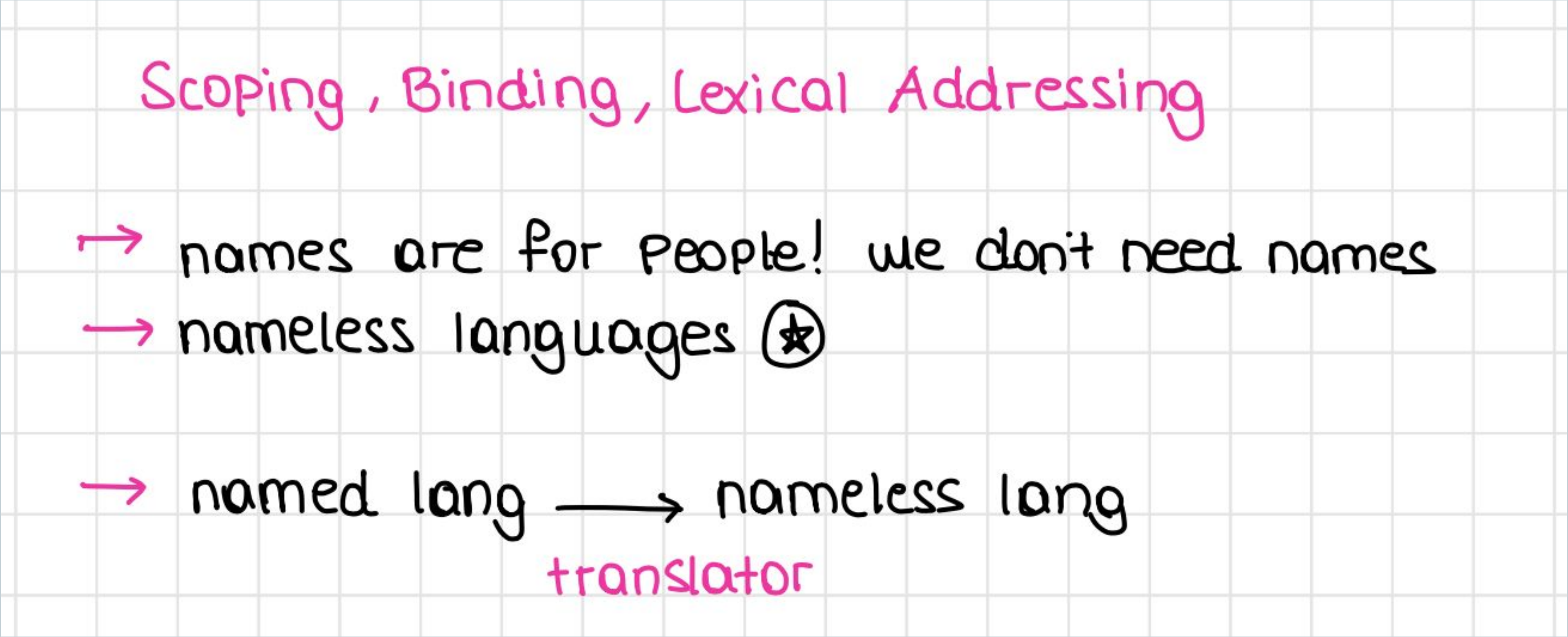
Scoping, Binding Lexical Addressing Review

