Presented at the *Workshop on (Constraint) Logic Programming and Software Engineering, LPSE2000*, London, July 2000

Server Side Web Scripting in Curry

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Abstract

In this paper we propose a new approach to implement web services based on the Common Gateway Interface (CGI). Since we use the multi-paradigm declarative language Curry as an implementation language, many of the drawbacks and pitfalls of traditional CGI programming can be avoided. For instance, the syntactical details of HTML and passing values with CGI are hidden by a wrapper that executes abstract HTML forms by translating them into concrete HTML code. This leads to a high-level approach to server side web service programming where notions like event handlers, state variables and control of interactions are available. Thanks to the use of a functional logic language, we can structure our approach as an embedded domain specific language where the functional *and* logic programming features of the host language are exploited to abstract from details and frequent errors in standard CGI programming.

1 Motivation

In the early days of the World Wide Web (in the following called the web), most of the documents were static, i.e., stored in files which can be viewed in a nicely formatted layout. With the introduction of the Common Gateway Interface (CGI), more and more documents become dynamic, i.e., they are computed on the web server at the time they are requested from a client. In combination with input forms specified in HTML documents, more complex forms of interactions become possible so that clients can retrieve or store specific data via their web browsers.

An advantage of CGI is that it is supported by most web servers. Thus, the use of CGI does not need any special extensions on the server or the client side (e.g., no servlets or cookies), which is a requirement for our development. On the other hand, CGI offers only a very primitive form of interaction so that the programming of web services often becomes awkward. Although general scripting languages like Perl provide libraries for decoding input form data, they do not support the programmer in the construction of correct output data or to control a sequence of interactions with the client. This demands for specialized languages (e.g., MAWL [12], DynDoc [15]) or specialized libraries in existing languages (e.g., [2, 13, 17]). In this paper we take the latter approach. We show how the features of an integrated functional logic language (see [3] for a survey on these kind of languages) can be exploited to provide a flexible and high-level approach to programming web services without any language extensions. In particular, our approach offers the following features for implementing web services:

- The HTML documents requested by the clients can be flexibly generated depending on the computed data (in contrast to MAWL [12] which uses fixed templates with a simple list iteration construct).

*This research has been partially supported by the German Research Council (DFG) under grant Ha 2457/1-1 and by the DAAD under the PROCOPE programme.

- The data filled in a form by the user can be easily retrieved by an environment model using logical variables as references.
- The different actions to be taken when a user has completed a form are specified by an event handler model.
- The sequence (or iterations) of interactions with the web server is described in one script and not distributed over a set of script files. In particular, a form is described together with the handler for this form which avoids typical CGI programming errors (e.g., undefined input fields).
- State variables which should persist between different interactions are directly supported.
- The CGI interaction (usually, by environment variables and value decoding) is hidden to the user and encapsulated in a wrapper that translates the high-level scripts into HTML code.

Our library is completely implemented in Curry [4, 9], a modern multi-paradigm declarative language which integrates functional, logic, and concurrent programming paradigms. Thus, we show that Curry is an appropriate language for writing web service scripts. On the other hand, Curry is a complete programming language offering static typing, higher-order functions, constraints, and features for concurrent and distributed programming, which are useful for building complex web applications.

This paper is structured as follows. The next section provides a short overview of the main features of Curry as relevant for this paper. Sections 3 and 4 introduce our approach for modeling basic HTML documents and interactive forms. The subsequent sections discuss the use of our CGI programming model by various examples before we sketch in Section 9 the implementation of our library and conclude in Section 10 with a discussion of related work.

2 Basic Elements of Curry

Since we assume familiarity with the basic structure of HTML and CGI programming, we review in this section only the basic elements of Curry as necessary to understand the ideas presented in this paper. More details about Curry's computation model and a complete description of all language features can be found in [4, 9].

Curry combines in a seamless way features from functional programming (nested expressions, lazy evaluation, higher-order functions), logic programming (logical variables, partial data structures, built-in search), and concurrent programming (concurrent evaluation of expressions with synchronization on logical variables). Curry also provides additional features in comparison to the pure paradigms (compared to functional programming: search, computing with partial information and constraints; compared to logic programming: more efficient evaluation due to the deterministic and demand-driven evaluation of functions, more flexible search strategies) and supports programming-in-the-large with specific features (types, modules, encapsulated search). From a syntactic point of view, a Curry program is a functional program[1] extended by the possible inclusion of free (logical) variables in conditions and right-hand sides of defining rules. Thus, a Curry program consists of the definition of functions and the data types on which the functions operate. Functions are evaluated in a lazy manner. To provide the full power of logic programming, functions can be called with partially instantiated arguments and defined by conditional equations with constraints in the conditions. The behavior of function calls with free variables depends on

