Frame VM

A virtual machine using scopes as frames

Chiel Bruin

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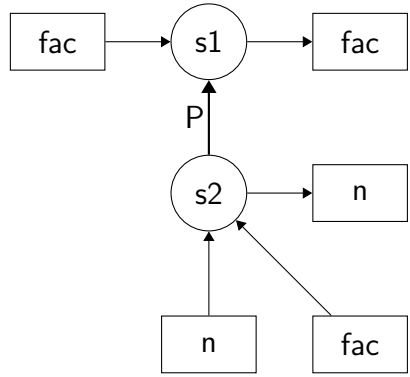
Outline

- Scopes as frames
  - Scope graphs
  - Memory layout
- Frame VM design
  - Instructions
- Continuation Passing Style
  - VM sugar
- Demo / Examples
- Call/cc
  - Scheme
- What next

Scope graphs - functions

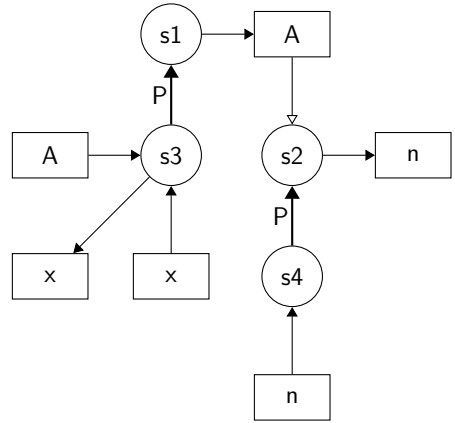
```
let fac =
    fun (n : Int) : Int {
        if (n == 0) {
            1
        } else {
            n * fac(n - 1)
        }
    }
```



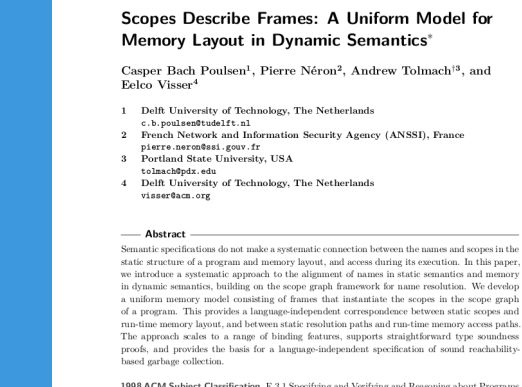
Scope graphs - records

```
record A {
    n : Int
}

begin
    var x : A;
    x = new A
    x.n = 1
```



Scopes describe frames



Scopes Describe Frames: A Uniform Model for Memory Layout in Dynamic Semantics*

Casper Bach Poulsen[1], Pierre Néron[2], Andrew Tolmach[!3], and Eelco Visser[4]

1 Delft University of Technology, The Netherlands
c.b.poulsen@tudelft.nl
2 French Network and Information Security Agency (ANSSI), France
pierre.neron@ssi.gouv.fr
3 Portland State University, USA
tolmach@pdx.edu
4 Delft University of Technology, The Netherlands
visser@acm.org

Abstract

Semantic specifications do not make a systematic connection between the names and scopes in the static structure of a program and memory layout, and access during its execution. In this paper, we introduce a systematic approach to the alignment of names in static semantics and memory in dynamic semantics, building on the scope graph framework for name resolution. We develop a uniform memory model consisting of frames that instantiate the scopes in the scope graph of a program. This provides a language-independent correspondence between static scopes and run-time memory layout, and between static resolution paths and run-time memory access paths. The approach scales to a range of binding features, supports straightforward type soundness proofs, and provides the basis for a language-independent specification of sound reachability-based garbage collection.

