Working with Bytecodes:

IRBuilder and ByteSurgeon

Marcus Denker

Reasons for working with Bytecode

- Generating Bytecode
  - Implementing compilers for other languages
  - Experimentation with new language features

- Bytecode Transformation
  - Adaptation of running Systems
  - Tracing / Debugging
  - New language features

Overview

1. Introduction to Squeak Bytecodes
2. Generating Bytecode with IRBuilder
3. Introduction to ByteSurgeon

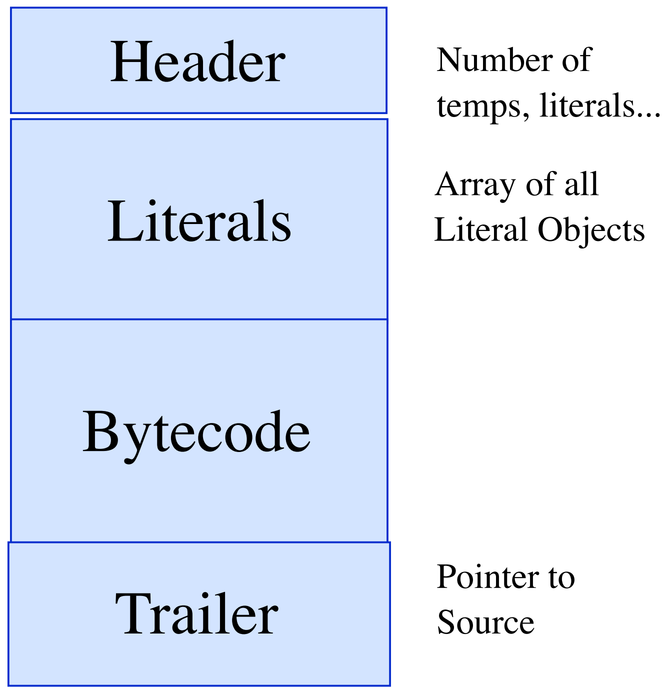
The Squeak Virtual Machine

- From last lecture:
  - Virtual machine provides a virtual processor
  - Bytecode: The 'machine-code' of the virtual machine
  - Smalltalk (like Java): Stack machine

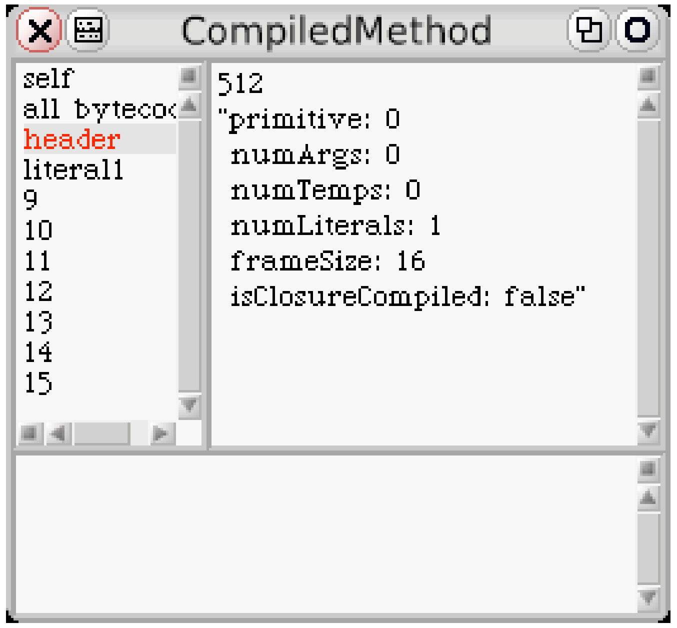
- Today:
  - Closer look at Squeak bytecode

Bytecode in the CompiledMethod

- CompiledMethods format:



```
(Number>>#asInteger)inspect
```



```
self              512
all bytecoc       "primitive: 0
header             numArgs: 0
literal1           numTemps: 0
9                  numLiterals: 1
10                 frameSize: 16
11                 isClosureCompiled: false"
12
13
14
15
```

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Example: Number>>asInteger

- Smalltalk code:

```
Number>>asInteger
   "Answer an Integer nearest the receiver toward zero."

   ^self truncated
```

