Specification and Automatic Code Generation of the Data Layer for Data-Intensive Web-Based Applications

Master of Science in Computer Science
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What is this thesis about?

Overall purpose:

Propose new approach to developing data-intensive web-based applications

Hypothesis:

It is possible to build a code generator which will significantly improve development of these apps by generating at least 50% of the data access code based on a specification of the application's data model

Testing the hypothesis:

* design data definition language
* develop rules for deriving required data access
* implement code generator
* apply approach to real-world apps and measure results

Data-intensive and web-based applications: systems, which require comprehensive data access functionality for providing web-based access to data stored in a data repository, such as a database

Today’s agenda

I will discuss:

- Code generation, why it is useful and how it works
- Data definition language designed for this project
- How to derive data access methods from a data model
- Implementing a code generator
- Generating code for real applications and measuring results
- Major findings and lessons learned

I will not discuss:

- Architecture of a data-intensive web-based application
  (very large topic – no time to discuss / available in thesis online)

The Hypothesis

Motivation

- Multiple recurring patterns in application development > lots of repetitive work.
- Primary motivation: search for a way to simplify development

Current research

- Most approaches: the developer is required to specify all data access functionality
- The only alternative: automatically generating the very basic operations

My big idea

- Specifying the data model of the application *is enough* for automatically generating most of the required data access functionality.

Hypothesis

It is possible to build a code generator which will significantly improve development of data-intensive web-based applications by generating at least 50% of the data access code based on a specification of the application's data model.

Why does code generatation improve development?

Generating repetitive code is still repetitive code!

BUT: does not lead to any of the problems caused by code duplication: any edits are made to the specification – the code itself is never manually altered.

Benefits of Code Generation:

- Writing a specification is much faster than writing all the code
- Less manual refactoring: less errors
- Specifications: easier to read, write, edit, debug, and understand
- Separation of concerns
- Generate docs, tests, diagrams, etc...
- Consistency of modifications
- Correctness of generated code
- Build models and focus on areas which cannot be generated by a machine

What are we generating?

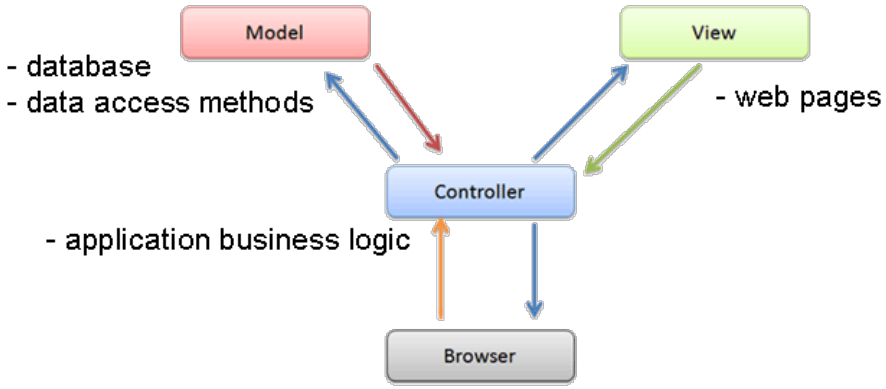
Where to start?

- Describe to the machine what exactly it must generate
- Describing is more complicated than just writing the code

  - Makes sense only if we had to write the same code multiple times
  - First step: **identify recurring code patterns**

Decomposing the Application:

Model-View-Controller



Model = data layer

View = presentation layer

Controller = business logic layer

Business Layer
unique for each app

Presentation Layer
contains recurring patterns

Data Layer
very similar across applications

The role of modeling

Code generator: a program that translates a domain specific language or specification into application source code

Code generation:
- modeling the features to be generated
- translating the model into code

Other systems model (more or less):
- structure of underlying data: data layer
- data access operations: data layer
- navigation or hyperlink structure: presentation layer
- web pages: presentation layer

Modeling web pages:
- too much detail, the only solution – simplification of requirements

Modeling navigation:
- web pages and website navigation menu are two different systems
- website's structure becomes static

CONCLUSION: Model the data layer

How to model the data layer?

