

An ER-based Framework for Declarative Web Programming*

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Abstract. We describe a framework to support the implementation of web-based systems to manipulate data stored in relational databases. Since the conceptual model of a relational database is often specified as an entity-relationship (ER) model, we propose to use the ER model to generate a complete implementation in the declarative programming language Curry. This implementation contains operations to create and manipulate entities, supports authentication, authorization, session handling, and the composition of individual operations to user processes. Furthermore and most important, the implementation ensures the consistency of the database w.r.t. the data dependencies specified in the ER model, i.e., updates initiated by the user cannot lead to an inconsistent state of the database. In order to generate a high-level declarative implementation that can be easily adapted to individual customer requirements, the framework exploits previous works on declarative database programming and web user interface construction in Curry.

1 Motivation

Many web applications are in essence interfaces on top of standard web browsers to manipulate data stored in databases. The use of web browsers demands for access control, e.g., users must be authenticated, the authentication must be stored in a session across various web pages, the access to various parts of the data must be authorized, etc. These requirements makes the implementation of such applications a non-trivial and often error-prone task [8]. In order to support the programmer in the design and implementation of such web-based applications, various *web frameworks* had been developed for different implementation languages. For instance, the popular Ruby on Rails framework¹ supports the implementation of web applications in the object-oriented language Ruby. An interesting idea of this framework to enable the quick construction of an initial system, which can be stepwise modified or extended, is *scaffolding*, i.e., the code of an initial implementation is generated from the data model. This initial code gives the programmer a good idea how to structure and organize the code of the system under development.

Our work presented in this paper is based on a similar idea but exploits declarative programming to obtain a compact implementation and provides reliability in various

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¹ <http://www.rubyonrails.org/>

aspects (type safety, database consistency, etc). For this purpose, we use the declarative multi-paradigm language Curry [3, 7] as an implementation language and exploit previous works on declarative database programming [1] and declarative construction of web user interfaces [5]. Our framework, called “Spicey”, supports the following features:

ER-based: The framework is based on a specification of the data model as an entity-relationship (ER) model. Thus, the complete source code of an initial system is generated from an ER model.

Web-based: The generated system is web-based, i.e., all data can be manipulated (i.e., created, shown, modified, deleted) via standard web browsers. The initial system provides operations to insert new entities, show entities, modify or delete existing entities as specified in the ER model. Relations between entities are manipulated together with the corresponding entities. For instance, if there is a one-to-many relation between E and E' , an instance of E' can be created only if a corresponding instance of E is selected.

Typed: The source code is statically typed so that many programming errors are detected at compile time (in contrast to applications implemented in Perl, PHP, Ruby, etc). Moreover, the data types specified in the ER model are also respected, i.e., it is not possible to submit web forms containing ill-typed data.

Sessions: Since HTTP is a stateless protocol, our framework provides a session concept so that any kind of data (e.g., the contents of a virtual shopping basket) can be stored in a user session. Sessions are also used to store login information or navigate the user through a sequence of interactions.

Authentication: The generated application contains an initial structure for authentication, i.e., login/logout operations. Since the concrete authentication methods usually depend on the application (e.g., kind of login names, passwords), this initial structure must be extended by the programmer.

Authorization: The generated application has methods for authorization, i.e., each controller that is responsible for showing or modifying data is authorized before execution. A central authorization module is generated where the programmer can easily specify authorization rules based on login or similar information.

User processes: Individual operations provided by the framework can be composed to user processes that can be selected to initiate longer interaction sequences. For instance, if it is necessary to create various entities in a database, the individual “create” operations can be connected to a complex user process. Such processes are specified as graphs using functional logic programming techniques.

Routing: The routes (i.e., URLs to call some functionality of the system) are decoupled from the physical structure of the source code. This enables simple URLs and bookmarking of URLs that persist restructurings of the implementation. Therefore, our framework generates applications that contain a specification of a mapping from URLs into controllers of the application.

In the remainder of the paper, we present the ideas of our framework and show how declarative programming is useful to get a compact and maintainable implementation of web-based applications. Due to lack of space, we omit many details that are described in the full version of this paper available at <http://www.informatik.uni-kiel.de/~pakcs/spicey/>.

2 Web Programming with Curry

We briefly survey the basic concepts of Curry and their use for high-level web programming as required to understand the main part of this paper. More details of Curry can be found in a recent survey [6] and in the definition of Curry [7].

