

# Language Based Virtual Machines

*... or why speed matters*

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*by Lars Bak, Google Inc*





# Agenda

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- *Motivation for virtual machines*
- *HotSpot*
- *V8*
- *Dart*
- *What I've learned*



# Background

- *25+ years optimizing implementations of Object-oriented programming languages*





# What I Have Worked On

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- *86-91 Beta runtime system*
- *91-94 Self virtual machine and IDE*
- *94-95 Strongtalk virtual machine*
- *95-00 Hotspot JVM \**
- *00-02 Monty JVM \**
- *02-06 OOVM Smalltalk*
- *06-11 V8 JavaScript engine \**
- *11-12 Dart programming platform*



# In Case You Forgot Beta

```
productDescription:
  (# name: @text;
    price: @integer;
    noOfSoldUnits: @integer;
    order:
      (# orderDate: @date;
        c: ^customer;
        print:<
          (#
            do name[] -> puttext;
            'Price: '->puttext; price -> putint; ' '->put;
            ' No of units sold: '->puttext;
            noOfSoldUnits->putint; ' '->put;
            orderDate.print;
            C.print;
            inner
          #)
        #)
      #);
```



# Why Language Based VMs

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- *Platform independent execution*
- *Sandboxing*
- *Optimization can take place at runtime*
- *Debugging is possible in production*
- *Loading of third part code at runtime*



# VM Side Effect

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- *When the VM gets faster*
  - *Existing programs run faster*
  - *Programmers get space for innovation*



# The Origin of Hotspot

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- *The Self Project, 1989-1995*
  - *Research from Stanford University and Sun Microsystems Labs. Inc.*
  - *Groundbreaking adaptive compilation technology*
  - *Efficient memory management*
  - *Managed by David Ungar and Randall B. Smith*
  - *... but was space traded for speed?*



# The Startup

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- *Longview Technologies, 1994-1997*
  - *David Griswold, Gilad Bracha, Urs Hoelzle, Robert Griesemer, Steffen Grarup, Srdjan Mitrovic, and me*
  - *Startup acquired by Sun 1997*



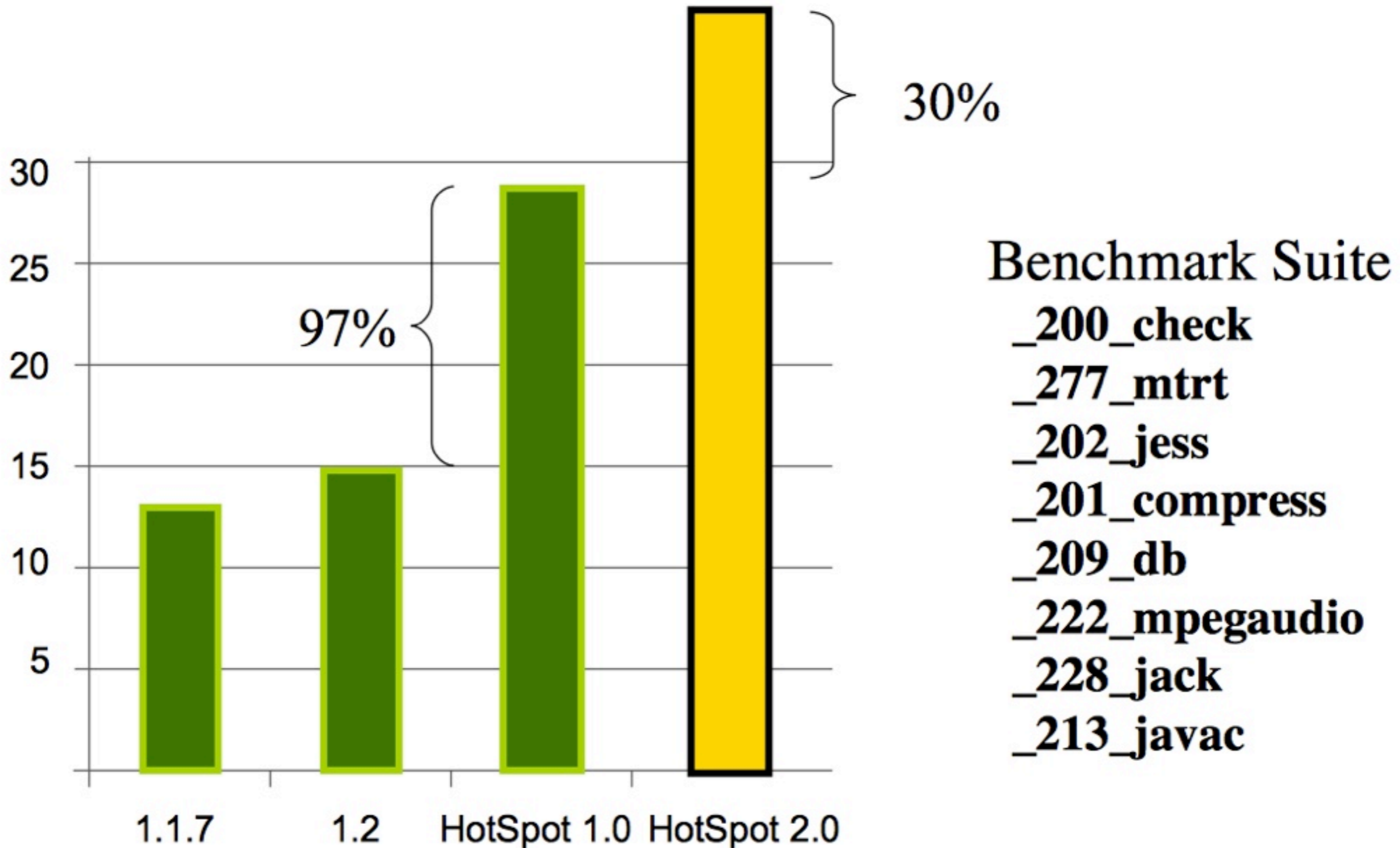
# Hotspot

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- *Technology*
  - *Based on the Strongtalk VM internals*
  - *Interpreter + simple JIT*
  - *Generational GC*
  - *Fast synchronization*
  - *First implemented with cooperative threads*



