

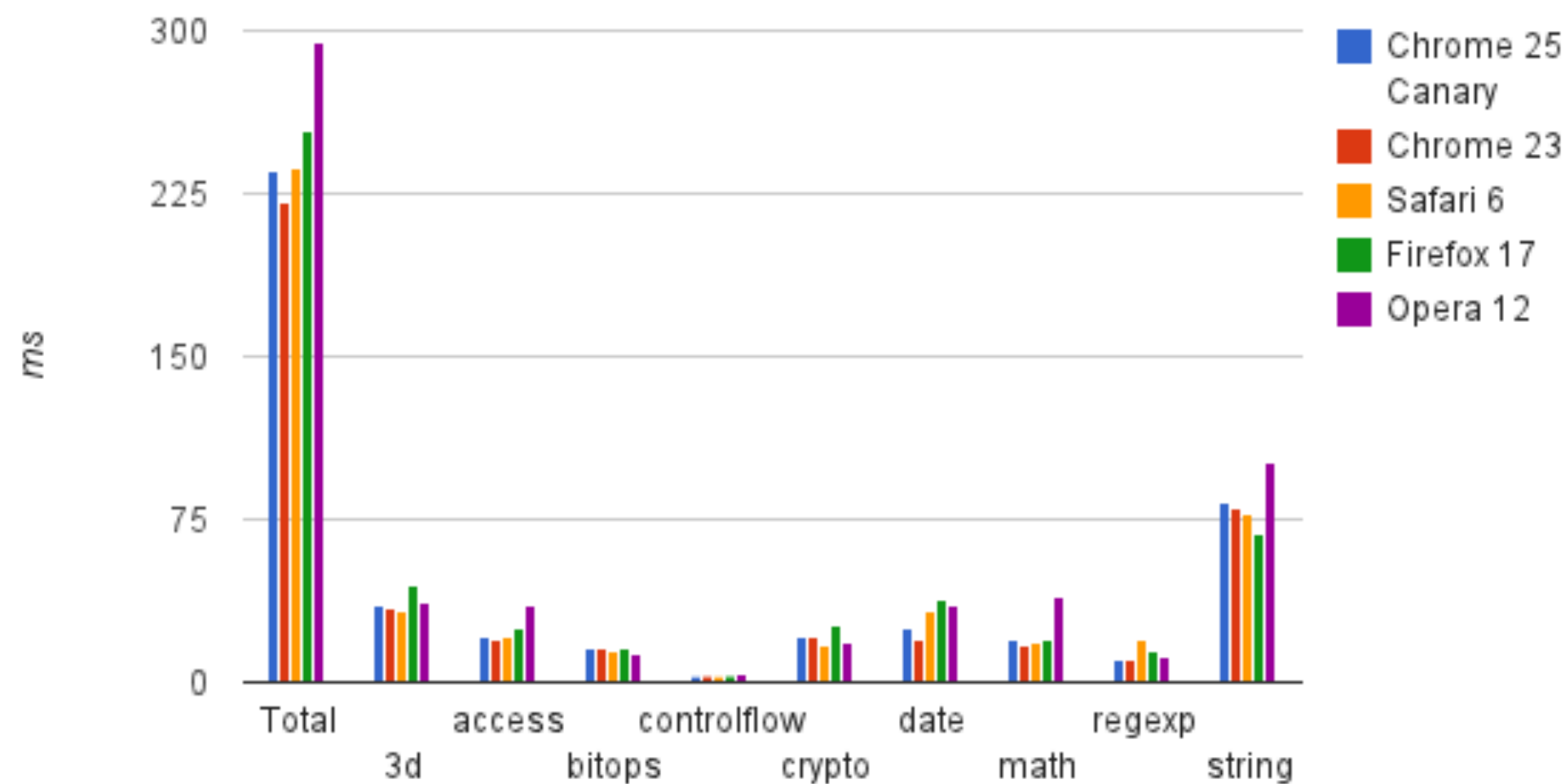
JavaScript Profiling and Optimization on V8