- Symbolic Bytecode

```
9 <70> self
10 <D0> send: truncated
11 <7C> returnTop
```

Example: Step by Step

- `9 <70> self`
  - The receiver (self) is pushed on the stack
- `10 <D0> send: truncated`
  - Bytecode 208: send literal selector 1
  - Get the selector from the first literal
  - start message lookup in the class of the object that is top of the stack
  - result is pushed on the stack
- `11 <7C> returnTop`
  - return the object on top of the stack to the calling method

Squeak Bytecodes

- 256 Bytecodes, four groups:
  - Stack Bytecodes
    - Stack manipulation: push / pop / dup
  - Send Bytecodes
    - Invoke Methods
  - Return Bytecodes
    - Return to caller
  - Jump Bytecodes
    - Control flow inside a method

Stack Bytecodes

- Push values on the stack, e.g., temps, instVars, literals
  - e.g: 16 - 31: push instance variable
- Push Constants (False/True/Nil/1/0/2/-1)
- Push self, thisContext
- Duplicate top of stack
- Pop

Sends and Returns

- Sends: receiver is on top of stack
  - Normal send
  - Super Sends
  - Hard-coded sends for efficiency, e.g. +, -

- Returns
  - Return top of stack to the sender
  - Return from a block
  - Special bytecodes for return self, nil, true, false (for efficiency)

Jump Bytecodes

- Control Flow inside one method
- Used to implement control-flow efficiently
- Example:

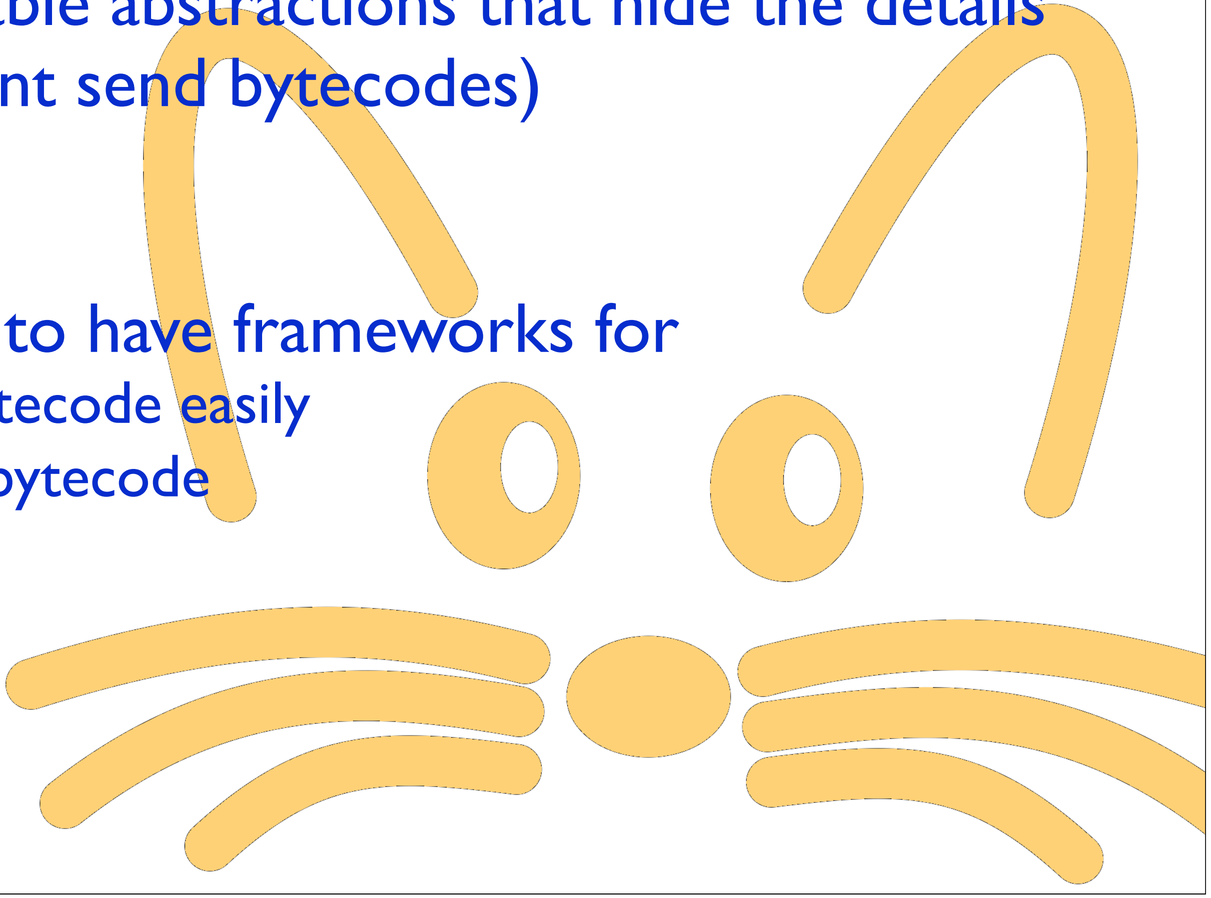
```
^ 1<2 ifTrue: ['true']
```

```
9 <76> pushConstant: 1
10 <77> pushConstant: 2
11 <B2> send: <
12 <99> jumpFalse: 15
13 <20> pushConstant: 'true'
14 <90> jumpTo: 16
15 <73> pushConstant: nil
16 <7C> returnTop
```