# SPEC jvm98 [www.spec.org/jvm98](http://www.spec.org/jvm98)



Pentium II 400Mhz with 128Mb memory running Windows NT



# Hotspot Still Going Strong

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- *After 17 years, Hotspot is still an active project*
- *Caveat: I left the Java world 10 years ago*



# Hotspot Reflections

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- *Conservative collectors hide problems*
  - *JSR bytecode caused int/pointer slots*
  - *Raw pointers are likely to leak*
- *Allowing virtual behavior on heap objects from C++ is problematic*
  - *'this' subject to GC*
- *Bug-tail for multi-threaded execution is long*



# V8: A JavaScript Engine

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- *Hired by Google in fall 2006 to improve performance of JavaScript*
- *Matched strategy for Chrome*
  - *Simple, secure, and fast*



# V8 Targets

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- *Make JavaScript 10 times faster*
- *Enable JavaScript apps to scale*
- *Open source the project*
- *Raise the industry performance bar*



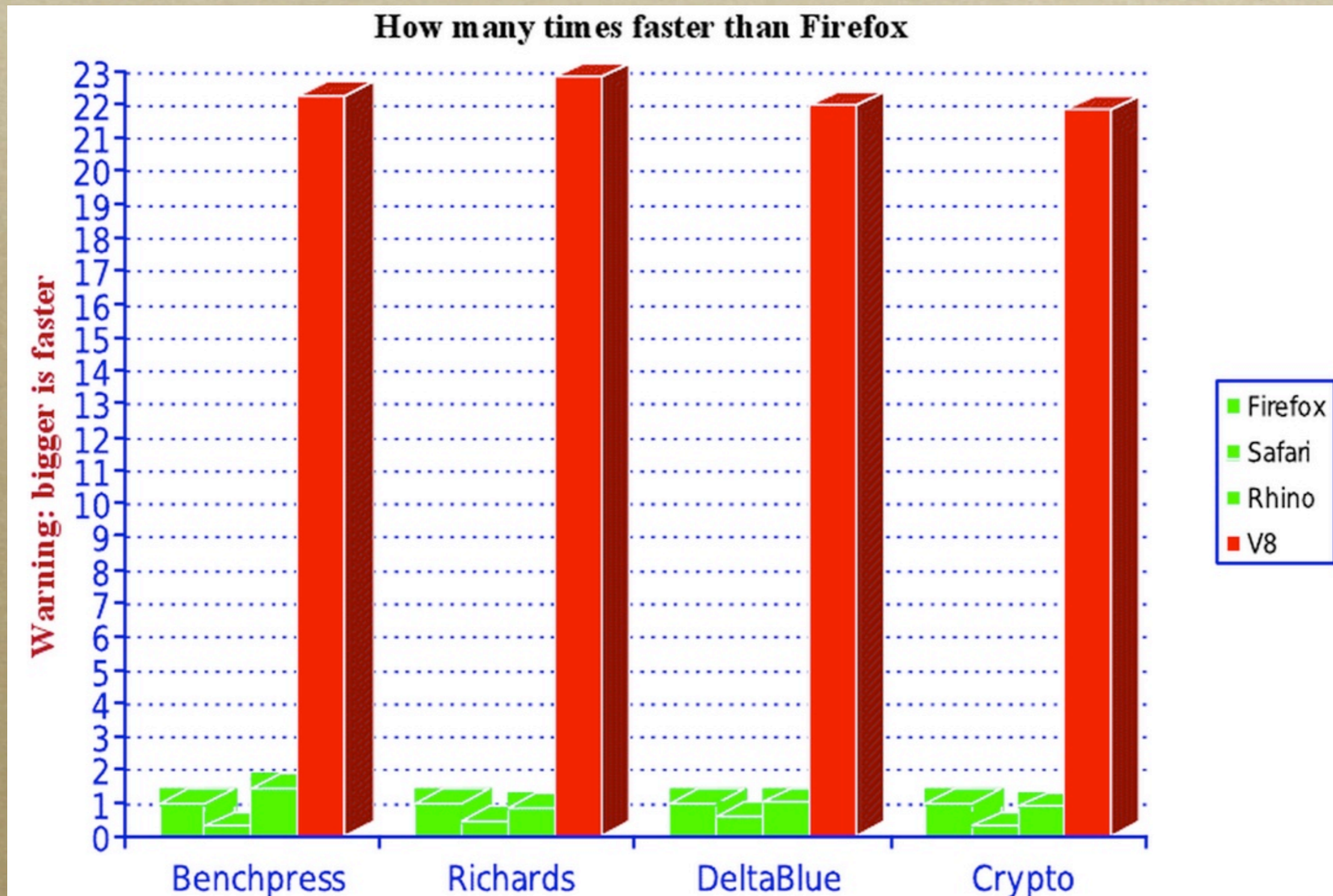
# The Ideas Behind V8

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- *Introduced map transitions*
  - *to allow for standard optimizations*
- *Direct from source to machine code*
- *Efficient garbage collection*



# Progress After 4 Months





# Benchmarking

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- *Sunspider suite*
  - *Hardly any object allocations*
  - *Hardly any property accesses and calls*
  - *A non OO micro-benchmark*



