Hosting a Standard ML Compiler in a Web Browser

Martin Elsman

SimCorp A/S

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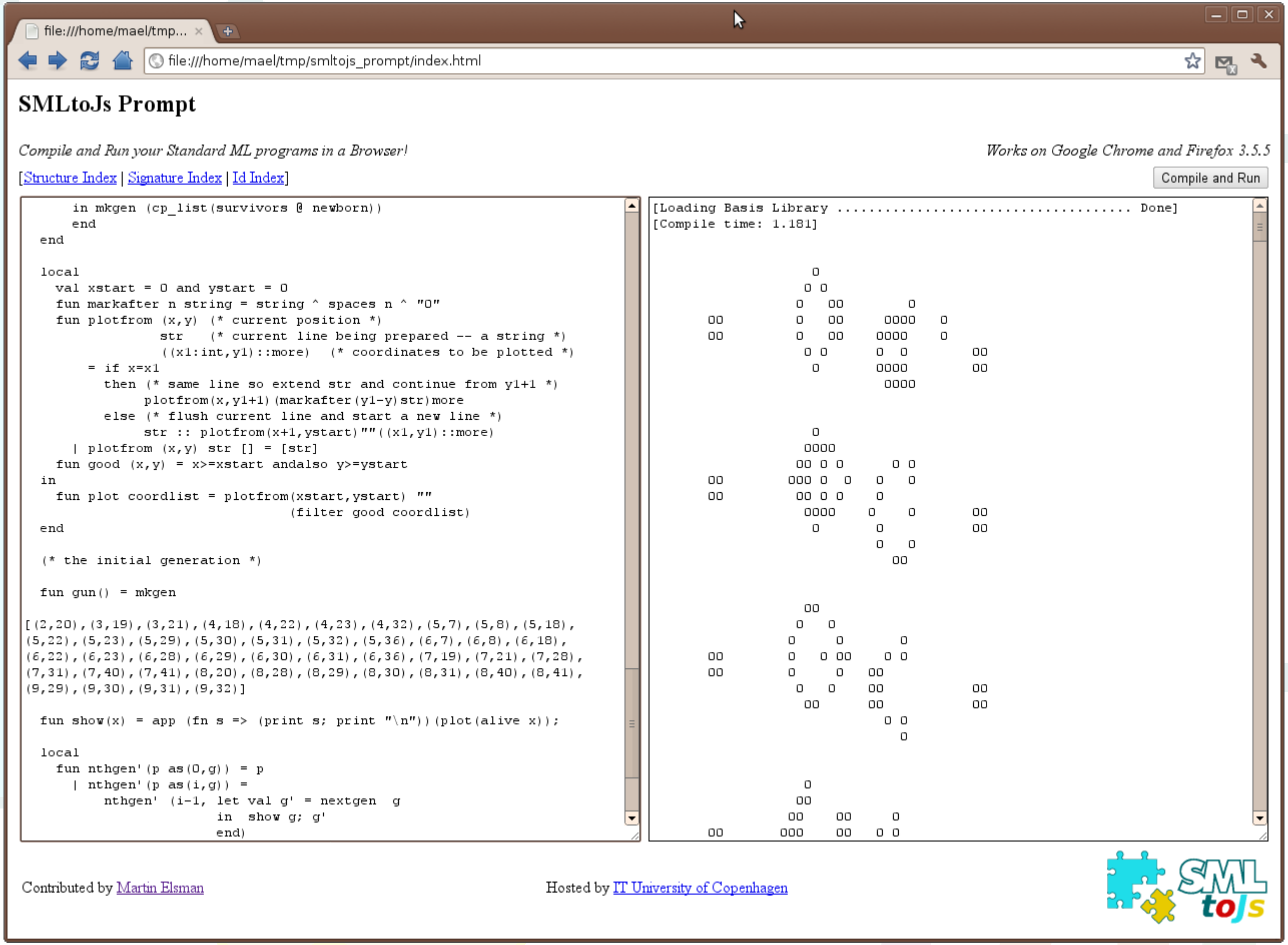
Compiling and Running the Game of Life in a Browser



SMLtoJs Prompt

Compile and Run your Standard ML programs in a Browser!

