Google™ 09 I O

V8 Internals

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Agenda

- Why a new JavaScript engine?
- V8 design overview
- V8 internals
  - Hidden classes
  - Inline caching
  - Precise generational garbage collection
- Recent developments
  - Irregexp: new JS regular expression engine
  - New compiler infrastructure
- Object heap scalability
- Performance bottlenecks

Why a New JavaScript Engine?

Why Build a New JavaScript Engine?

- When the development of V8 started, the existing JavaScript engines were slow
  - Interpreters operating on AST or bytecodes
  - Poor memory management with big GC pauses
- High performance JavaScript engines are key to continued innovation for web applications
- Starting from scratch seemed like the best approach
- The goal is to push the performance bar for JavaScript

The Challenge

- JavaScript is a highly dynamic language
- Objects are basically hash maps
- Properties are added and removed on-the-fly
- Prototype chains are modified during execution
- 'eval' can change the calling context
- 'with' introduces objects in the scope chain dynamically

V8 Design Decisions

Design Goals

- Make large object-oriented programs perform well
- Fast property access
- Fast function calls
- Fast and scalable memory mangement

Key V8 Components

- Hidden classes and class transitions
- Compilation to native code with inline caching
- Efficient generational garbage collection

V8 Internals

V8 Memory Model

- 32-bit tagged pointers
- Objects are 4-byte aligned, so two bits available for tagging
- Small 31-bit signed integers are immediate values distinguished from pointers by tags

Small integer	XXXX...XXXX0
Pointer	XXXX...XXX01

- Base JavaScript objects consists of three words

Hidden Class Pointer
Properties Pointer
Elements Pointer

Hidden Classes

- Wanted to take advantage of optimization techniques from statically typed object oriented languages
- Introduced the concept of hidden classes to get there
- Hidden classes group objects that have the same structure

Hidden Classes by Example

- JavaScript objects constructed in the same way should get the same hidden class

```
function Point(x, y) {
  this.x = x;
  this.y = y;
}
var p1 = new Point(0,1);
var p2 = new Point(2,3);
```

Hidden Classes by Example

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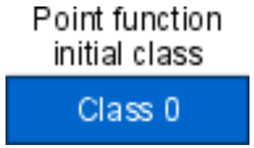

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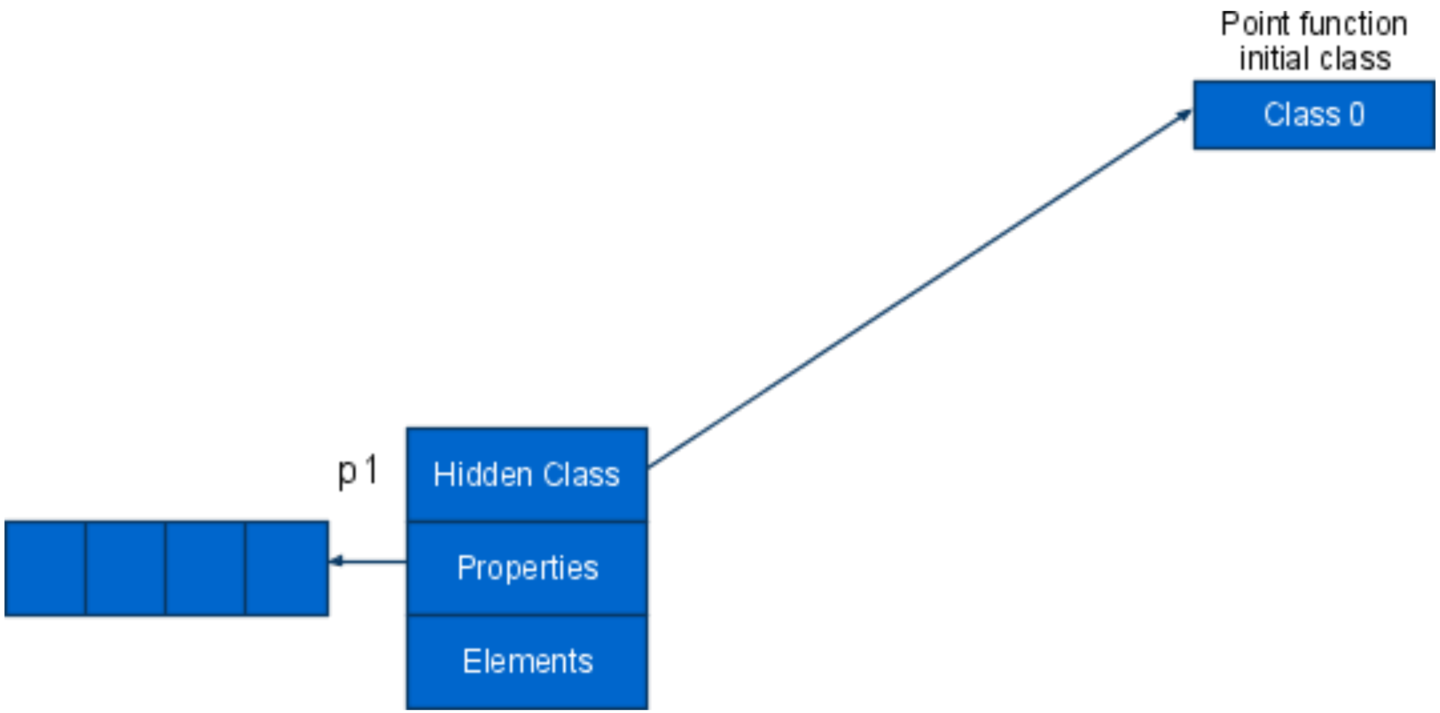