# V8 Benchmark Suite

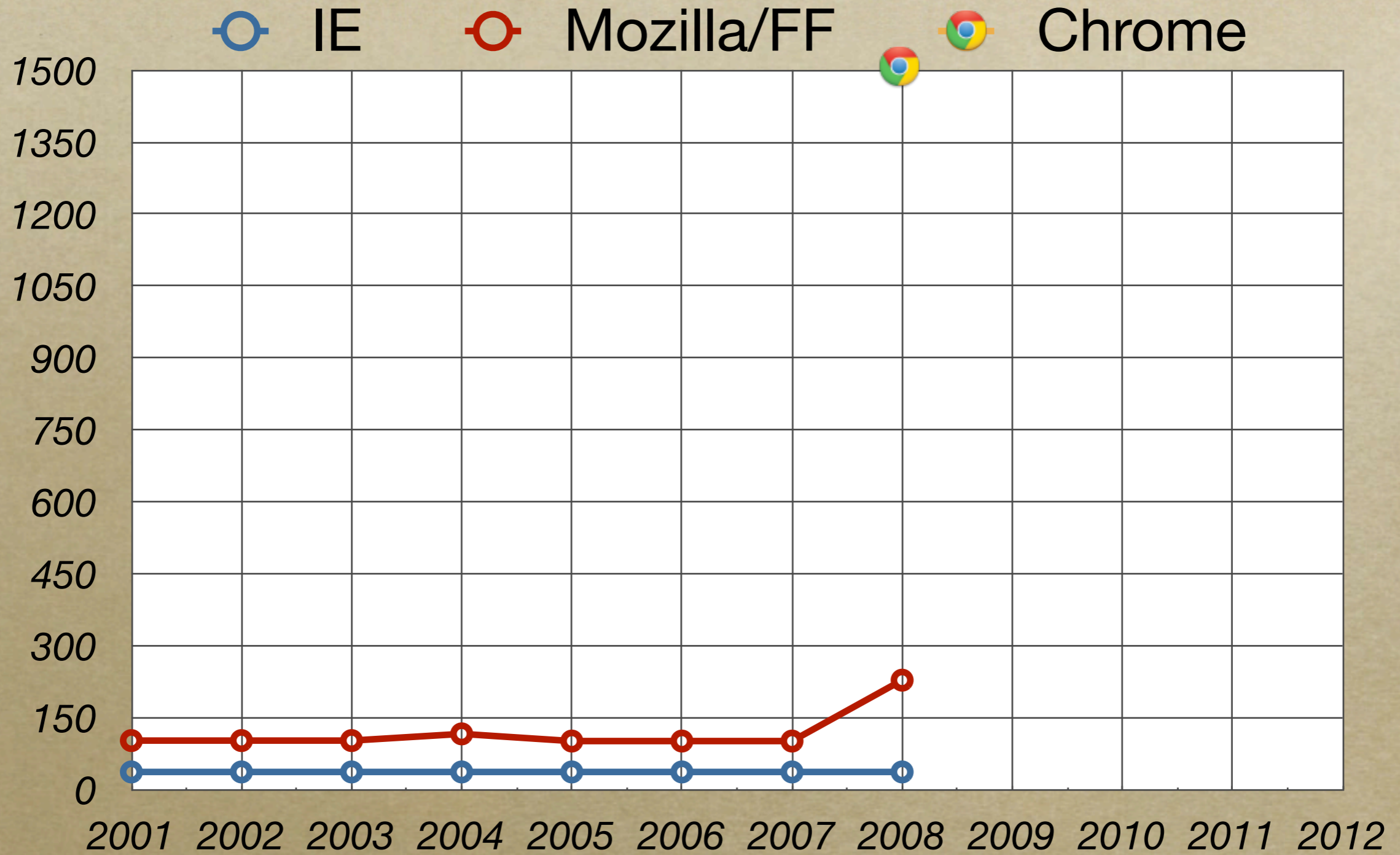
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- *Richards*
- *DeltaBlue*
- *Crypto*
- *RayTrace*
- *EarleyBoyer*
- *RegExp*
- *Splay*
- *NavierStokes*



# JavaScript Performance Timeline

(V8 benchmark v3 - higher is better)

