Smalltalk Implementation:
Optimization Techniques

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Optimization Ideas

• Just-In-Time (JIT) compiling
  When a method is first invoked, compile it into native code.

• Caching the Method Dictionary
  Method Look-up will be speeded up.

• Inline Method Sending
  Will turn many SENDs into native CALL instructions

• Use the hardware calling stack
  MethodContexts \rightarrow activation records allocated on a stack

• Code the VM directly in Smalltalk
  Automatic translation into “C”
Porting the Smalltalk Interpreter

The virtual machine is implemented in Smalltalk!
Using a subset of Smalltalk, called “Slang”

The image also includes a translator / compiler
Slang → “C”

Steps to porting:
• Produce automatically generated interpreter in “C”
• Hand-code the machine-dependent parts in “C”
• Compile
• Use any existing image
Misc Points

Porting Images

Each VM executes the same bytecodes. Any image can be executed on by any VM.

EXAMPLE: An image produced on MAC OS X can be executed on Windows.

Porting Code Fragments
Misc Points

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Porting Code Fragments

Also, code fragments can be filed out … and filed in to another image

Will it work?
The Smalltalk language is uniform. What pre-existing classes does the code use?
Misc Points

Hash Values

Some classes rely on “hash values”.

*Dictionary*, *Set*, etc.

Every object must be capable of providing its hash value:

```
i := x hashValue.
```
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Two objects can contain exactly the same values. They differ only in where they are in memory …and GC will move objects around
Smalltalk Implementation

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...and GC will move objects around

Need special VM support for hash values!

- Each object contains a hash value.
- 12 bits
- Stored in it header
- Initialized when the object is created
Optimizations to the Interpreter

Virtual Machine

Does not match underlying hardware well

Examples:

- OOP/SmallInteger Tagging
- Registers versus Stacks in Context objects

Bytecodes vs. Machine Instructions

The bytecodes are interpreted

- Fetch-decode-execute done at two levels.
- Difficult to optimize bytecodes

Bytecodes are complex operations

- Corresponding to several machine level instructions
“Just in Time” Compiling

Translate bytecodes into native machine language
… and execute them directly

Do it “on the fly”
… on individual methods
Source $\rightarrow$ bytecodes $\rightarrow$ machine instructions

When the method is first invoked…
- Call the JIT compiler
- Translate bytecodes to native instructions
- Save the native code for next time.
“Just in Time” Compiling

**Benefits:**

- Optional
  - Compatible with existing system
- Still have bytecodes
  (for the debugging tools)
- Can perform many optimizations at the native code level
- Can do it just to frequently invoked methods
- Running out of memory?
  - Throw away some of the compiled methods
“Just in Time” Compiling

Problem:
Activation records are user-visible

MethodContexts, BlockContexts
Activation record contains a pointer to the current bytecode
“instructionPointer” = “Program Counter (PC)”

Used by the debugging tools!

Solution:
“Just in Time” Compiling

Problem:
Activation records are user-visible

*MethodContexts, BlockContexts*

Activation record contains a pointer to the current bytecode

“instructionPointer” = “Program Counter (PC)”

*Used by the debugging tools!*

Solution:
Whenever an activation record becomes user-visible…
Map the native code PC back into a bytecode PC
Allocating Contexts on the Hardware Stack

The hardware supports stacks & procedure CALLs well.

“stack frame” = “activation record”
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Smalltalk VM…
- linked list of Context objects
- Want to use the hardware stack
  - Want to store each Context as a “stack frame”

Contexts are usually allocated in LIFO (stack) order.
- Not usually accessed as an object
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Asks for a pointer to the current context
Treats it as (non-stack) data

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The Idea:

Store stack frames on hardware stack, not as objects.

When a pointer is generated to the current context…

Convert the stack frame into a real object.
Details

Converting a stack frame into a real object…

Allocate a new Context object and fill in its fields
  Convert the program counter (PC)
    absolute address $\rightarrow$ byte offset into a CompiledMethod object

Contexts point to other Contexts
  But other Contexts are still on hardware stack
  Convert all frames into Objects…? No!

The Technique:

stack-frame

hybrid

MethodContext
Caching the Method Dictionary

Method Lookup:

Given:  • the receiver’s class
        • the message selector

Find:   • the right CompiledMethod

The Idea:
Caching the Method Dictionary

Method Lookup:

Given:  
- the receiver’s class
- the message selector

Find:
- the right CompiledMethod

The Idea:
Use a Hash Table
Maintained by the VM
(it is not an object)
Not in the hash table?
- Do a full method lookup
- Add an entry to the hash table
Inline Method Caching

Assume methods are compiled into native code.

**Code to send a message:**

```smalltalk
< code to push receiver >
< code to push args >
CALL MessageSend (arg = selector)
```

A routine that searches for the proper method/routine and then calls it.

A machine-language CALL instruction
Inline Method Caching

Assume methods are compiled into native code.

*Code to send a message:*

```
< code to push receiver >
< code to push args >
CALL MessageSend (arg = selector)
```

*The Idea:*

- Upon locating the correct routine…
  Replace the CALL to the “MessageSend” routine … with a CALL straight to the native code routine!
- Next time we execute the above code, we CALL the right routine immediately.
- Gradually all message sends are replaced with native code CALL instructions.
Inline Method Caching

**Problem:**

*Dynamic Look-Up*

The receiver’s class determines which method to invoke.
Different class? → Different method!

**Assumption:**

**Approach:**
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*Any particular SEND will invoke the same method*

…almost always!

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**Approach:**

At the beginning of each method:

- Check the class of the receiver
- If it is what this method expects
  → continue with this method.
- If the receiver has the wrong class…
  - Perform a full method lookup.
  - Overwrite the CALL (to jump to the correct method next time)
  - Jump to the correct method.
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<thead>
<tr>
<th>Optimization Type</th>
<th>Space</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Straight interpreter</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Compiler</td>
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<td>.69</td>
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<tr>
<td>Compiler w/ inline caching</td>
<td>3.4</td>
<td>.62</td>
</tr>
<tr>
<td>Compiler w/ peephole optimizer</td>
<td>5.0</td>
<td>.56</td>
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<tr>
<td>Compiler w/ inline caching w/ optimizer</td>
<td>5.0</td>
<td>.51</td>
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