What you should have learned...

- ... dealing with bytecodes directly is possible, but very boring.
- We want reusable abstractions that hide the details (e.g. the different send bytecodes)

- We would like to have frameworks for
  - Generating bytecode easily
  - Transforming bytecode



Generating Bytecodes

- IRBuilder: A tool for generating bytecode
- Part of the new compiler for Squeak 3.9

- Idea: a symbolic Assembler for Squeak

IRBuilder: Simple Example

- Number>>asInteger

```
iRMethod := IRBuilder new
   numRargs: 1;
   addTemps: #(self); "receiver"
   pushTemp: #self;
   send: #truncated;
   returnTop;
   ir.

aCompiledMethod := iRMethod compiledMethod.

aCompiledMethod valueWithReceiver:3.5
                arguments: #()
```

IRBuilder: Step by Step

- Number>>asInteger

```
iRMethod := IRBuilder new
```

  - Make a instance of IRBuilder

IRBuilder: Step by Step

- Number>>asInteger

```
iRMethod := IRBuilder new
   numRargs: 1;
```

  - Define arguments. Note: “self” is default argument

IRBuilder: Step by Step

- Number>>asInteger

```
iRMethod := IRBuilder new
   numRargs: 1;
   addTemps: #(self); "receiver"
```

  - define temporary variables. Note: arguments are temps

IRBuilder: Step by Step

- Number>>asInteger

```
iRMethod := IRBuilder new
   numRargs: 1;
   addTemps: #(self); "receiver"
   pushTemp: #self
```

  - push “self” on the stack

IRBuilder: Step by Step

- Number>>asInteger

```
iRMethod := IRBuilder new
   numRargs: 1;
   addTemps: #(self); "receiver"
   pushTemp: #self
   send: #truncated;
```

  - call method truncated on “self”

IRBuilder: Step by Step

- Number>>asInteger

```
iRMethod := IRBuilder new
   numRargs: 1;
   addTemps: #(self); "receiver"
   pushTemp: #self
   send: #truncated;
   returnTop;
```

  - return Top of Stack

IRBuilder: Step by Step

- Number>>asInteger

```
iRMethod := IRBuilder new
   numRargs: 1;
   addTemps: #(self); "receiver"
   pushTemp: #self
   send: #truncated;
   returnTop;
   ir.
```

  - tell IRBuilder to generate Intermediate Representation (IR)

IRBuilder: Step by Step

- Number>>asInteger

```
iRMethod := IRBuilder new
   numRargs: 1;
   addTemps: #(self); "receiver"
   pushTemp: #self
   send: #truncated;
   returnTop;
   ir.

aCompiledMethod := iRMethod compiledMethod.
```

  - Generate method from IR

IRBuilder: Step by Step

- Number>>asInteger

```
iRMethod := IRBuilder new
   numRargs: 1;
   addTemps: #(self); "receiver"
   pushTemp: #self
   send: #truncated;
   returnTop;
   ir.

aCompiledMethod := iRMethod compiledMethod.

aCompiledMethod valueWithReceiver:3.5
                   arguments: #()
```