Yilin Zhang C. Vic Hu

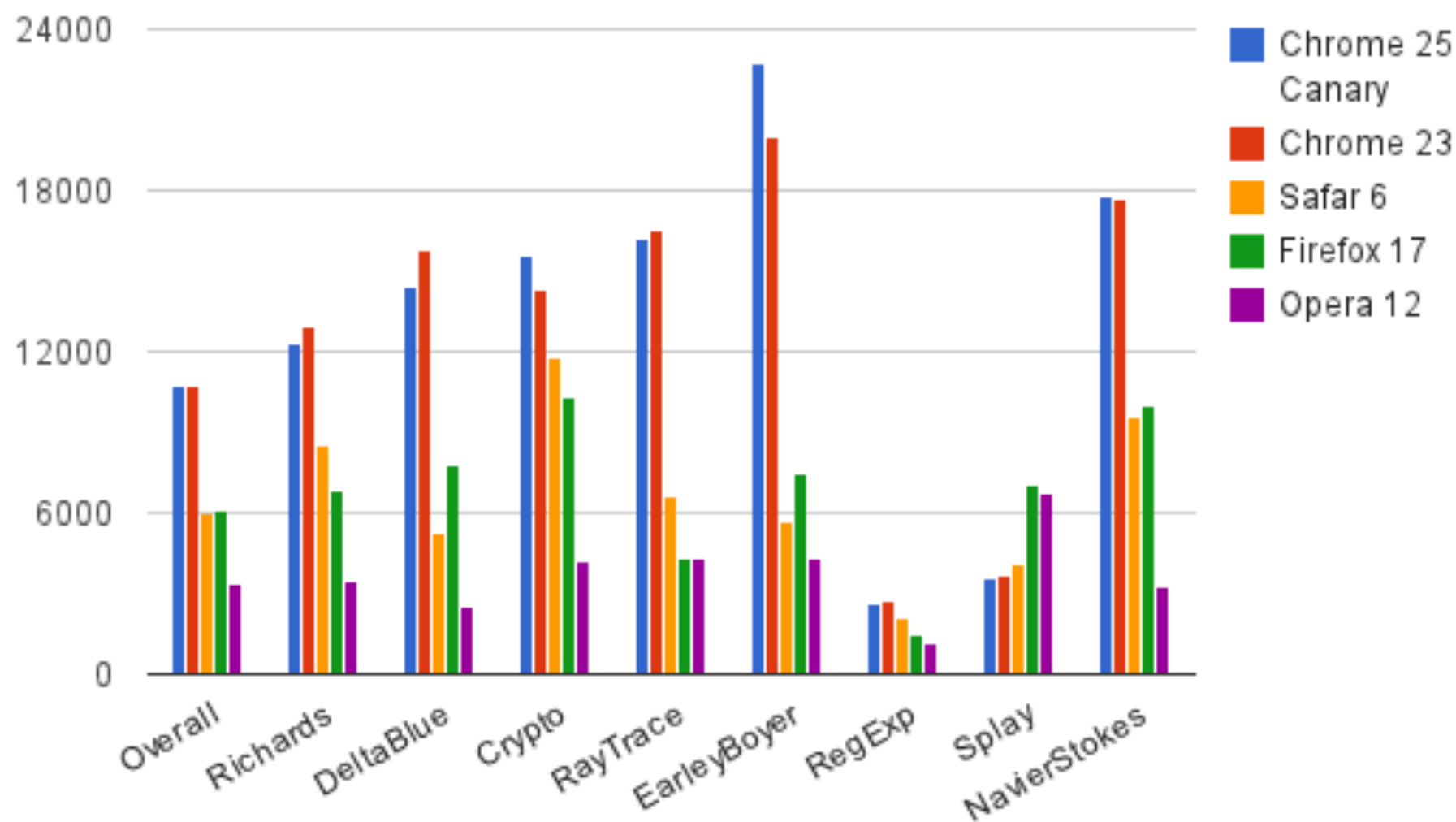
About JavaScript

- ECMAScript
- Used in Adobe Flash, Mac OS Dashboard widgets, Yahoo! widgets, browser bookmarklets, etc.
- Client-side scripting, DOM manipulation, Ajax

SunSpider 0.9.1 (smaller is better)



V8 Benchmark Suite v7 (bigger is better)



V8

- Open source JS engine by Google
- Written in C++ and used in Chrome
- Implements ECMAScript (ECMA-262, 5E)
- Can run standalone or embedded in any C++ applications
- Designed to be fast and efficient, like a V8 engine should be



What makes V8 so fast?