T. METIN SEZGIN

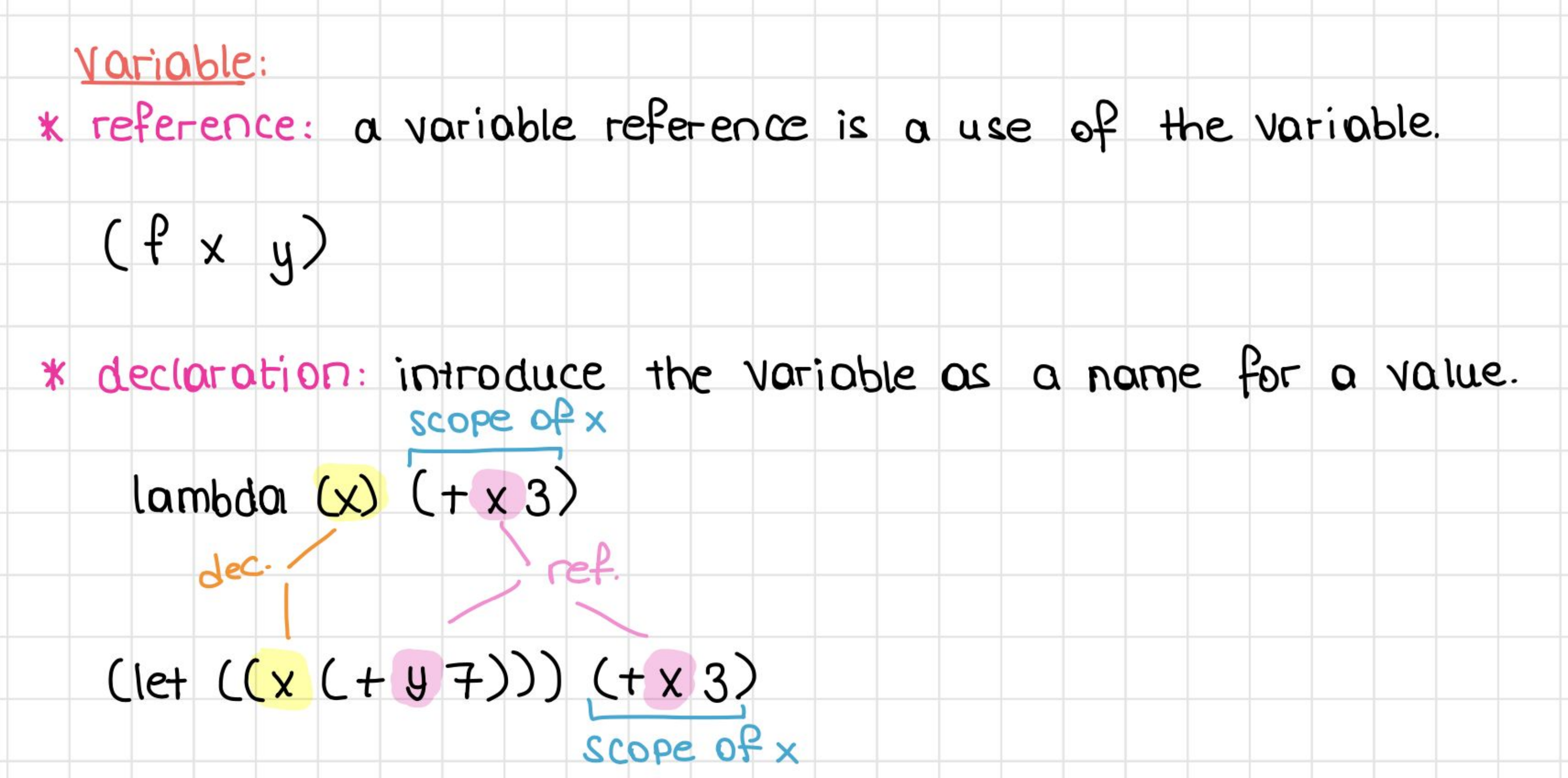


Scoping, Binding, Lexical Addressing

→ names are for people! we don't need names

→ nameless languages ✪

→ named lang $\xrightarrow[\text{translator}]{}$ nameless lang



Variable:

* reference: a variable reference is a use of the variable.

```
(f x y)
```

* declaration: introduce the variable as a name for a value.

scope of x

```
lambda (x) (+ x 3)
```

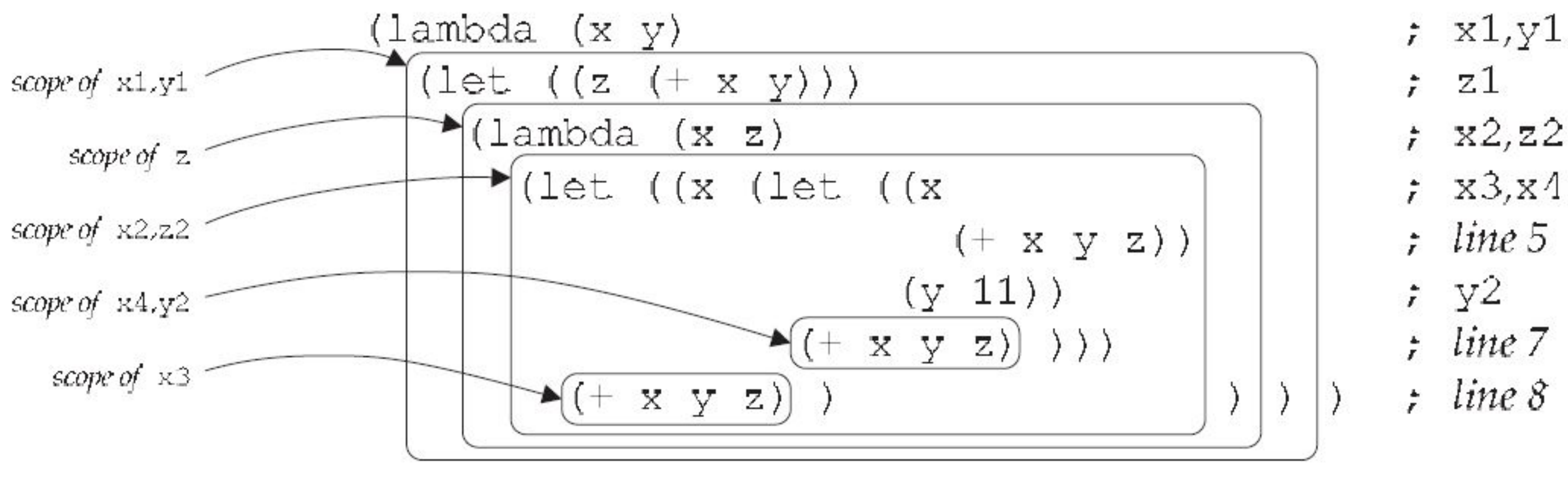
dec.