1998 ACM Subject Classification F.3.1 Specifying and Verifying and Reasoning about Programs

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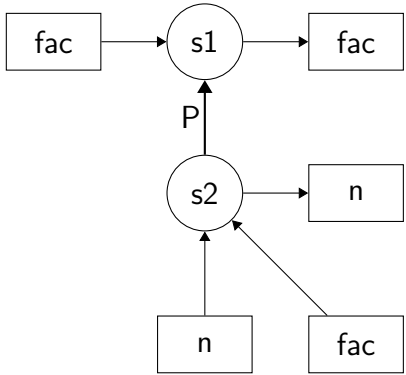
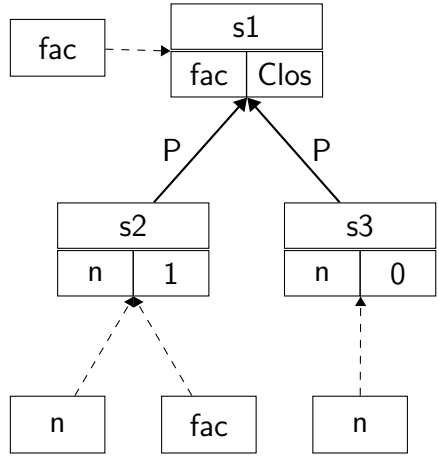
1 Introduction

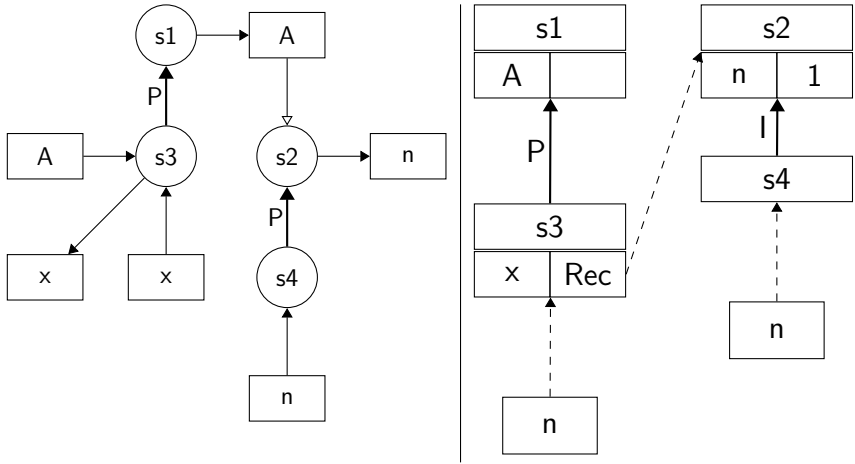
- Scope graph ⇔ memory layout
- Resolution paths ⇔ memory access

Scopes as frames - functions





Scopes as frames - records

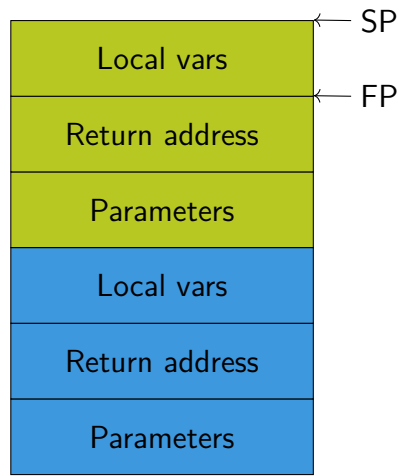


Scopes as frames

- Language independent representation of memory layout
  - Data sharing between languages
  - Garbage collection
- Simplify code generation by using scope graph
  - Given a Dynsem spec and scope graph, get a compiler
  - Control flow

Conventional machine

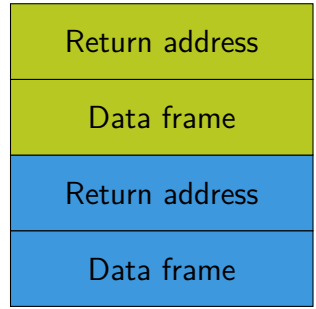
- Languages like C use a heap and (call)stack
- The stack stores local variables, parameters and return addresses
- The heap stores data frames
- Elements on the heap are accessed using pointers stored on the stack