- Fast property access
- Dynamic machine code
- Efficient garbage collection

Fast Property Access

- JS is a dynamic language
- Hidden class vs. dictionary lookup
- High degree of structure-sharing

Fast Property Access

- JS is a dynamic language
- **Hidden class** vs. dictionary lookup
- High degree of structure-sharing

Hidden Class

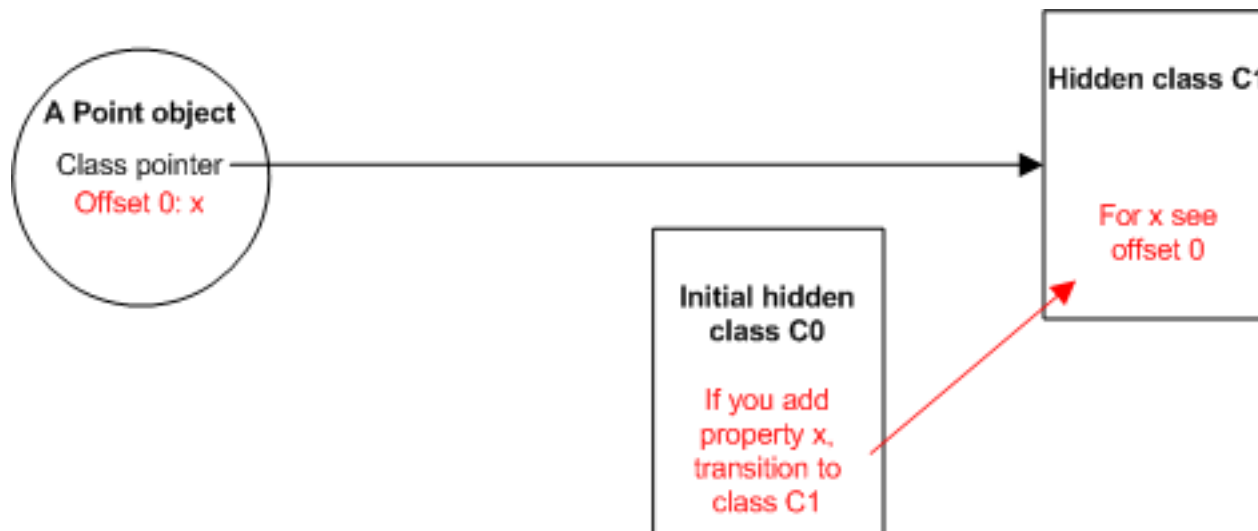
- Created dynamically behind the scene
- Changed when a new property is added

```
function Point(x, y) {  
  this.x = x;  
  this.y = y;  
}
```

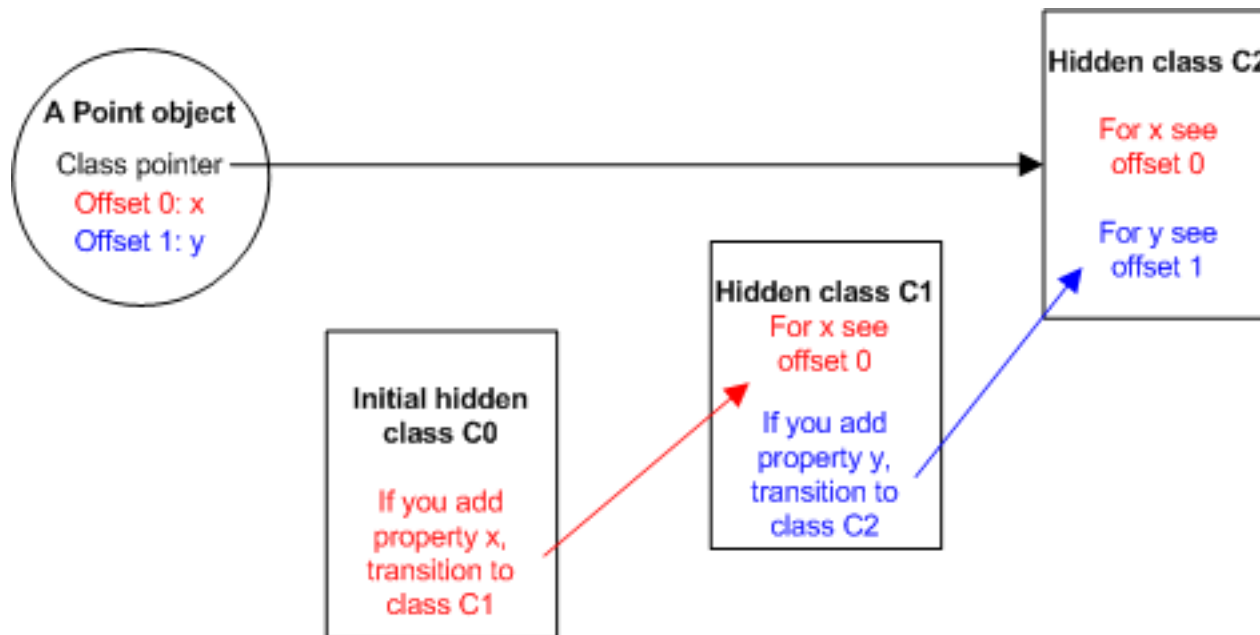
```
function Point(x, y) {  
  this.x = x;  
  this.y = y;  
}
```



```
function Point(x, y) {  
  this.x = x;  
  this.y = y;  
}
```



```
function Point(x, y) {  
  this.x = x;  
  this.y = y;  
}
```