ref.

```
(let ((x (+ y 7))) (+ x 3)
```

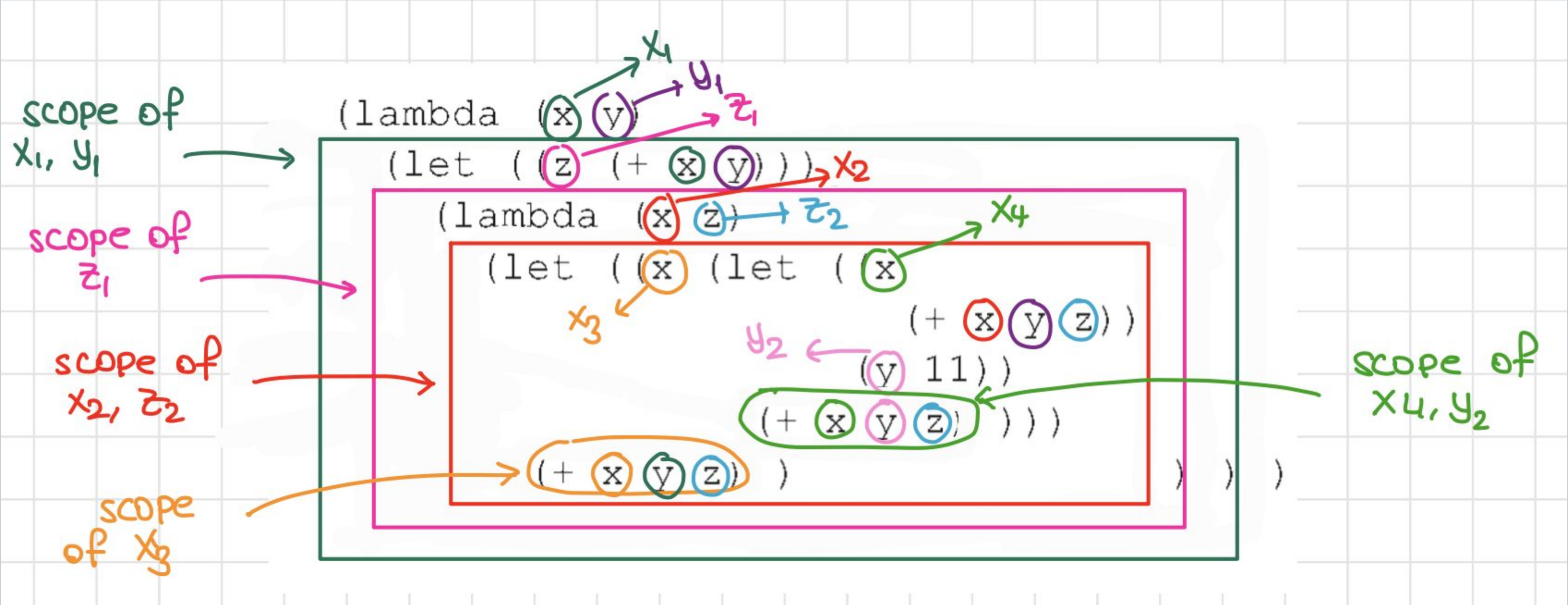
scope of x

Lexical depth



```
(lambda (x y)                                  ; x1,y1
 (let ((z (+ x y)))                            ; z1
  (lambda (x z)                                ; x2,z2
   (let ((x (let ((x                           ; x3,x4
                       (+ x y z))              ; line 5
                   (y 11))                     ; y2
              (+ x y z) )))                    ; line 7
    (+ x y z) )                   ) ) )        ; line 8
```

Lexical depth



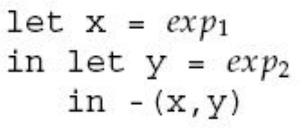
```
(lambda (x y)
  (let ((z (+ x y)))
    (lambda (x z)
      (let ((x (let ((x
                      (+ x y z))
                     (y 11))
                 (+ x y z)))
        (+ x y z)  )          )   )   )
```

Nugget

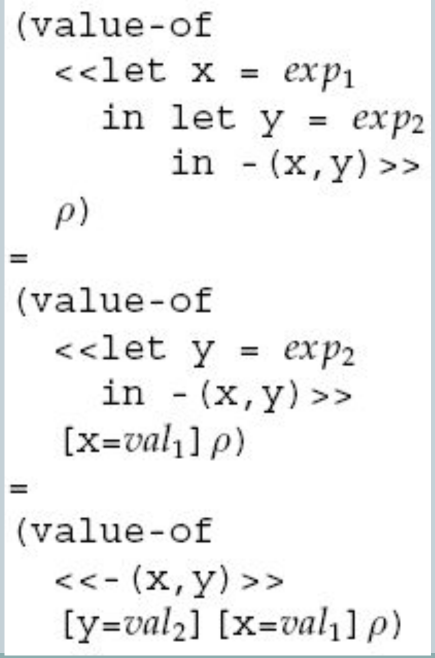
Arguments to procedures always found at the expected places

Evaluating expressions

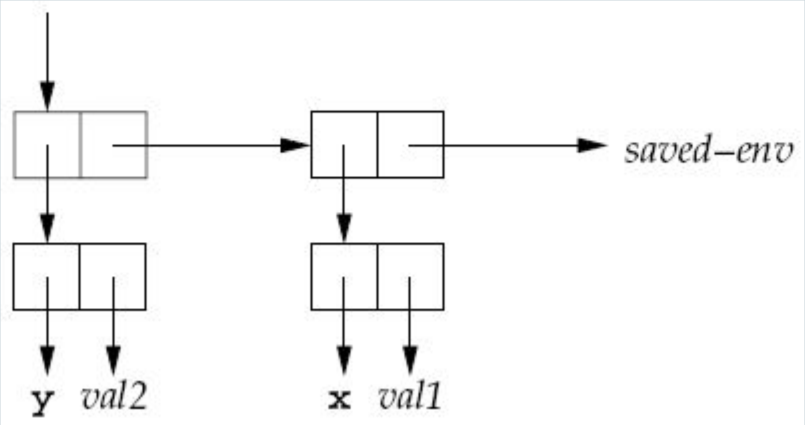
- Consider the following execution trace:



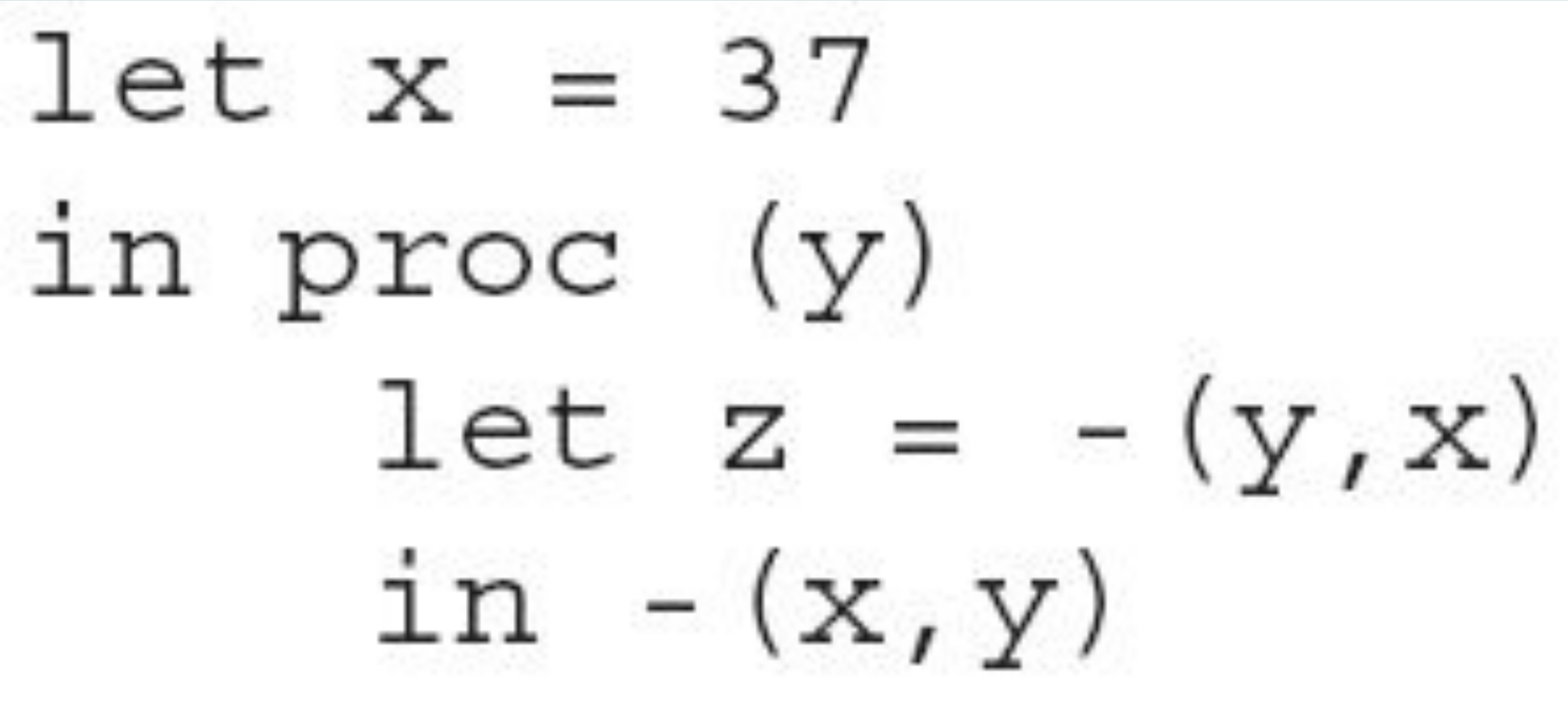
```
let x = exp1
in let y = exp2
   in -(x,y)
```



```
(value-of
  <<let x = exp1
    in let y = exp2
       in -(x,y)>>
  ρ)
=
(value-of
  <<let y = exp2
    in -(x,y)>>
   [x=val1]ρ)
=
(value-of
  <<-(x,y)>>
   [y=val2] [x=val1]ρ)
```



