Inline-threading for Tracemonkey

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Outline

Introduction
JavaScript

- Developed at Netscape in the mid-90s
- Originally intended for dynamic web content

Introduction
JavaScript

- C-like syntax (curly braces)
- Object-Oriented (prototype-based)
- First-class functions
- Dynamically typed

Introduction
JavaScript

- Douglas Crockford calls it the "World's Most Popular Programming Language."
- "Web 2.0" and AJAX rely on JavaScript
- A lot of the *browser* is written in JavaScript

The Need for Speed
Making JavaScript faster...

- Makes the browser faster
- Makes running tests faster
- Makes the *web* faster

The Need for Speed
New kinds of webapps

- Facial recognition
- Video manipulation
- Chrome demos

The Need for Speed
Other browsers competing on JS speed

- Apple's SquirrelFish Extreme (er... "Nitro")
- Google's V8

TraceMonkey

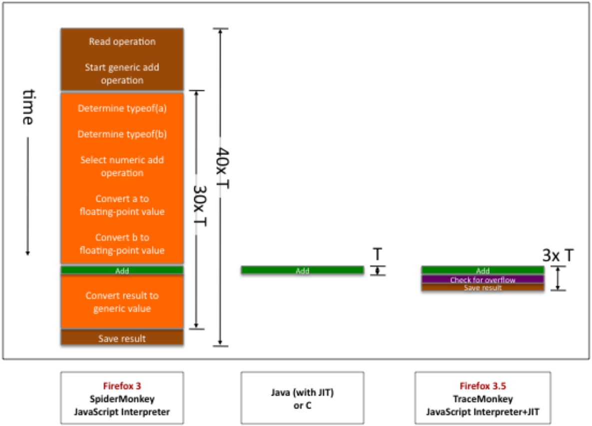
Overview
Details
Limitations

Overview

- Mozilla's recent JS engine upgrade
- Trace-based Just-in-Time Type Specialization

Details
Why making JS fast is hard

- The biggest impediment to JS speed is dynamic typing
- The type of something isn't known for sure until runtime



Details
Figuring out the types

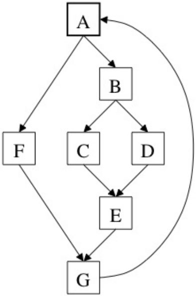
- If you can't figure out the types until runtime...

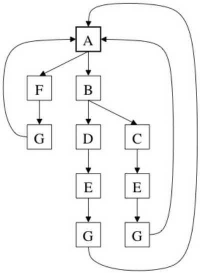
Details
Figuring out the types

- If you can't figure out the types until runtime...
- Then observe them at runtime

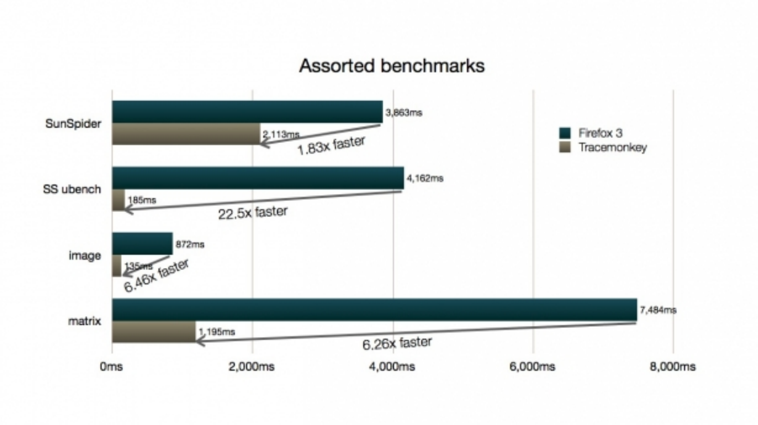
Details
How it works

- Each time through a loop, the code takes one path
- TraceMonkey monitors the types of variables through one path and generates native code for it
- Only worth doing for “hot” loops





Details
Some perf numbers



Limitations
Trace recording is expensive

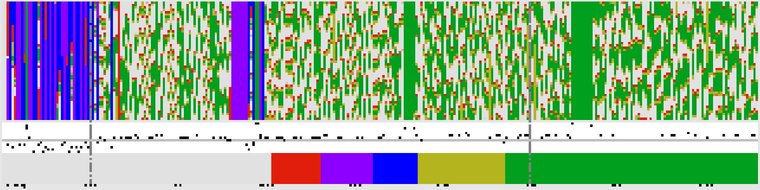
- Recording a trace isn't free
- Recording a trace takes about 400x as long as it would to interpret it
- A loop needs to be executed a lot to take advantage of it

Limitations
Not everything is traced

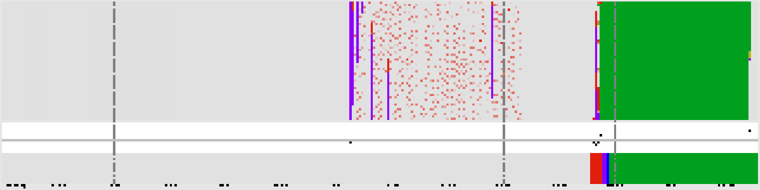
- The tracer still doesn't support some constructs
  - Generators
  - Recursion