[1] Curry has a Haskell-like syntax [14], i.e., (type) 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 ("$f\ e$").

the evaluation annotations of functions which can be either *flexible* or *rigid*. Calls to rigid functions are suspended if a demanded argument, i.e., an argument whose value is necessary to decide the applicability of a rule, is uninstantiated ("*residuation*"). Calls to flexible functions are evaluated by a possibly non-deterministic instantiation of the demanded arguments to the required values in order to apply a rule ("*narrowing*").

Example 1 The following Curry program defines the data types of Boolean values, polymorphic lists and trees (first three lines) and functions for computing the concatenation of lists and the last element of a list:

```
data Bool   = True | False
data List a = []   | a : List a
data Tree a = Leaf a | Node a (List (Tree a))

conc :: [a] -> [a] -> [a]
conc eval flex

conc []     ys = ys
conc (x:xs) ys = x : conc xs ys

last xs | conc ys [x] =:= xs   = x   where x,ys free
```

The data type declarations define `True` and `False` as the Boolean constants, `[]` (empty list) and `:` (non-empty list) as the constructors for polymorphic lists (`a` is a type variable ranging over all types and the type `List a` is usually written as `[a]` for conformity with Haskell), and `Leaf` and `Node` as the constructors for trees.

The (optional) type declaration ("`::`") of the function `conc` specifies that `conc` takes two lists as input and produces an output list, where all list elements are of the same (unspecified) type.[2] Since `conc` is explicitly defined as flexible[3] (by "`eval flex`"), the equation "`conc ys [x] =:= xs`" can be solved by instantiating the first argument `ys` to the list `xs` without the last argument, i.e., the only solution to this equation satisfies that `x` is the last element of `xs`.

In general, functions are defined by (*conditional*) *rules* of the form "l `|` c `=` e `where` vs `free`" where l has the form $f\,t_1 \ldots t_n$ with f being a function, $t_1, \ldots, t_n$ data terms and each variable occurs only once, the *condition* c is a constraint, e is a well-formed *expression* which may also contain function calls, lambda abstractions etc, and vs is the list of *free variables* that occur in c and e but not in l (the condition and the `where` parts can be omitted if c and vs are empty, respectively). The `where` part can also contain further local function definitions which are only visible in this rule. A conditional rule can be applied if its left-hand side matches the current call and its condition is satisfiable. A *constraint* is any expression of the built-in type `Success`[4]. Each Curry system provides at least equational constraints of the form e_1 `=:=` e_2 which are satisfiable if both sides e_1 and e_2 are reducible to unifiable data terms (i.e., terms without defined function symbols). However, specific Curry systems can also support more powerful constraint structures, like arithmetic constraints on real numbers or finite domain constraints for applications in operation research problems, as in the PAKCS implementation [7].

The operational semantics of Curry, as precisely described in [4, 9], is a conservative extension of lazy functional programming (if no free variables occur in the program or the initial goal) and

[2] Curry uses curried function types where α`->`β denotes the type of all functions mapping elements of type α into elements of type β.

[3] As a default, all functions except for constraints are rigid.

[4] `Success` was called `Constraint` in previous versions of Curry

(concurrent) logic programming. Due to the use of an optimal evaluation strategy [1], Curry can be considered as a generalization of concurrent constraint programming [16] with a lazy (optimal) evaluation strategy. Due to this generalization, Curry supports a clear separation between the sequential (functional) parts of a program, which are evaluated with an efficient and optimal evaluation strategy, and the concurrent parts, based on the concurrent evaluation of constraints, to coordinate concurrent program units.

Monadic I/O: Since web service programs usually interact with their environment (e.g., retrieve or store information in files on the server), some knowledge about performing I/O in a declarative manner is required. The I/O concept of Curry is identical to the monadic I/O concept of Haskell [18], i.e., an interactive program is considered to compute a sequence of actions which are applied to the outside world. *Actions* have type "`IO` α" which means that they return a result of type α whenever they are applied to (and change) the outside world. For instance, `getChar` of type `IO Char` is an action which reads a character from the standard input whenever it is executed, i.e., applied to a world. Similarly, "`readFile f`" is an action which returns the contents of file `f` in the current world. Actions can only be sequentially composed. For instance, the action `getChar` can be composed with the action `putChar` (which has type `Char -> IO ()` and writes a character to the terminal) by the sequential composition operator `>>=` (which has type `IO` α `->` (α `->IO` β) `->IO` β), i.e., "`getChar >>= putChar`" is a composed action which prints the next character of the input stream on the screen. The second composition operator `>>` is like `>>=` but ignores the result of the first action. Furthermore, "`return` e" is the "empty" action which simply returns e (see [18] for more details). For instance, a function which takes a string (list of characters) and produces an action that prints it to the terminal can be defined as follows:

```
putStr []     = return ()
putStr (c:cs) = putChar c >> putStr cs
```