The concept of lexical depth



```
let x = 37
in proc (y)
    let z = -(y,x)
    in -(x,y)
```

Nameless Let
Translation & Interpretation

T. METIN SEZGIN

Nuggets of the lecture

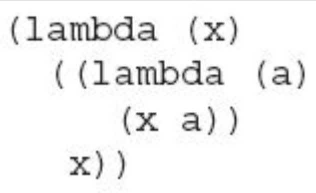
- Arguments to procedures always found at the expected places
- We don’t need names
- We can create a new “nameless” language
- We can translate named language to the nameless one

Nugget

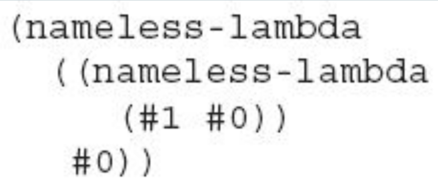
We don’t need names

We don’t need names

- We can create a new “nameless” language



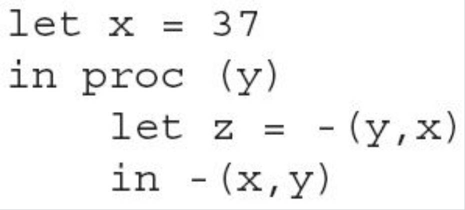
```
(lambda (x)
  ((lambda (a)
     (x a))
   x))
```



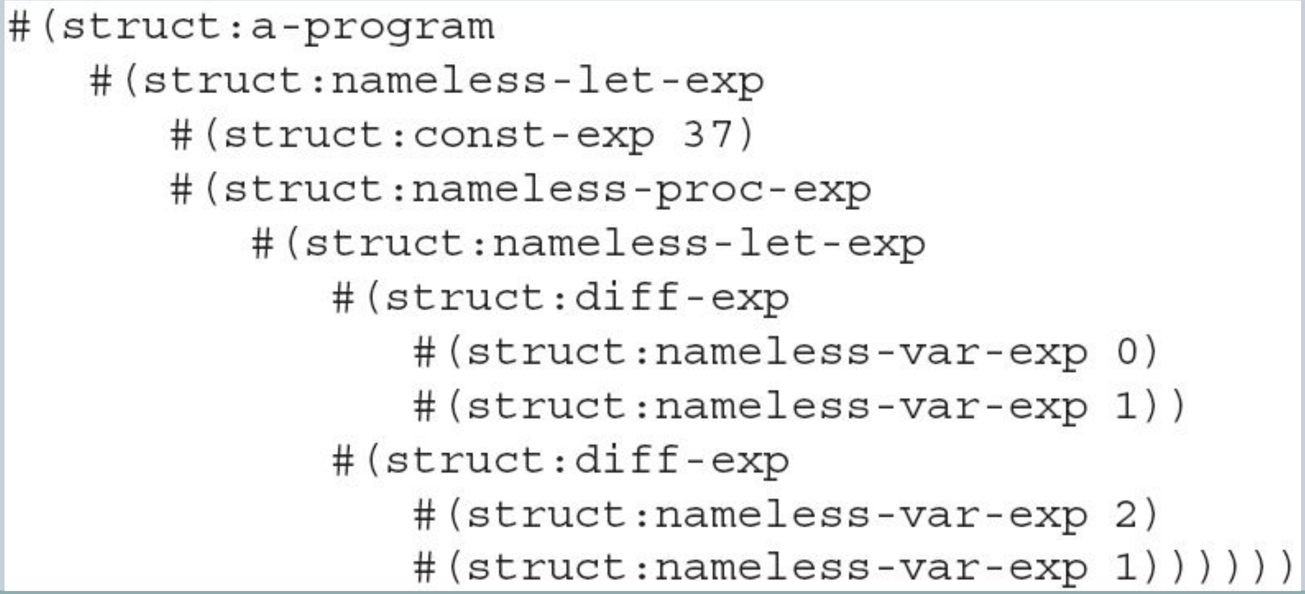
```
(nameless-lambda
  ((nameless-lambda
     (#1 #0))
   #0))
```

Implementing lexical addressing

The Idea: rewrite **`value-of`** (i.o.w. write a translator)



```
let x = 37
in proc (y)
     let z = -(y,x)
     in -(x,y)
```