Advantages of using hidden class

- No dictionary lookup for property access
- Enable V8 to use inline caching

Inline Cache (IC)

- Caches type-dependent code
- Needs to validate type assumptions
- Changed at runtime

Dynamic Machine Code

- Directly compiled into machine code
- No intermediate byte code or interpreter
- Inline caching for correct prediction on hidden classes

Efficient Garbage Collection

- Stops program execution
- Processes only part of the object heap
- Accurate objects and pointers locating in memory to avoid memory leaks

V8 Compilation Process

1. Base compiler
2. Runtime profiler
3. Optimizing compiler
4. Deoptimization support

1. Base Compiler

- A full compiler to generate machine code upon execution
- No assumption about types at compilation time
- Uses ICs to retrieve types at runtime
- Fast, but not optimized

2. Runtime Profiler

- Sampling every milliseconds
- In preparation for the optimization

3. Optimizing Compiler

- SSA form
- Loop-invariant code motion
- Common subexpression elimination
- Linear-scan register allocation
- Function inlining

4. Deoptimization Support

- What if overly optimistic?
- An opportunity to 'bail-out'
- Easily observed with the profiler

JavaScript is Slow

Problem:

Compute the 25,000th prime

Algorithm:

For $x = 1$ to infinity: if x not divisible by any member of an initially empty list of primes, add x to the list until we have 25,000

[2012 Google I/O]

The Contenders

C++

```
class Primes {
public:
    int getPrimeCount() const { return
prime_count; }
    int getPrime(int i) const { return primes[i]; }
    void addPrime(int i) { primes[prime_count++] =
i; }

    bool isDivisibe(int i, int by) { return (i %
by) == 0; }

    bool isPrimeDivisible(int candidate) {
        for (int i = 1; i < prime_count; ++i) {
            if (isDivisibe(candidate, primes[i]))
return true;
        }
        return false;
    }

private:
    volatile int prime_count;
    volatile int primes[25000];
};int main() {
    Primes p;
    int c = 1;
    while (p.getPrimeCount() < 25000) {
        if (!p.isPrimeDivisible(c)) {
            p.addPrime(c);
        }
        c++;
    }
    printf("%d\n",
p.getPrime(p.getPrimeCount()-1));
```

JavaScript

```
function Primes() {
    this.prime_count = 0;
    this.primes = new Array(25000);
    this.getPrimeCount = function() { return
this.prime_count; }
    this.getPrime = function(i) { return this.primes[i]; }
    this.addPrime = function(i) {
        this.primes[this.prime_count++] = i;
    }

    this.isPrimeDivisible = function(candidate) {
        for (var i = 1; i <= this.prime_count; ++i) {
            if ((candidate % this.primes[i]) == 0) return true;
        }
        return false;
    }
};function main() {
    p = new Primes();
    var c = 1;
    while (p.getPrimeCount() < 25000) {
        if (!p.isPrimeDivisible(c)) {
            p.addPrime(c);
        }
        c++;
    }
    print(p.getPrime(p.getPrimeCount()-1));
}

main();
```



```

class Primes {
public:
    int getPrimeCount() const { return prime_count; }
    int getPrime(int i) const { return primes[i]; }
    void addPrime(int i) { primes[prime_count++] = i; }

    bool isDivisibe(int i, int by) { return (i % by) == 0; }

    bool isPrimeDivisible(int candidate) {
        for (int i = 1; i < prime_count; ++i) {
            if (isDivisibe(candidate, primes[i])) return true;
        }
        return false;
    }
private:
    volatile int prime_count;
    volatile int primes[25000];
};

int main() {
    Primes p;
    int c = 1;
    while (p.getPrimeCount() < 25000) {
        if (!p.isPrimeDivisible(c)) {
            p.addPrime(c);
        }
        c++;
    }
    printf("%d\n", p.getPrime(p.getPrimeCount()-1));
}