Similarly, the composed action "`readFile f >>= putStr`" prints the contents of file `f`.

Curry offers further features, like the encapsulation and control of non-deterministic computations [8] or for the development of distributed systems [5]. Since these are not important for the topic of this paper, we do not discuss them here.

3 Modeling Basic HTML

In order to avoid certain syntactical errors (e.g., unbalanced parenthesis) during the generation of HTML documents by a web server, the programmer should not be forced to generate the explicit text of HTML documents (as in CGI scripts written in Perl or with the Unix shell). A better approach is the introduction of an abstraction layer where HTML documents are modeled as terms of a specific data type together with a wrapper function which is responsible for the correct textual representation of this data type. Such an approach can be easily implemented in a language supporting algebraic data types. Similarly to the data type of trees in Example 1, we introduce the type of HTML expressions in Curry as follows:

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

Thus, an HTML expression is either a plain string or a structure consisting of a tag (e.g., `B`,`EM`,`H1`,`H2`,...), a list of attributes, and a list of HTML expressions contained in this structure. The translation of such HTML expressions into their corresponding textual representation is straight-

forward: an `HtmlText` is represented by its argument, and a structure with tag t is enclosed in the brackets <t> and </t> (where the attributes are eventually added to the open bracket). Since there are a few HTML elements without a closing tag (like <HR> or <BR>), we have included the alternative `HtmElem` to represent these elements.

Since writing HTML documents in this form might be tedious, we define several functions as useful abbreviations (the function `htmlQuote` transforms characters with a special meaning in HTML, like <, >, &, ", into their HTML quoted form):

```
htxt   s     = HtmlText (htmlQuote s)    -- plain string
h1     hexps = HtmlStruct "H1" [] hexps  -- main header
...
bold   hexps = HtmlStruct "B"  [] hexps  -- bold font
italic hexps = HtmlStruct "I"  [] hexps  -- italic font
...
hrule        = HtmlElem "HR" []          -- horizontal rule
...
```

As a simple example, the following expression defines a "Hello World" document consisting of a header and two words in italic and bold font, respectively:

```
[h1 [htxt "Hello World"],
 italic [htxt "Hello"], bold [htxt "world!"]]
```

Although the list of attributes is empty in the abbreviations above, we can add arbitrary attributes by the function `addAttr` which is defined by

```
addAttr :: HtmlExp -> (String,String) -> HtmlExp
addAttr (HtmlText s) _ = HtmlText s    -- strings have no attributes
addAttr (HtmlStruct tag params hexps) attr =
                                       HtmlStruct tag (params++[attr]) hexps
addAttr (HtmlElem tag params) attr = HtmlElem tag (params++[attr])
```

Note that we do not check the validity of the attributes for each structure. This can be done by defining HTML expressions with a reacher type structure, as shown in [17]. The wrapper function to convert these HTML expressions into valid HTML documents will be shown in the next section where we discuss the modeling of input forms.

4 Input Forms

In order to enable more sophisticated interactions between clients using standard browsers and a web server, HTML defines so-called `FORM` elements which usually contains several input elements to be filled out by the client. When the client submits such a form, the data contained in the input elements is encoded and sent (on the standard input or with the URL) to the server which starts a CGI program to react to the submission. The activated program decodes the input data and performs some application-dependent processing before it returns an HTML document on the standard output which is then sent back to the client.

In principle, the type `HtmlExp` is sufficient to model all kinds of HTML documents including input elements like text fields, check buttons etc. For instance, an input field to be filled out with a text string can be modeled as

```
HtmlElem "INPUT" [("TYPE","TEXT"),("NAME",name),("VALUE",contents)]
```

where the string `contents` defines an initial contents of this field and the string `name` is used to identify this field when the data of the filled form is sent to the server. This direct approach is taken in CGI libraries for scripting languages like Perl or also in the CGI library for Haskell [13]. In this case, the program running on the web server is an I/O action that decodes the input data (contained in environment variables and the standard input stream) and puts the resulting HTML document on the output stream. Therefore, CGI programs can be implemented in any programming language supporting access to the system environment. However, this basic view results in an awkward programming style when sequences of interactions (i.e., HTML forms) must be modeled where state should be passed between different interactions. Therefore, we propose a higher abstraction level and we will show that the functional and logic features of the underlying language Curry can be exploited to provide an appropriate programming infrastructure.