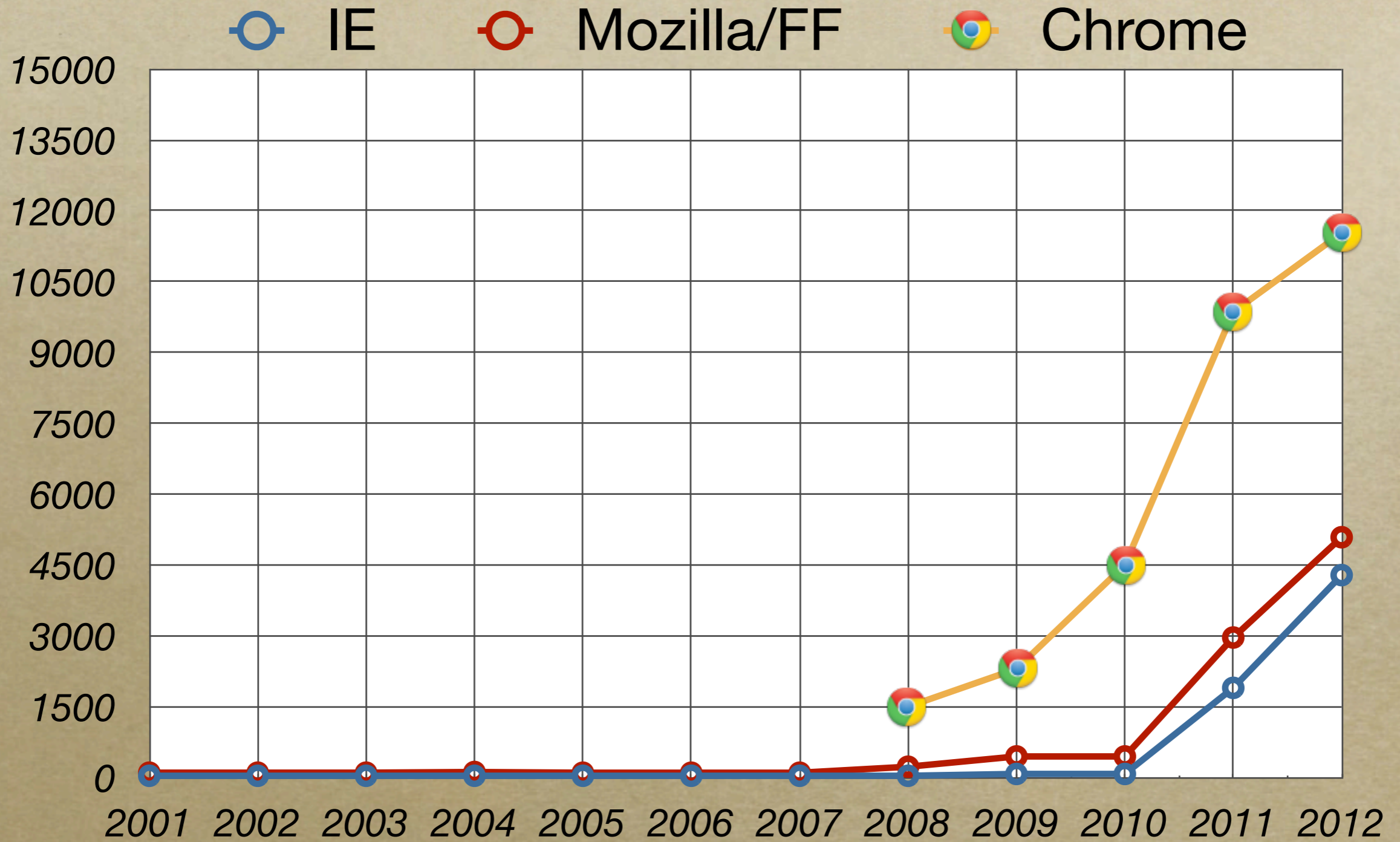


by Jim Hugunin



# JavaScript Performance Timeline

(V8 benchmark v3 - higher is better)



by Jim Hugunin

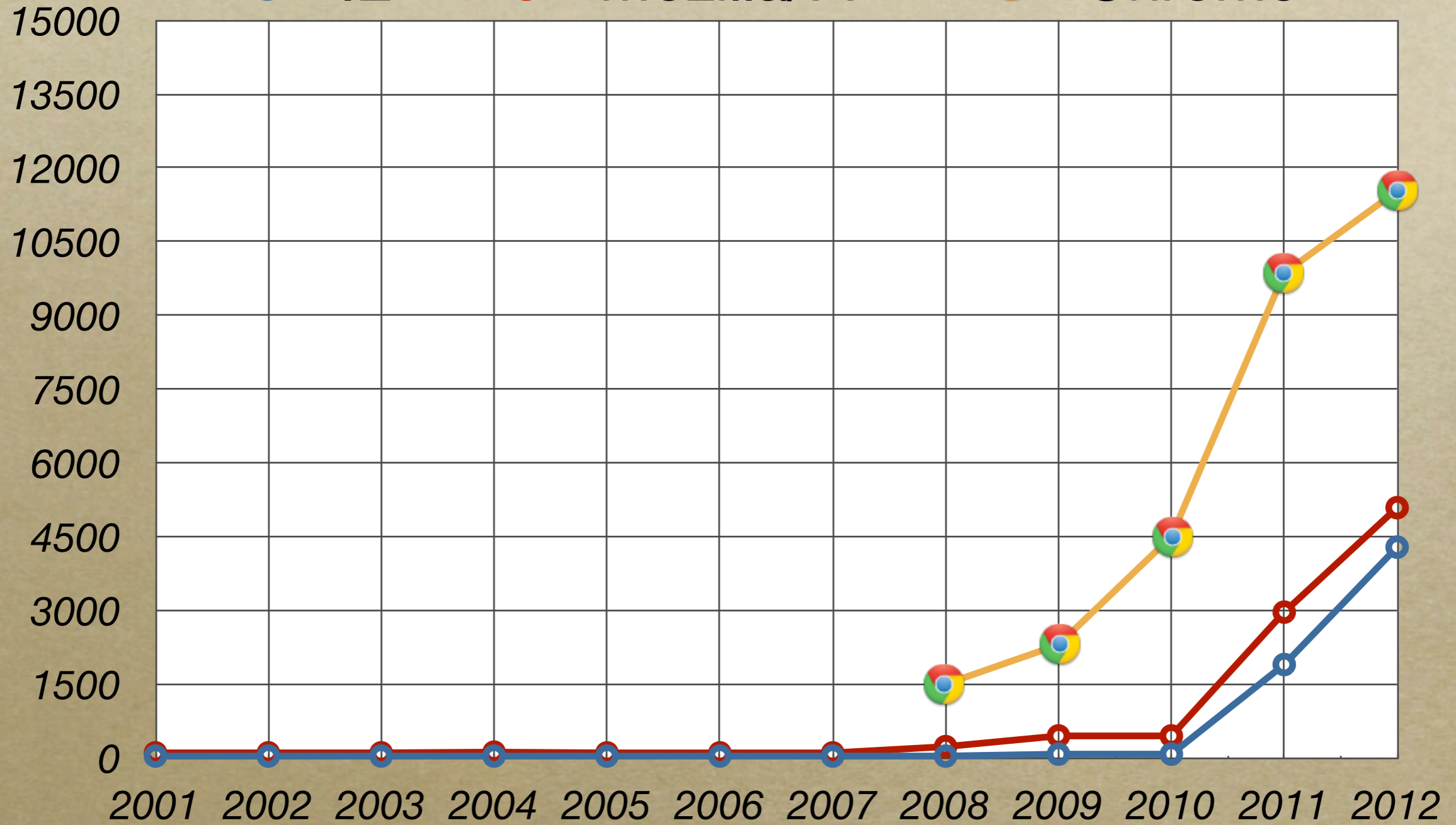


# JavaScript Performance Timeline

(V8 benchmark v3 - higher is better)