Works on Google Chrome and Firefox 3.5.5

[Structure Index | Signature Index | Id Index]

```
      in mkgen (cp_list(survivors @ newborn))
      end
  end

  local
    val xstart = 0 and ystart = 0
    fun markafter n string = string ^ spaces n ^ "0"
    fun plotfrom (x,y) (* current position *)
                 str   (* current line being prepared -- a string *)
                 ((x1:int,y1)::more)  (* coordinates to be plotted *)
        = if x=x1
          then (* same line so extend str and continue from y1+1 *)
               plotfrom(x,y1+1)(markafter(y1-y)str)more
          else (* flush current line and start a new line *)
               str :: plotfrom(x+1,ystart)""((x1,y1)::more)
      | plotfrom (x,y) str [] = [str]
    fun good (x,y) = x>=xstart andalso y>=ystart
  in
    fun plot coordlist = plotfrom(xstart,ystart) ""
                                 (filter good coordlist)
  end

  (* the initial generation *)

  fun gun() = mkgen

[(2,20),(3,19),(3,21),(4,18),(4,22),(4,23),(4,32),(5,7),(5,8),(5,18),
(5,22),(5,23),(5,29),(5,30),(5,31),(5,32),(5,36),(6,7),(6,8),(6,18),
(6,22),(6,23),(6,28),(6,29),(6,30),(6,31),(6,36),(7,19),(7,21),(7,28),
(7,31),(7,40),(7,41),(8,20),(8,28),(8,29),(8,30),(8,31),(8,40),(8,41),
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  fun show(x) = app (fn s => (print s; print "\n"))(plot(alive x));

  local
    fun nthgen'(p as(0,g)) = p
      | nthgen'(p as(i,g)) =
          nthgen' (i-1, let val g' = nextgen  g
                        in  show g; g'
                        end)
```

```
[Loading Basis Library ..................................... Done]
[Compile time: 1.181]


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       OO       OOO    OO   O O
```

Contributed by Martin Elsman

Hosted by IT University of Copenhagen

Outline of the Talk

- Motivation for SMLtoJs — A Compiler from Standard ML to Javascript
- SMLtoJs — Inner workings and examples
- The online version of SMLtoJs
  - `http://www.smlserver.com/smltojs_prompt`
- Other uses of SMLtoJs
  - A **Reactive Web Programming** library for SMLtoJs
  - AJAX programming
- Related work

Motivation for SMLtoJs — a Compiler from SML to Javascript

HIGHER-ORDER AND TYPED (HOT) WEB BROWSING:

- Easy development and maintainance of advanced Web browser libraries (e.g., Reactive Web Programming libraries, similar to FlapJax)
- Allow developers to build **AJAX applications** in a HOT language

ALLOW FOR EXISTING CODE TO EXECUTE IN BROWSERS:

- Programs (e.g., SMLtoJs itself — it is itself written in SML)
- Libraries (e.g., The **IntInf** Basis Library module)
- Support all of SML and (almost) all of the SML Basis Library

WEB PROGRAMMING WITHOUT TIERS:

- Allow the same code to run both in the browser and on the server (e.g., complex serialization code)
- AJAX applications using a single language

Features of SMLtoJs

Supports All Browsers:

- SMLtoJs compiles Standard ML programs to Javascript for execution in all main Internet browsers.

Compiles All of Standard ML:

- SMLtoJs compiles **all of SML**, including higher-order functions, pattern matching, generative exceptions, and modules.

Basis Library Support:

- Support for most of the Standard ML Basis Library, including:

  `Array2 ArraySlice Array Bool Byte Char CharArray CharArraySlice`
  `CharVector CharVectorSlice Date General Int Int31 Int32 IntInf`
  `LargeWord ListPair List Math Option OS.Path Pack32Big Pack32Little`
  `Random Real StringCvt String Substring Text Time Timer Vector`
  `VectorSlice Word Word31 Word32 Word8 Word8Array Word8ArraySlice`
  `Word8Vector Word8VectorSlice`
- Additional Libraries: `JsCore Js Html Rwp`

Features of SMLtoJs — continued

JAVASCRIPT INTEGRATION AND DOM ACCESS:

- ML code may **call** Javascript functions and **execute** Javascript statements.
- SMLtoJs has support for **simple DOM access** and for **installing ML functions** as DOM event handlers and timer call back functions.

OPTIMIZING COMPILATION:

- Module constructs, including functors, functor applications, and signature constraints, are **eliminated** at compile time.
- Further optimizations include
  - **Function inlining** and **constant propagation**
  - **Specialization** of higher-order recursive functions (map, foldl)
  - **Tail-call optimization** of so-called *straight tail calls*
  - **Unboxing** of certain datatypes (lists, certain trees, etc.)
- SMLtoJs uses the **MLKit** frontend.