The design of the declarative multi-paradigm language Curry is an attempt to integrate the most important features of functional and logic languages in a seamless way in order to provide a variety of programming concepts to the programmer. From a conceptual point of view, Curry combines demand-driven evaluation, parametric polymorphism, and higher-order functions from functional programming with logic programming features like computing with partial information (logic variables), unification, and non-deterministic search for solutions. As shown in previous works on database programming [1] or web programming [4, 5], this combination enables better abstractions in application programs. Curry has a Haskell-like syntax² [11] and concepts (e.g., “IO α ” denotes the type of an I/O action that returns values of type α) but additionally supports “don’t-know” non-determinism and the inclusion of free (logic) variables in conditions and right-hand sides of defining rules.

To support basic web programming in Curry, [4] proposes an HTML library that defines a type `HtmlExp` to represent HTML structures:

```
data HtmlExp = HtmlText   String
              | HtmlStruct String [(String,String)] [HtmlExp]
```

Thus, an HTML expression is either a plain string or a structure consisting of a tag, a list of attributes (name/value pairs), and a list of HTML expressions contained in this structure. A *dynamic web page* is an HTML document that is computed by a program at the time when the page is requested by a client (e.g., a web browser). Dynamic web pages usually process user inputs, placed in various input elements (e.g., text fields, text areas, check boxes) of an HTML form, in order to generate a user-specific result. For this purpose, the HTML library of Curry [4] provides an abstract programming model that can be characterized as *programming with call-back functions*. A web page with user input and submit buttons is modeled by attaching an *event handler* to each submit button that is responsible for computing the answer document. For instance, the HTML library defines an operation to represent submit buttons in an HTML page:

```
button :: String -> HtmlHandler -> HtmlExp
```

In order to access the user input, the event handler (of type `HtmlHandler`) has an environment containing the actual user input as a parameter and computes a new web page. We omit further details here since our framework is mainly based on a more abstract layer to construct *web user interfaces (WUIs)* [5]. Such WUIs are constructed in a type-oriented manner, i.e., for each type in the application program one can construct a WUI that is an implementation of a web-based interface to manipulate values of this type. Thus, the (tedious) code for checking the validity of values in the input fields and providing appropriate error messages is automatically derived from the WUI specification. The corresponding WUI library [5] contains predefined WUIs to manipulate strings

² Variables and function names usually start with lowercase letters and the names of type and data constructors start with an uppercase letter. The application of f to e is denoted by juxtaposition (“ $f e$ ”).

(wString) or to select a value (wSelect) from a given list of values (where the first argument shows a value as a string):

```
wString :: WuiSpec String
wSelect :: (a -> String) -> [a] -> WuiSpec a
```

Here, “WuiSpec a” denotes the type of a WUI to modify values of type a. To construct WUIs for complex data types, there are *WUI combinators* that are mappings from simpler WUIs to WUIs for structured types. For instance, there is a family of WUI combinators for tuple types:

```
wPair    :: WuiSpec a -> WuiSpec b -> WuiSpec (a,b)
wTriple  :: WuiSpec a -> WuiSpec b -> WuiSpec c -> WuiSpec (a,b,c)
w4Tuple  ...
```

Hence, “wPair wString (wSelect show [1..100])” defines a WUI to manipulate a pair of a string and a number between 1 and 100. An important feature of WUIs is their easy adaptation to specific requirements. For instance, there is an operator `withCondition` that combines a WUI and a predicate on values so that the resulting WUI accepts only values satisfying the predicate. Thus,

```
wRequiredString = wString 'withCondition' (not . null)
```

defines a WUI that accepts only non-empty strings. Similarly, there are combinators to change the default rendering of WUIs (`withRendering`) or to change the default error messages. This allows a compact and declarative description of complex user interfaces.

Note that the functional as well as logic features of Curry are exploited to implement this high-level abstraction: event handlers and environments are functions attached to data structures (HTML documents), input elements in a document have logic variables as references [4], and static type checking is used to ensure type-safe web forms [5].

3 Entity-Relationship Models and Database Programming

The entity-relationship model [2] is an established framework to specify the structure and specific constraints of data stored in a database. It is often used with a graphical notation, called entity-relationship diagrams (ERDs), to visualize the conceptual model. The ER framework proposes to model the part of the world that is interesting for the application by entities that have attributes and relationships between the entities. The relationships have cardinality constraints that must be satisfied in each valid state of the database, e.g., after each transaction.