  - Execute the method with reveiver 3.5 and no arguments.
  - “3.5 truncated”

IRBuilder: Stack Manipulation

- popTop - remove the top of stack
- pushDup - push top of stack on the stack
- pushLiteral:
- pushReceiver - push self
- pushThisContext

IRBuilder: Symbolic Jumps

- Jump targets are resolved:
- Example: false ifTrue: [’true’] ifFalse: [’false’]

```
iRMethod := IRBuilder new
   numRargs: 1;
   addTemps: #(self); "receiver"
   pushLiteral: false;
   jumpAheadTo: #false if: false;
   pushLiteral: 'true';          "ifTrue: ['true']"
   jumpAheadTo: #end;
   jumpAheadTarget: #false;
   pushLiteral: 'false';         "ifFalse: ['false']"
   jumpAheadTarget: #end;
   returnTop;
   ir.
```

IRBuiler: Instance Variables

- Access by offset
- Read: getField:
  - receiver on top of stack
- Write: setField:
  - receiver and value on stack
- Example: set the first instance variable to 2

```
iRMethod := IRBuilder new
        numRargs: 1;
        addTemps: #(self); "receiver"
        pushLiteral: 2;
        pushTemp: #self;
        setField: 1;
        pushTemp: #self;
        returnTop;
        ir.

    aCompiledMethod := iRMethod compiledMethod.
    aCompiledMethod valueWithReceiver: 1@2 arguments: #()
```

IRBuilder: Temporary Variables

- Accessed by name
- Define with addTemp: / addTemps:
- Read with pushTemp:
- Write with storeTemp:
- Examle: set variables a and b, return value of a

```
iRMethod := IRBuilder new
      numRargs: 1;
      addTemps: #(self); "receiver"
      addTemps: #(a b);
      pushLiteral: 1;
      storeTemp: #a;
      pushLiteral: 2;
      storeTemp: #b;
      pushTemp: #a;
      returnTop;
      ir.
```

IRBuilder: Sends

- normal send

```
builder pushLiteral: ‘hello’
builder send: #size;
```

- super send

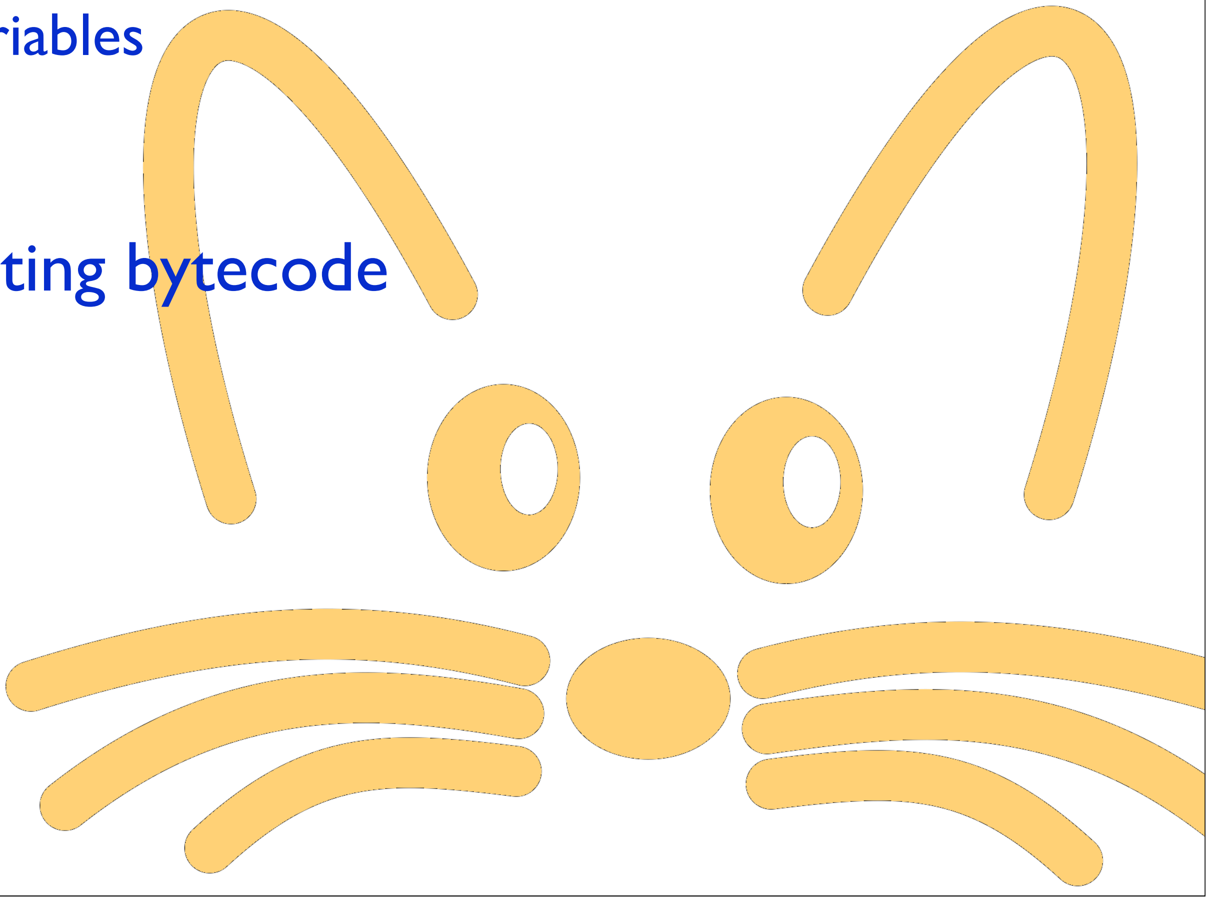
```
....
builder send: #selector toSuperOf: aClass;
```