SMLtoJs in Action

EXAMPLE: COMPILING THE FIBONACCI FUNCTION (`fib.sml`):

```
fun fib n = if n < 2 then 1 else fib(n-1) + fib(n-2)
val _ = print(Int.toString(fib 23))
```

RESULTING JAVASCRIPT CODE:

```
var fib$45 =
 function fib$45(n$48){
  if (n$48<2) { return 1; }
  else { return SmlPrims.chk_ovf_i32(
                  fib$45( SmlPrims.chk_ovf_i32(n$48-1) ) +     // Overflow
                  fib$45( SmlPrims.chk_ovf_i32(n$48-2) )       // checking
                ); };
 };
 basis$General$.print$156(basis$Int32$.toString$447(fib$45(23))); // Printing
```

Interfacing with Javascript

- “Native” Javascript code can be executed with **JsCore** module:

```
signature JS_CORE = sig
    type ’a T
    val unit   : unit T
    val int    : int T
    val string : string T
    val fptr   : foreignptr T
    val exec2 : {stmt: string, arg1: string * ’a1 T,
                 arg2: string * ’a2 T, res: ’b T}
                -> ’a1 * ’a2 -> ’b
    ...
end
```

- Phantom types are used to ensure proper interfacing:

```
fun documentWrite d s =
    J.exec2 {stmt="return d.write(s);",
             arg1=("d",J.fptr), arg2=("s",J.string), res=J.unit} (d,s)
```

- SMLtoJs inlines **stmt** if it is known statically; otherwise a **Function object** is created and **stmt** resolved and executed at runtime.

Library for Manipulating the DOM and Element Events

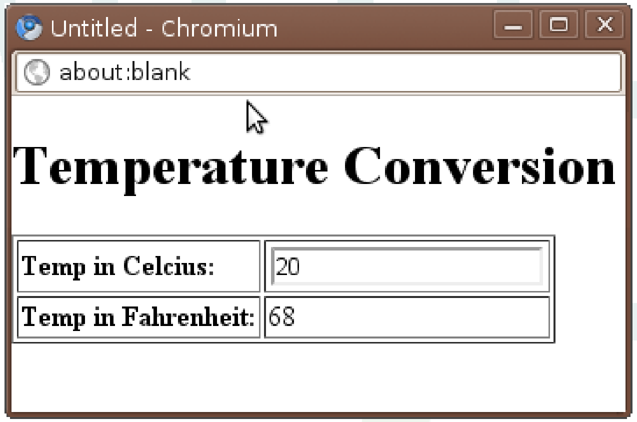
Interaction with the DOM and other Javascript libraries is implemented using the **JsCore** module.

```
signature JS = sig
  eqtype win and doc and elem                            (* dom *)
  val openWindow      : string -> string -> win
  val document        : doc
  val windowDocument  : win -> doc
  val documentElement : doc -> elem
  val getElementById  : doc -> string -> elem option
  val value           : elem -> string
  val innerHTML       : elem -> string -> unit

  datatype eventType  = onclick | onchange              (* events *)
  val installEventHandler : elem -> eventType
                            -> (unit->bool) -> unit
  type intervalId
  val setInterval     : int -> (unit->unit) -> intervalId
  val clearInterval   : intervalId -> unit
  val onMouseMove     : (int*int -> unit) -> unit
  ...
end
```

Example: Temperature Conversion — `temp.sml`

```
val win = Js.openWindow "" "height=200,width=400"
val doc = Js.windowDocument win
val elem = Js.documentElement doc
val _ = Js.innerHTML elem
      ("<html><body><h1>Temperature Conversion</h1>" ^
       "<table border='1'>" ^
       "<tr><th align='left'>Temp in Celcius:</th>" ^
       "<td><input type='text' id='tC'></td></tr>" ^
       "<tr><th align='left'>Temp in Fahrenheit:</th>" ^
       "<td><div id='tF'>?</div></td></tr>" ^
       "</table></body></html>")
fun get id = case Js.getElementById doc id of
      SOME e => e
    | NONE => raise Fail ("Missing id: " ^ id)
fun comp () =
   let val v = Js.value (get "tC")
       val res = case Int.fromString v of
                     NONE => "Err"
                   | SOME i => Int.toString(9 * i div 5 + 32)
   in Js.innerHTML (get "tF") res; false
   end
val () = Js.installEventHandler (get "tC") Js.onchange comp
```



