What can Scheme learn from JavaScript?

Scheme Workshop 2014

Andy Wingo
Me and Scheme

Guile co-maintainer since 2009

Publicly fumbling towards good Scheme compilers at wingolog.org

Scheme rules everything around me
Me and JS

2011: JavaScriptCore (“JSC”, in Safari) dabbles (failure, mostly)

2012-2013: V8 (Chrome): random little things, generators, iteration

2013-2014: SpiderMonkey (Firefox): generators, iteration, block scope

Currently V8 (destructuring binding)

(Very little JS coding though!)
Scheme precedes JS

Closures

Specification people (brendan, samth, dherman)

Implementors (e.g. Florian Loitsch, Maciej Stachowiak)

Benchmarks (cross-compiled from Scheme!)

Practitioner language (e.g. continuations)
Scheme precedes JS

Hubris
Scheme precedes JS (?)

Hubris (?)
Scheme precedes JS (?)
Hubris (?)
How could JavaScript precede Scheme?
A brief history of JS

1996-2008: slow
2014: fastish
A brief history of JS

1996-2008: slow
2014: fastish
Environmental forcing functions
Visiting a page == installing an app
Cruel latency requirements
Why care about performance?

Expressiveness a function of speed (among other parameters)

Will programmers express idiom $x$ with more or less abstraction?

60fps vs 1fps
Speed limits, expression limits

We sacrifice expressiveness and extensibility when we write fast Scheme

- Late binding vs. inlining
- Mutable definitions vs. static linking
- Top-level vs. nested definitions
- Polymorphic combinators vs. bespoke named let
- Generic vs. specific functions

We are our compilers’ proof assistants, and will restrict the problem space if necessary
Lexical scope: the best thing about Scheme

Precise, pervasive design principle
Scope == truth == proof
Happy relationship to speed
Big closed scopes == juicy chunks for an optimizer to munch on
Lexical scope: the worst thing about Scheme

Limit case of big closed scope: Stalin, the best worst Scheme

We contort programs to make definitions lexically apparent, to please our compilers

With Scheme implementations like JS implementations we would write different programs
JS: speed via dynamic proof

“Adaptive optimization”

A revival of compilation techniques pioneered by Smalltalk, Self, Strongtalk, Java

`expr ifTrue: block`

Inlining key for performance: build sizable proof term

JS contribution: *low-latency* adaptive optimization (fast start)
SpiderMonkey (Firefox)
- Interpreter
- Baseline
- IonMonkey

JavaScriptCore (WebKit, Safari)
- Interpreter
- Baseline
- DFG
- FTL

V8 (Chrome)
- Baseline
- Crankshaft/Turbofan
All about the tiers

“Method JIT compilers”; Java’s HotSpot is canonical comparison

The function is the unit of optimization

Other approaches discussed later; here we focus on method JITs
All about the tiers

Conventional wisdom: V8 needs interpreter
V8 upgrading optimizing compiler
asm.js code can start in IonMonkey / Turbofan; embedded static proof pipeline
Optimizing compiler awash in information

Operand and result types
Free variable values
Global variable values
Sets of values: mono-, poly-, mega-morphic
Optimizations: An inventory

Inlining

Code motion: CSE, DCE, hoisting, sea-of-nodes

Specialization

- Numeric: int32, uint32, float, ...
- Object: Indexed slot access
- String: Cons, packed, pinned, ...

Allocation optimization: scalar replacement, sinking

Register allocation
Dynamic proof, dynamic bailout

Compilation is proof-driven term specialization

Dynamic assertions: the future will be like the past

Dynamic assertion failure causes proof invalidation: abort ("bailout") to baseline tier

Bailout enables static compilation techniques (FTL)
What could Schemers do with adaptive optimization?
Example: fmt

(fmt #f
  (maybe-slashified "foo"
   char-whitespace? #\"))

⇒ "foo"

Hesitation to use: lots of allocation and no inlining

Compare: Dybvig doing static compilation of format
Example: `fmt`

With adaptive optimization there would be much less hesitation

If formatting strings is hot, combinators will be dynamically inlined

Closure allocations: gone

Indirect dispatch: gone

Inline string representation details
Example: Object orientation

CLOSsy or not, doesn’t matter

(define-generic head)
(define-method (head (obj <string>))
  (substring obj 0 1))
(head "hey")
⇒ "h"

Lots of indirect dispatch and runtime overhead
Example: Object orientation

If call site is hot, everything can get inlined
Much better than CLOS: optimization happens at call-site, not at callee

(Inline caches)
Example: Dynamic linking

(define-module (queue)
  #:use-module (srfi srfi-9)
  #:export (head push pop null))

(define-record-type queue
  (push head tail)
  queue?
  (head head)
  (tail pop))

(define null #f)
Example: Dynamic linking

(define-module (foo)
    #:use-module (queue))
(define q (push 1 null))
...