Most common approach: the **entity-relationship model** (ER): using sets and relations, model objects of the real world and their inter-relationships

However:
- no fine-grain control over database
- yet another level of abstraction - additional implementation complexity

Conclusion: use database logical model

Define data operations

```
<content>
        <object name="User">
                <attribute name="Name" type="string"/>
        </object>
</content>
<operations>
        <object name="User">
                <add/><modify/><delete/>
                <sort attribute="Name" direction="ascending">
                        <filter compare="equal" attributes="Name"/>
                </sort>
        </object>
</operations>
```

1. Unnecessary to specify the obvious
2. Repetitive patterns in retrieval

Derive data operations from model

For each data object:

1. adding, modifying, reading and deleting a record,
2. reading a collection of records based on some criteria – with a record representing an entity or a relationship.

HAS NOT BEEN DONE

Data access requirements

Add, modify, display, delete a single record - *trivial*
Display multiple records – ***not so trivial***

Sorting

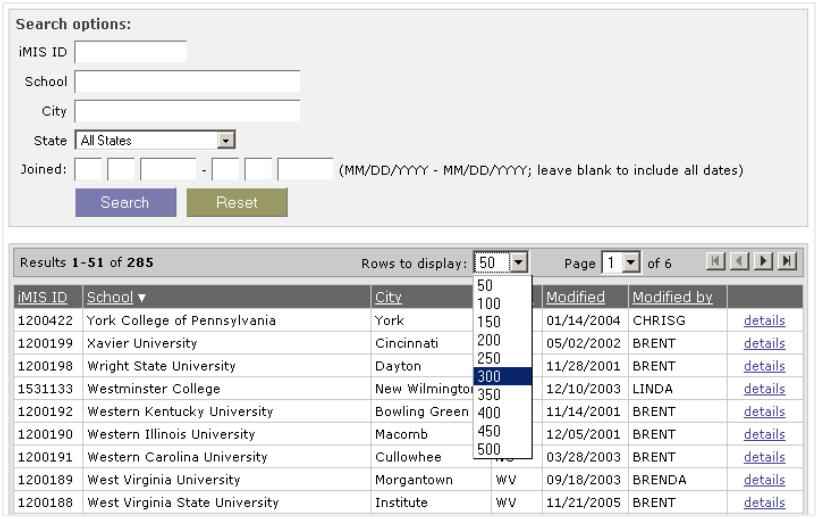
Records must be sortable by all fields displayed in a list

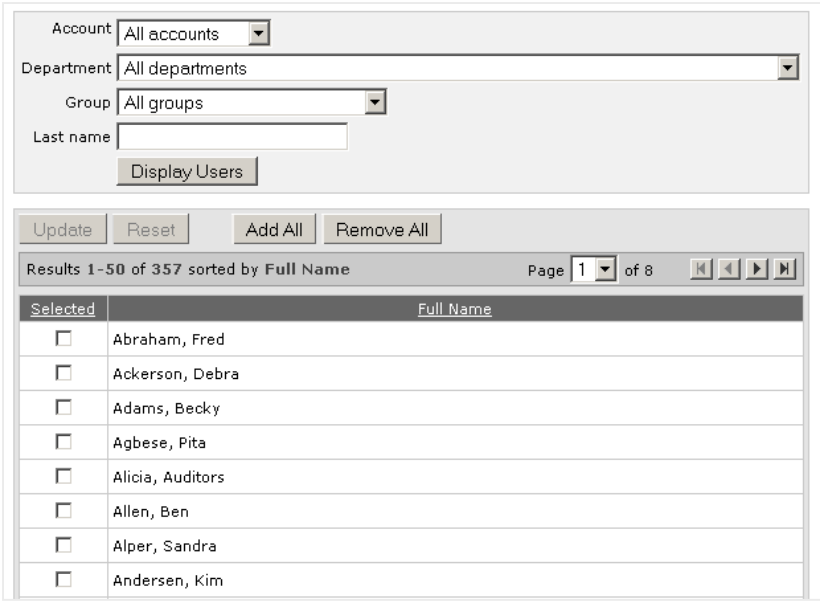
Filtering

The size of the displayed collection may be (or should be) reduced by entering search criteria

Paging

View collection “one page at a time.”
Becomes absolutely necessary with large collections





