CS652 Smalltalk VM Operational Semantics

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Smalltalk	**Context stack at** $\hookleftarrow$

`"Test testEvalReturnBlock"`
`class T [`
`  f [|x| x := 1. ^[x := 5] ]`
`]`
`t := T new.`
`t f value` $\hookleftarrow$
	Start `send 0,'value'`:
	$main[\_, nil, \_]\ f\text{-}block0[\_, ,]$
	Notes: no f on stack during eval of $f\text{-}block0$ but enclosing scope of $f\text{-}block0$ still points at f's `BlockContext`.

Smalltalk	**Context stack at** $\hookleftarrow$

`"Test testRemoteMethodCanSetMyLocal"`
`class T [`
`   f [|x| self g:[x := 5` $\hookleftarrow$`]]`
`   g:  blk [ blk value]`
`]`
`T new f`
	`@store_local` Δ=`1`,i=0:
	$main[\_, ,]\ \underbrace{f[\_, nil,]\ g[\_, f^{block_0},]\ f}_{\overleftarrow{\qquad}\text{enclosing context } \Delta=1}\ ^{block_0}[\_, , \mathbf{5}]$
	After `block_return`:
	$main[\_, ,]\ f[\_, \mathbf{5},]\ g[\_, f^{block_0}, \mathbf{5}]$

Smalltalk	**Context stack at** $\hookleftarrow$

`"Test testRemoteReturn"`
`class T [`
`   f [ self g:[^99] ]`
`   g:blk [ blk value` $\hookleftarrow$`]`
`]`
`|t|`
`t := T new.`
`t f`
	Start `send 0,'value'`:
	$main[\_, t,]\ f[\_, ,]\ g[\_, f^{block_0},]\ f^{block_0}[\_, ,]$
	After `return` in `[^99]` block:
	$main[\_, t, 99]$
	Notes: Despite eval in g, `[^99]` unrolls stack to $main$, the caller of f.

$T \bowtie x$	Resolve x in scope T
$o \in \texttt{X}$	o is instance of X
$\mathbf{v} \in \texttt{STObject}$	a single object
$\boldsymbol{l}_i \in \texttt{STObject}$	the i^{th}argument or local variable object
$o_{class} \in \texttt{STMetaClassObject}$	Metaclass (type) of object o
$o_{class_{class}} = o_{class}$	A metaclass object is its own type
$o_{superclass} \in \texttt{STMetaClassObject}$	Superclass (type) of object o
o_{field_i}	The i^{th}field of object o
$f_{literal_i}$	The i^{th}literal of method f
$f_s^{block_i} \in \texttt{BlockDescriptor}$	The i^{th}block of method f associated with instance self=s
$f_s^{block_i}[\_,\_,\_] \in \texttt{BlockContext}$	The i^{th}block of method f invoked with self=s
$f_s^{block_i}[\_,\_,\_]^d \in \texttt{BlockContext}$	The i^{th}block of method f invoked with self=s and having depth d counting from zero at the method block; e.g., `f [|x| [|y|]]` has a method block at depth 0 with `x` and a nested block at depth 1 with `y`
$\gamma \in \texttt{MethodContext}^*$	Stack of method invocations growing to the right
$\delta \in \texttt{STObject}^*$	Operand stack of objects growing to the right
$\mathbb{S}$	The state of the VM system dictionary
$(\mathbb{S}, \gamma)$	VM state is the system dictionary and a method invocation stack with zero or more elements
$(\mathbb{S}, \gamma) \Rightarrow (\mathbb{S}', \gamma')$	VM state transition
$(\mathbb{S}, \gamma) \Rightarrow^* (\mathbb{S}', \gamma')$	Zero-or-more state transitions
$f_s[ip, l_0, ..l_{n-1}, \delta]$	Method invocation context that derived from sending message f to receiver s (self); $f \in$ `MethodContext`; l_i is local variable or argument, indexed from 0 and arguments first; δ is the operand stack; f *can also represent a nested code block not just a method*
$f[ip, l_0, ..l_{n-1}, \delta]$	Same as previous but the receiver is unknown or irrelevant
$f[ip, \_, \_]$	A method invitation context with “don’t care” for locals and operand stack