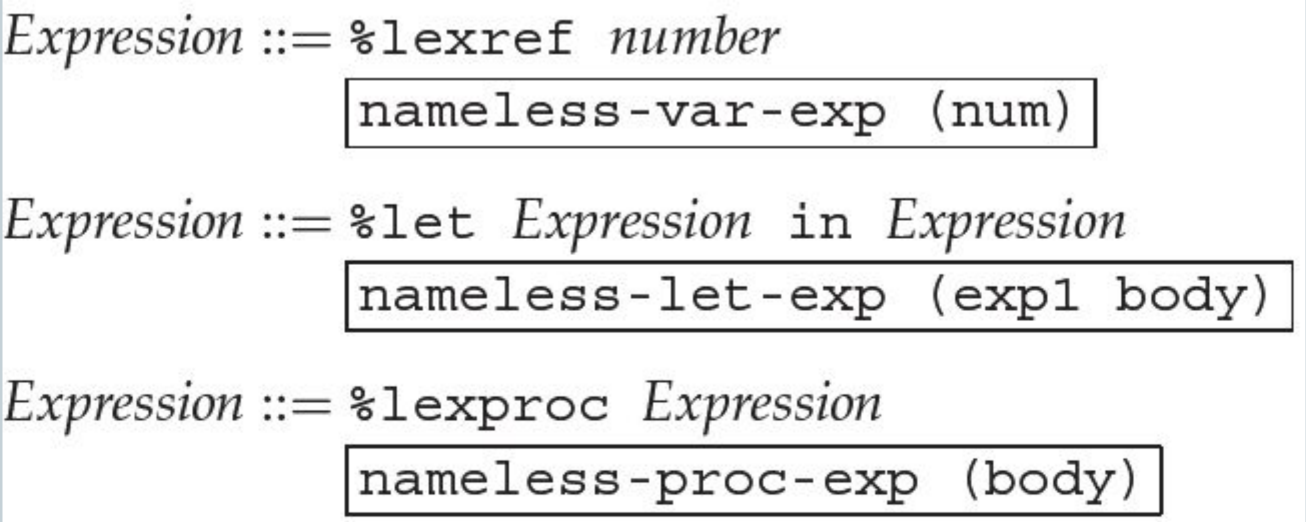


```
#(struct:a-program
   #(struct:nameless-let-exp
      #(struct:const-exp 37)
      #(struct:nameless-proc-exp
         #(struct:nameless-let-exp
            #(struct:diff-exp
               #(struct:nameless-var-exp 0)
               #(struct:nameless-var-exp 1))
            #(struct:diff-exp
               #(struct:nameless-var-exp 2)
               #(struct:nameless-var-exp 1))))))
```