There are two basic ideas of our CGI programming model:

1. The input fields are not referenced by strings but by elements of a specific abstract data type. This has the advantage that the names of references correspond to names of program variables so that the compiler can check inconsistencies in the naming of references.

2. The program that is activated when a form is submitted is implemented together with the program generating the form. This has the advantage that sequences of interactions can be simply implemented using the control abstractions of the underlying language and state can be easily passed between different interactions of a sequence using the references mentioned above.

For dealing with references to input fields, we use logical variables since it is well known that logical variables are a useful notion to express dependencies inside data structures [6, 19]. To be more precise, we introduce a data type

```
data CgiRef = CgiRef String
```

denoting the type of all references to input elements in HTML forms. This data type is abstract, i.e., its constructor `CgiRef` is not exported by the CGI library. This is essential since it avoids the construction of wrong references. The only way to introduce such references are logical variables, and the global wrapper function is responsible to instantiate these variables with appropriate references (i.e., instantiate each reference variable to a term of the form `CgiRef` n where n is a unique name).

To include references in HTML forms, we extend the definition of our data type for HTML expressions by the following alternative:

```
data HtmlExp = ... | HtmlCRef HtmlExp CgiRef
```

A term "`HtmlCref hexp cr`" denotes an HTML element `hexp` with a reference to it. Usually, `hexp` is one of the input elements defined for HTML, like text fields, text areas, check boxes etc. For instance, a text field is defined by the following abbreviation in our library:[5]

```
textfield :: CgiRef -> String -> HtmlExp
textfield eval flex
textfield (CgiRef ref) contents =
  HtmlCRef (HtmlElem "INPUT" [("TYPE","TEXT"),("NAME",ref),("VALUE",contents)])
           (CgiRef ref)
```

[5]Note that this function must be flexible so that the first argument, which can only be a logical variable, is instantiated by the application of this function.

Note that `ref` is unbound when this function is applied but it will be bound to a unique name (string) by the wrapper function executing the form (see below).

A complete HTML form consists of a title and a list of HTML expressions to be displayed by the client's browser, i.e., we represent HTML forms as expressions of the following data type:

```
data HtmlForm = Form String [HtmlExp]
```

Thus, we can define a simple form containing a single input element (a text field) as follows:

```
Form "Form" [h1 [htxt "A Simple Form"],
             htxt "Enter a string:", textfield sref ""]    where sref free
```

In order to submit a form to the web server, HTML supports "submit" buttons (we only discuss this submission method here although there are others). The actions to be taken are described by CGI programs that decode the submitted values of the form before they perform the appropriate actions. To simplify these actions and combine them with the program generating the form, we propose an event handling model for CGI programming. For this purpose, each submit button is associated with an event handler responsible to perform the appropriate actions. An *event handler* is a function from a CGI environment into an I/O action (in order to enable access to the server environment) that returns a new form to be sent back to the client. A *CGI environment* is simply a mapping from CGI references into strings. When an event handler is executed, it is supplied with a CGI environment containing the values entered by the client into the form. Thus, event handlers have the type

```
(CgiRef -> String) -> IO HtmlForm
```

To attach an event handler to an HTML element, we finally extend the definition of our data type for HTML expressions by:

```
data HtmlExp = ... | HtmlEvent HtmlExp ((CgiRef->String) -> IO HtmlForm)
```

A term "`HtmlEvent hexp handler`" denotes an HTML element `hexp` (typically a submit button) with an associated event handler. Thus, submit buttons are defined as follows:

```
button :: String -> ((CgiRef->String) -> IO HtmlForm) -> HtmlExp
button label handler =
  HtmlEvent
       (HtmlElem "INPUT" [("TYPE","SUBMIT"),("NAME","EVENT"),("VALUE",label)])
       handler
```

The argument `label` is the text shown on the button and the attribute `NAME` is later used to identify the selected submit button (since several buttons can occur in one form, see Section 9).