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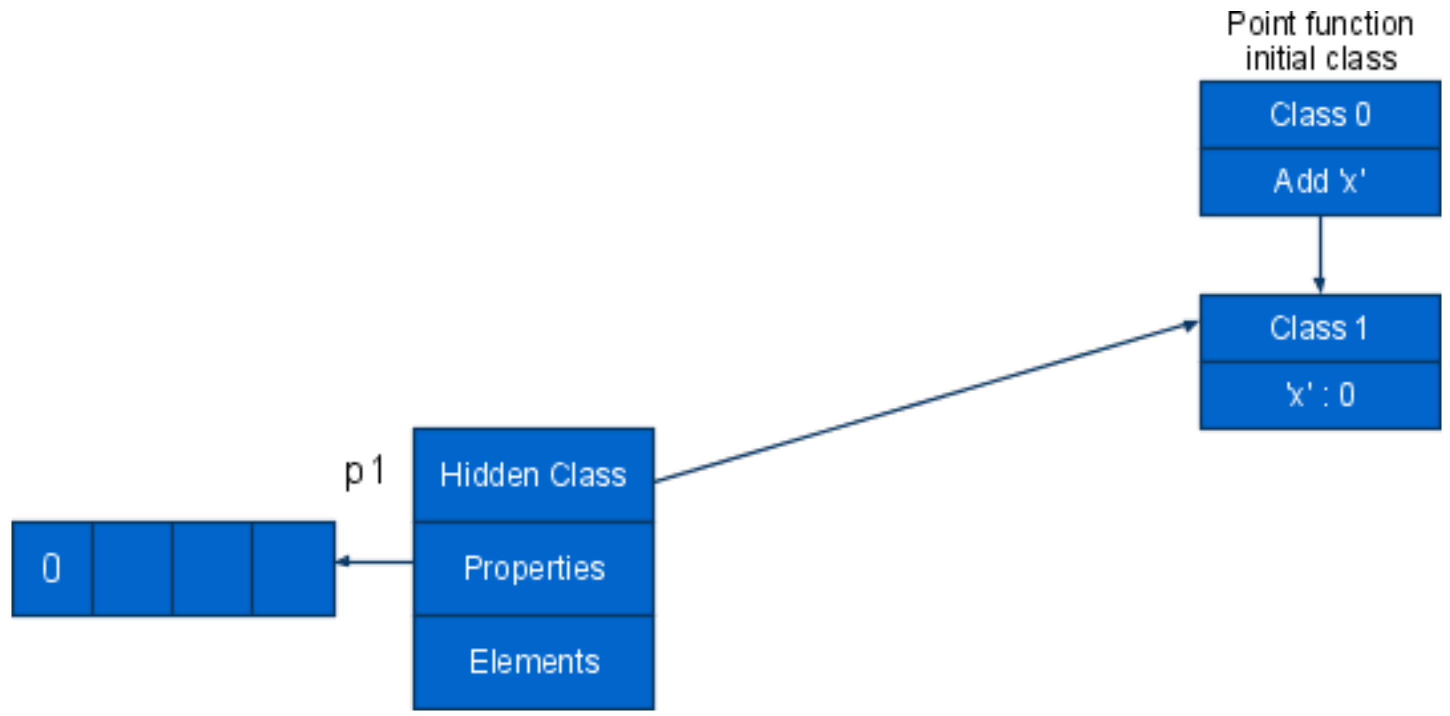

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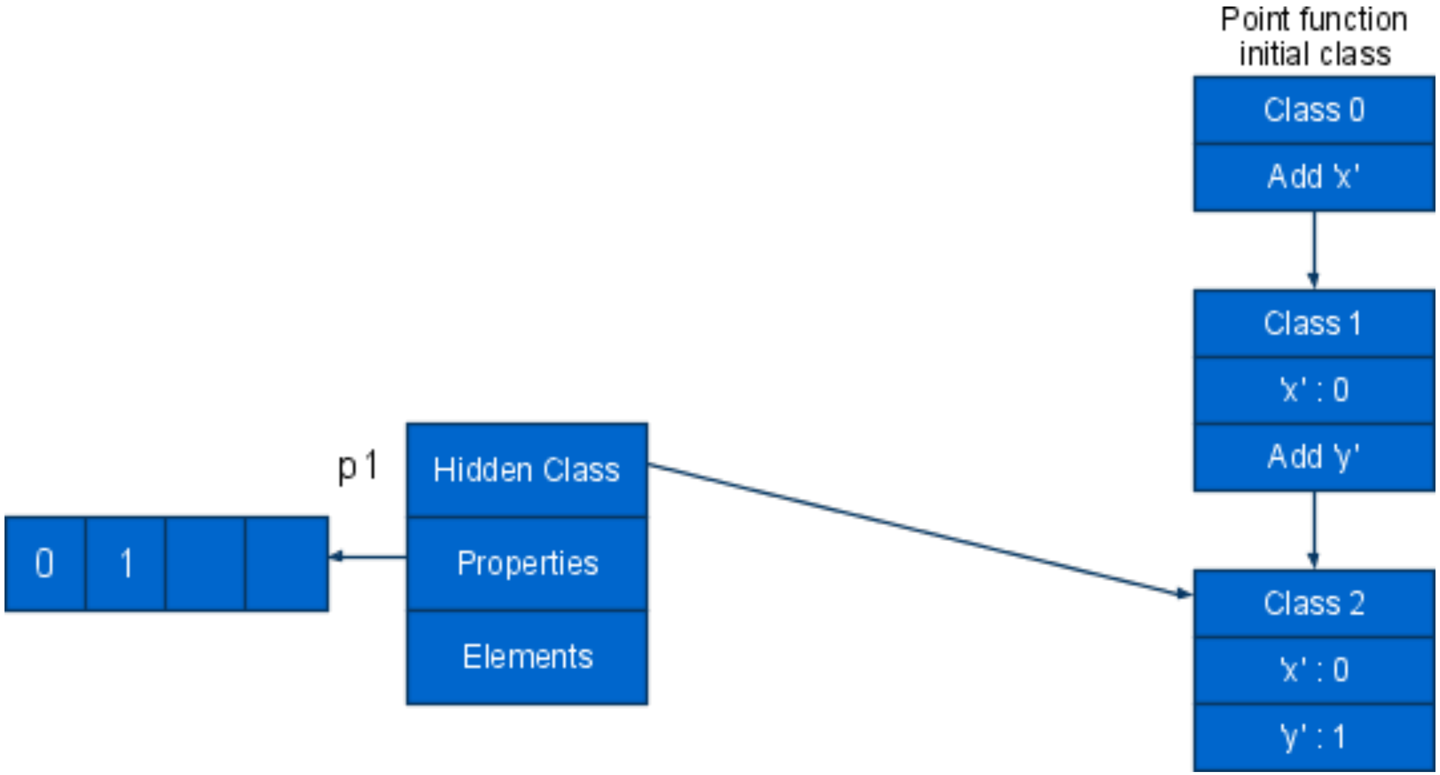