```

```

function Primes() {
    this.prime_count = 0;
    this.primes = new Array(25000);
    this.getPrimeCount = function() { return this.prime_count; }
    this.getPrime = function(i) { return this.primes[i]; }
    this.addPrime = function(i) {
        this.primes[this.prime_count++] = i;
    }

    this.isPrimeDivisible = function(candidate) {
        for (var i = 1; i <= this.prime_count; ++i) {
            if ((candidate % this.primes[i]) == 0) return true;
        }
        return false;
    }
};function main() {
    p = new Primes();
    var c = 1;
    while (p.getPrimeCount() < 25000) {
        if (!p.isPrimeDivisible(c)) {
            p.addPrime(c);
        }
        c++;
    }
    print(p.getPrime(p.getPrimeCount()-1));
}main();

```

The Results

```
% g++ primes.cc -o primes
% time ./primes287107

real 0m2.955s
user 0m2.952s      C++
sys   0m0.001s
```

```
% time d8 primes.js287107

real    0m15.584s
user    0m15.612s
sys     0m0.073s      JavaScript
```

C++ is about 5x faster than JavaScript

Inline Caches

Candidate % this.primes[i]

No calls in this code

Inline Caches

Candidate % this.primes[i]

this.primes[i]

->call LoadIC_Initialize

-> call 0x311286e0

-> move eax, [edi+0fx]

Logging What Gets Optimized

Command:

```
./out/ia32.release/d8 --trace-opt samples/  
primes.js
```

Log name of optimized functions to stdout:
addPrime, IsPrimDivisible, main...

Profiling the JavaScripts

```
./out/ia32.release/d8 samples/primes.js --prof  
287107
```

```
./tools/mac-tick-processor v8.log
```

Profiling the JavaScripts

Statistical profiling result from v8.log, (10868 ticks, 81 unaccounted, 0 excluded).

[JavaScript]:

ticks	total	nonlib	name
1254	11.5%	11.5%	LazyCompile: *main samples/primes.js:18
959	8.8%	8.8%	LazyCompile: MOD native runtime.js:238
643	5.9%	5.9%	Stub: CEntryStub
468	4.3%	4.3%	KeyedLoadIC: A keyed load IC from the snapshot
388	3.6%	3.6%	Stub: BinaryOpStub_MOD_Alloc_SMI+Oddball
1	0.0%	0.0%	LazyCompile: ~Primes.isPrimeDivisible samples/primes.js:10

[C++]:

ticks	total	nonlib	name
3274	30.1%	30.1%	_atanhl\$fenv_access_off
1301	12.0%	12.0%	v8::internal::Runtime_NumberMod
979	9.0%	9.0%	v8::internal::Heap::NumberFromDouble

Something is Wrong with the Code

```
this.isPrimeDivisible = function(candidate) {  
    for (var i = 1; i <= this.prime_count; ++i) {  
        if ((candidate % this.primes[i]) == 0)  
            return true;  
    }  
    return false;  
}
```

Profiling Again

`/out/ia32.release/d8 samples/primes.js --prof`
`287107`

`./tools/mac-tick-processor v8.log`

Profiling Again

[JavaScript]:

ticks	total	nonlib	name
-------	-------	--------	------

1426	99.4%	99.4%	LazyCompile: *main samples/primes-2.js:18
------	-------	-------	---

5	0.3%	0.3%	LazyCompile: *Primes.isPrimeDivisible samples/primes-2.js:10
---	------	------	--

[C++]:

ticks	total	nonlib	name
-------	-------	--------	------

1	0.1%	0.1%	v8::internal::StaticVisitorBase::GetVisitorId
---	------	------	---

1	0.1%	0.1%	v8::internal::Runtime_FunctionSetName
---	------	------	---------------------------------------

1	0.1%	0.1%	v8::internal::Map::LookupDescriptor
---	------	------	-------------------------------------