Figure 1: Smalltalk VM Bytecode Specification Notation

Bytecode Instruction	**Transition**
initial state	$state_0 = (\mathbb{S}[\texttt{Transcript}], \texttt{main}_m[0, \epsilon, \epsilon])$ for $m \in$ `MainClass`; program terminates if $\exists\ state_0 \Rightarrow^* (\mathbb{S}', \epsilon)$
`nil`	$(\mathbb{S}, \gamma f[ip, \_, \delta]) \ \Rightarrow\ (\mathbb{S}, \gamma f[ip+1, \_, \delta\, \texttt{nil}])$
`self`	$(\mathbb{S}, \gamma f_s[ip, \_, \delta]) \ \Rightarrow\ (\mathbb{S}, \gamma f_s[ip+1, \_, \delta\, s])$
`true`	$(\mathbb{S}, \gamma f[ip, \_, \delta]) \ \Rightarrow\ (\mathbb{S}, \gamma f[ip+1, \_, \delta\, \texttt{true}])$
`false`	$(\mathbb{S}, \gamma f[ip, \_, \delta]) \ \Rightarrow\ (\mathbb{S}, \gamma f[ip+1, \_, \delta\, \texttt{false}])$
`push_char` c	$(\mathbb{S}, \gamma f[ip, \_, \delta]) \ \Rightarrow\ (\mathbb{S}, \gamma f[ip+3, \_, \delta\, c])]$
`push_int` i	$(\mathbb{S}, \gamma f[ip, \_, \delta]) \ \Rightarrow\ (\mathbb{S}, \gamma f[ip+5, \_, \delta\, i])$
`push_float` i	$(\mathbb{S}, \gamma f[ip, \_, \delta]) \ \Rightarrow\ (\mathbb{S}, \gamma f[ip+5, \_, \delta\, \mathit{intBitsToFloat}(i)])$
`push_field` i	$(\mathbb{S}, \gamma f_s[ip, \_, \delta]) \ \Rightarrow\ (\mathbb{S}, \gamma f_s[ip+3, \_, \delta\, s_{field_i}])$
`push_local` $0, i$	$(\mathbb{S}, \gamma f[ip, \cdots l_i \cdots, \delta]) \ \Rightarrow\ (\mathbb{S}, \gamma f[ip+5, \cdots l_i \cdots, \delta\, l_i])$
`push_local` $n > 0, i$	$(\mathbb{S}, \gamma g^{block}[\_, \cdots \boldsymbol{l}_i \cdots, \_]^{d-n} \ \cdots\ g^{block'}[ip, \_, \_]^{d-1} \ \cdots\ g^{block''}[ip, \_, \delta]^d) \ \Rightarrow$ $(\mathbb{S}, \gamma\ \cdots\ g^{block''}[ip+5, \_, \delta \boldsymbol{l}_i]^d)$
`push_literal` i	$(\mathbb{S}, \gamma f[ip, \_, \delta]) \ \Rightarrow\ (\mathbb{S}, \gamma f[ip+3, \_, \delta\, f_{literal_i}])$
`push_global` i	$(\mathbb{S}, \gamma f[ip, \_, \delta]) \ \Rightarrow\ (\mathbb{S}, \gamma f[ip+3, \_, \delta\, \mathbb{S}[f_{literal_i}]])$
`push_array` n	$(\mathbb{S}, \gamma f[ip, \_, \delta\, a_1..a_n]) \ \Rightarrow\ (\mathbb{S}, \gamma f[ip+3, \_, \delta A])$ where $A = \mathit{Array}(a_1..a_n)$
`store_field` i	$(\mathbb{S}, \gamma f_s[ip, \_, \delta\, \mathbf{v}]) \ \Rightarrow\ (\mathbb{S}[s_{field_i} = \mathbf{v}], \gamma f_s[ip+3, \_, \delta\, \mathbf{v}])$
`store_local` n, i	$(\mathbb{S}, \gamma f[ip, \cdots l_i \cdots, \delta\, \mathbf{v}]) \ \Rightarrow\ (\mathbb{S}, \gamma f[ip+5, \cdots l_{i-1} \mathbf{v}\, l_{i+1} \cdots, \delta\, \mathbf{v}])$
`pop`	$(\mathbb{S}, \gamma f[ip, \_, \delta\, \mathbf{v}]) \ \Rightarrow\ (\mathbb{S}, \gamma f[ip+1, \_, \delta])$
`send` n, i	$(\mathbb{S}, \gamma f[ip, \_, \delta\, r\, p_1..p_n]) \Rightarrow (\mathbb{S}, \gamma f[ip+5, \_, \delta]\ (r_{class} \bowtie f_{literal_i})_r[0, p_1..p_n, \epsilon])$
`send_super` n, i	$(\mathbb{S}, \gamma f[ip, \_, \delta\, r\, p_1..p_n]) \Rightarrow (\mathbb{S}, \gamma f[ip+5, \_, \delta]\ (r_{superclass} \bowtie f_{literal_i})_r[0, p_1..p_n, \epsilon])$
`block` i	$(\mathbb{S}, \gamma f[ip, \_, \delta]) \ \Rightarrow\ (\mathbb{S}, \gamma f[ip+3, \_, \delta\, f_s^{block_i}])$
`block_return`	$(\mathbb{S}, \gamma f[ip, \_, \delta]\ g^{block}[\_, \_, \delta'\, \mathbf{v}]) \ \Rightarrow\ (\mathbb{S}, \gamma f[ip, \_, \delta\, \mathbf{v}])$
(*method local*) `return`	$(\mathbb{S}, \gamma f[ip, \_, \delta]\ g[\_, \_, \delta'\, \mathbf{v}]) \ \Rightarrow\ (\mathbb{S}, \gamma f[ip, \_, \delta\, \mathbf{v}])$
(*method nonlocal*) `return`	$(\mathbb{S}, \gamma f[ip, \_, \delta]\ g_s[\_, \_, \_]\ \cdots\ h[\_, \_, \_]\ g_s^{block}[\_, \_, \delta'\, \mathbf{v}]) \ \Rightarrow\ (\mathbb{S}, \gamma f[ip, \_, \delta\, \mathbf{v}])$
`dbg` i, loc	$(\mathbb{S}, \gamma f[ip, \_, \_]) \Rightarrow (\mathbb{S}[\mathit{file}{=}f_{literal_i}, \mathit{line}{=}\mathit{loc}[31{:}8], \mathit{col}{=}\mathit{loc}[7{:}0]], \gamma f[ip+7, \_, \_])$ Set VM current filename to $f_{literal_i}$ and split *loc* into char position (indexed from 0) from lower 8 bits and line number from the upper 24 bits.