To see a simple but complete example, we show the specification of a form where the user can enter a string and choose between two actions (reverse or duplicate the string, see Figure 1):[6]

```
revdup = return $ Form "Question"
            [htxt "Enter a string: ", textfield tref "",
             hrule,
             button "Reverse string"   revhandler,
             button "Duplicate string" duphandler]

  where tref free
```

[6] The predefined right-associative infix operator $f\,\$\,e$ denotes the application of f to the argument e.

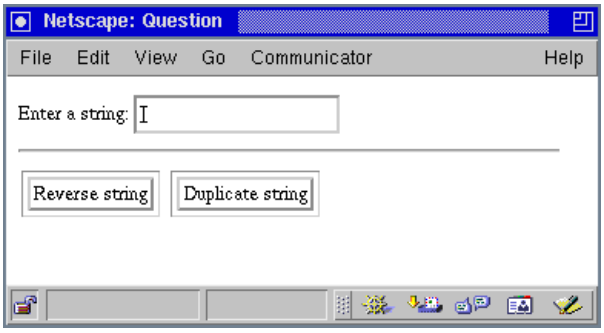

Figure 1: A simple string reverse/duplication form

```
revhandler env = return $ Form "Answer"
  [h1 [htxt ("Reversed input: " ++ rev (env tref))]]

duphandler env = return $ Form "Answer"
  [h1 [htxt ("Duplicated input: " ++ env tref ++ env tref)]]
```

Note the simplicity of retrieving values entered into the form: since the event handlers are called with the appropriate environment containing these values, they can easily access these values by applying the environment to the appropriate CGI reference, like `(env tref)`. This simple structure of CGI programming is made possible by the functional as well as logic programming features of the underlying language Curry.

As mentioned above, forms are executed by a special wrapper function that performs the translation into concrete HTML code, decoding the entered values and invoking the right event handler. This wrapper function has the following type:

```
runcgi :: String -> IO HtmlForm -> IO ()
```

It takes a string (the URL under which this CGI program is accessible on the server) and an I/O action returning a form and returns an I/O action which, when executed, returns the HTML code of the form. Thus, the above form is executed by the following main function

```
main = runcgi "revdup.cgi" revdup
```

provided that the executable of this program is stored in `revdup.cgi`.

In the following sections we will show by various examples that the components for CGI programming introduced so far (i.e., logical variables for CGI references, associated event handlers depending on CGI environments) are sufficient to solve typical problems in CGI programming in an appropriate way, like handling sequences of interactions or holding intermediate states between interactions.

5 Accessing the Web Server Environment

From the previous example it might be unclear why the event handlers as well as the wrapper function assumes that the form is encapsulated in an I/O action. Although this is unnecessary for applications where the web server is used as a "computation server" (where the result depends only on the form inputs), in many applications the clients want to access or manipulate data stored on the server. In these cases, the web service program must be able to access the server environment which is easily enabled by running it in the I/O monad.

As a simple example for such kinds of applications, we show the definition of a (not recommendable) form to retrieve the contents of an arbitrary file stored at the server:

```
getfile = return $ Form "Question"
            [htxt "Enter local file name:", textfield fileref "",
             button "Get file!" handler]

  where fileref free

        handler env = readFile (env fileref) >>= \contents ->
                      return $ Form "Answer"
                        [h1 [htxt ("Contents of file " ++ env fileref)],
                         verbatim contents]
```

Here it is essential that the event handler is executed in the I/O monad, otherwise it has no possibility to access the contents of the local file via the I/O action `readFile` before computing the contents of the returned form. In a similar way, arbitrary data can be retrieved or stored by the web server while executing CGI programs.

6 Interaction Sequences

In this section we show how one deal with sequences of interactions in our CGI programming model. In the previous examples the interaction between the client and the web server is quite simple: the client sends a request by filling a form which is answered by the server with an HTML document containing the requested information. In realistic applications it is often the case that the interaction is not finished by sending back the requested information but the client requests further (e.g., more detailed) information based on the received results. Thus, one has to deal with sequences of longer interactions between the client and the server.

Our CGI programming model provides a direct support for interaction sequences. Since the answer provided by the event handler is an HTML form rather than an HTML expression, this answer can also contain further input elements and associated event handlers. By nesting event handlers, it is straightforward to implement bounded sequences of interactions and, therefore, we omit an example here.

A more interesting question is whether we can implement other control abstractions like arbitrary loops. For this purpose, we show the implementation of a simple number guessing game: the client has to guess a number known by the server, and for each number entered by the client the server responds whether this number is right, smaller or larger than the number to be guessed. If the guess is not right, the answer form contains an input field where the client can enter the next guess.