Observable differences as to whether compiler inlines `push` or not; can the user

- re-load the queue module at run-time?
- re-link separately compiled modules?
- re-define the queue type?
Example: Dynamic linking
Adaptive optimization enables late binding
Minimal performance penalty for value-level exports
Example: Manual inlining

```
(define-syntax define-effects
  (lambda (x)
    (syntax-case x ()
      ((_ all name ...) (with-syntax (((n ...) (iota (length #'(name ...))))
        #'(begin
          (define-syntax name
            (identifier-syntax (ash 1 (* n 2))))
          ...
          (define-syntax all
            (identifier-syntax (logior name ...))))))))

(define-effects &all-effects
  &mutable-lexical
  &toplevel
  &fluid
  ...)

Stockholm syndrome!
```
Example: Arithmetic

Generic or specific?

fl+ or fx+?

Adaptive optimizations lets library authors focus on the algorithms and let the user and the compiler handle representation.
Example: Data abstraction

http://mid.gmane.org/
20111022000312.228558C0903@voluntocracy.org

However, it would be better to abstract this:

```
(define (term-variable x) (car x))
(define (term-coefficient x) (cdr x))
```

That would run slower in interpreters. We can do better by remembering that Scheme has first-class procedures:

```
(define term-variable car)
(define term-coefficient cdr)
```
Example: Data abstraction

Implementation limitations urges programmer to break data abstraction

Dynamic inlining removes these limitations, promotes better programs
Example: DRY Containers

Clojure’s iteration protocol versus map, vector-map, stream-map, etc

Generic array traversal procedures (array-ref et al) or specific (vector-ref, bytevector-u8-ref, etc)?

Adaptive optimization promotes generic programming

Standard containers can efficiently have multiple implementations: packed vectors, cons strings
Example: Other applicables

Clojure containers are often applicable:

```
(define v '(a b c))
(v 1) ⇒ b
```

Adaptive optimization makes different kinds of applicables efficient
Example: Open-coding

(define (inc x) (1+ x))
(define + -)
(inc 1) ⇒ ?
Example: Debugging

JS programmers expect inlining...

...but also ability to break on any source location
Example: Debugging

Adaptive optimization allows the system to go fast, while also supporting debugging in production.

Hölzle’s “dynamic de-optimization”: tiering down.
Caveats
Caveats

There are many
Method JITs: the one true way?

Tracing JITs

- Higgs (https://github.com/maximecb/Higgs, experiment)
- TraceMonkey (SpiderMonkey; failure)
- PyPy (mostly for Python; success?)
- LuaJIT (Lua; success)
Use existing VM?

Pycket: Implementation of Racket on top of PyPy (http://www.ccs.neu.edu/home/samth/pycket-draft.pdf)

Graal: Interpreter-based language implementation (“One VM to rule them all”, Würthinger et al 2013)
Engineering effort

JS implementations: heaps of C++, blah

To self-host Scheme, decent AOT compiler also needed to avoid latency penalty (?)

No production self-hosted adaptive optimizers (?)
Polymorphism in combinators

Have to do two-level inlining for anything good to happen

$$(\text{fold } (\text{lambda } (a \ b) (+ a b)) \ 0 \ l)$$

$\Rightarrow (\text{let } lp ((l \ l) \ (\text{seed} \ 0))$

$\quad (\text{if } (\text{null? } l) \ \text{seed}$

$\quad \quad (lp \ (\text{cdr } l)$

$\quad \quad \quad ((\text{lambda } (+ a b) (+ a b))$

$\quad \quad \quad \quad (\text{car } l)$

$\quad \quad \quad \quad \text{seed})))))$

$\Rightarrow (\text{let } lp ((l \ l) \ (\text{seed} \ 0))$

$\quad (\text{if } (\text{null? } l) \ \text{seed}$

$\quad \quad (lp \ (\text{cdr } l) (+ (\text{car } l) \ \text{seed}))))$$
Polymorphism in combinators

Polymorphism of call-site in fold challenging until fold is inlined into caller

Challenging to HotSpot with Java lambdas

Challenging to JS (Array.prototype.foreach; note SM call-site cloning hack)
Lack of global visibility

JIT compilation not a panacea
Some optimizations hard to do locally

- Contification
- Stream fusion
- Closure optimization

Tracing mitigates but doesn’t solve these issues
Latency, compiled files, macros

One key JS latency hack: lazy parsing/codegen

Scheme still needs an AOT pass to expand macros

Redefinition not a problem in JS; all values on same meta-level

JS doesn’t have object files; does Scheme need them?
Tail calls versus method jits

JS, Java don’t do tail calls (yet); how does this relate to dynamic inlining and method-at-a-time compilation?

How does it relate to contification, loop detection, on-stack replacement?

Pycket embeds CEK interpreter; loop detection tricky
Things best left unstolen

undefined, non-existent property access, sloppy mode, UTF-16, coercion, monkey-patching (or yes?), with, big gnarly C++ runtimes, curly braces, concurrency, ....
Next steps?

For Guile:

✧ Native self-hosted compiler
✧ Add inline caches with type feedback cells
✧ Add IR to separate ELF sections
✧ Start to experiment with concurrent recompilation and bailout

For your scheme? Build-your-own or try to reuse Graal/HotSpot, PyPy, ...?
For users

Dance like no one is watching
Write lovely Scheme!
For implementors
Steal like no one is watching
Add adaptive optimization to your Schemes!
Thanks

wingo@pobox.com
wingo@igalia.com
http://wingolog.org/
@andywingo