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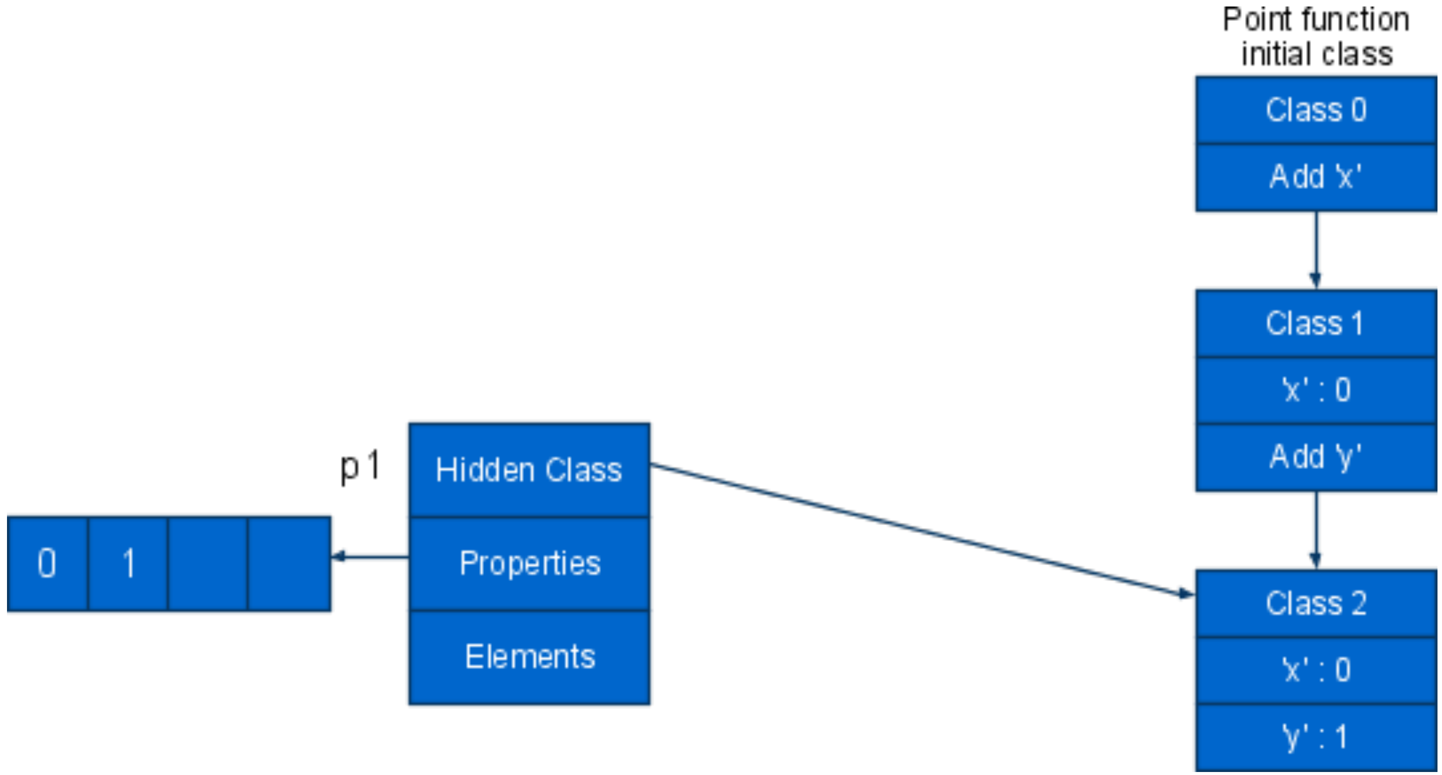