Due to the underlying declarative language, we implement looping constructs by recursion. Thus, the event handler computing the answer for the client contains a recursive call to the initial form which implements the interaction loop. The entire implementation of this number guessing game is as follows:

```
guessform = return $ Form "Number Guessing" guessinput

guessinput =
  [htxt "Guess a number: ", textfield nref "",
   button "Check" (guesshandler nref)]   where nref free

guesshandler nref env =
```

```
let nr = readInt (env nref)
in return $ Form "Answer"
             (if nr==42
              then [htxt "Right!"]
              else [htxt (if nr<42 then "Too small!" else "Too large!"),
                    hrule] ++ guessinput)
```

`guessinput` is an HTML expression corresponding to the initial form which contains an input field for entering the client's guess. `guesshandler` is the associated event handler where the CGI reference to the input field is the first argument of the handler. It checks the number entered by the client (`readInt` converts a string into a number) and returns the different answers depending on the client's guess. If the guess is not right, the `guessinput` is appended to the answer which implements the recursive call.

It should be clear that this general recursion pattern can be extended in various ways. For instance, counting the number of guesses made by the client is quite simple: the only change to the above program is the addition of a count argument to `guessinput` and `guesshandler` which is initialized in the main function `guessform` and incremented in each recursive call.

7 Handling Intermediate States

A nasty problem in many CGI applications is the handling of intermediate states due to the fact that HTTP is a stateless protocol. For instance, in electronic commerce applications, the clients have shopping baskets where the already selected items are stored, and the contents of these baskets must be kept between the interactions. Storing this information on the server side has several drawbacks. For instance, the client wants to identify himself only after he really orders the items, i.e., during the selection phase the server cannot uniquely associate the selections to a client. Furthermore, the client might not proceed with his selections so that the server does not know whether the basket information can be deleted (which is necessary at some point to avoid a memory overflow). Therefore, it is often better to store such client-dependent information on the client side. For this purpose, one can have HTML forms with input elements of type `HIDDEN` which have no visual representation but can be used to pass client-dependent information between interactions. "Raw" HTML/CGI programmers must explicitly handle these fields which is awkward and a source of many programming problems.

Our CGI programming model offers a much simpler solution to this problem. By nesting event handlers (which is allowed in languages with lexical scoping like Curry), one can directly refer to input elements in previous forms. To be more concrete, we consider a sequence of HTML forms where the client enters his first name in the first form and his last name in the second form. The complete name is returned in the third form. This example can be implemented as follows:

```
nameform = return $ Form "First Name Form"
  [htxt "Enter your first name: ", textfield firstref "",
   button "Continue" fhandler]

 where firstref free

       fhandler _ =
          return $ Form "Last Name Form"
            [htxt "Enter your last name: ", textfield lastref "",
             button "Continue" lhandler]
```

```
where lastref free

      lhandler env =
        return $ Form "Answer"
          [htxt ("Hello, " ++ env firstref ++ " " ++ env lastref)]
```

Note that, due to lexical scoping, the variable `firstref` is visible in the `lhandler` without explicitly passing it as an argument.

8 Extending HTML

It is well known that an advantage of functional programming is the direct support for building application-oriented abstractions, thus, increasing modularity [10]. In this section, we exploit this property of our base language by extending the set of HTML elements.

As an example, consider an application where one wants to show the contents of unbounded hierarchical structures (e.g., the directory structure of a file system). Thus, we assume that our data is an expression of type `Tree String` (see Example 1 for the definition of the type `Tree`) which should be represented in HTML as a nested list. Our library already contains the following definitions for (unordered) lists:

```
ulist       :: [[HtmlExp]] -> HtmlExp
ulist items = HtmlStruct "UL" [] (map litem items)

litem hexps = HtmlStruct "LI" [] hexps
```

Thus, each item of a list consists of a sequence of HTML expressions. `litem` transforms such a sequence into an HTML structure representing a list item, and `ulist` puts them together to a HTML structure representing an unordered list (the standard higher-order function `map` applies its first argument, a function, to all elements in the second argument, a list).