Note: Scale shifted by 10x

○ IE      ○ Mozilla/FF      🌐 Chrome



by Jim Hugunin

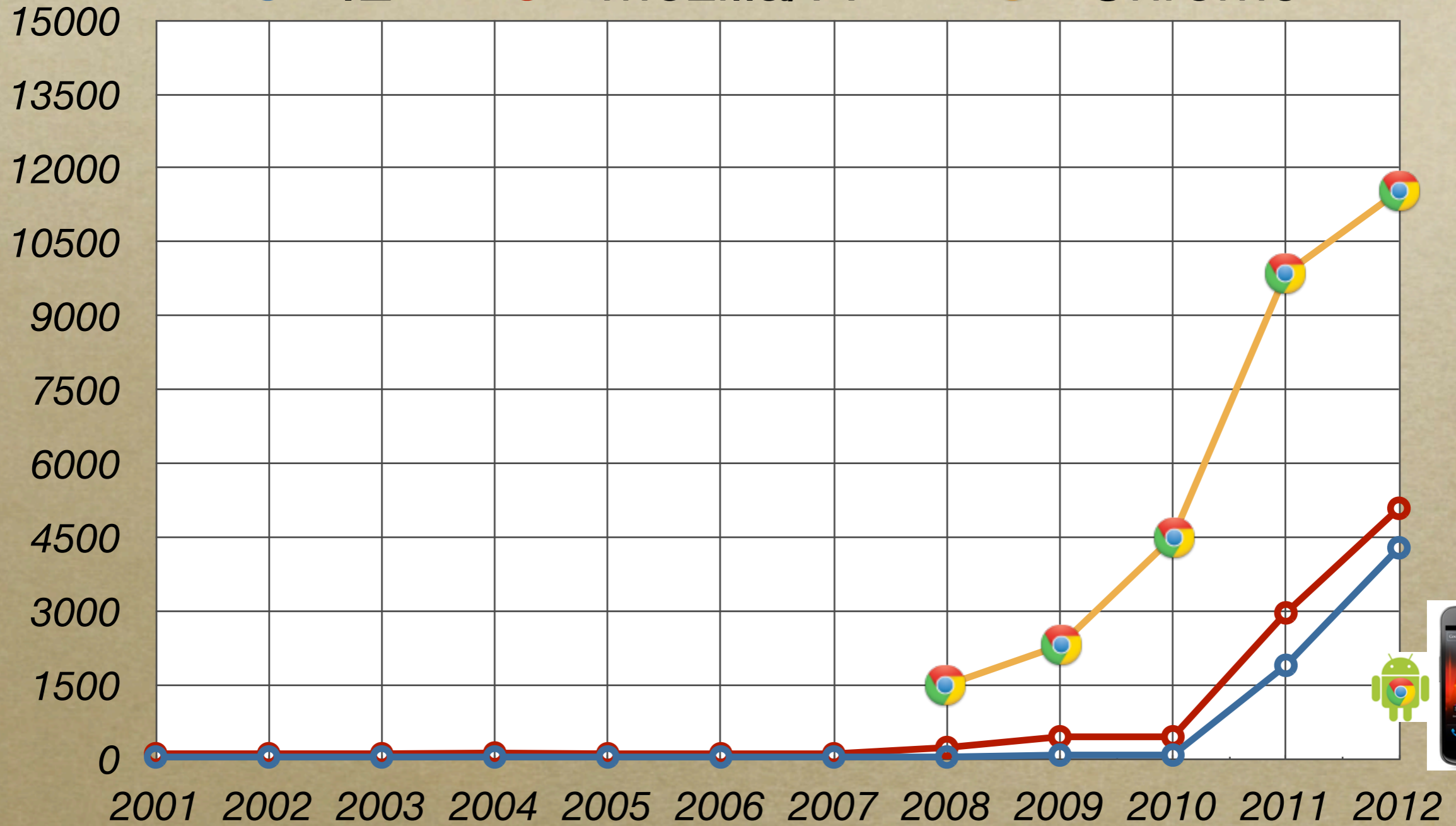


# JavaScript Performance Timeline

(V8 benchmark v3 - higher is better)

Note: Scale shifted by 10x

○ IE      ○ Mozilla/FF      🌐 Chrome



by Jim Hugunin



# Speed Enables Applications

The screenshot shows the Google+ homepage. At the top is the Google+ logo and navigation icons. Below it, there are sections for "People in your circles (17)", "People who've added you (17)", "Find and Invite (0)", and "Selected (3)". A "Sort by: Relevance" dropdown is visible. A grid of user profile cards follows, including Paul Dupree, Nathan Garcia, Lauren Thompson, Erika Nansen, Courtney Wilson, Brett Glider, Bill Crosby, Arlene Garcia, Alexander Kenine, Eileen Alvarez, Devin Sandroz, Becca, and Anne Meriwether. Below the grid is a YouTube search bar. On the left, there are two circular buttons: "Drop here to create a new circle" and "Friends 6". The main content area features a video player for the movie "Warrior" with the text "FROM THE DIRECTOR OF 'MIRAGE'", "TOM HARDY JOEL EDGERTON WARRIOR IN THEATERS SEPTEMBER 9", "WHAT DO YOU FIGHT FOR?", "I FIGHT FOR LOVE", and "SUBMIT YOUR STORY". Below the video is a call to action: "Join the largest worldwide video-sharing community!" with "Create Account" and "Sign In" buttons. The bottom section is categorized into "Music", "Entertainment", and "Sports", each with a grid of video thumbnails and titles.