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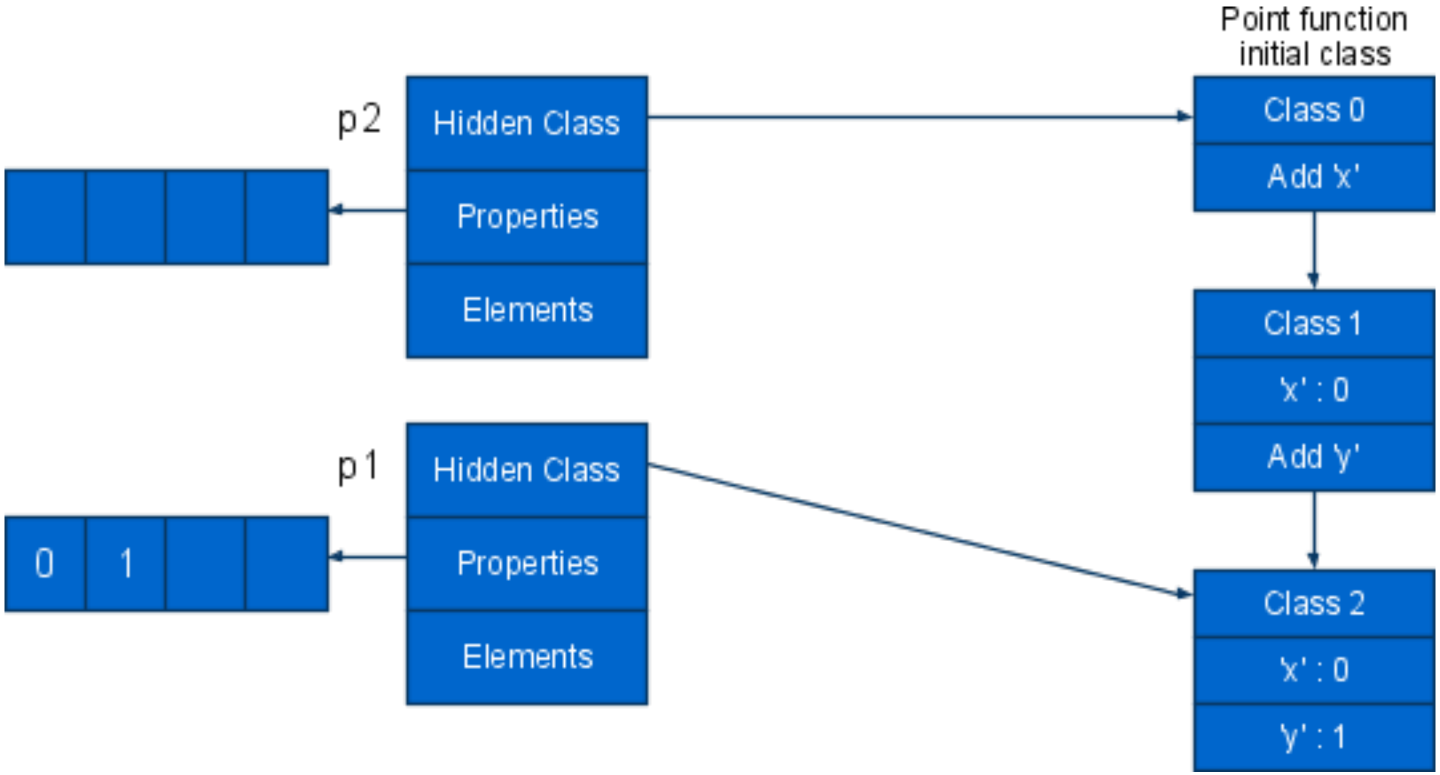

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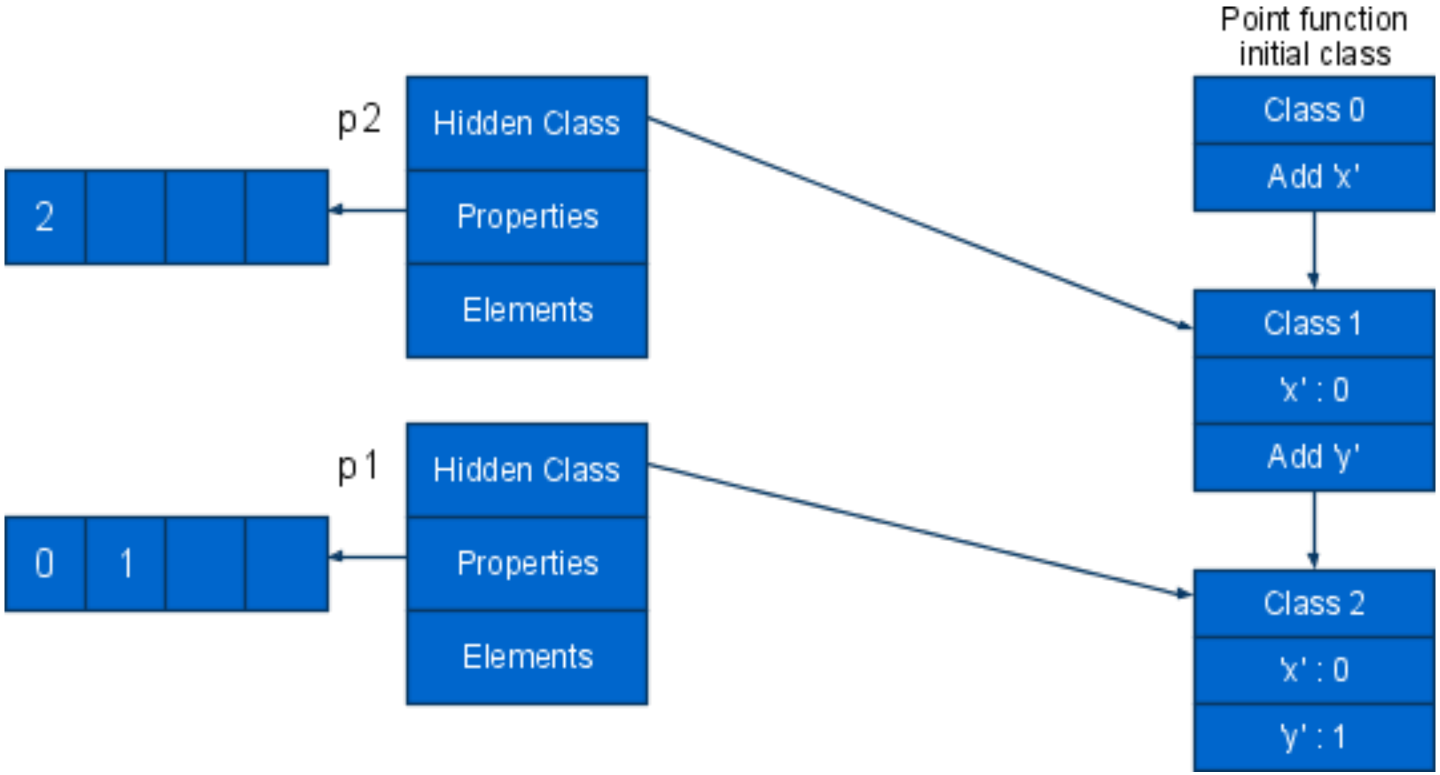