Using these definitions, the introduction of a new "HTML tree structure" is straightforward. A leaf is represented by its contents and a node is representing by its mark followed by the list of its subtree representations:

```
htmlTree :: Tree String -> [HtmlExp]
htmlTree (Leaf s)       = [htxt s]
htmlTree (Node s trees) = [htxt s] ++ [ulist (map htmlTree trees)]
```

Now we can use `htmlTree` in HTML expressions wherever a list of HTML expressions is required. For instance, the following expression is valid:

```
[h1 [htxt "File structure:"]] ++
 htmlTree (Node "/"
            [Node "/etc" [Leaf "/etc/aliases", Leaf "/etc/passwd"],
             Node "/usr" [Node "/usr/bin"
                           [Leaf "/usr/bin/grep", Leaf "/usr/bin/java"],
                          Node "/usr/lib"
                           [Leaf "/usr/lib/tclConfig.sh"]]])
```

In a similar way, one can implement arbitrary application-oriented abstractions which can significantly simplify the generation of web pages.

9 Implementation

Our CGI library is completely implemented in Curry. It does not require any extension to web servers but uses only the standard features of CGI. Since these are supported by most web servers, our library can be used with most web servers (where a Curry system is also installed). In this section, we discuss the implementation of our CGI programming model with CGI references and event handlers on top of the standard CGI features.

The entire implementation is performed by the main wrapper function `runcgi` which basically takes a specification of an HTML form and translates it into the corresponding concrete HTML text. Moreover, it performs the following tasks:

- Assigning unique identifiers (strings) to the CGI references occurring in the form specification, i.e., the logical variables in the CGI references are instantiated to these string identifiers.
- Assigning unique identifiers (strings) to each event handler occurring in the form specification. For instance, each submit button contains after this assignment a name attribute of the form `EVENT_`s, where s is a string uniquely identifying the event handler associated to the button that the client has pressed to submit the form.
- Adding the input values of the previous (enclosing) forms as hidden inputs.

If `runcgi` is executed as a CGI program on a web server, it first checks the environment variables in order to decode the list of input values entered by the user (which might be empty for the initial form). If there is no input value named `EVENT_`s, then this is the call of the top-level form and not a submission of a previous form. In this case, the top-level form is translated and written on the standard output stream so that the web server returns it to the client. For instance, the form `revdup` for reversing or duplicating the input (cf. Section 4) is translated into the following textual representation:

```
Content-type: text/html

<HTML>
<HEAD>
<TITLE>Question</TITLE>
</HEAD>
<BODY>
<FORM METHOD="POST" ACTION="revdup.cgi">
<INPUT TYPE="HIDDEN" NAME="DEFAULT" VALUE="EVENT_0">
Enter a string: <INPUT TYPE="TEXT" NAME="FIELD_1" VALUE="">
<HR>
<INPUT TYPE="SUBMIT" NAME="EVENT_revhandler..." VALUE="Reverse string">
<INPUT TYPE="SUBMIT" NAME="EVENT_duphandler..." VALUE="Duplicate string">
</FORM>
</BODY>
</HTML>
```

The definition of the hidden input value named `DEFAULT` is provided since in some situations a form is also submitted by the client's browser without pressing a submit button, (e.g., by pressing the enter key in the last text input field). In this case, the value associated to the name `DEFAULT` (usually, the first event handler) is used as the default event handler.

If the wrapper function `runcgi` decodes the input values and there is a value identifying the selected handler (i.e., the name `EVENT_`s is defined in the input environment), `runcgi` selects the

associated event handler in the form specification and executes it together with the current CGI environment as an argument.

The current CGI environment is computed as follows. First, the list of name/value pairs passed in a string representation to the CGI program is decoded and stored in a list of pairs of strings. The selection of the value associated to a CGI reference in this list is implemented by a simple list lookup function

```
cgiGetValue :: [(String,String)] -> CgiRef -> String
```

If `cenv` denotes the current list of decoded name/value pairs, the corresponding CGI environment can be computed by the partial application `(cgiGetValue cenv)` which has the required type `CgiRef -> String`. Although the implementation of environments can be improved by more sophisticated data structures (e.g., balanced search trees), our practical experience indicates that this simple implementation is sufficient.

10 Conclusions and Related Work

In this paper we have presented a new model for programming web services based on the standard Common Gateway Interface. Since this model is put on top of the multi-paradigm language Curry, we could exploit functional as well as logic programming techniques to provide a high abstraction level for our programming model. We have used functional abstractions for specifying HTML forms as expressions of a specific data type so that only well-formed HTML structures can be written. Furthermore, higher-order functional abstractions are used to attach event handlers to particular HTML elements like buttons and to provide a straightforward access to input values via an environment model. Since event handlers can be nested, we have a direct support to define sequences (or sessions) of interactions between the client and the server where states or input values of previous forms are available in subsequent interactions. This overcomes the stateless nature of HTTP. On the other hand, the logical features of Curry are used to deal with references to input values in HTML forms. Since a form can have an arbitrary number of input values, we consider them as "holes" in an HTML expression which are filled by the user so that event handlers can access these values through an environment. Using logical variables to refer to input values seems more appropriate than the use of strings as in raw HTML since some errors (e.g., mispelled names) are detected at compile time.

