explorer could and does benefit from established design patterns and built-in functionality offered by an ORM library (Object Relational Mapping). ORMs are a design pattern for mapping database schema to an object whose methods/properties correspond to attributes in DB, DB queries, etc.

We already saw use of the ORM model to express and implement associations between models (the eager withGraphFetched), the other features are:

Validations: Exactly what they sound like, example of Aspect-oriented programming (i.e. these validations are relevant everywhere the model is created/used. Instead re-implementing that code, we do it once).

Virtual attributes: Convenience "attributes" derived from actual attributes/columns in DB.

Just how different of a database can a given ORM support? Some... Across different RDMSs, e.g. sqlite, MySQL and PostgreSQL. Yes. Relational vs. Non-relational? No.
These ORM models exist only on the server

Communicate with client via JSON (POJO)

3-tier Architecture
- Web Server (e.g. Apache, NGinx)
- App. Server (e.g. Node.js)
- Database (e.g. Mongo, PostgreSQL)

Presentation Tier
Logic Tier
Persistence Tier

MVC
- Routing & Controllers (e.g. Express)
- Models (e.g. knex, objection)
Validation (recall aspects & AOP)

Mechanisms for validating model data?
• Schema itself (unique, not null, etc.)
• Requirements specified in Model

```javascript
Film.query().patchAndFetchById(..., { rating: 10 })

↓

Film.fromJson .................. properties: {       Model Schema
                                 ...
                                 rating: {
                                 type: ['integer', 'null'],
                                 minimum: 0,
                                 maximum: 5
                                 }
```

400 Bad Request

Schema alone, i.e. type, is insufficient to enforce the range. Note that any constraint could be implemented in this way (not just range).
“When invalid movie data is sent in a request, then the requester should receive a '400 Bad Request' response”. Which of the below, if any, is NOT required to implement this scenario in a DRY manner?

A. Model validations
B. Express middleware
C. Code in one or more Express route handlers
D. All of the above elements are actually required

Answer: C

No specific code should be required in the route handlers. A validation error should result in a rejected Promise, that rejected promise could be detected by the router to invoke the error handling middleware. This exactly what the express-promise-router package does! As a practical matter you can also make a generic change to the route handlers that accomplish the same (we will see that in the practical).

Adapted from Armando Fox and David Patterson (Berkeley cs169) under CC-BY-SA-NC license.