Braßel et al. [1] developed a technique to generate high-level and safe database operations (i.e., the cardinality constraints of the ER model hold after database updates) from a given ERD. In order to be largely independent of a specific ER modeling tool, [1] defines a representation of ERDs in Curry so that graphical modeling tools can be connected by implementing a translator from the tool format into the Curry representation. Since this representation is also the starting point of our framework, we briefly describe it in the following.

The representation of ERDs as data types in Curry is straightforward. An ERD consists of a name and lists of entities and relationships:

```
data ERD = ERD String [Entity] [Relationship]
```

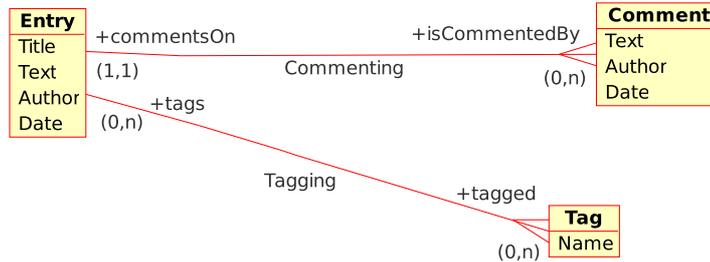


Fig. 1. An ER diagram of a web log

Instead of showing the detailed definition of all ER data types (which can be found in [1]), we show the ER specification of an example which we use throughout this paper: a web log. The structure of our “blog” is visualized as an ERD in Fig. 1. A blog consists of Entry articles having title, text, author, and date as attributes, and Comments to each entry. Furthermore, there are a number of Tags to classify Entry articles. One can generate from the ERD a data term specifying the details of the blog structure:

```

ERD "Blog"
  [Entity "Entry"
    [Attribute "Title" (StringDom Nothing) Unique False,
      Attribute "Text" (StringDom Nothing) NoKey False,
      Attribute "Author" (StringDom Nothing) NoKey False,
      Attribute "Date" (DateDom Nothing) NoKey False],
    Entity "Comment" ..., Entity "Tag" ... ]
  [Relationship "Commenting"
    [REnd "Entry" "commentsOn" (Exactly 1),
      REnd "Comment" "isCommentedBy" (Range 0 Nothing)],
    Relationship "Tagging"
    [REnd "Entry" "tags" (Range 0 Nothing),
      REnd "Tag" "tagged" (Range 0 Nothing)] ]
  
```

Each attribute specification consists of the attribute name, the domain type of the attribute values together with a possible default value, and specifications of the key and null value property. For instance, the Title attribute of the entity Entry is a string that is unique in each valid state of the database. Furthermore, Commenting is a one-to-many relationship between Entry and Comment entities, i.e., each Entry article has an arbitrary number of comments and each Comment belongs to exactly one Entry, and Tagging is a many-to-many relationship between Entry and Tag entities.

As mentioned above, [1] proposed a method to generate database operations from an ERD specification that ensures the integrity of the database (w.r.t. the constraints present in the ERD) after performing update operations. For instance, there is an operation

```

newEntry :: String -> String -> String -> Date -> Transaction Entry
  
```

that takes values of the Entry attributes and inserts a new Entry entity into the database. The return type is a transaction (see [1]), i.e., the insertion might fail (without changing the database state but returning some informative error message) if the value of the title attribute is not unique. Similarly, there is a generated operation of type



Fig. 2. The web interface of an application generated by Spicey

```
newCommentWithEntryCommentingKey
```

```
:: String -> String -> Date -> EntryKey -> Transaction Comment
```

that takes values of the attributes of a new `Comment` entry *and* a key of an existing `Entry` entity since each comment is related to a unique `Entry` entity. In the following sections, we describe the generation of a web application that implements a user-friendly interface to these database operations.

4 Scaffolding

In this section, we present the basic scaffolding of Spicey, i.e., the generation of an initial executable system that provides access to the data via standard web browsers. As an example, consider the ER description of the blog presented in the previous section. From this description, Spicey automatically generates the Curry source code of an application that implements the interface shown in Fig. 2. As one can see, the interface has buttons to create new entities and list existing ones, as well as buttons to show, edit, or delete any existing entity.