Nugget

We can create a new “nameless” language

The translator: the target language



Expression ::= `%lexref` *number*

`nameless-var-exp (num)`

Expression ::= `%let` *Expression* `in` *Expression*

`nameless-let-exp (exp1 body)`

Expression ::= `%lexproc` *Expression*

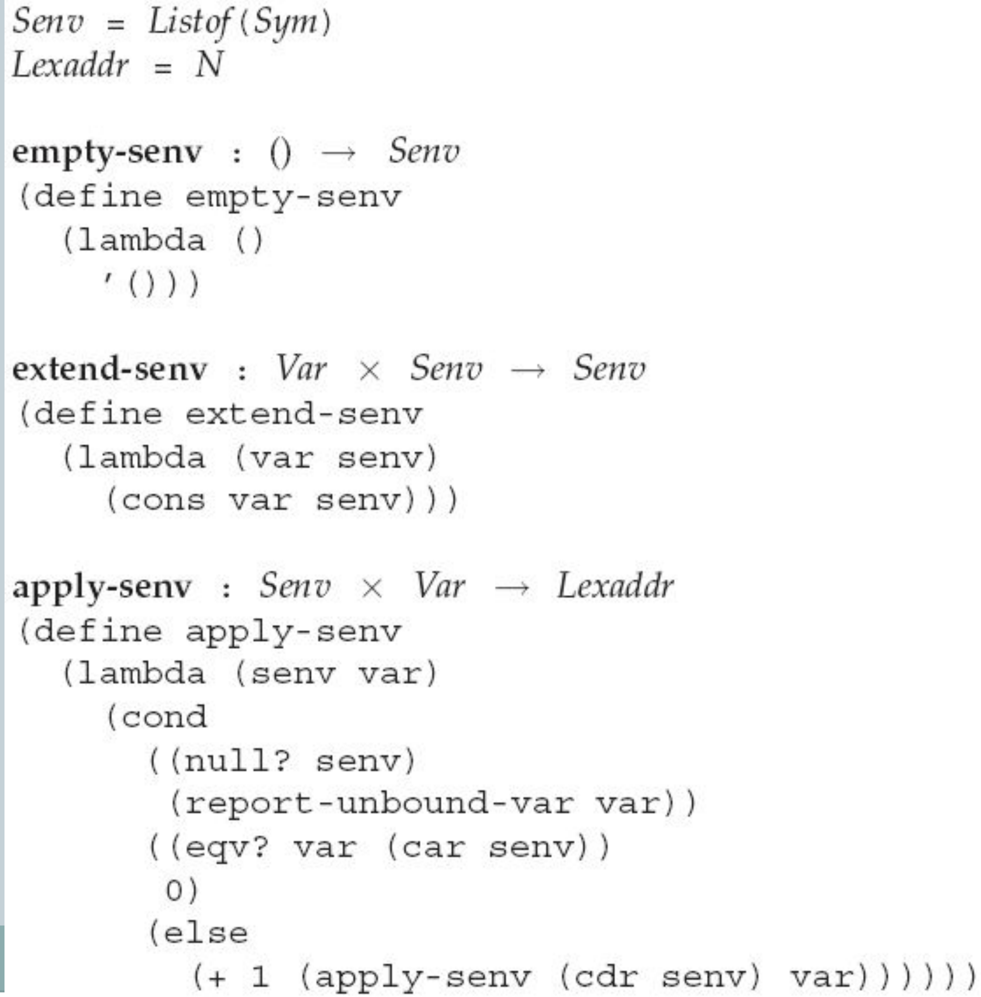
`nameless-proc-exp (body)`

Nugget

We can translate the named language to the nameless one

The translator: Exp x Senv □ NamelessExp

Static Environment



Senv = *Listof*(*Sym*)
Lexaddr = *N*

empty-senv : () → *Senv*

```
(define empty-senv
  (lambda ()
    '()))
```

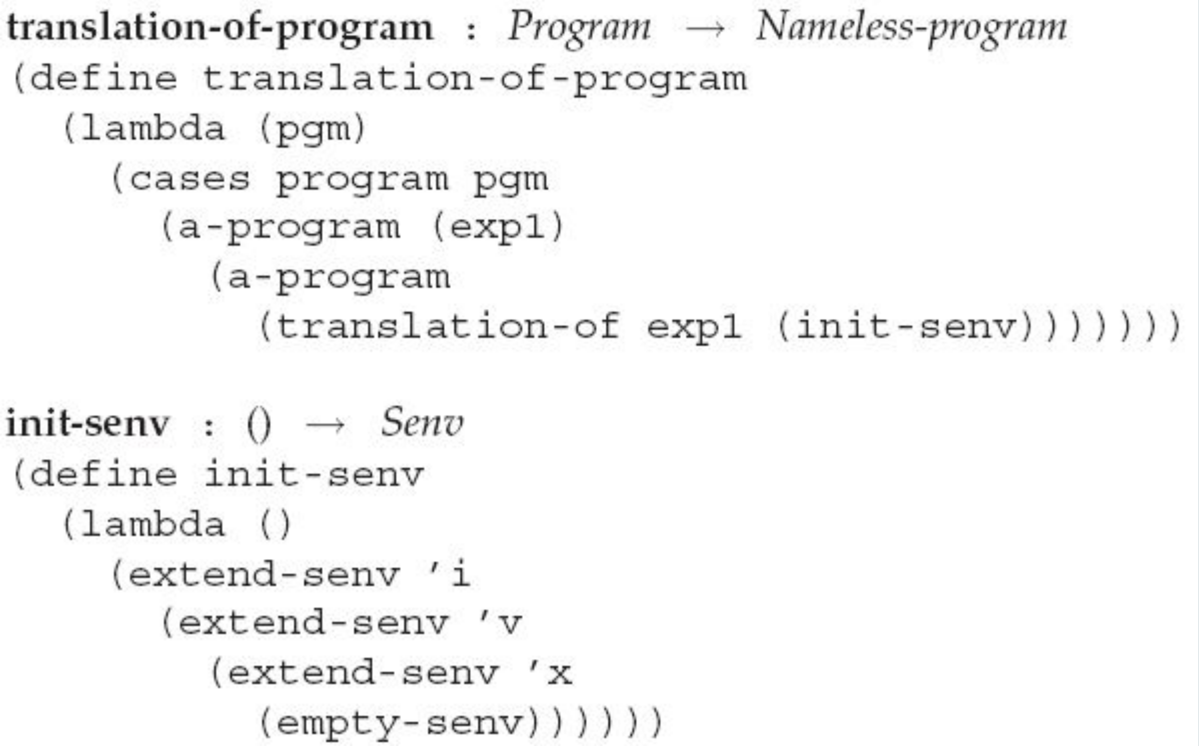
extend-senv : *Var* × *Senv* → *Senv*

```
(define extend-senv
  (lambda (var senv)
    (cons var senv)))
```

apply-senv : *Senv* × *Var* → *Lexaddr*

```
(define apply-senv
  (lambda (senv var)
    (cond
      ((null? senv)
       (report-unbound-var var))
      ((eqv? var (car senv))
       0)
      (else
        (+ 1 (apply-senv (cdr senv) var))))))
```

Translator 1



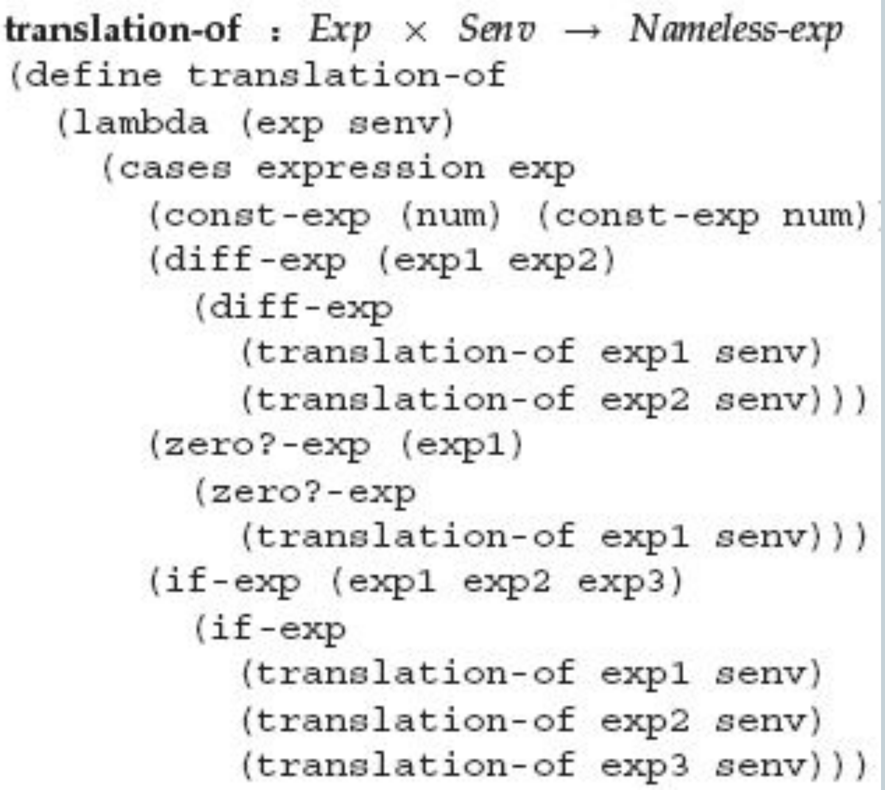
translation-of-program : *Program* → *Nameless-program*

```
(define translation-of-program
  (lambda (pgm)
    (cases program pgm
      (a-program (exp1)
        (a-program
          (translation-of exp1 (init-senv)))))))
```