Figure 2: Smalltalk VM State Transition Rules

Bytecode Instruction	**Description**
`nil`	Push `nil` onto the operand stack of the *current block or method context.*
`self`	Push `self`, the current method's receiver object, onto the operand stack
`true`	Push `true` onto the operand stack
`false`	Push `false` onto the operand stack
`push_char` c	Push character c onto the operand stack
`push_int` i	Push integer i onto the operand stack
`push_float` f	Push floating-point f
`push_field` i	Push field at index i of `self`
`push_local` $0, i$	Push the local variable or method argument at index i of the current context onto the operand stack of the current context
`push_local` $n > 0, i$	Push the local variable or method argument at index i of the context n callers above (stack growing downwards) onto the operand stack of the current context
`push_literal` i	Push string literal at literal index i onto the stack
`push_global` i	Look up string at literal index i in the global scope and push that object onto the operand stack of the current context. This is used to look up class definition objects primarily as in `Array new`.
`push_array` n	Pop n items from the operand stack, create an array of them, push the array back to the operand stack
`store_field` i	Store the top of the operand stack into field i of `self`; does *not* pop the operand stack
`store_local` n, i	Store the top of the operand stack into local i of the current context; does *not* pop the operand stack
`pop`	Pop the top of the operand stack off
`send` n, i	Send message with n arguments to method identified by string literal i (in current context). The receiver of the message send is pushed on the stack before the arguments so this instruction pops $n+1$ items from the operand stack. The method is looked up in the class of the receiver object
`send_super` n, i	Same as `send` except that the method is looked up in the superclass of `self`'s class. The receiver is always `self`
`block` i	Push the block descriptor identified by index i onto the operand stack of the current context
`block_return`	Pop the return value on the top of the operand stack of the current context and push it on the operand stack of the caller's context. Pop the context stack.
(*method local*) `return`	Pop the top of the operand stack of the current context and push it on the operand stack of the caller's context. Pop the context stack.
(*method nonlocal*) `return`	Pop the top of the operand stack of the current context, unwind the call stack until the *enclosing method* of the current block, pop to the caller, push the return value onto the operand stack
`dbg` i, loc	Set VM current filename to $f_{literal_i}$ and split *loc* into char position (indexed from 0) from lower 8 bits and line number from the upper 24 bits. *line*=*loc*[31:8], *col*=*loc*[7:0]]