However, generating a standard interface is not sufficient for real applications since there are many requirements that are not present in the ER description. For instance, one might want to choose a different table layout or show only the first 30 characters of the `Text` attribute in the list of entries. One could extend the ER descriptions to add specifications of these requirements, but there are so many of these requirements in real applications so that this leads to a complex specification structure that is difficult to manage. As an alternative, we propose to use the high abstraction level of declarative programming for this purpose. Instead of putting any possible customer requirement in the specification language of the data model, we generate high-level declarative code from the ER descriptions. Thanks to the works on high-level database programming and web user interface construction sketched above, the generated source code is compact

and comprehensible so that it can be easily adapted to individual customer requirements, as demonstrated below.

An important issue in the design and development of a complex system is the distribution of the functionality in an appropriate module structure. The model-view-controller (MVC) paradigm [9] provides a well-established structure for interactive systems. Therefore, Spicey’s scaffolding uses the same structure for the generated source code, i.e., if we execute Spicey to generate a web application from an ER description, the generated code is distributed in directories like `models` (containing the Curry module implementing the access to the database), `controllers`, `views`, etc. In the following, we sketch some parts of the generated code.

In order to obtain a compact and maintainable code, the *views* to create or update entities exploit WUIs (see Section 2) to implement type-safe web forms in a high-level declarative manner. Thus, Spicey generates for each entity a WUI specification of a web form to manipulate the attributes of this entity (e.g., see Fig. 3). However, the internal primary database keys of an entity should not be changed and, thus, they are not part of the WUI specification. Moreover, if an entity is related to other entities, this relation should be modifiable in the web form. For instance, each comment in our blog example is related to a unique Entry entity. Hence, a single Entry entity must be selected in the form to insert or change a comment (see the lower selection box in Fig. 3). As a consequence, we have to pass related entities to the web form in order to enable their selection. In the generated code, we do not pass all associated entities (e.g., it is not reasonable to select the associated comments when editing an Entry entity) but only the uniquely related entities from one-to-many relationships and “one side” of many-to-many relationships. More precisely, if E is an entity with attributes A_1, \dots, A_n , $(E_1, E), \dots, (E_k, E)$ are all one-to-many relationships (to E) and $(E, E'_1), \dots, (E, E'_l)$ are all many-to-many relationships (with E as the first component), then the form generated to edit an E entity contains input fields for editing A_1, \dots, A_n and selection fields for $E_1, \dots, E_k, E'_1, \dots, E'_l$ (where the latter l fields are multiple selection fields). Thus, one could select in our blog example an Entry entity in a form to edit a Comment (due to the one-to-many relationship `Commenting`) and a set of Tag entities in a form to edit an Entry (due to the many-to-many relationship `Tagging`).

Hence, Spicey generates from the Blog ERD the following WUI specification for Comment entities:

```
wComment :: [Entry] -> WuiSpec (String,String,Date,Entry)
wComment entries =
  (w4Tuple wRequiredString wRequiredString wDateType
   (wSelect entryToShortView entries))
  'withRendering' (renderLabels commentLabelList)
```

Thus, `wComment` takes a list of available entries and returns a web form to manipulate the three attributes of a Comment entity together with the uniquely associated Entry entity. The available entries are shown in a selection box (`wSelect`) where each entry is shown as a short string by the transformation function `entryToShortView`. As a default, the first unique attribute is used for this purpose (if present), i.e., in case of an Entry entity, the title of the corresponding entry is shown.