1	0.1%	0.1%	v8::internal::LAllocator::TraceAlloc
---	------	------	--------------------------------------

Runtime

```
time v8 primes-2.js
```

```
287107
```

```
real 0m1.829s
```

```
user 0m1.827s
```

```
sys 0m0.010s
```

Optimize Your Algorithm

```
this.isPrimeDivisible = function(candidate) {  
    for (var i = 1; i < this.prime_count; ++i) {  
        var current_prime = this.primes[i];  
        if (current_prime * current_prime > candidate)  
        {  
            return false;  
        }  
        if ((candidate % current_prime) == 0) return  
true;  
    }  
    return false;  
}
```

Optimize Your Algorithm

```
time v8 primes-3.js
```

```
287107
```

```
real 0m0.044s
```

```
user 0m0.038s
```

```
sys 0m0.004s
```

Crankshaft

Hydrogen-SSA in Crankshaft [Wingolog]

1. To permit inlining. Inlining is truly the mother of all optimizations, in that it permits more optimizations to occur.
2. To facilitate loop-invariant code motion and common subexpression elimination.

SSA Data Structures

HGraph

```
HBasicBlock* blocks[];  
HPhi* all_phis[]; // facilitates analysis  
HValue* all_values[]; // allows lookup by index
```

HBasicBlock

```
int id;  
HGraph* graph;  
HPhi* phis[]  
HInstruction* first;  
HControlInstruction* last;  
HLoopInformation* loop_info;  
HBasicBlock* predecessors[];  
HBasicBlock* dominator;  
HBasicBlock* dominated[];
```

HValue

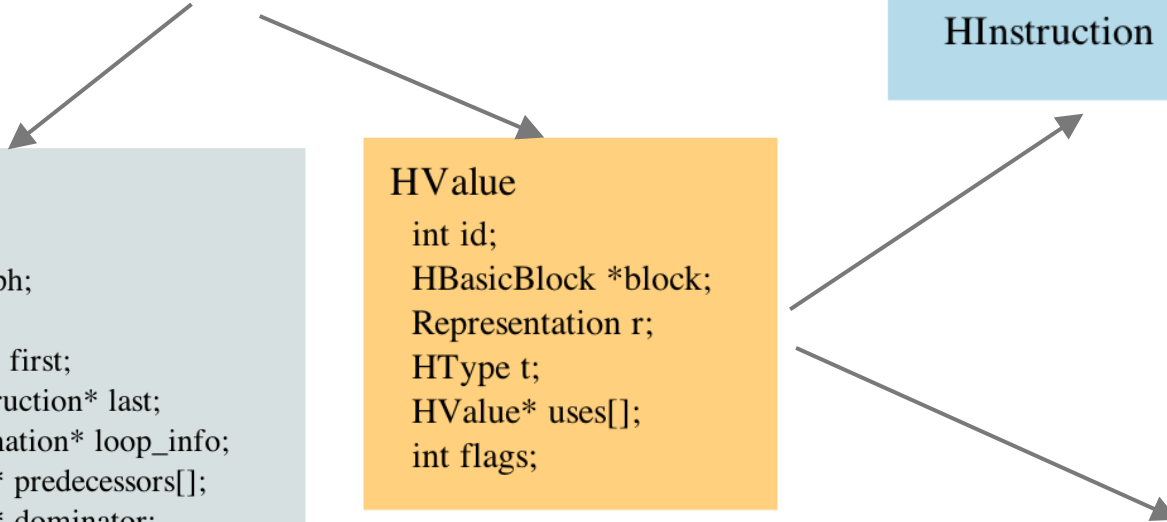
```
int id;  
HBasicBlock *block;  
Representation r;  
HType t;  
HValue* uses[];  
int flags;
```

HInstruction : HValue

```
HInstruction *next, *prev;
```

HPhi : HValue

```
HValue* inputs[];
```



Optimization Proposal

- More sophisticated algorithms in determining the 'hot code': frequency alone might not be the best way to define 'hot'
 - Use counter instead of sampling every millisecond
- Phi node insertion optimization

Conclusion

- Chrome with V8 engine outperforms other browsers in most benchmarks, especially V8 benchmarks
- Hidden classes introduces inline caching and type assumption
- Use run-time profiling to optimize hot code, and do nothing if the profiler decided it's not hot