Figure 3: Smalltalk VM Bytecode

Smalltalk | **Context stack at $\hookleftarrow$**

```
"Test returnFromNestedCallViaBlock"
class Test [
   f [ self g: [^99↩] ]
   g: blk [ self h: blk ]
   h: blk [ blk value ]
]
Test new f
```

Before `return`:

$$main[\_,,]\ \underbrace{f[\_,,]\ g[\_,f^{block_0},]\ h[\_,f^{block_0},]\ f}_{\text{enclosing context }\Delta=1}{}^{block_0}[\_,,99]$$

After `return`:

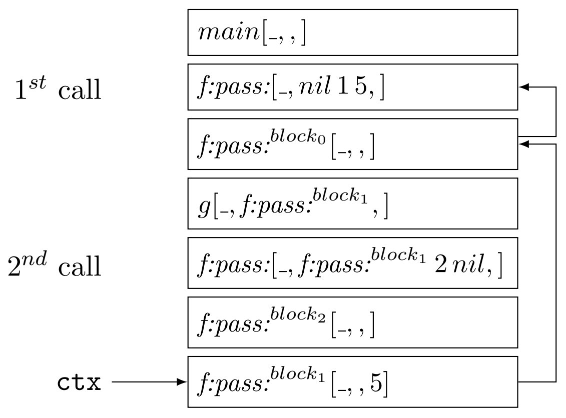
$$main[\_,,99]$$

Notes: Despite eval in g, `[^99]` unrolls stack to $main$, the caller of f.

Smalltalk | **Context stack at $\hookleftarrow$**

```
"Test testSendBlockBackToSameMethod-
AndSetLocal"
class T [
   f: blk pass: p [
     |x|
     p=1 ifTrue: [self g: [x:=5↩]]
         ifFalse: [blk value].
     ^x
   ]
   g: blk [ self f: blk pass: 2 ]
]
T new f: nil pass: 1
```

At `store_local` Δ=2,i=2:



$main[\_,,]$
1st call
$f{:}pass{:}[\_, nil\ 1\ 5,]$
$f{:}pass{:}^{block_0}[\_,,]$
$g[\_, f{:}pass{:}^{block_1},]$
2nd call
$f{:}pass{:}[\_, f{:}pass{:}^{block_1}\ 2\ nil,]$
$f{:}pass{:}^{block_2}[\_,,]$
ctx
$f{:}pass{:}^{block_1}[\_,,5]$

Stack

Notes: The enclosing block of `[x:=5]` (called $f{:}pass{:}^{block_1}$) is `[self g:[x:=5]]` (called $f{:}pass{:}^{block_0}$). The enclosing block of $f{:}pass{:}^{block_0}$ is the first call, not the second call, to $f{:}pass{:}$.

Smalltalk fragment	**Visitor method result**	**Side-effects**
ϵ	ϵ (object `Code.None`)	
`class T : S [ ]`	ϵ	

main	*main*
	`pop`
	`self`
	`return`	

`f <primitive:#`*primitive-name*`>`	ϵ	

`f [ ]`	ϵ	$\texttt{f}_{code}$ =
		`self`
		`return`

`f [` *body* `]`	ϵ	$\texttt{f}_{code}$ =
		body
		`pop`
		`self`
		`return`

operator `[` *body* `]`	ϵ	$operator_{code}$ =
		body
		`pop`
		`self`
		`return`

`a: x b: y c: z [` *body* `]`	ϵ	$\texttt{a:b:c:}_{code}$ =
		body
		`pop`
		`self`
		`return`

$\underbrace{\texttt{[}args\texttt{\vert}\ \ \texttt{\vert}locals\texttt{\vert}\ \texttt{]}}_{\texttt{f}^{block_i}}$	`block` i	$\texttt{f}_{block_i}$ =
		`nil`
		`block_return`