Temperature Conversion

Temp in Celcius:	20
Temp in Fahrenheit:	68

The Inner Workings of SMLtoJs (no tail calls)

- SMLtoJs compiles SML to Javascript through an **MLKit** IL.
- SML **reals**, **integers**, **words**, and **chars** are implemented as Javascript **numbers** with explicit checks for overflow.
- SML **variables** are compiled into Javascript **variables**.
- SML **functions** are compiled into Javascript **functions**:

$$[\![\textbf{fn}\ x \Rightarrow e]\!]_{\text{exp}} \;=\; \textbf{function}(x)\{[\![e]\!]_{\text{stmt}}\}$$

- SML **variable bindings** compiles to JS **function applications**:

$$[\![\textbf{let val}\ x\ \textbf{=}\ e\ \textbf{in}\ e'\ \textbf{end}]\!]_{\text{exp}} \;=\; \textbf{function}(x)\{[\![e']\!]_{\text{exp}}\}([\![e]\!]_{\text{exp}})$$

- When compilation naturally results in a Javascript statement, the statement is converted into an expression:

$$\frac{[\![e]\!]_{\text{stmt}} \;=\; \textit{stmt}}{[\![e]\!]_{\text{exp}} \;=\; \textbf{function}()\{\textit{stmt};\}()}$$

Optimizing Straight Tail Calls

- A *straight tail call* is a tail call to the nearest enclosing function with a tail call context containing no function abstractions.
- Example SML code:

```
fun sum (n,acc) = if n <= 0 then acc else sum (n-1,acc + n)
val _ = print (Int.toString (sum (10000,0)))
```

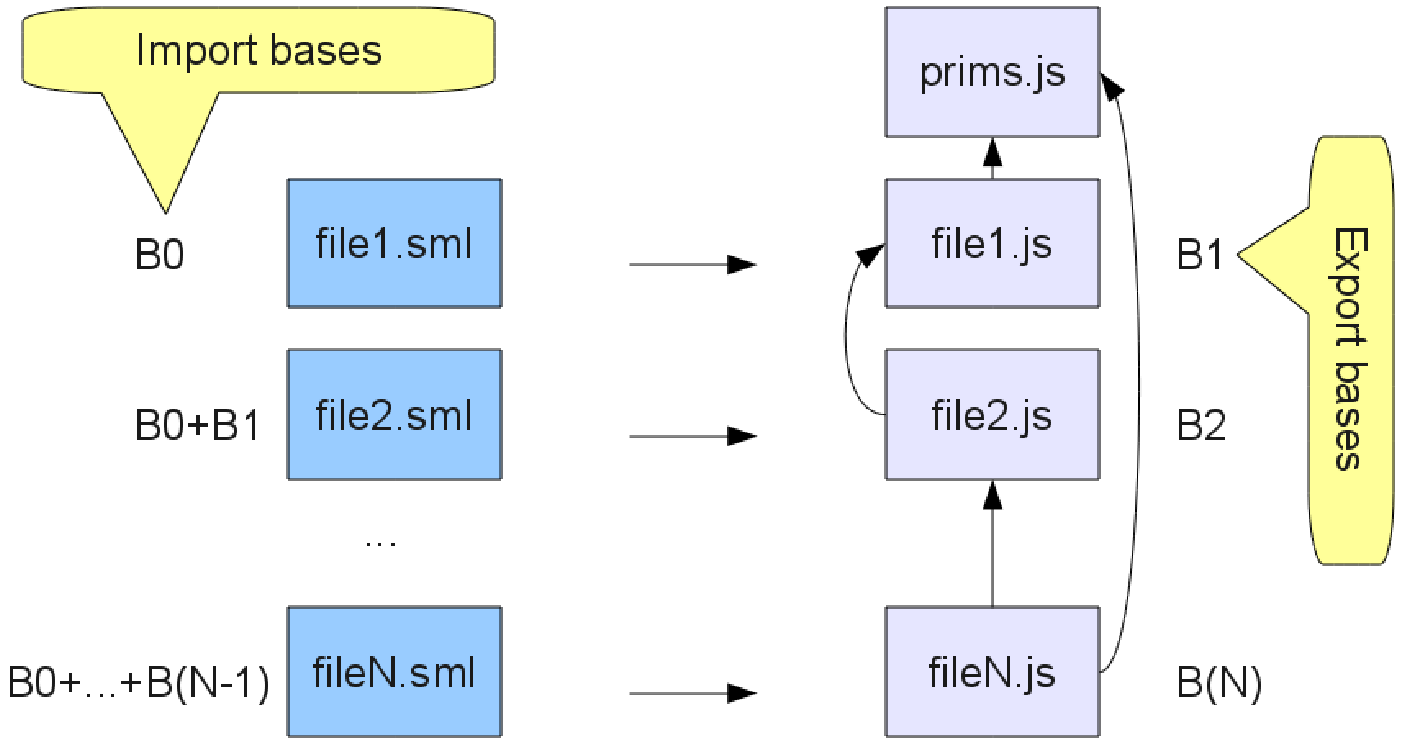
- Generated Javascript code:

```
var sum$45 = function(v$54,v$55) {
  lab$sum:
  while (true) {
     if (v$54 <= 0) { return v$55; }
     else { var t$89 = SmlPrims.chk_ovf_i32(v$54 - 1);
            var t$90 = SmlPrims.chk_ovf_i32(v$55 + v$54);
            var v$54 = t$89;
            var v$55 = t$90;             // Argument reassignment
            continue lab$sum; };
  };
};
basis$General$.print$156(basis$Int32$.toString$449(sum$45(10000,0)));
```