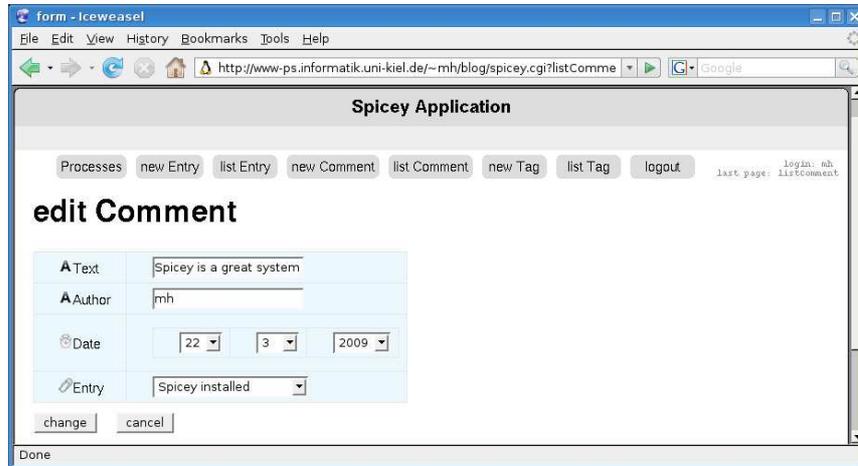


Fig. 3. An edit form for blog comments generated by Spicey

We want to remark that this and other defaults used in the standard web form created by this WUI specification (see Fig. 3) can be easily adapted by changing this declaration. For instance, one can use another interface for manipulating dates by replacing `wDateType` by another WUI for dates, or if the name of the author is not required (i.e., if comments are accepted with an empty `Author` string), one can replace the second `wRequiredString` by `wString`. Moreover, the complete default rendering can be changed by using another rendering function than `renderLabels` (see also [5]).

The WUI operation `wComment` is used to implement the views to insert or update a `Comment` entity. For instance, for editing comments, Spicey generates an operation

```
editCommentView :: Comment -> Entry -> [Entry]
                -> (Comment -> IO [HtmlExp]) -> [HtmlExp]
```

that takes the current comment, the `Entry` entity related to this comment, a list of available `Entry` entities, and an I/O operation (a controller) to update the modified comment in the database (note that the `Comment` data type contains the foreign key of the associated `Entry` entity so that it need not be explicitly passed to the update operation, see also [1]).

The main view to browse and manipulate entities is the list view as shown in Fig 2. Since the list view contains buttons (show/edit/delete) associated to individual entities, the controllers implementing the functionality of these buttons are passed as arguments to the view. For instance, the operation implementing the list view for `Comment` entities has the type

```
listCommentView :: [Comment]
                -> (Comment -> IO [HtmlExp])
                -> (Comment -> IO [HtmlExp])
                -> (Comment -> IO [HtmlExp]) -> [HtmlExp]
```

where the arguments are the list of comments and the controllers to show, edit, and delete a comment entity.

Following the MVC paradigm, *controllers* are responsible to react on user requests and call the corresponding views supplied with data contained in the model. For instance, the list controller for comments retrieves all comments from the model (i.e., the database) and calls the operation `listCommentView` with these comments and the controllers to process individual comments:

```
listCommentController :: [String] -> IO [HtmlExp]
listCommentController args = do
  comments <- runQ (queryAll (\c->let key free in comment key c))
  return (listCommentView comments showCommentController
          editCommentController deleteCommentController)
```

The argument `args` contains the possible parameters passed with the URL. This enables the implementation of listing a restricted set of comments according to the parameters.

The other controllers are similarly defined. Note that controllers to create or modify entities require a second controller, passed to the view (e.g., see `editCommentView` above), that is responsible to perform the actual modification of the model. All controllers for an entity generated by Spicey are put into a module, e.g., the module `CommentController` contains the various controllers associated to `Comment` entities.

As shown in Fig. 2, some controllers (like `new` or `list`) can be directly called by specific URLs in the application. In order to decouple the structure of URLs from the structure of the implementation, Spicey generates a *routing* module containing the names of the available controllers and their URLs. Altogether, a Spicey application performs a request for a web page as follows. First, the path component of the URL is extracted. Then, a dispatcher matches this path against the list of controllers specified in the routing module. Finally, the code of this controller is executed and the computed HTML contents is decorated with the standard layout of the application.

5 Sessions, Authentication, Authorization, Processes

In a web-based application, one needs a concept of a *session* in order to pass information between different web pages. For instance, the login name of a user or the contents of a virtual shopping basket should be stored across several web pages. Therefore, Spicey supports a general concept to store arbitrary information in a user session.

Typically, sessions are implemented in web-based systems via cookies stored in the client's browser. For security and performance reasons, these cookies should not contain the information stored in the session but only a unique session identifier that is passed to the web server in any interaction. Therefore, a Spicey application implements sessions by managing a *session identifier* in each web page. If a session identifier does not exist (i.e., the browser did not send a corresponding cookie), a fresh session identifier is created and stored in a cookie sent with any subsequent web page. However, the application programmer has not to deal with session identifiers since Spicey provides the following operations to manipulate session information (where the type variable "a" denotes the type of the session information):

```
getSessionData    :: Global (SessionStore a) -> IO (Maybe a)
putSessionData    :: a -> Global (SessionStore a) -> IO ()
removeSessionData :: Global (SessionStore a) -> IO ()
```

`getSessionData` retrieves information of the current session (and returns `Nothing` if there is no information stored), `putSessionData` stores information in the current session, and `removeSessionData` removes such information. “`SessionStore a`” is an abstract type to represent session information containing data of type `a`. This interface is based on the concept of “globals” (available through the Curry library `Global`³) that implements objects having a globally declared name in some module of the program. The values associated to the name can be modified by IO actions.