Limitations
Bad trace performance

3d-cube



string-tagcloud



Limitations
Exponential trace explosion

- n independent, frequently taken branches means 2^n traces

Limitations
Exponential trace explosion

- *n* independent, frequently taken branches means 2^n traces
- This runs twice as slowly with tracing on:

```
var v1, v2, v3, v4, v5, v6, v7, v8, v9, v10;
v1 = v2 = v3 = v4 = v5 = v6 = v7 = v8 = v9 = v10 = 0;
for (var i = 0; i < 1<<22; i++) {
    if ((i & (1 << 1)) != 0)
        v1++;
    if ((i & (1 << 2)) != 0)
        v2++;
    if ((i & (1 << 3)) != 0)
        v3++;
    /* ... */
}
```

Inline threading
What to do

- Tracing is great, but but we'd like to be fast even when it doesn't work
- So we need to speed up what we are doing when we aren't tracing: the interpreter

Interpreter overview
The structure of the interpreter

- The bytecode compiler takes JavaScript source and generates bytecode (a sort of high level assembly)
- The interpreter (or virtual machine) then executes the bytecodes
- This should sound familiar: it is made explicit in Java

Interpreter overview
Stack based VM

- The SpiderMonkey VM is stack-based
- Most operations operate on the top elements of a stack of values
- Similar to a reverse polish notation calculator

Interpreter overview
Bytecodes

- Opcodes exist to do all of the little tasks required to execute JavaScript, like
  - Add the top two numbers on the stack
  - Push the contents of a local variable onto the stack
  - Push the contents of an object property onto the stack
  - Call another function
  - Jump to another code address

Interpreter overview
Not all bytecodes are created equal

- Some bytecodes are small and simple (pushing a local variable to the stack)
- Some are big and complicated (pushing a property on the stack, calling a function)
- And some fall in the middle (adding two numbers)
    - It's easy if they are both integers, but they could also be doubles, strings, chunks of XML...

Interpreter overview
The interpreter loop

```
for(;;) {
    JSOp opcode = code[pc];
    switch (opcode) {
    case ADD:
        /* Add... */
        pc += ADD_LENGTH;
        break;
    case EQ:
        /* Compare things for equality... */
        pc += EQ_LENGTH;
        break;
    case GOTO:
        pc = get_target(code, pc);
        break;
    /* ... */
}
```

Interpreter overview
Interpreter overhead

- There is a lot of fixed overhead
  - Looking up next opcode
  - Bounds check for the switch
  - Table lookup for the switch
  - Indirect jump to correct case
  - Jump back to the top of the loop
  - Incrementing program counter
- And since the switch does an indirect jump, the processor has trouble predicting it

Call threading
An insight

- Most of the overhead comes from figuring out what opcode to execute next

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- But with the exception of control flow operations, we know what opcodes are executed in what order
- Is there a way we can express this?

Call threading
The reveal

- We can generate native code to invoke the operations we want
- Express the operations as functions instead of cases in a switch

Call threading
Opcode functions

```
void ADD_func(state *st, int argument) {
    /* Add... */
}
void EQ_FUNC(state *st, int argument) {
    /* Compare things for equality... */
}
```

Call threading
An example

- So if we have the following code (a = a + b):
  - GETLOCAL 0
  - GETLOCAL 1
  - ADD
  - SETLOCAL 0
- We generate code that does:
  - GETLOCAL_func(st, 0)
  - GETLOCAL_func(st, 1)
  - ADD_func(st, ...)
  - SETLOCAL_func(st, 0);

Call threading
Great success?

- So, we have eliminated
    - Looking up next opcode
    - Bounds check for the switch
    - Table lookup for the switch
    - Indirect jump to correct case
    - Jump back to the top of the loop
    - Incrementing program counter
- And all of the opcode dispatches are direct calls, so the branch predictor can go to town
- So this should be a major win, right?

Call threading
The problem

- Not so much. 20% performance *loss*
- We've introduced a bunch of new overhead as well
  - Loading arguments into registers
  - Calling the function
  - Function prologue
- And worst of all, the C compiler doesn't have as much room to optimize

Inline threading
Eliminating the new overhead

- Is there a way to eliminate this overhead?

Inline threading
Inlining

- A lot of opcodes are small and simple
- Instead of generating code that calls functions to perform them...
- Just generate code that does them
- This eliminates *all* the overhead

Inline threading
Inlining

- While "most" opcodes are big, the frequently executed ones tend to be small
- And small opcodes benefit the most from eliminating overhead
- 70% of the opcodes executed in SunSpider are easily inlinable

Inline threading
An example

- Returning to our previous example:
  - GETLOCAL 0
  - GETLOCAL 1
  - ADD
  - SETLOCAL 0
- We generate code that does:
  - // push local 0 onto the stack
  - // push local 1 onto the stack
  - ADD_func(st, ...)
  - // set local 0 to the top stack value

Inline threading
Perf Numbers

- Now we start to win.
- 6% speedup on SunSpider on OS X, 12% on Windows
- 3x speedup on some microbenchmarks

Conclusion

- Still not finalized
- Needs to integrate with tracing
- Lacks support for some language constructs (that require more nanojit features)
- Bug 506182