init-senv : () → *Senv*

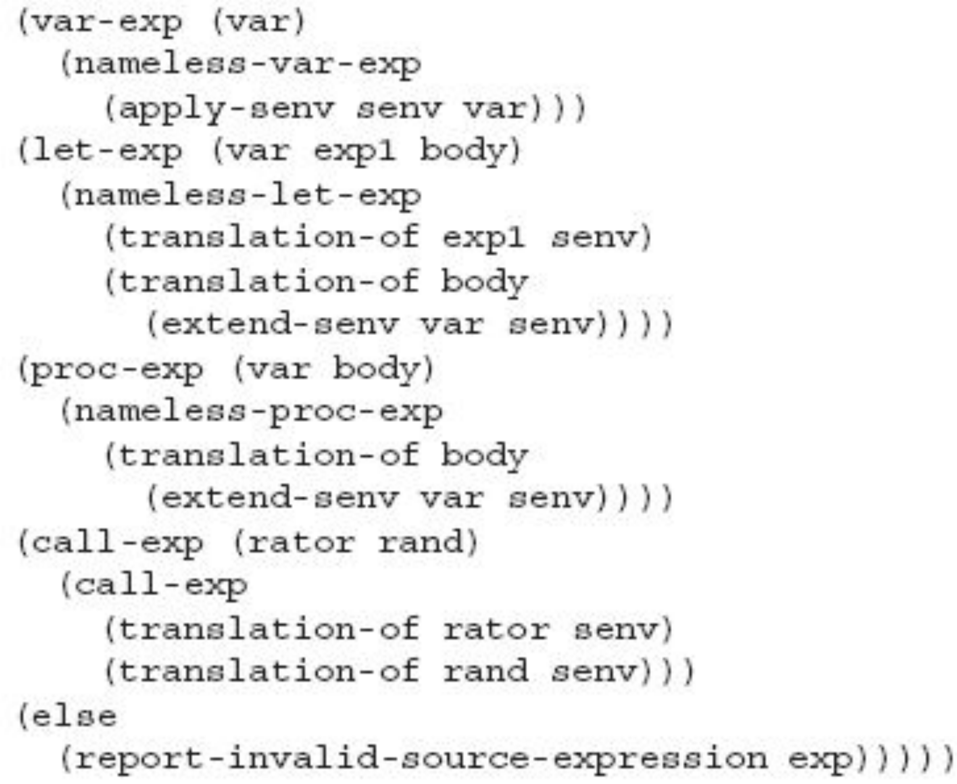
```
(define init-senv
  (lambda ()
    (extend-senv 'i
      (extend-senv 'v
        (extend-senv 'x
          (empty-senv))))))
```

Translator 2



translation-of : *Exp* × *Senv* → *Nameless-exp*

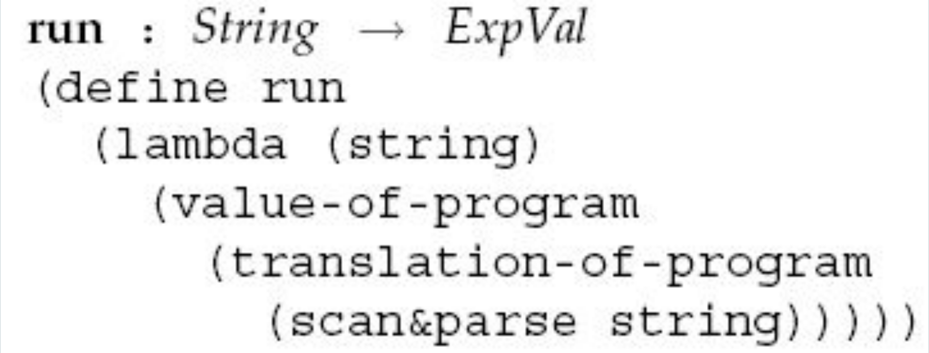
```
(define translation-of
  (lambda (exp senv)
    (cases expression exp
      (const-exp (num) (const-exp num))
      (diff-exp (exp1 exp2)
        (diff-exp
          (translation-of exp1 senv)
          (translation-of exp2 senv)))
      (zero?-exp (exp1)
        (zero?-exp
          (translation-of exp1 senv)))
      (if-exp (exp1 exp2 exp3)
        (if-exp
          (translation-of exp1 senv)
          (translation-of exp2 senv)
          (translation-of exp3 senv)))
```



```
(var-exp (var)
  (nameless-var-exp
    (apply-senv senv var)))
(let-exp (var exp1 body)
  (nameless-let-exp
    (translation-of exp1 senv)
    (translation-of body
      (extend-senv var senv))))
(proc-exp (var body)
  (nameless-proc-exp
    (translation-of body
      (extend-senv var senv))))
(call-exp (rator rand)
  (call-exp
    (translation-of rator senv)
    (translation-of rand senv)))
(else
  (report-invalid-source-expression exp)))))
```