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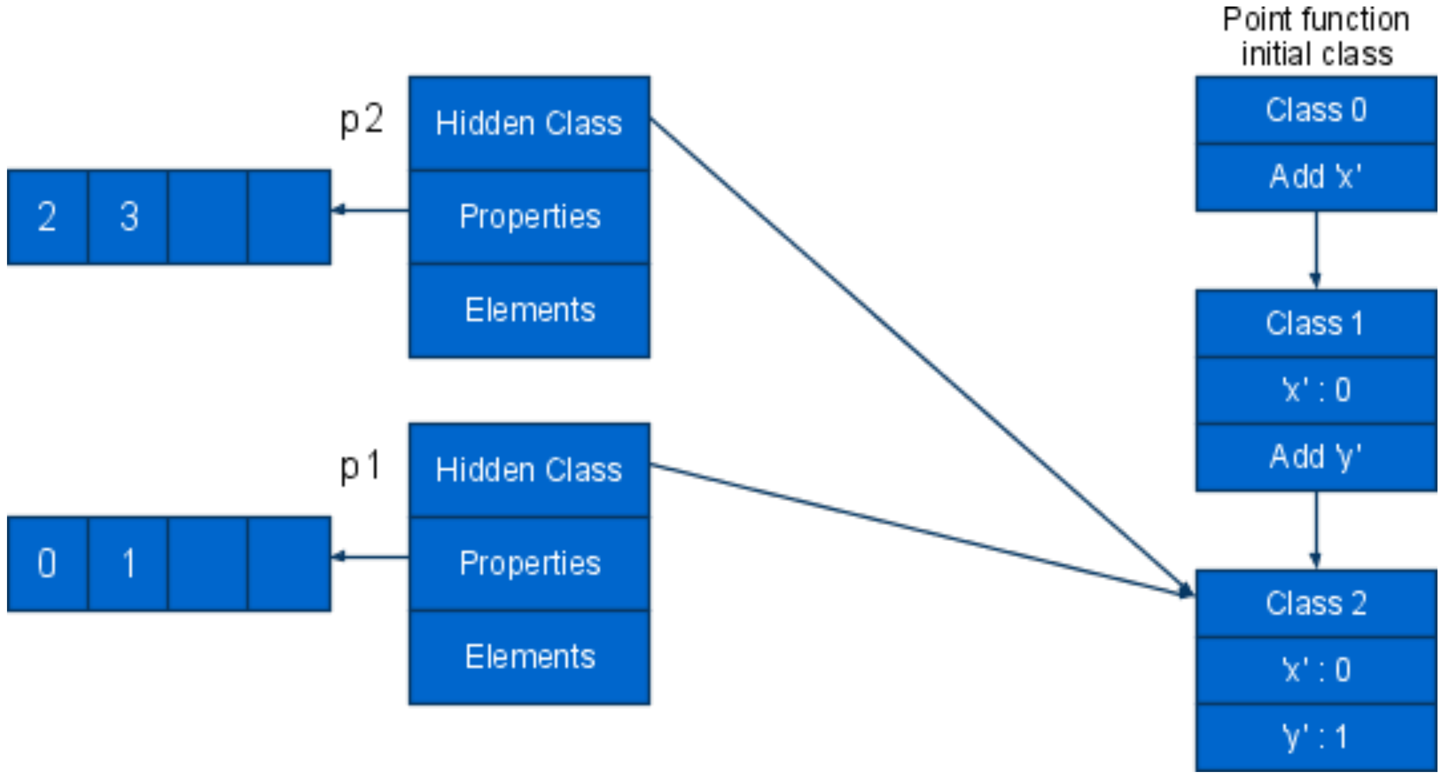

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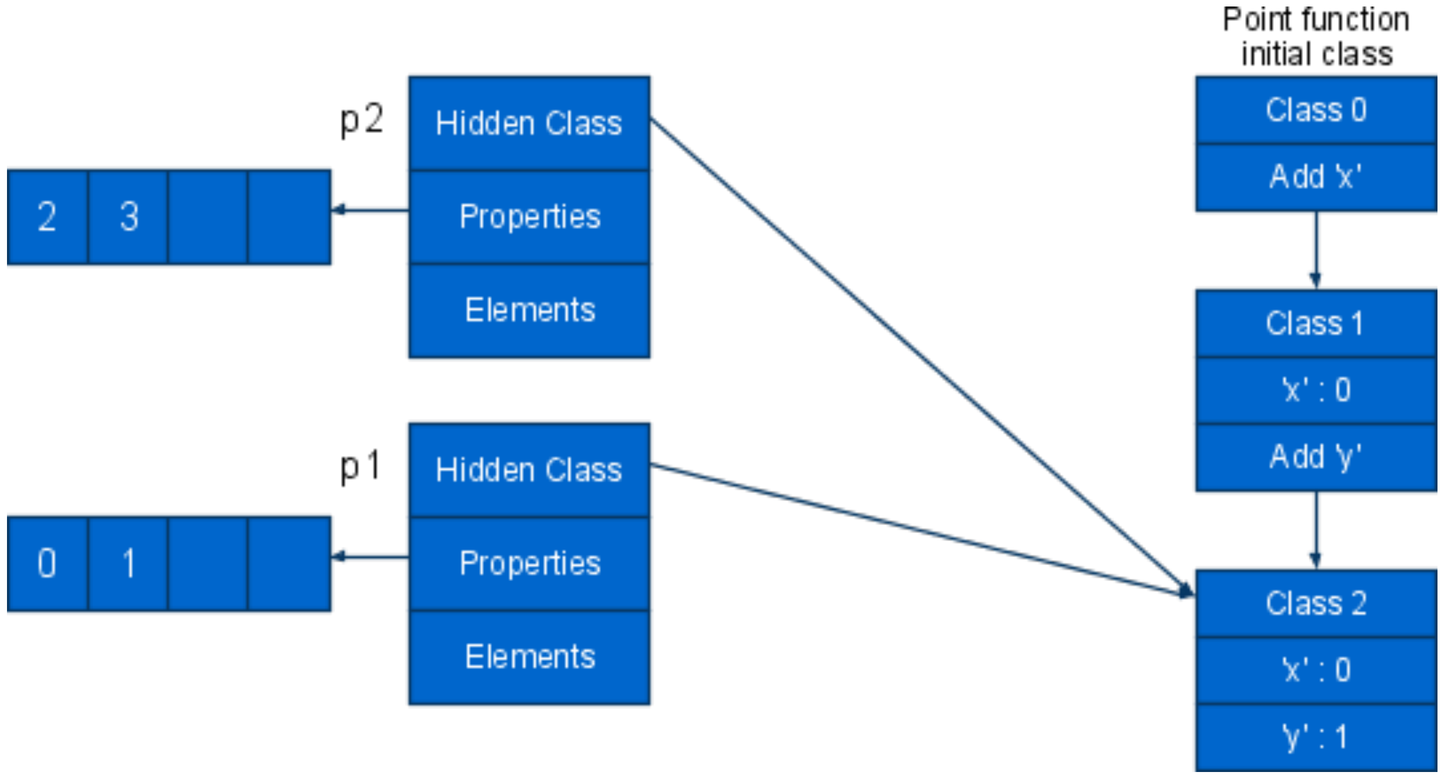


How Dynamic is JavaScript?