Data model specification

```
Application (1)
   Namespace (1 or more)
      Name (1)
      Class (1 or more)
         Name (1)
         Type (1): record, link, readonly, final
         Table (1)
            Name (1)
            External (0 or 1): true, false
            Field (1 or more)
                Name (1)
                SqlDataType (1)
                Identity (1): true, false
                PrimaryKey (1): true, false
                ForeignKey (0 or more)
                    RefTable (1)
                    RefField (1)
                Unique (0 or 1): true, false
                Encrypted (0 or 1): true, false
                Display (0 or 1)
                ExcludeFromTable (0 or 1): true, false
                IncludeWithParentTable (0 or 1): true, false
                IncludeInList (0 or 1): true, false
                DefaultSort (0 or 1): true, false
                ReadonlyType (0 or 1): created, modified, timestamp
            AdditionalField
                Name (1)
                SqlDataType (1)
                Sql (1)
                SortExpression (1)
                Display (0 or 1)
                ExcludeFromTable (0 or 1): true, false
                IncludeWithParentTable (0 or 1): true, false
                IncludeInList (0 or 1): true, false
                DefaultSort (0 or 1): true, false
         AdditionalSproc (0 or more)
             Name (1)
             Param (0 or more)
```

```
<class>
 <name>User</name>
 <type>record</type>
</class>
<class>
 <name>Permission</name>
 <type>readonly</type>
</class>
<class>
  <name>UserPermission</name>
  <type>link</type>
  <table>
   <field>
     <name>UserId</name>
     <primarykey>true</primarykey>
     <sqldatatype>int</sqldatatype>
     <foreignkey>
       <reftable>User</reftable>
       <reffield>Id</reffield>
     </foreignkey>
   </field>
   <field>
     <name>PermissionId</name>
     <primarykey>true</primarykey>
     <sqldatatype>int</sqldatatype>
     <foreignkey>
       <reftable>Permission</reftable>
       <reffield>Id</reffield>
     </foreignkey>
   </field>
  </table>
</class>
```

etc...

Defining data access methods

Problems:
1. attributes which are generated or updated automatically
2. weak entities
3. different sets of fields for collections of records

Solutions:
1. “read-only” field types are treated in a special way
2. “delete children” parameter in delete method
3. special field attributes: ExcludeFromTable, IncludeWithParent, etc…

Defining the set of methods:

1. Decompose into 5 types of data access:
- Instance-related for data objects (retrieve, update)
- Non-instance-related for data objects (getRecords, delete)
- Non-instance-related for data objects for each one-to-many relationship
- Non-instance-related for data objects for each many-to-many relationship
- Non-instance-related for data object links for each many-to-many relationship

2. Generate specific methods for each type

List of Generated Data Access Methods

Instance-related data object functionality
get record
update record

Non-instance-related data object functionality
create new record
delete record
get list
get records
get records with paging
get records with paging and a filtering criteria

Non-instance-related data object functionality for each one-to-many relationship:
get records by relationship
get records by relationship with paging
get records by relationship with paging and a filtering criteria

Non-instance-related data object functionality for each many-to-many relationship:
get records by link
get records by link with paging
get records by link with paging and a filtering criteria
get links
get links with paging
get links with paging and a filtering criteria

Non-instance-related functionality for each many-to-many relationship:
create link
create all links by first data object
create all links by second data object
delete link
delete links by first data object
delete links by second data object

Implementing the code generator

Approaches to code generation:
- Passive: generates code only once (or re-generates each time)
- Active: updates previously generated and manually edited code

My code generator implementation:
Application-level: passive. For manual edits, create classes extending generated classes
Database-level: combination of both

The code generation process:

Accepts a file with the description of the application and -
1. A Parser parses input and generates a parse tree. Validates the syntax and structural integrity of the schema in the input file
2. A SchemaValidator checks the schema as a whole, guarding against duplicate class names, duplicate primary keys, maintaining correct references in foreign key descriptors, etc.
3. A set of objects load the current database schema, compare it with the new schema and update the database
4. An ApplicationLoader object takes the parse tree as input and creates an abstract syntax tree, which is passed on to objects, generating the code