Since Curry has more features than used in the examples of this paper, we shortly discuss the advantages of using them. Curry subsumes logic programming, i.e., it offers not only logical variables but also built-in search facilities and constraint solving. Thus, one can easily provide web services where constraint solving and search is involved (e.g., web services with a natural language interface), as shown in the (purely logic-based) PiLLoW library [2]. Since event handlers must be deterministic functions, the encapsulation of search in Curry [8] becomes quite useful for such kind of applications. Furthermore, Curry exploits the logic programming features to support concurrent and distributed programming by the use of port constraints [5]. This can be used to retrieve information from other Internet servers (as done in the web pages for Curry to generate the members of the Curry mailing list[7] where the web server interacts with a database server) or to coordinate the access to data stored on a web server by a Linda-like coordination model, which is easily implementable with these features [5].

Finally, we compare our approach with some other proposals for providing a higher level for web programming than the raw CGI. MAWL [12] is a domain-specific language for programming

[7] `http://www.informatik.uni-kiel.de/~curry`

web services. In order to allow the checking of well-formedness of HTML documents, in MAWL documents are written in HTML with some gaps that are filled by the server before sending the document to the client. Since these gaps are filled only with simple values, the generation of documents whose structure depends on some computed data is largely restricted. To overcome this restriction, MAWL offers special iteration gaps which can be filled with list values but more complex structures, like unbounded hierarchical structures (as shown in Section 8), are not supported in contrast to our approach. On the positive side, MAWL has a special (imperative) language to support the handling of sequences of interactions with traditional imperative control structures and the management of state variables. However, the programming model is different than ours. In MAWL the presentation of an HTML document is considered as a remote procedure call in the sequence of interaction statements. Therefore, there is exactly one program point to continue the handling of the client's answer where our model allows several event handlers that can be called inside one document (see the form `revdup` in Section 4).

The restrictions of MAWL to create dynamic documents have been weakened in DynDoc [15] that supports higher-order document templates, i.e., the gaps in a document can be filled with other documents that can also contain gaps. Thus, unbounded hierarchically structured documents can be easily created. On the negative side, DynDoc concentrates on the creation of well-formed documents and does not support the programming of interaction sequences or the handling of states.

Similarly to our library-based approach, there are also libraries to support HTML and CGI programming in other functional and logic languages. Meijer [13] has developed a CGI library for Haskell that defines a data type for HTML expressions together with a wrapper function that translates such expressions into a textual HTML representation. However, it does not offer any abstraction for programming sequences of interactions. These must be implemented in the traditional way by choosing strings for identifying input fields, passing states as hidden input fields etc. Similarly, the representation of HTML documents in Haskell proposed by Thiemann [17] concentrates only on ensuring the well-formedness of documents and do not support the programming of interactions. Nevertheless, his approach is interesting since it demonstrates how a sophisticated type system can be exploited to include more static checks on the document structure, in particular, to check the validity of the attributes assigned to HTML elements. Hughes [11] proposes a generalization of monads, called arrows, to deal with sequences of interactions and passing state in CGI programming but, in contrast to our approach, his proposal does not contain specific features for dealing with references to input fields. The PiLLoW library [2] is an HTML/CGI library for Prolog. Due to the untyped nature of Prolog, static checks on the form of HTML documents are not supported. Furthermore, there is no higher-level support for sequences of interactions.

Since the programming model proposed in this paper needs no specific extension to Curry, it provides appropriate support to implement web-based interfaces to existing Curry applications. Moreover, it can be considered as a domain-specific language for writing CGI scripts. Thus, this demonstrates that a multi-paradigm declarative language like Curry can also be used as a scripting language for server side web applications. We have shown that the functional as well as the logic features provides a good infrastructure to design such a domain-specific language. The implementation of this library is freely available with our Curry development system PAKCS [7]. All examples in this paper have been tested with this implementation. Furthermore, the library is currently used to dynamically create parts of the web pages for Curry[8] and to handle the submission information for the Journal of Functional and Logic Programming[9].

[8] `http://www.informatik.uni-kiel.de/~curry`

[9] `http://www-i2.informatik.rwth-aachen.de/~hanus/jflp.cgi`

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