Frames as memory

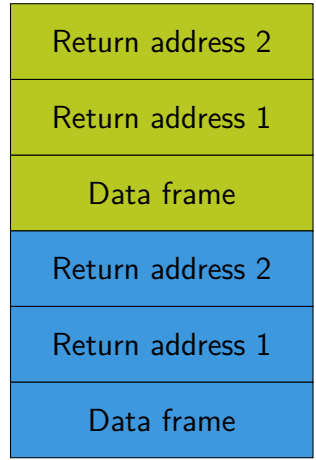
- Local variables are in the scope graph
- Parameters are in the scope graph

$\Rightarrow$ Replaced by a (data) frame



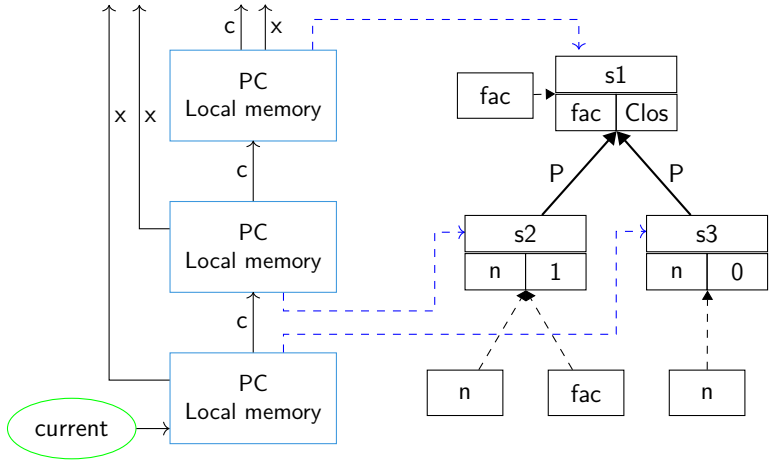
Control frames

- Why only have one return address?
- Having multiple allows for:
  - Exceptions
  - Search algorithms
  - Exit



VM overview

Combining the control graph and data frames into a single system



VM modes

- Two modes
- Stacy
  - Stack machine
  - Used in this presentation
- Roger
  - Register machine
  - Higher level, easier to compile to
  - Early in development

Blocks

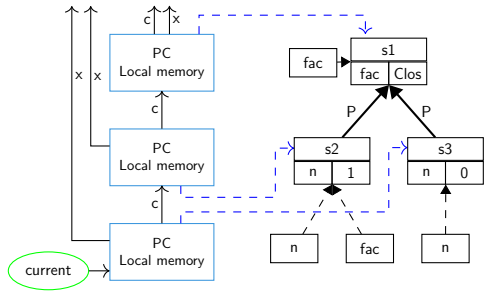
- A program consists of blocks
- A block has a label
- A block ends on jumping instruction

```
MAIN:
  ipush 1
  ipush 2
  addi
  print
  jump LBL
```

Instructions

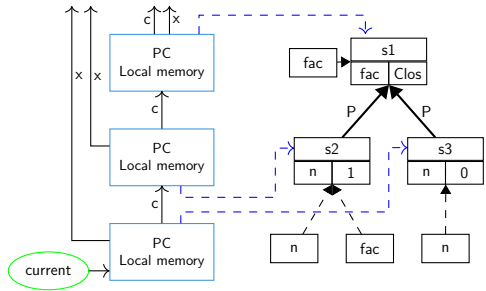
- Arithmetic, stack, ...

```
ipush 1
addi
dup
swap

print
debug
```



Instructions

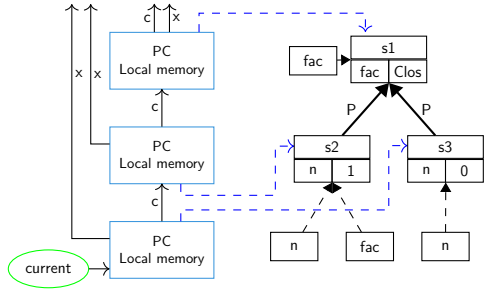
- Current data frame
  `mkcurrent`
  `getcurrent`
  `get [P, 0]`
  `set [0]`
  `link [] P`
- Data frame
  `getr [P, 0]`
  `setr [0]`
  `linkr P`
  `new`