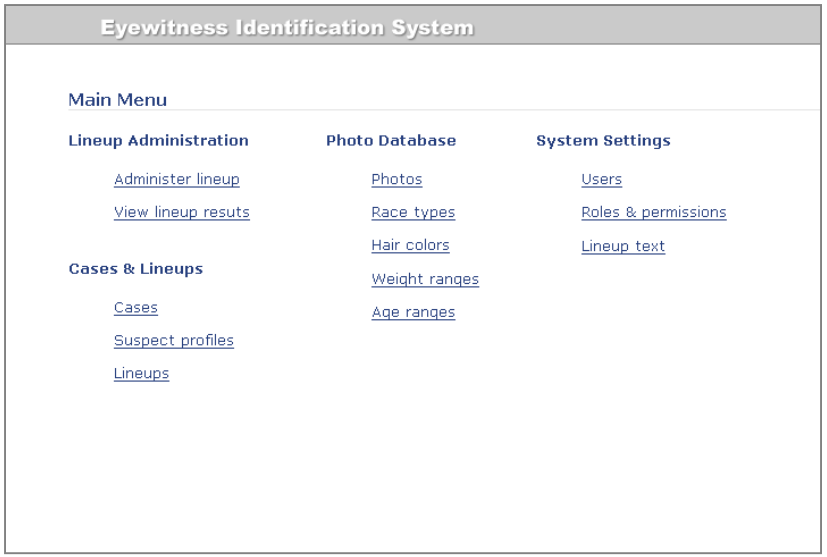
- Implemented in c# on the .Net platform. Generates SQL, and c# or VB.Net

The “real world” applications

1. Witness Identification

Used in criminology for eyewitness identification. A user (a witness) is presented with a sequence of head shots of suspects, selected from a set of several hundred thousand images

Main challenge: manipulation of a very large set of data

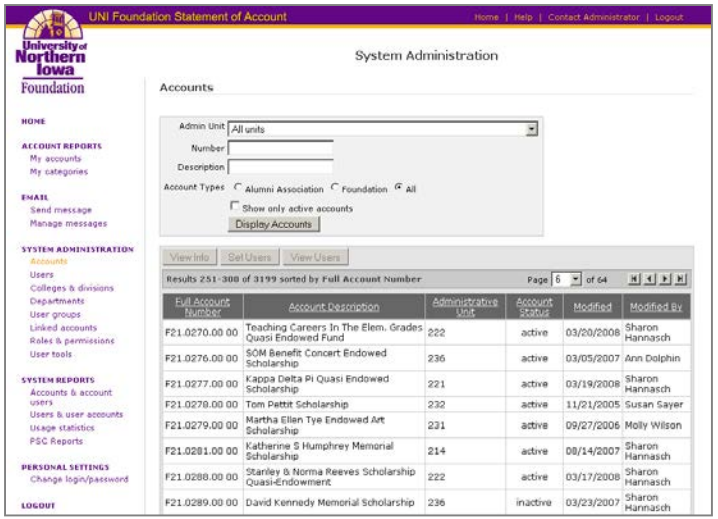


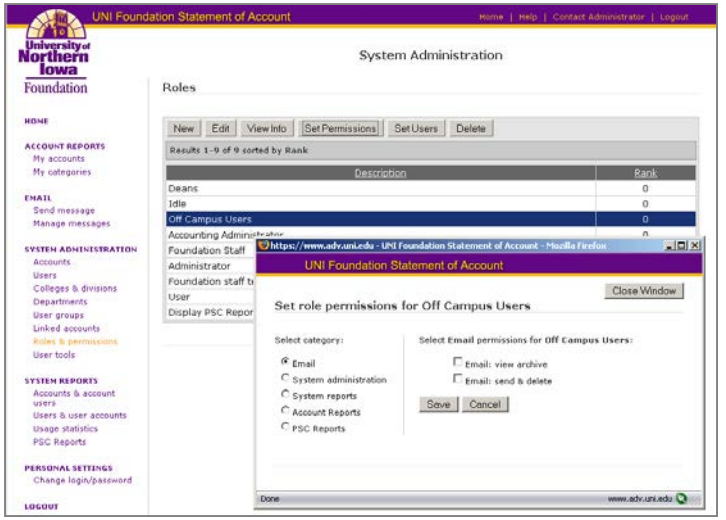
The “real world” applications

2. Account Reporting

Provides university’s constituents with access to various university accounts

Main challenge: uses multiple databases and requires elaborate data access functionality to generate complex data reports