The screenshot shows a Google Hangouts video chat interface. The main window displays a large video of a woman with dark hair smiling. Below her is a horizontal strip of smaller video thumbnails for other participants. At the bottom, there is a control bar with icons for "Invite", "Chat", "YouTube", "Mute Video", "Mute Mic", "Settings", and "Exit".

The screenshot shows a YouTube channel page. At the top, it says "YouTube Creators Go To School!". Below that is a description: "Meet the inaugural class of the YouTube Creator Institute. Learn more about how you can improve your content creation skills. Presented by: creators". The page features a list of video thumbnails with titles and view counts, including "Re-introductions: It's Gonna Be a Thing", "Time Lapse Acrylic Painting of 'Amber Night'. T...", "Joe vs. The Occult", "My Favorite Youtubers Pt WHEEZY WAITER", and "Trends".



# Using V8

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- *Chrome web browser*
- *Android web browser*
- *node.js (server side JavaScript)*
- *Web OS*



# Using V8

---

- *Chrome web browser*
- *Android web browser*
- *node.js (server side JavaScript)*
- *Web OS*

*Over 11000 revisions since being open sourced*



# V8 Reflections

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- *Map transitions worked much better than expected*
- *Exposing raw pointers in the C++ runtime system was a mistake*
- *JavaScript speed competition is still going strong*



# WAT

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- *Presentation by Gary Bernhardt from CodeMash 2012*



# JavaScript is Now Faster but ...

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- *Promotes spaghetti style programming*
- *Object-oriented programming is hard*
- *Objects can be changed on-the-fly*
- *No support for libraries*
- *Tool support is weak*
- *Slow application startup*
- *Runtime performance is unpredictable*



# The Web is Great

---

- *Developing small applications is easy*
- *Platform independence*
- *No installation of applications*
- *Supports incremental development*



# The Web is Great

---

- *Developing small applications is easy*
- *Platform independence*
- *No installation of applications*
- *Supports incremental development*

*... but innovation is crucial for survival*



# Dart: A New Web Platform

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- *Support for programming in the large*
- *Ultra-fast startup*
- *Predictable performance*
- *Backwards compatibility*



# The Dart Language

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- *A simple and unsurprising OO language*
  - *Class-based single inheritance*
  - *Interfaces with default implementation*
  - *Optional static types*
  - *Real lexical scoping*
  - *Single-threaded*
  - *... and it is readable*



# Designed for a VM

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- *Straight forward semantics*
- *Simple object model*
- *No class initialization*
- *Application are declared*



# Dart Sample

---

```
class Point {
  Point(this.x, this.y);
  var x, y;
  operator +(other) => new Point(x + other.x, y + other.y);
  scale(factor) => new Point(x * factor, y * factor);
  distance() => Math.sqrt(x*x + y*y);
}

main() {
  var a = new Point(10, 10);
  var b = new Point(2, 3).scale(10);
  print("distance=${(a+b).distance()}");
}
```



# Dart Sample With Types

```
class Point {
  Point(this.x, this.y);
  num x, y;
  Point operator +(Point other)
    => new Point(x + other.x, y + other.y);
  Point scale(num factor) => new Point(x * factor, y * factor);
  num distance() => Math.sqrt(x*x + y*y);
}

main() {
  Point a = new Point(10, 10);
  Point b = new Point(2, 3).scale(10);
  print("distance=${(a+b).distance()}");
}
```



# Dart Optional Type System

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- *Static types convey the intent of the programmer*
- *Checkable documentation for code and interfaces*
- *Type annotations have no effect on runtime semantics*
- *Types can be added later*



# Dart Isolates

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- *Erlang inspired execution model*
- *Lightweight units of execution*
- *Nothing is shared - no object locking*
- *All communication takes place via message passing*
- *Supports concurrent execution*



# Dart Components

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- *Programming language with spec.*
- *Libraries*
- *Virtual machine*
  - *Integrated into build of Chrome*
  - *Standalone for server execution*
- *Translator to JavaScript*



# Dart Project

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- *The Dart web site: <http://dartlang.org>*
  - *Dart language specification*
  - *Dart language tutorial*
- *The Dart project: <http://dart.googlecode.com>*
  - *Libraries and code samples*
  - *Dart virtual machine*
  - *Dart-to-JavaScript compiler*
- *Expect beta version of Dart SDK later this year*



# Credits

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- *Object model inspired by **Smalltalk***
- *Compilation strategy inspired by **Self***
- *Optional types inspired by **Strongtalk***
- *Isolates design inspired by **Erlang***
- *Syntax inspired by **JavaScript & C***



# Things I Have Learned

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- *Always start small with a small team*
- *Focus on solving the hardest problem first*
- *Competitive situation fuels motivation*
- *Only hire people that are smarter...*



# Things I Have Learned...

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- *Open source projects work*
  - *Help industry*
  - *Keep your work honest*



# Things I Have Learned...

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- *So far, I have not needed any Scrum, Agile, pair programming, or any other software development methodology*
- *Common sense has been sufficient*



# Things I Have Learned...

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- *Track performance from day one*
  - *Run all benchmarks ...*
  - *on all revisions ...*
  - *on all platforms*