Instructions

- Control frame

```
jump LBL
jumpz THEN ELSE
cget [c]
cset [c]
ccall LBL
transfer 1
```



Continuation Passing Style

- Continuations can be seen as *the rest of the computation*
- In CPS this next step is made explicit

```
(+ 1 (+ 2 3))
```

```
(+' 2 3 (lambda (x) (+ 1 x)))
```

CPS function calls

```
(define inc
    (lambda (x)
        (+ 1 x)
    )
)
```

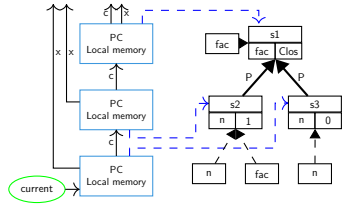
```
(+ 1 (inc 40))
```

```
(define inc'
    (lambda (x, k)
        (k (+ 1 x))
    )
)
```

```
(inc' 40 (lambda (x)
    (+ 1 x)
))
```

CPS and the Frame VM

- Continuation of execution $\rightarrow$
  Some scope, PC and local memory
- Return addresses are continuations*
- Bookkeeping is required



CPS exceptions

```
(define func (lambda (n k x)
  (if (> n 0)
    (k (+ n 1))
    (x 'error)
  )
))

(func 41 (lambda (x) x) (lambda (x) x))
```

Sugar

- Takes care of the bookkeeping
- Designed for a language with exceptions

```
newscope P
exitscope [P]
call FUNC RET
return
try TRY CATCH LBL
throw
```

Sugar

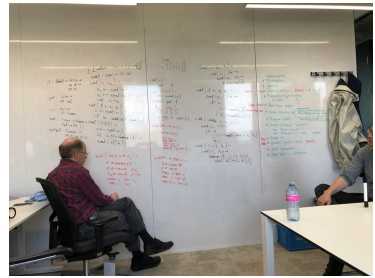
```
call FUNC RET ⇒

cnew FUNC 2
dup
cget [x]
csetr [x]
dup
cget []
csetr [c]
ccall RET
```

Examples

- Records
- Functions
- Recursion
- Tail-recursion
- Debugging

Code generation

- Handcrafted bytecode
  - Exception handling
  - Generator functions
  - Cooperative multithreading
- Scheme compiler*
- LEP projects
  - Prolog
  - Rust
  - Haskell
- Dynsem
- Dynamix



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Call/cc

- Call-with-current-continuation
- Get the current execution state
  (The explicit rest of the computation in CPS)
- This state can be called like a function
- Making a sandwich
- Expensive operation

Call/cc in Scheme

```
(define add-two #f)
(+ 2 (call-cc (
  lambda (cont)
    (set! add-two cont)
    3
  ))
)
(add-two 10)
(add-two 40)
```

What is the next instruction?

Call/cc in Scheme

```
(define add-x #f)
(define x 6)
(+ x (call-cc (
  lambda (cont)
    (set! add-x cont)
    3
  ))
)
(add-x 10)
(set! x 2)
(add-x 40)
```

What should this do?

Call/cc in Scheme

```
(define add-x #f)
(define x 6)
(+ (call-cc (
  lambda (cont)
    (set! add-x cont)
    3
  )) x
)
(add-x 10)
(set! x 2)
(add-x 40)
```

And what about this?

Call/cc issues

- The big question is what data needs to be copied
  - Elements on the stack
  - Continuation slots
  - Current data frame
  - Children of the data frame
  - Parents of the data frame
  - Global variables
- These policies are not yet implemented

What next?

- Modeling memory copy operations
- Modules
- Register machine
- Dynamix
- Stratego interpreter to actual VM

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