- No major browser implements tail calls efficiently and the ECMAScript Specification (ano 2009) says nothing about tail calls!

Composing Javascript Fragments

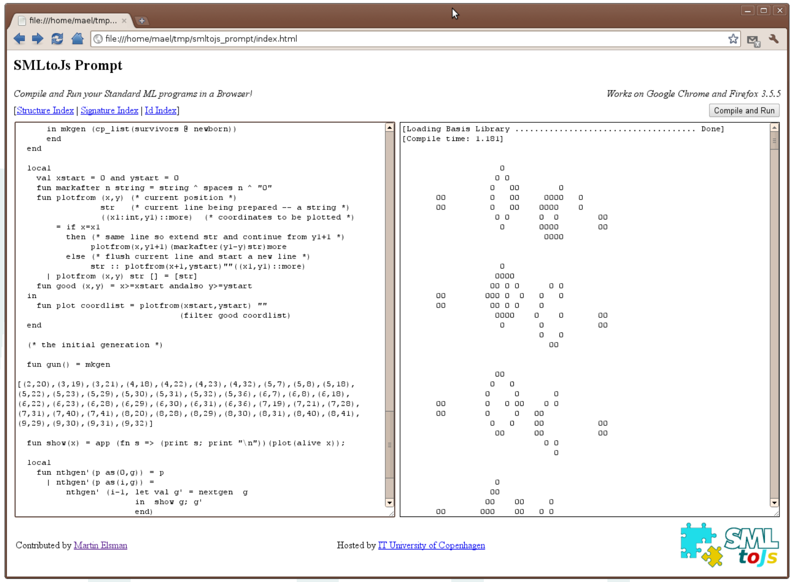
- Compilation of an **sml-file** or an **mlb-file** (a project) results in an **html-file** that loads a series of **js-scripts**.



- Basis library files are precompiled and availble to user programs without recompilation (by reading export bases).

Hosting SMLtoJs in a browser

- Compile SMLtoJs sources, including code for a **read-eval loop**, with offline version of SMLtoJs.
- During offline compilation, arrange that export **bases for the basis library are serialized**, written into Javascript strings, and stored in js-script files.



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```

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- Once a browser visits the SMLtoJs online site, the export bases for the basis library are loaded and deserialized.

NOTICE:

- The serialization and deserialization code is used both by the offline SMLtoJs compiler (when serializing) and by the online SMLtoJs compiler (when deserializing).

Benchmarks — Running Times

	Firefox*	Chromium*	Native**
fib35	36.65	3.93	0.69
kkb	25.94	2.75	0.28
life	12.34	1.15	0.48
simple	88.01	6.66	0.85