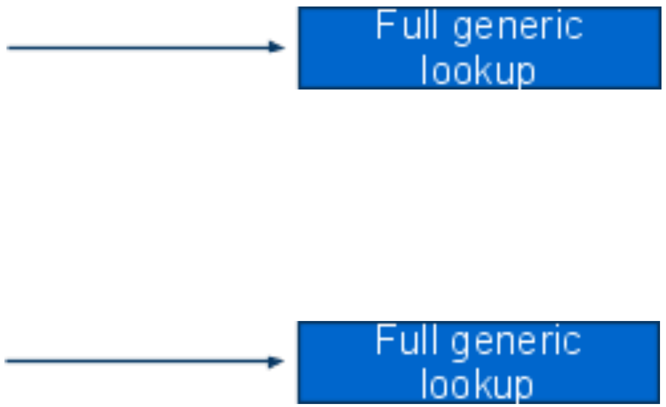
- In 90% of the cases, only objects having the same map are seen at an access site
- Hidden classes provides enough structure to use optimization techniques from more static object-oriented language
- We do not know the hidden class of objects at compile time
- We use runtime code generation and a technique called inline caching

Inline Caching

...

load 'x'

load 'y'



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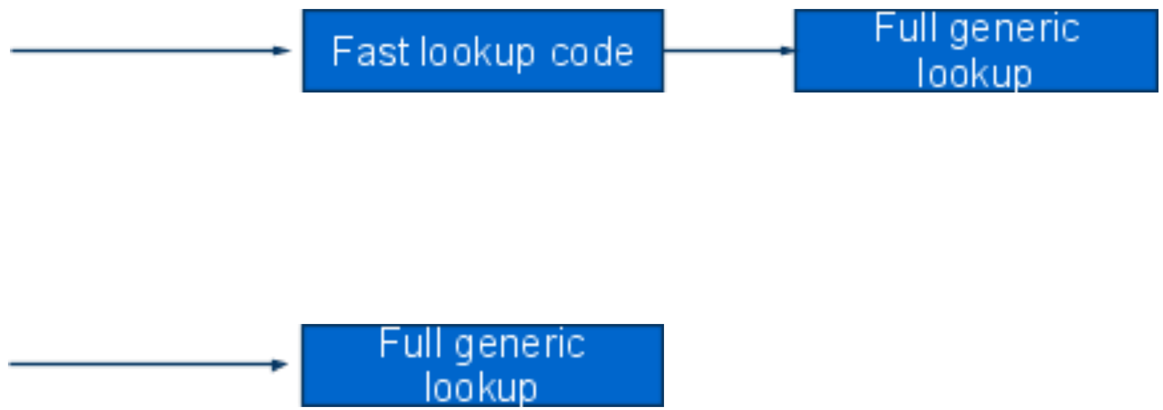

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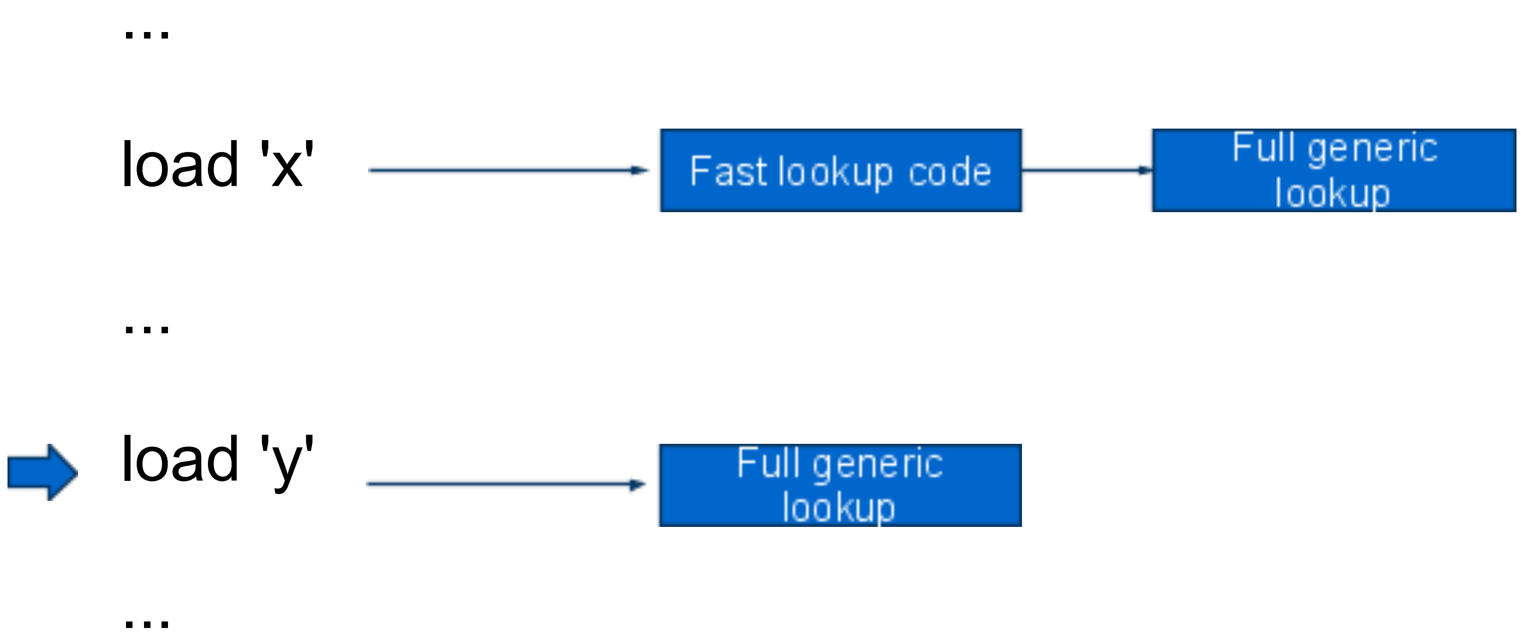