$\underbrace{\texttt{[}\ body\ \texttt{]}}_{\texttt{f}^{block_i}}$	`block` i	$\texttt{f}_{block_i}$ = *body* `block_return`
$expr_1.\, expr_2.\, \cdots\, expr_n$	$expr_1$ `pop` $expr_2$ `pop` $\cdots$ $expr_n$	

Figure 4: Smalltalk Class/Method/Block Compilation Rules

Smalltalk fragment	**Visitor method result**	**Side-effects**
`class T` $[\|x_0x_1..x_n\| \cdots \texttt{f}\ [\cdots\ x_i{:=}\,expr$	*expr* `store_field` i	
`a:`x_0 `b:`x_1 $[\|x_2..x_n\| \cdots\ x_i{:=}\,expr$	*expr* `store_local` $0, i$	
`f` $[\|x_0..x_n\| \cdots\ x_i{:=}\,expr$	*expr* `store_local` $0, i$	
`f` $[\cdots\ [\|x_0..x_n\| \cdots\ x_i{:=}\,expr$	*expr* `store_local` $0, i$	
$\underbrace{\texttt{f:x}\ [\cdots[}_{\Delta = \#scopes}\ \cdots\ \texttt{x}{:=}\,expr$	`store_local` $\Delta, 0$	
`f` $[\cdots\underbrace{[\|\texttt{x}\|\cdots[}_{\Delta}\cdots\ \texttt{x}{:=}\,expr$	*expr* `store_local` $\Delta, 0$	
`class T` $[\|x_0x_1..x_n\| \cdots \texttt{f}\ [\cdots\ x_i$	`push_field` i	
`a:`x_0 `b:`x_1 $[\|x_2..x_n\| \cdots\ x_i$	`push_local` $0, i$	
$\underbrace{\texttt{f:x}\ [\cdots[}_{\Delta = \#scopes}\ \cdots\ \texttt{x}$	`push_local` $\Delta, 0$	
`f` $[\cdots\underbrace{[\|\texttt{x}\|\cdots[}_{\Delta}\cdots\ \texttt{x}$	`push_local` $\Delta, 0$	
`99`	`push_int 99`	
`$a`	`push_char` *ASCII('a')*	
`1.2`	`push_float` *asIntBits(1.2)*	
`class T` $[\cdots$ `'a string'`	`push_literal` i	$\texttt{T}_{literal_i}$ = "`a string`"
`nil`	`nil`	
`self`	`self`	
`true`	`true`	
`false`	`false`	
$\{\ expr_1 .\ expr_2 .\ \cdots\ expr_n\ \}$	$expr_1$ $expr_2$ $\cdots$ $expr_n$ `push_array` n	

Figure 5: Smalltalk Expression Compilation Rules

Smalltalk fragment	**Visitor results**	**Side-effects**
(unary msg) `class T` [$\cdots$ `f` `[`$\cdots$ $expr\, w$	$expr$ `send` $0, i$	$\mathtt{T}_{literal_i}$ = "w"
(binary msg) `class T` [$\cdots$ `f` `[`$\cdots$ $expr_1\, op\, expr_2$	$expr_1$ $expr_2$ `send` $1, i$	$\mathtt{T}_{literal_i}$ = "op"
`class T` [$\cdots$ `f` `[`$\cdots$ $expr\ w_1{:}e_1\ w_2{:}e_2\ \cdots\ w_n{:}e_n$	$expr$ e_1 e_2 $\cdots$ e_n `send` n, i	$\mathtt{T}_{literal_i}$ = "$w_1{:}w_2{:}\cdots w_n{:}$"
`class T` [$\cdots$ `f` `[`$\cdots$ `super` w	`self` `send_super` $0, i$	$\mathtt{T}_{literal_i}$ = "w"
`class T` [$\cdots$ `f` `[`$\cdots$ `super` $w_1{:}e_1\ w_2{:}e_2\ \cdots\ w_n{:}e_n$	`self` e_1 e_2 $\cdots$ e_n `send_super` n, i	$\mathtt{T}_{literal_i}$ = "$w_1{:}w_2{:}\cdots w_n{:}$"
`^`$expr$	$expr$ `return`	

Figure 6: Smalltalk Message Expression Compilation Rules