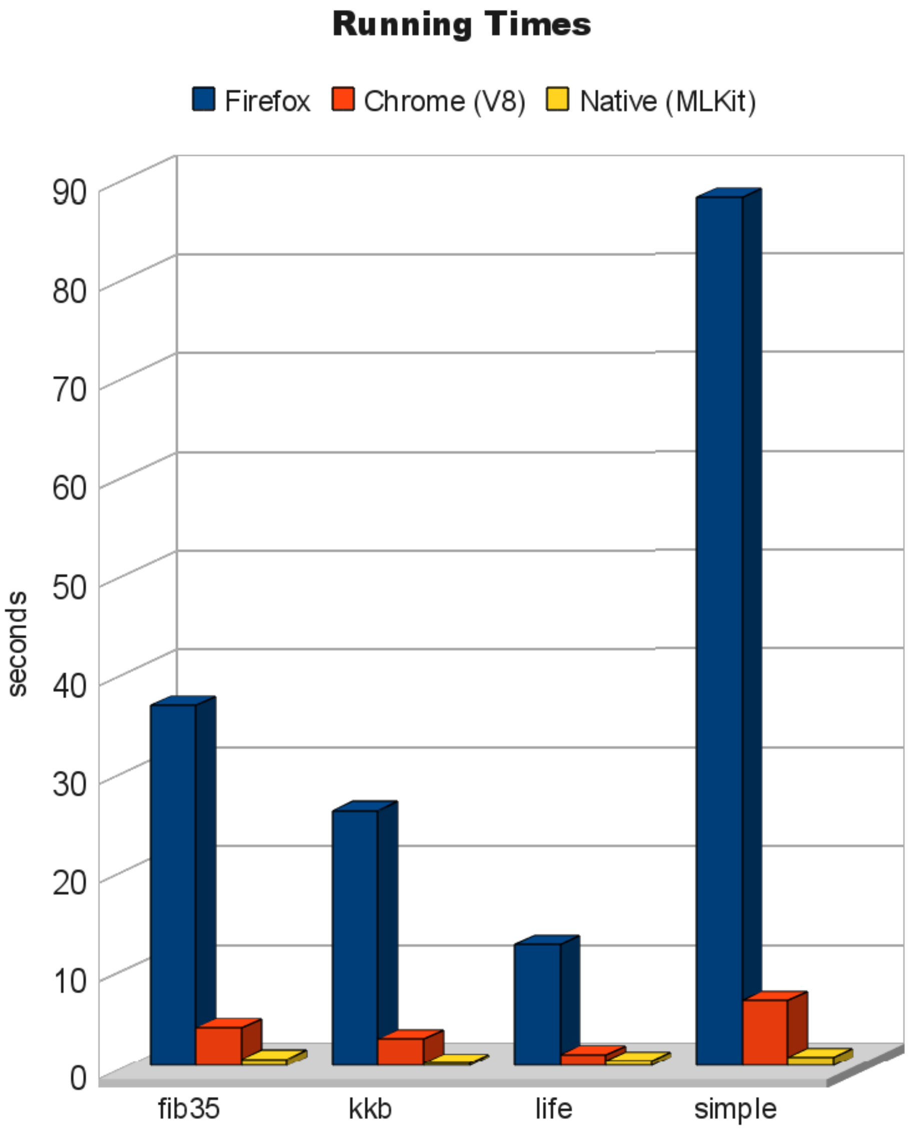
(*) Running in the browser.

(**) Running in an OS shell.

Measurements done on a Thinkpad T42, 1GB RAM, Ubuntu 10.04.

Firefox version 3.6.10.

Chromium version 6.0.472.53.