Inline Caching

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load 'x'

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load 'y'

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Monomorphic Load Inline Cache

```
0xf7c0d32d (size = 37):
 0 mov eax,[esp+0x4]
 4 test al,0x1
 6 jz 32
12 cmp [eax+0xff],0xf78fab81
19 jnz 32
25 mov ebx,[eax+0x3]
28 mov eax,[ebx+0x7]
31 ret
32 jmp LoadIC_Miss
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Monomorphic Load Inline Cache

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Monomorphic Load Inline Cache

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31 ret
32 jmp LoadIC_Miss           ; fallback to
                          ; generic lookup
```

Inline Cache States

- Three inline cache states
  - Uninitialized
  - Monomorphic
  - Megamorphic
- In the megamorphic state a cache of generated stubs is used
- Inline caches are cleared on full garbage collections
  - Allows us to get rid of unused code stubs
  - Gives all inline caches a new chance to hit the monomorphic case

Efficient Memory Management

- Precise generational garbage collection
- Two generations
  - Young generation is one small, contiguous space that is collected often
  - Old generation is divided into a number of spaces that are only occasionally collected
    - Code space (executable)
    - Map space (hidden classes)
    - Large object space (>8K)
    - Old data space (no pointers)
    - Old pointer space
- Objects are allocated in the young generation and moved to the old generation if they survive in the young generation

Types of Garbage Collection

- Scavenge
  - Copying collection of only the young generation
  - Pause times ~2ms
- Full non-compacting collection
  - Mark-Sweep collection of both generations
  - Free memory gets added to free lists
  - Might cause fragmentation
  - Pause times ~50ms
- Full compacting collection
  - Mark-Sweep-Compact collection of both generations
  - Pause times ~100ms

Recent developments

Irregexp: New Regular Expression Engine

- V8 initially used a library from WebKit called JSCRE
- JSCRE did not fit well with the string types in V8 and did not perform well
- Implemented Irregexp giving a 10x speedup on regular expression matching on benchmark programs
- Irregexp implements full JS regular expressions and there is no fallback to other libraries

Irregexp Internals

- Builds an automaton from the input regular expression
- Performs analysis and optimization on the automaton
- Generates native code
- Uses a number of tricks to avoid backtracking
- Reorders operations to perform the least expensive operations first

Irregexp Examples

- Use masks to search for common parts in alternatives first
- To search for

/Sun|Mon/

- First search for

/??n/

- Avoids a lot of backtracking

Irregexp Examples

- Will match up to four characters at a time on ASCII strings
- For

/foobar/

- It will search for

0x666f6f62 0x6172

Irregexp Examples

- Perform cheap operations first
- For

/([fF]oo[bB]ar)/

- Perform the following actions
  - Match **oo** and **ar** at positions 1 and 4
  - Match **[fF]**at position 0
  - Match **[bB]**at position 3
  - Perform capture

New Compiler Infrastructure

- Original compiler was very simple
- No static analysis of any kind
- No register allocation
- We have implemented a new compiler infrastructure which performs register allocation
- Still a one pass compiler
- Forms the basis for further native code optimizations