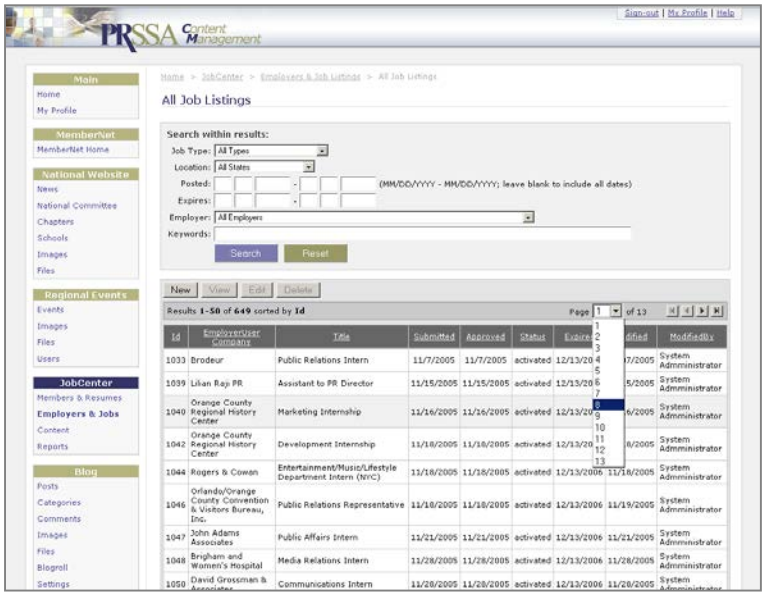


The “real world” applications

3. PRSSA

Collection of web sites with a complex content management system, including regular web sites, a blog, a career web site and numerous administrative functionality

Main challenge: the amount of different features



Results

Scope of application
and amount of generated code

	Witness Identification	Account Reporting	PRSSA
Data objects	16	14	48
Data object links	4	8	11
Data object attributes	92	97	449
Generated database tables	20	22	59
Generated stored procedures / lines of code	251 / 8,372	315 / 8,899	577 / 26,072
Generated classes / lines of code	70 / 9,956	116 / 17,181	204 / 34,397
Total generated lines of code	18,328	26,080	60,469

Effectiveness

What part of the application's data access code was generated

	Witness Identification	Account Reporting	PRSSA
Lines of code: (stored procedures + code in files)			
- total	18,410	30,710	63,228
- generated	18,328	26,080	60,469
- percentage of generated	99%	85%	96%
Stored procedures:			
- total	257	375	658
- generated	251	315	577
- percentage of generated	98%	84%	88%

Efficiency

What part of the generated data access code was used in the application

	Witness Identification	Account Reporting	PRSSA
Stored procedures:			
- generated	251	315	577
- generated and used in application	88	63	179
- percentage of used	35%	20%	31%

Concern: 12,000 + 21,000 + 42,000 lines of generated code useless!

Conclusion: hypothesis supported in part:
- more than 50% of data access code was generated
- development was not improved as expected due to added complexity

Lesson learned / Further research

Observed patterns:

- Single-object methods: add, retrieve, modify, delete are always used
- Only half of data object link methods are used (based on one of the 2 objects)
- When a collection is retrieved with paging, retrieving it without paging - only as a minimized list

Possibilities for improvement:

- Better XML syntax: attributes vs. elements
- Using values for derived fields
- Data views to specify structure of collections
- Intermediate code representation
- Code templates

```
<class>
  <name>User</name>
  <type>record</type>
  <table>
    <field>
      <name>Id</name>
      <datatype>int</datatype>
      <identity>true</identity>
      <primarykey>true</primarykey>
    </field>
  </table>
</class>
```

```
<class name="User" type="record">
  <table>
    <field name="Id" datatype="Id" identity="true" primarykey="true"/>
  </table>
</class>
```

Main Lesson Learned: Simplicity Versus Flexibility

a) Flexible, yet complex system allows the specification of numerous criteria

b) Rigid, yet simple system, has most of the options hard-coded

This experiment has proved that “keeping it simple” is a better approach

Questions, please?

Thesis and code available at lordofthewebs.com