  - The second parameter specifies the class were the lookup starts.

IRBuilder: Lessons learned

- IRBuilder: Easy bytecode generation
  - Jumps
  - Instance variable
  - Temporary variables
  - Sends

- Next: Manipulating bytecode



ByteSurgeon

- Library for bytecode transformation in Smalltalk
- Full flexibility of Smalltalk Runtime
- Provides high-level API
- For Squeak, but portable

- Runtime transformation needed for
  - Adaptation of running systems
  - Tracing / debugging
  - New language features (MOP, AOP)

Example: Logging

- Goal: logging message send.
- First way: Just edit the text:

```
example
   self test.
```

```
example
   Transcript show: ‘sending #test’.
   self test.
```

Logging with Bytesurgen

- Goal: Change the method without changing program text
- Example:

```
(Example>>#example)instrumentSend: [:send |
   send insertBefore:
      ‘Transcript show: ‘’sending #test’’ ‘.
]
```

Logging: Step by Step

```
(Example>>#example)instrumentSend: [:send |
   send insertBefore:
      'Transcript show: ''sending #test'' '.
]
```

```
Example >> #example
```

Class

Name of Method

>>: - takes a name of a method
- returns the CompiledMethod object

Logging: Step by Step

```
(Example>>#example)instrumentSend: [:send |
   send insertBefore:
      'Transcript show: ''sending #test'' '.
]
```

- instrumentSend:
  - takes a block as an argument
  - evaluates it for all send bytecodes

Logging: Step by Step

```
(Example>>#example)instrumentSend: [:send |
   send insertBefore:
      ‘Transcript show: ‘’sending #test’’ ‘.
]
```

- The block has one parameter: send
- It is executed for each send bytecode in the method

Logging: Step by Step

```
(Example>>#example)instrumentSend: [:send |
   send insertBefore:
      'Transcript show: ''sending #test'' '.
]
```

- Objects describing bytecode understand how to insert code
  - insertBefor
  - insertAfter
  - replace