# Things I Have Learned...

---

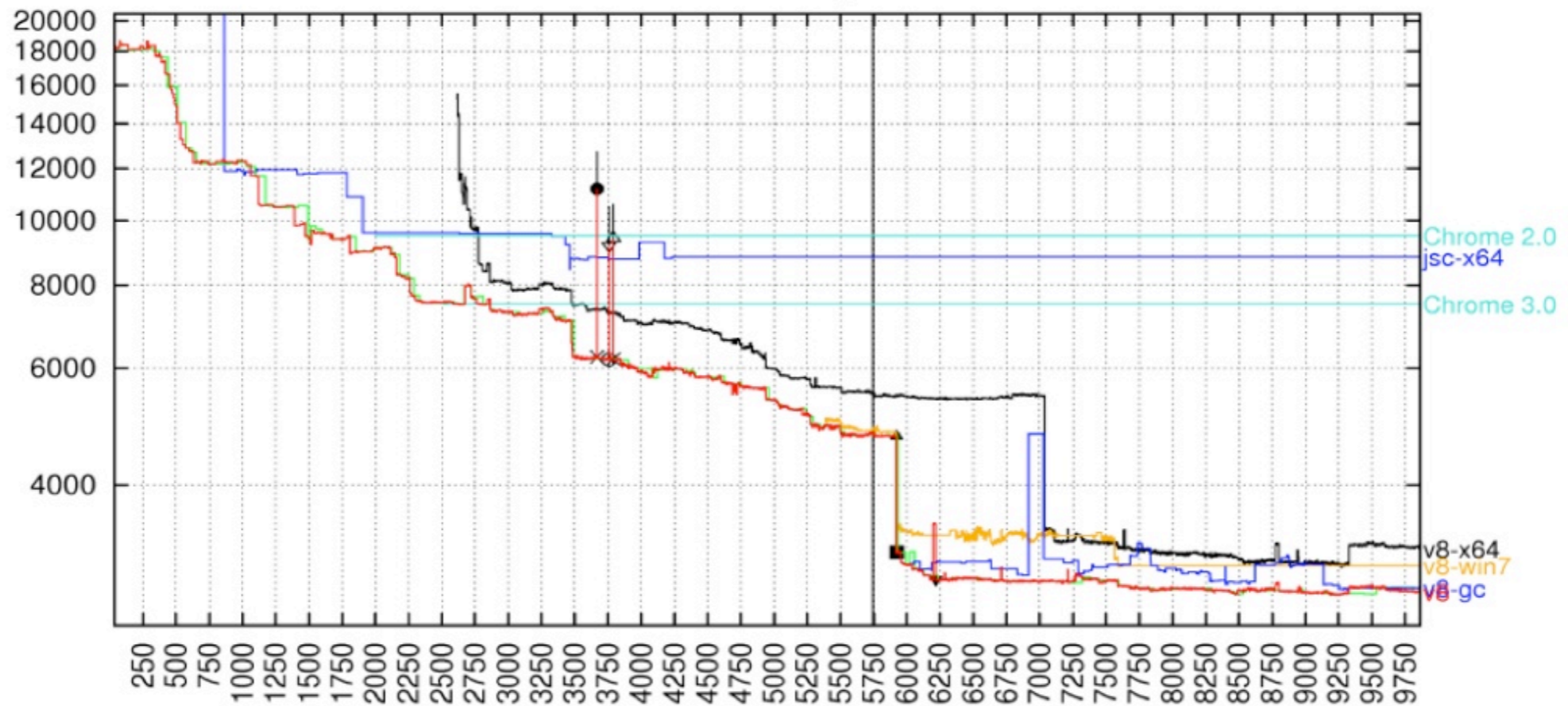
- *Track performance from day one*
  - *Run all benchmarks ...*
  - *on all revisions ...*
  - *on all platforms*

*... if not, performance deteriorates*



# Performance Tracking

## V8BenchmarkSuite-geometric-mean





# Things I Have Learned...

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- *Testing must run from day one*
  - *Execute all tests ...*
  - *for all revisions ...*
  - *on all platforms*



# Things I Have Learned...

---

- *Testing must run from day one*
  - *Execute all tests ...*
  - *for all revisions ...*
  - *on all platforms*