For instance, consider the implementation of “page messages” that are shown in the next page (e.g., error messages, status information), like the “Logged in as” message shown in Fig. 2. In order to enable the setting of such messages in any part of a Spicey application, we define the page message as session data by the following definition of a global entity:

```
pageMessage :: Global (SessionStore String)
pageMessage = global emptySessionStore Temporary
```

“`global v Temporary`” denotes a global entity with initial value `v` that is not persistently stored, and `emptySessionStore` denotes a session store that does not contain any information. Using the session operations above, we can define an operation to set the page message in any part of a Spicey application:

```
setPageMessage :: String -> IO ()
setPageMessage msg = putSessionData msg pageMessage
```

The current page message is retrieved and then removed by the following operation:

```
getPageMessage :: IO String
getPageMessage = do msg <- getSessionData pageMessage
                  removeSessionData pageMessage
                  return (maybe "" id msg)
```

This operation can be used by the main operation that wraps a view output with the standard layout containing the page message, global menu etc.

Due to this general session concept, one can easily attach any information entities to a session. For instance, one can store the login name in order to support authentication:

```
sessionLogin :: Global (SessionStore String)
sessionLogin = global emptySessionStore Temporary
```

and use the session data operations to set, retrieve, or delete a login name. These operations can be used in specific login/logout web pages. Since authentication is required in almost any web-based system keeping some data, Spicey provides an initial implementation (see Fig. 2) that is intended for extension during the adaption of the system.

An equally important aspect of web-based systems is *authorization*, i.e., the checking whether a user is allowed to call a distinct functionality, like showing or updating particular entities. In our framework, this check can be performed before starting a controller. In order to avoid the distribution of these checks over the entire implementation and to keep the authorization rules at a centralized place, Spicey decorates the code of each controller with a call to some authorization code. For this purpose, there is a data type

```
data AccessResult = AccessGranted | AccessDenied String
```

³ <http://www.informatik.uni-kiel.de/~pakcs/lib/CDOC/Global.html>

and an operation

```
checkAuthorization :: IO AccessResult -> IO [HtmlExp] -> IO [HtmlExp]
```

which takes an IO operation for authorization checking (returning an `AccessResult`) and a controller as arguments. If the authorization returns `AccessGranted`, the controller is executed, otherwise an error message is displayed. In order to define concrete authorization rules for the various controllers, Spicey generates a data type to classify the controllers:

```
data AccessType a = NewEntity | ListEntities | ShowEntity a
                  | UpdateEntity a | DeleteEntity a
```

Now, the execution of each controller is protected by adding an authorization check to the controller's code. For instance, the generated code of the controller to list all `Comment` entities (see Section 4) is extended as follows:

```
listCommentController args =
  checkAuthorization (commentOperationAllowed ListEntities) $ do
    comments <- runQ ...
```

Thus, the actual authorization rules are collected in a single module containing the definition of all operations used in the calls to `checkAuthorization`. For instance, the default definition of `commentOperationAllowed` is

```
commentOperationAllowed :: AccessType Comment -> IO AccessResult
commentOperationAllowed _ = return AccessGranted
```

authorizing all `Comment` operations. By refining this definition, one can specify restrictions on the controllers depending on the various operations, specific entities, or login information of the user. Note that the logic programming features of Curry can be quite useful here to specify authorization policies in a rule-oriented manner.

A web-based application generated by Spicey supports individual interactions to insert, show, and change any entity. If the data model is complex and consists of many entity types, it might be necessary to combine single interactions to longer interaction sequences. For instance, if one wants to insert new data where different entities are involved, it is reasonable to define an interaction sequence where the controllers to insert the various new entities are sequentially activated. Thus, one wants to offer *user processes* (which can be also considered as parts of complex business processes) that are structured compositions of elementary interactions. For this purpose, a generated Spicey application has an infrastructure to define and execute such processes. Since a process can be considered as a sequence of calls to controllers, Spicey allows the weaving of processes into the default structure of controllers. For this purpose, each controller which terminates an individual interaction has a “continuation” controller that is called in the next step. For instance, a controller responsible for creating a new entity calls the list controller of the same entity type, as in the controller which adds a new `Tag` entity:

```
createTagController name = runT (newTag name) >>=
  either (\_ -> nextInProcessOr listTagController Nothing)
         (\error -> displayError ...)
```