Object Heap Scalability

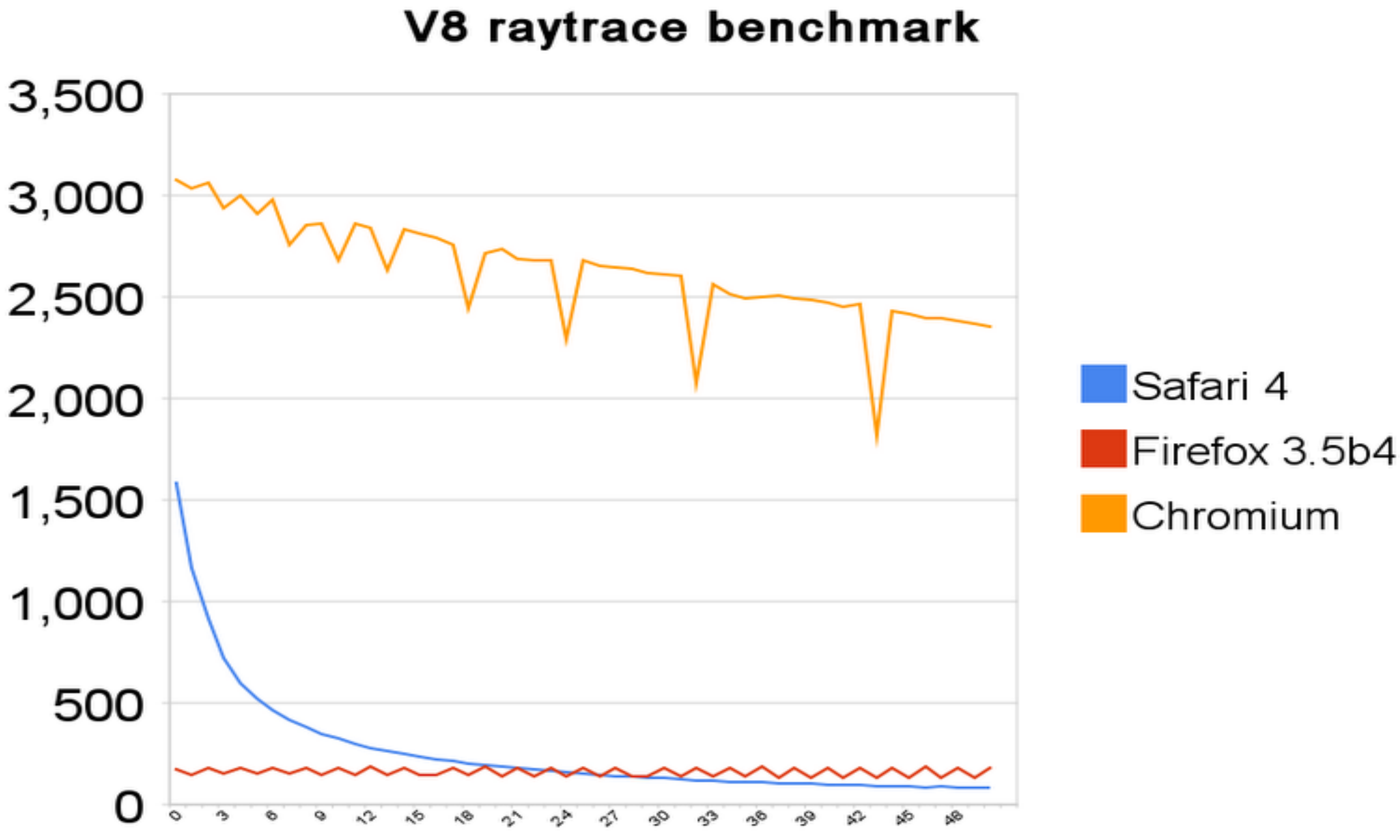
Scalability

- Users use multiple tabs running full applications
    - Mail
    - Calendar
    - News
- Applications are becoming bigger with more objects
- JavaScript execution should be fast in these situations
- The challenge is to scale well with respect to the size of the object heap
- The key to scaling well is generational garbage collection

Scalability Experiment

- Artificial scalability experiment approximating this situation
  - Raytrace benchmark from the V8 benchmark suite
  - Allocate extra live data on the side
  - 1MB of extra data per iteration

Scalability Experiment - Execution Speed



Bigger is better!

Scalability

- This experiment is artificial

- Try loading GMail in different browsers and then run JavaScript benchmarks in another tab

- Try out your own scalability experiments!

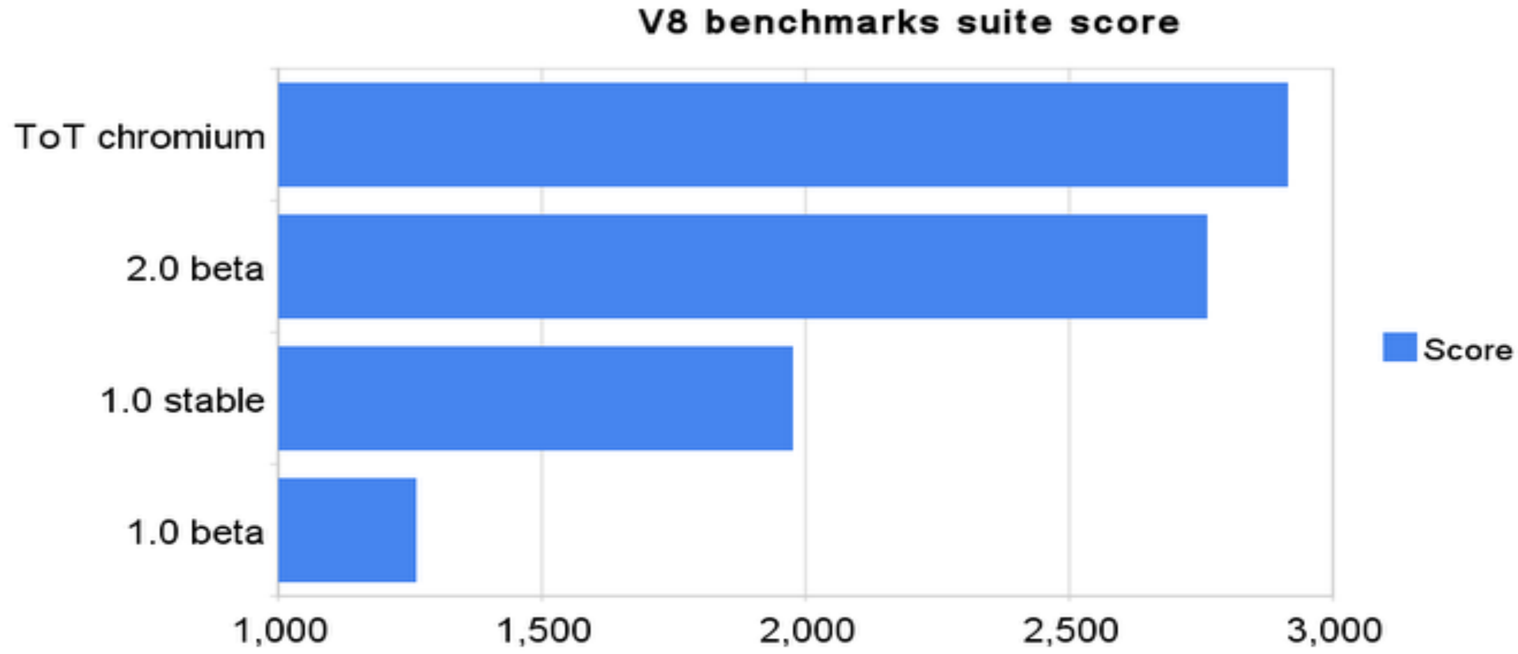
Performance Bottlenecks

Performance bottlenecks

- One fully general version of generated code
  - Generate optimized versions with more assumptions that falls back to fully general code
- Inline caching based on calls to stubs
  - Inline the fast common case directly and avoid the calls
- Slow write barrier
  - Experiment with other implementations
- No special handling of the global object
  - Loading of global properties can be much faster if we generate context specific code for global loads

Summary

- V8 was designed for speed and scalability
- The goal is to raise the performance bar for JavaScript



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