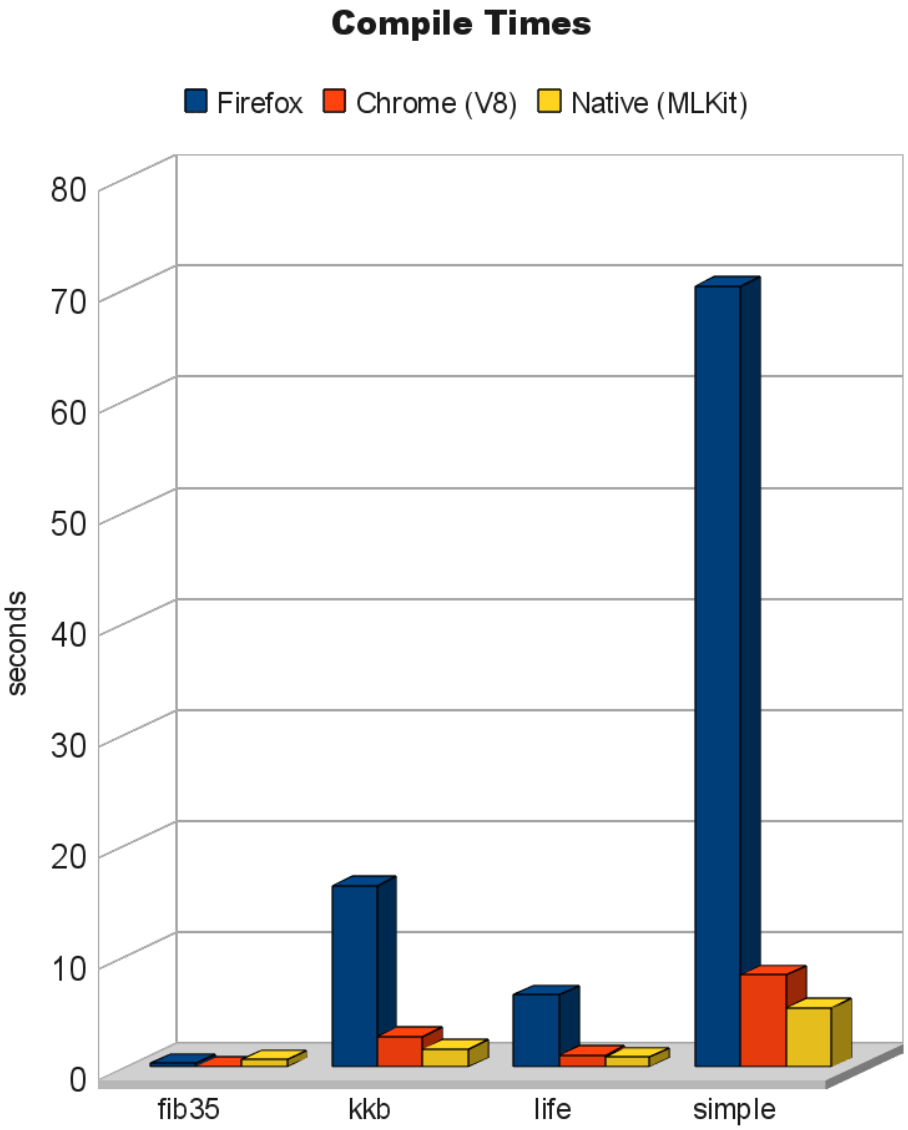


Benchmarks — Compile Times

	Firefox*	Chromium*	Native
fib35	0.29	0.04	0.64
kkb	16.27	2.70	1.59
life	6.47	1.04	0.85
simple	70.23	8.24	5.29

	Lines of Code
fib35	7
kkb	617
life	211
simple	1064

(∗) Compilation in the browser.



Other Uses (and Possible Uses) of SMLtoJs

REACTIVE WEB PROGRAMMING (RWP):

- Replace the DOM event handler architecture with library support for **behaviors** and **event streams**.
- Allow behaviors to be installed directly in the DOM tree.

TYPE-SAFE AJAX PROGRAMMING:

- By integrating SMLtoJs with **SMLserver**, for server-side Web programming, a service API (a signature) may be implemented natively on the server and as a PROXY on the client.
- The two implementations may make use of the **same signature** file, which facilitates **cross-tier type-safety**.
- The two tiers may communicate data using low- bandwidth serialization implemented in only one language.

Reactive Web Programming (RWP)

REACTIVE WEB PROGRAMMING:

- A **behavior** denotes a value that may change over time:

```
open Rwp
val t : Time.time b =
   timer 100  (* time updated every 100ms *)
```

- An SML function may be lifted to become a behavior **transformer**:

```
val bt : Time.time b -> string b =
   arr (Date.toString o Date.fromTimeLocal)
```

- Behaviors of type **string b** may be installed in the DOM tree:

```
val _ = print ("<html><body><h2>Time: <span id='time'>?"
               ^ "</span></h2></body></html>")
val _ = insertDOM "time" (bt t)
```

- **Example behaviors**: mouse position, time, form field content.
- An **event stream** is another RWP concept — mouse clicks...

John Hughes' Arrows — A Generalisation of Monads

REACTIVE WEB PROGRAMMING IS BASED ON ARROWS:

```
signature ARROW = sig
  type ('b,'c,'k) arr
  (* basic combinators *)
  val arr : (''b -> ''c) -> (''b,''c,'k) arr
  val >>> : (''b,''c,'k)arr * (''c,''d,'k)arr -> (''b,''d,'k)arr
  val fst : (''b,''c,'k)arr -> (''b*''d,''c*''d,'k)arr
  (* derived combinators *)
  val snd : (''b,''c,'k)arr -> (''d*''b,''d*''c,'k)arr
  val *** : (''b,''c,'k)arr * (''d,''e,'k)arr -> (''b*''d,''c*''e,'k)arr
  val &&& : (''b,''c,'k)arr * (''b,''d,'k)arr -> (''b,''c*''d,'k)arr
end
```

NOTICE:

- The ARROW signature specifies combinators for creating **basic** arrows and for **composing** arrows.
- Specifically, we model **behavior transformers** and **event stream transformers** as arrows.
- The **'k**'s are instantiated either to **B** (behavior) or to **E** (events).