Thus, the execution (`runT`) of the transaction (`newTag name`), that should insert a new `Tag` name into the database, calls, if successful, the `listTagController`, or dis-

plays an error message if the transaction fails (e.g., since the new name already exists). However, the next controller is not directly called but indirectly through the operation `nextInProcessOr`. This operation checks whether the system executes a process. If no process is active, the given controller is called, otherwise the controller specified in the next process state is executed. In order to make the selection of the next process state dependent on some information provided by the previous controller (this is useful to implement loops or branches in processes), the second argument of `nextInProcessOr` might contain such information. Thus, the application programmer can replace the default value `Nothing` by some information available in the previous controller.

The concrete structure of processes is defined in a distinguished module `UserProcesses` as data of the following type:

```
data Processes st = ProcSpec [(String,st)]
                        (st -> ControllerFunctionReference)
                        (st -> Maybe ControllerResult -> st)
```

The type parameter `st` is the type of the states of a process, which could be a number or some more informative enumeration type. Hence, a process specification consists of a list of start states together with a textual description (these start states can be selected in the process menu), a mapping of each state into a corresponding controller to be executed in this state, and a state transition function that maps a state into a new state depending on some optional result provided by the previous controller (the type of these results is `ControllerResult`, which is identical to `String` in the default case).

We can use all features available in Curry to define processes. For instance, one can compute the next state in a process based on solving constraints w.r.t. the data in the model. In general, the state transition function is partial, i.e., if a process state has no successor, the process will be terminated. If a state has more than one successor, the first one is selected (multiple successor states can occur in situations like the insertion of several entities in an arbitrary order). As a concrete example, consider a simple process to insert a new tag followed by the creation of a new `Entry` entity and terminated with showing the list of all tags. If we use numbers as state identifiers, we can specify this process as follows:

```
let controllerOf 0 = NewTagController
    controllerOf 1 = NewEntryController
    controllerOf 2 = ListTagController
    next 0 _ = 1
    next 1 _ = 2
    in ProcSpec ["Insert new tag and entry",0] controllerOf next
```

If this specification is contained in the module `UserProcesses`, the process can be selected and stepwise executed in the web application.

6 Related Work

Although `Spicey` is the first web programming framework for a declarative language based on ER models and with support for typical requirements in the area (e.g., safe transactions, sessions, authentication, authorization, processes), there are many related approaches. The relation of `Spicey` to some of them are discussed in the following.

In contrast to other systems implemented in scripting languages like Perl, PHP, or Ruby, our implementation is statically typed so that many programming errors that easily occur in such complex systems are detected at compile time. Compared to Ruby on Rails, a framework with similar objectives, Spicey can be considered as an approach to show that declarative programming allows the compact construction of web-based systems with static type checking (thus, supporting programming safety) without the need for (unreliable) dynamic meta-programming techniques. In order to obtain this result, some design difficulties had to be solved, like avoiding mutual module dependencies by passing continuation controllers to views, routing, etc.

The Web Application Maker⁴ (WAM) is a framework with similar goals as Spicey. The WAM generates a web interface from the meta-data of a relational database and has opportunities to adapt the interface to specific user requirements. In contrast to WAM, Spicey uses ER models, which usually contain more structural information, to generate the database schema *and* the corresponding web interface.

The iData toolkit [12] is a framework, implemented with generic programming techniques in the functional language Clean, to construct type-safe web interfaces to data that can be persistently stored. In contrast to our framework, the construction of an application is done by the programmer who defines the various iData elements, where we generate the necessary code from an ER description. Hence, integrity constraints expressed in the ER description are automatically checked in contrast to the iData toolkit.

Turbinado⁵ is a web framework for Haskell. It is based on similar ideas as Ruby on Rails but exploits static type checking for more reliable programming, similarly to Spicey. In contrast to our framework, Turbinado supports scaffolding only to implement an object-relational mapping of the models, and it is not based on an ER specification to ensure integrity constraints in the application.