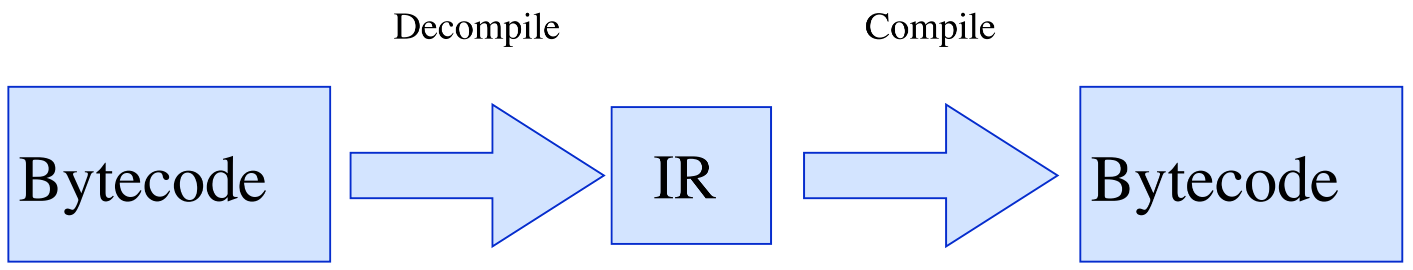
Logging: Step by Step

```
(Example>>#example)instrumentSend: [:send |
   send insertBefore:
      ‘Transcript show: ‘’sending #test’’ ‘.
]
```

- The code to be inserted.
- Double quoting for string inside string
  - `Transcript show: ’sending #test’`

Inside ByteSurgeon

- Uses IRBuilder internally



- Transformation (Code inlining) done on IR

ByteSurgeon Usage

- On Methods or Classes:

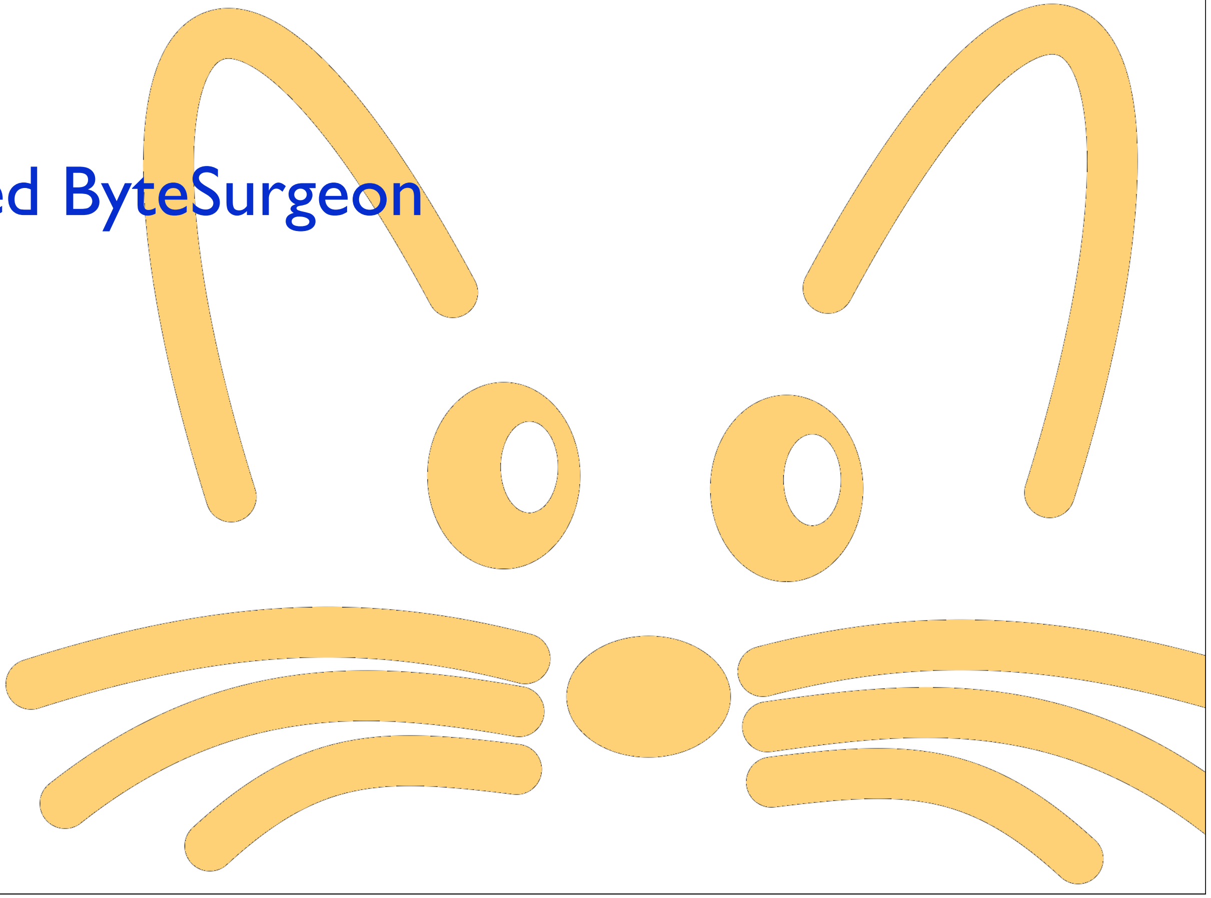
```
MyClass instrument: [.... ].
(MyClass>>#myMethod) instrument: [.... ].
```