*... if not, quality deteriorates*



# Testing Framework

		Legend: <span>Passed</span> <span>Failed</span> <span>Failed Again</span> <span>Running</span> <span>Exception</span> <span>Offline</span> <span>No data</span>														Personalized for...		Go		
		vm	dart2js	dartc	dart-editor	dartium						firefox	chrome	safari	ie	opera	frog	trunk		
5928	antonm@google.com	<span>Passed</span> <span>Passed</span> <span>Passed</span> <span>Passed</span> <span>Passed</span> <span>Passed</span>	<span>Passed</span> <span>Passed</span> <span>Passed</span> <span>Failed</span>	<span>Passed</span> <span>Passed</span>	<span>Passed</span> <span>Passed</span> <span>Passed</span> <span>Passed</span> <span>Passed</span>	<span>Running</span> <span>Running</span> <span>Running</span> <span>Running</span> <span>Running</span> <span>Running</span> <span>Running</span> <span>Running</span> <span>Running</span> <span>Running</span> <span>Running</span> <span>Running</span> <span>Running</span> <span>Running</span>	<span>Passed</span> <span>Exception</span>	<span>Passed</span> <span>Passed</span> <span>Passed</span> <span>Passed</span>	<span>Passed</span> <span>Passed</span>	<span>Passed</span> <span>Passed</span>	<span>Passed</span> <span>Passed</span>	<span>Passed</span> <span>Passed</span>	<span>Passed</span> <span>Passed</span>	<span>Passed</span> <span>Passed</span>	<span>Passed</span> <span>Passed</span> <span>Passed</span>	<span>Passed</span> <span>Passed</span> <span>Passed</span>	<span>Passed</span>			
Chrome roll 129159->129376.																				
5927	ahe@google.com	<span>Running</span> <span>Passed</span> <span>Passed</span> <span>Passed</span> <span>Passed</span> <span>Passed</span>	<span>Passed</span> <span>Passed</span> <span>Passed</span> <span>Passed</span>	<span>Passed</span> <span>Passed</span>	<span>Passed</span> <span>Failed Again</span> <span>Failed Again</span> <span>Failed Again</span> <span>Failed Again</span>	<span>Running</span> <span>Passed</span> <span>Passed</span> <span>Running</span> <span>Passed</span> <span>Passed</span> <span>Running</span> <span>Passed</span> <span>Passed</span> <span>Passed</span> <span>Passed</span> <span>Passed</span> <span>Passed</span> <span>Passed</span>	<span>Passed</span> <span>Passed</span>	<span>Passed</span> <span>Passed</span> <span>Passed</span> <span>Passed</span>	<span>Passed</span> <span>Passed</span>	<span>Passed</span> <span>Passed</span>	<span>Passed</span> <span>Passed</span>	<span>Passed</span> <span>Passed</span>	<span>Passed</span> <span>Passed</span>	<span>Passed</span> <span>Passed</span>	<span>Passed</span> <span>Passed</span> <span>Passed</span>	<span>Passed</span> <span>Passed</span> <span>Passed</span>	<span>Passed</span>			
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5926	ahe@google.com	<span>Passed</span> <span>Passed</span> <span>Passed</span> <span>Passed</span> <span>Passed</span> <span>Passed</span>	<span>Passed</span> <span>Passed</span> <span>Passed</span> <span>Running</span>	<span>Passed</span> <span>Passed</span>	<span>Failed</span> <span>Failed Again</span> <span>Failed Again</span> <span>Failed Again</span> <span>Failed Again</span>	<span>Running</span> <span>Running</span> <span>Running</span> <span>Running</span> <span>Running</span> <span>Running</span> <span>Running</span> <span>Running</span> <span>Running</span> <span>Running</span> <span>Running</span> <span>Running</span> <span>Running</span> <span>Running</span>	<span>Passed</span> <span>Passed</span>	<span>Passed</span> <span>Passed</span> <span>Passed</span> <span>Passed</span>	<span>Passed</span> <span>Passed</span>	<span>Passed</span> <span>Passed</span>	<span>Passed</span> <span>Passed</span>	<span>Passed</span> <span>Passed</span>	<span>Passed</span> <span>Passed</span>	<span>Passed</span> <span>Passed</span>	<span>Passed</span> <span>Passed</span> <span>Passed</span>	<span>Passed</span> <span>Passed</span> <span>Passed</span>	<span>Passed</span>			
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• dart-editor: annotated_steps - <a href="#">_stdio</a> - <a href="#">preamble</a>																				
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5924	ngeoffray@google.com	<span>Passed</span> <span>Passed</span> <span>Passed</span> <span>Passed</span> <span>Passed</span> <span>Passed</span>	<span>Passed</span> <span>Passed</span> <span>Passed</span> <span>Running</span>	<span>Passed</span> <span>Passed</span>	<span>Passed</span> <span>Failed</span> <span>Failed</span> <span>Failed</span> <span>Failed</span>	<span>Failed</span> <span>Failed</span> <span>Failed</span> <span>Failed</span> <span>Failed</span> <span>Failed</span> <span>Failed</span> <span>Failed</span> <span>Failed</span> <span>Failed</span> <span>Failed</span> <span>Failed</span> <span>Failed</span> <span>Failed</span>	<span>Passed</span> <span>Passed</span>	<span>Passed</span> <span>Passed</span> <span>Passed</span> <span>Passed</span>	<span>Passed</span> <span>Passed</span>	<span>Passed</span> <span>Passed</span>	<span>Passed</span> <span>Passed</span>	<span>Passed</span> <span>Passed</span>	<span>Passed</span> <span>Passed</span>	<span>Passed</span> <span>Passed</span>	<span>Passed</span> <span>Passed</span> <span>Passed</span>	<span>Passed</span> <span>Passed</span> <span>Passed</span>	<span>Passed</span>			
Make sure we have a toString method for native objects. Review URL: <a href="https://chromiumcodereview.appspot.com//9866036">https://chromiumcodereview.appspot.com//9866036</a>																				
<ul style="list-style-type: none"> <li>• dart-editor-win: dart-ide dart clients: dart-editor-win - <a href="#">_stdio</a></li> <li>• dart-editor-mac: dart-ide dart clients: dart-editor-mac - <a href="#">_stdio</a></li> <li>• dart-editor-linux: dart-ide dart clients: dart-editor-linux - <a href="#">_stdio</a></li> <li>• dartium-mac-full: dartium_upload_archive - <a href="#">_stdio</a></li> <li>• dartium-mac-inc: dartium_upload_archive - <a href="#">_stdio</a></li> </ul>																				



# Things I Have Learned...

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- *I'm glad I never caved in and designed a general multi language virtual machine*



# Things I Have Learned...

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- *Technology transfer from research/academia to industry does not happen through osmosis*
- *If you have great ideas, please go do a startup*



# Technical Summary

	<i>Precise GC</i>	<i>Adaptive optimizations</i>	<i>Incremental execution</i>	<i>Multi-threaded</i>	<i>Bytecodes</i>	<i>in C++</i>	<i>Open source</i>
<i>Beta</i>	●						
<i>Self</i>	●	●	●		●	●	●
<i>Strongtalk</i>	●	●	●		●	●	●
<i>Hotspot</i>	●	●		●	●	●	
<i>Monty</i>	●	●			●	●	
<i>OOVM</i>	●		●		●	●	
<i>V8</i>	●	●	●			●	●
<i>Dart</i>	●	●		/		●	●