Seam [13] is a complex framework for developing enterprise applications in Java. It integrates many other projects to support a wide range of technologies. The database abstraction is provided by an Enterprise Java Beans 3.0 implementation, Hibernate by default, which enables the programmer to generate the database schema directly from the model classes. In contrast to the ERD library used by Spicey, there is no graphical way to create the models of the application. Another disadvantage of Seam is the absence of a single place to define consistency rules for data. There are three places where consistency and validation rules may be defined. The first two are the code of the models and the generated database schema. Some, but not all, rules which are defined in the models through annotations are put into the database schema, but often the programmer has to assure database consistency by himself. Seam supports the definition of standard relationship types but provides no good way to enforce ranges for the multiplicity of those relationships as Spicey does. For example, a one-to-one relationship does not ensure that there is always an entity on the other side of the relation but that there may be an entity or null. As a consequence, a programmer in Seam has to check for the presence of an entity by himself. Hibernate provides an annotation for that, but it is not fully integrated into Seam yet. The third place to define validation rules are the views, for which Seam uses Java Server Faces. Rules defined in the model are not automatically reflected

⁴ <http://www.declarativa.com/wam/>

⁵ <http://www.turbinado.org/>

in the views, simple validation rules like required fields have to be defined again in the view, which leads to inconsistency if those rules for a model are defined differently in different views. Seam integrates the jBPM⁶ project for modeling business processes. jBPM defines the process in XML format where a graphical editor exists. Similarly to Spicey, the coupling of the process with the code is achieved by connecting controller methods with the process. For authorization another tool may be used in Seam, namely JBoss Rules⁷, which provides a logical language for defining authorization rules. This aspect is directly integrated into Spicey by the logic programming features of Curry.

The web framework Seaside⁸ is based on the object-oriented language Smalltalk. Seaside is one of the few frameworks that use the *Transform-View* pattern for views. This enables the compiler to check the integrity of the views because they are defined as program code instead of HTML templates. Spicey uses the same approach but provides for stronger code checks due to the static type system of Curry. Seaside supports process modeling by providing a stateful environment over multiple requests and enable the programmer to span a controller method over more than one page. In contrast to Spicey, processes are not decoupled from the controller logic so that a high abstraction level of processes as in Spicey is not obtained.

Django⁹ is a popular web framework for the language Python which has features very similar to Ruby on Rails. The implementation of routes for Spicey was inspired by the way Django handles routes. While Django offers only regular expressions for matching URLs, Spicey generalizes this concept and supports arbitrary computable functions for determining the controllers associated to URLs.

7 Conclusions

We have presented the tool Spicey to generate web applications for data models that are specified as entity-relationship models. Spicey enables the generation of a fully functional system from an ER description in a few seconds. This initial system is not only good for the evaluation of the feasibility of the data model. Due to the use of a declarative target language, the generated code is compact and comprehensible so that it can be easily extended and adapted to specific customer requirements. This has been also achieved by the use of previous works on declarative database and web programming that supports a compact executable description of web interfaces. Furthermore, the generated system has an infrastructure for many aspects related to web-based systems, like transactions that are safe w.r.t. the ER constraints, sessions, authentication, authorization, user-oriented processes, or routing.

To get an idea of the size of the generated source code that might be inspected by the application programmer to adapt the initial system, we counted the lines of code of the application generated for the Blog data model shown in Section 3. The generated views contain 280 lines of code, the generated controllers contain 180 lines of code, and the configuration files (e.g., routing, default authorization) contain 55 lines of code.

⁶ <http://www.jboss.com/products/jbpm/>

⁷ <http://www.jboss.com/products/rules/>

⁸ <http://www.seaside.st/>

⁹ <http://www.djangoproject.com/>

Of course, the complete executable has much more code, like system libraries, specific Spicey libraries, generated database code etc. However, this code is usually irrelevant when adapting the system to specific layout requirements. As usual in current web-based systems, many layout details are specified in a global style sheet file so that the views generate only the basic structure of each web page.

Spicey is completely implemented in Curry. The implementation is freely available.¹⁰ Apart from some example applications, it has also been used to provide web-based interfaces to existing databases by the definition of appropriate ER descriptions. For future work, it would be interesting to develop a concept for migration, i.e., to support changes in the ER model that might entail changes in the generated and possibly adapted application code. Furthermore, it would be useful to implement a tool that allows to mix Curry code with HTML code fragments (e.g., as shown with the Haskell Server Pages [10]) in order to allow an easier integration of layouts developed by HTML designers into the application programs.

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¹⁰ <http://www.informatik.uni-kiel.de/~pakcs/spicey/>