- Different instrument methods:
  - instrument:
  - instrumentSend:
  - instrumentTempVarRead:
  - instrumentTempVarStore:
  - instrumentTempVarAccess:
  - same for InstVar

ByteSurgeon: Lessons learned

- ByteSurgeon: Tool for editing bytecode
  - Simple example
  - Based on IRBuilder

- Next: Advanced ByteSurgeon



Advanced ByteSurgeon:

- Goal: extend a send with after logging

```
example
   self test.
```

→

```
example
      self test.
      Logger logSendTo: self.
```

Advanced ByteSurgeon

- With Bytesurgeon, something like:

```
(Example>>#example)instrumentSend: [:send |
   send insertAfter:
      ‘Logger logSendTo: ?’ .
]
```

- How can we access the receiver of the send?
- Solution: Metavariable

Advanced ByteSurgeon

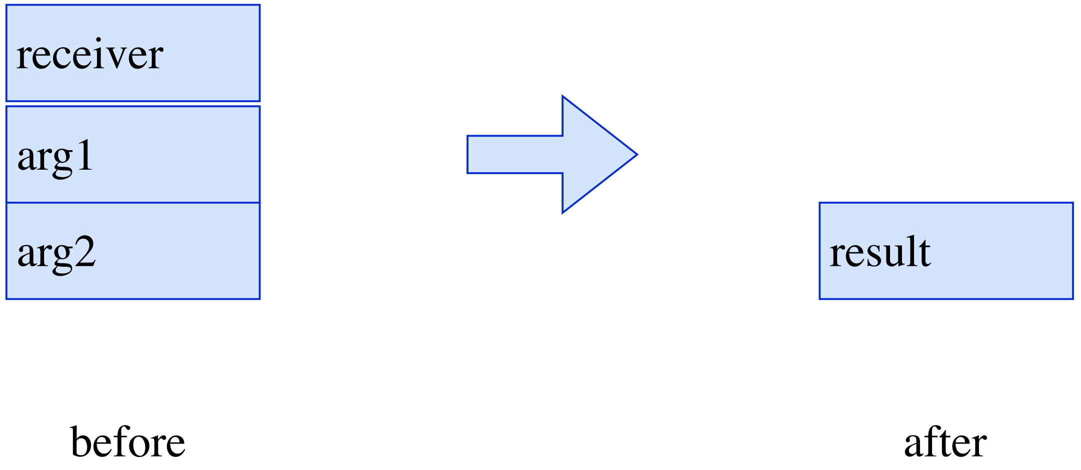
- With Bytesurgeon, something like:

```
(Example>>#example)instrumentSend: [:send |
   send insertAfter:
      'Logger logSendTo: <meta: #receiver>' .
]
```

- How can we access the receiver of the send?
- Solution: Metavariable

Implementation Metavariables

- Stack during send:



- Problem I: After send, receiver is not available
- Problem II: Before send, receiver is deep in the stack

Metavariables: Implementation

- Solution: ByteSurgeon generates preamble
  - Pop the arguments into temps
  - Pop the receiver into temps
  - Rebuild the stack
  - Do the send
  - Now we can acces the receiver even after the send

Metavariables: Implementation

```
25 <70> self
26 <81 40> storeIntoTemp: 0          Preamble
28 <D0> send: test
29 <41> pushLit: Transcript
30 <10> pushTemp: 0                  Inlined Code
31 <E2> send: show:
32 <87> pop
33 <87> pop
34 <78> returnSelf
```

End

- Short overview of Squeak bytecode
- Introduction to bytecode generation with IRBuilder
- Manipulating bytecode with ByteSurgeon

- Questions?