The Rwp library: Building Basic Behaviors and Event Streams

```
signature RWP = sig
  type B type E (* kinds: Behaviors (B) and Events (E) *)
  type (’a,’k)t
  type ’a b = (’a, B)t
  type ’a e = (’a, E)t
  include ARROW where type (’a,’b,’k)arr = (’a,’k)t -> (’b,’k)t
  val timer     : int -> Time.time b
  val textField : string -> string b
  val mouseOver : string -> bool b
  val mouse     : unit -> (int*int) b
  val pair      : ’’a b * ’’b b -> (’’a * ’’b) b
  val merge     : ’’a e * ’’a e -> ’’a e
  val delay     : int -> (’’a,’’a,B)arr
  val calm      : int -> (’’a,’’a,B)arr
  val fold      : (’’a * ’’b -> ’’b) -> ’’b -> ’’a e -> ’’b e
  val click     : string -> ’’a -> ’’a e
  val changes   : ’’a b -> ’’a e
  val hold      : ’’a -> ’’a e -> ’’a b
  val const     : ’’a -> ’’a b
  val flatten   : ’’a b b -> ’’a b
  val insertDOM : string -> string b -> unit
end
```

Example: Adding the Content of Fields

CODE:

```
open Rwp infix *** &&& >>>

val _ = print ("<h1>Add Content of Fields</h1>" ^
               "<input id=’a’ value=’0’/> + <input id=’b’ value=’0’/>" ^
               " = <span id=’c’>?</span>")

val si_t : (string,int,B)arr = arr (Option.valOf o Int.fromString)

val form = pair( textField "a", textField "b" )

val t = (si_t *** si_t) >>> (arr op +) >>> (arr Int.toString)

val _ = insertDOM "c" (t form)
```

NOTICE:

- `t` takes a behavior of pairs of integers and returns an integer behavior.

Example: Reporting the Mouse Position

CODE:

```
val _ = print ("<h1>Mouse Position</h1>" ^
               "<span id=’mouse0’>?</span><br />" ^
               "<span id=’mouse1’>?</span><br />" ^
               "<span id=’mouse2’>?</span><br />")
val t : (int⋆int,string,B) arr =
  arr (fn (x,y) => ("[" ^ Int.toString x ^ ","
                    ^ Int.toString y ^ "]"))
val bm = mouse()
val t10 : (int⋆int,int⋆int,B) arr =
  arr (fn (x,y) => (x div 10 ⋆ 10, y div 10 ⋆ 10))
val bm2 = (t10 >>> t) bm
val _ = insertDOM "mouse0" (t bm)
val _ = insertDOM "mouse1" (calm 400 bm2)
val _ = insertDOM "mouse2" (delay 400 bm2)
```

NOTICE:

- **calm** waits for the underlying behavior to be stable.
- **delay** transforms the underlying behavior in time.

Implementation Issues

- Behaviors and event streams are implemented using “listeners”:

```
type ('a,'k) t =
     {listeners: ('a -> unit) list ref,
      newValue : 'a -> unit,
      current: 'a ref option}
```

- Behaviors (of type `('a,B)t`) always have a *current* value, whereas event streams do not.
- Installing a behavior b in the DOM tree involves adding a listener to b that updates the element using `Js.innerHTML`.
- The implementations of **calm** and **delay** make use of `Js.setTimeout`.
- The implementation of **textField** makes use of `Js.installEventHandler`.
- The implementation of **mouse** makes use of `Js.onMouseMove`.

Related Work

RELATED COMPILER WORK:

- The Google Web Toolkit project (GWT).
- The SCM2JS project by Loitsch and Serrano.
- The Links project. Wadler et al. 2006.
- The AFAX F# project by Syme and Petricek, 2007.
- O'Browser (ML'08).

RELATED REACTIVE PROGRAMMING WORK:

- The **Flapjax** language and Javascript library by Shriram Krishnamurthi et al.
- John Hughes. Generalising Monads to Arrows. Science of Computer Programming 37. Elsevier 2000.
- The **Fruit** Haskell library by Courtney and Elliott.