Interpretation

Nameless interpreter

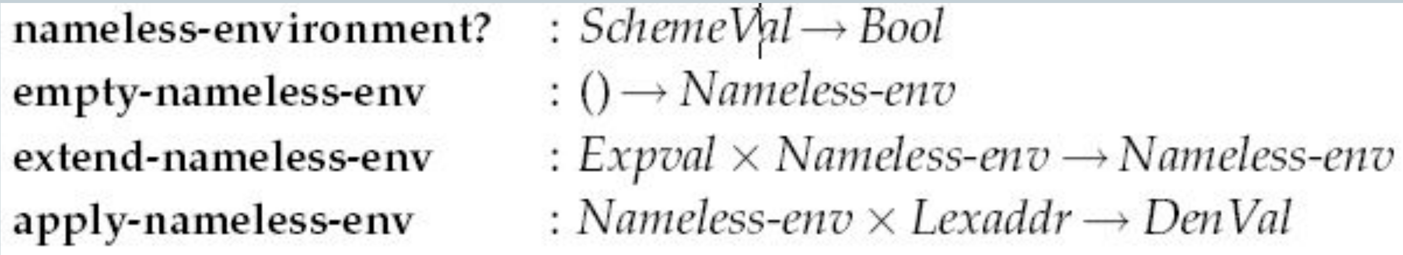


run : *String* → *ExpVal*

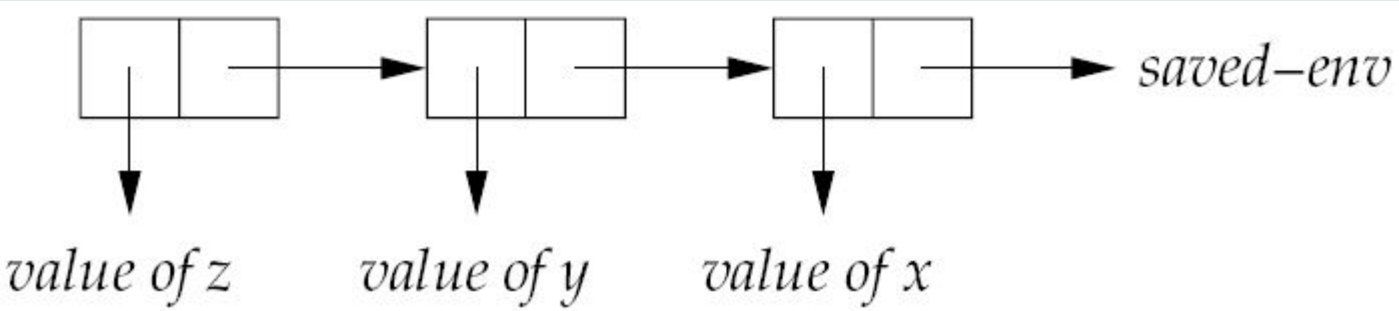
```
(define run
  (lambda (string)
    (value-of-program
      (translation-of-program
        (scan&parse string)))))
```

New environment interface

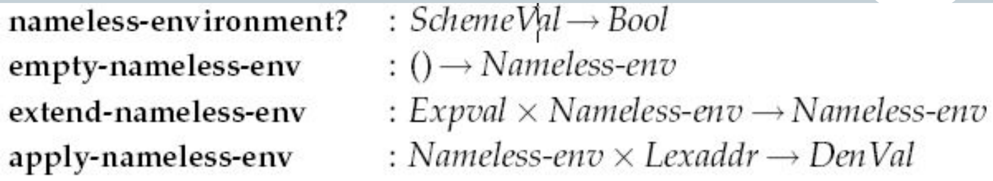
`nameless-environment`



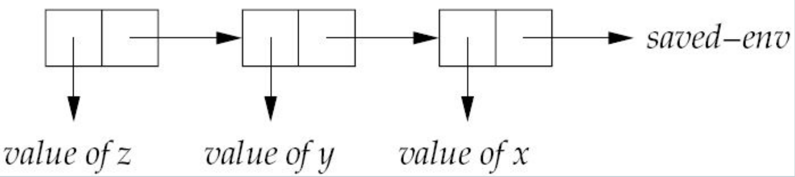
nameless-environment?	: $\mathit{SchemeVal} \rightarrow \mathit{Bool}$
empty-nameless-env	: $() \rightarrow \mathit{Nameless\text{-}env}$
extend-nameless-env	: $\mathit{Expval} \times \mathit{Nameless\text{-}env} \rightarrow \mathit{Nameless\text{-}env}$
apply-nameless-env	: $\mathit{Nameless\text{-}env} \times \mathit{Lexaddr} \rightarrow \mathit{DenVal}$

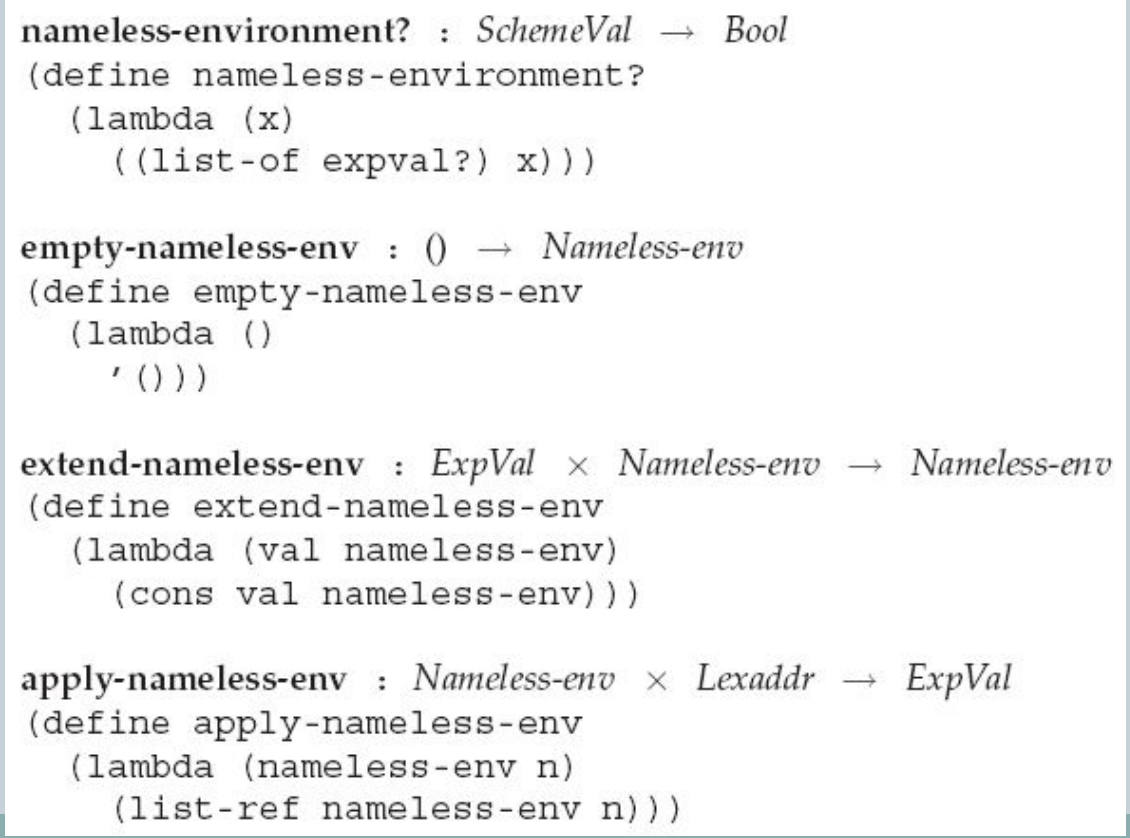


New environment interface



nameless-environment? : *SchemeVal* → *Bool*
empty-nameless-env : () → *Nameless-env*
extend-nameless-env : *Expval* × *Nameless-env* → *Nameless-env*
apply-nameless-env : *Nameless-env* × *Lexaddr* → *DenVal*





nameless-environment? : *SchemeVal* → *Bool*

```
(define nameless-environment?
  (lambda (x)
    ((list-of expval?) x)))
```

empty-nameless-env : () → *Nameless-env*

```
(define empty-nameless-env
  (lambda ()
    '()))
```

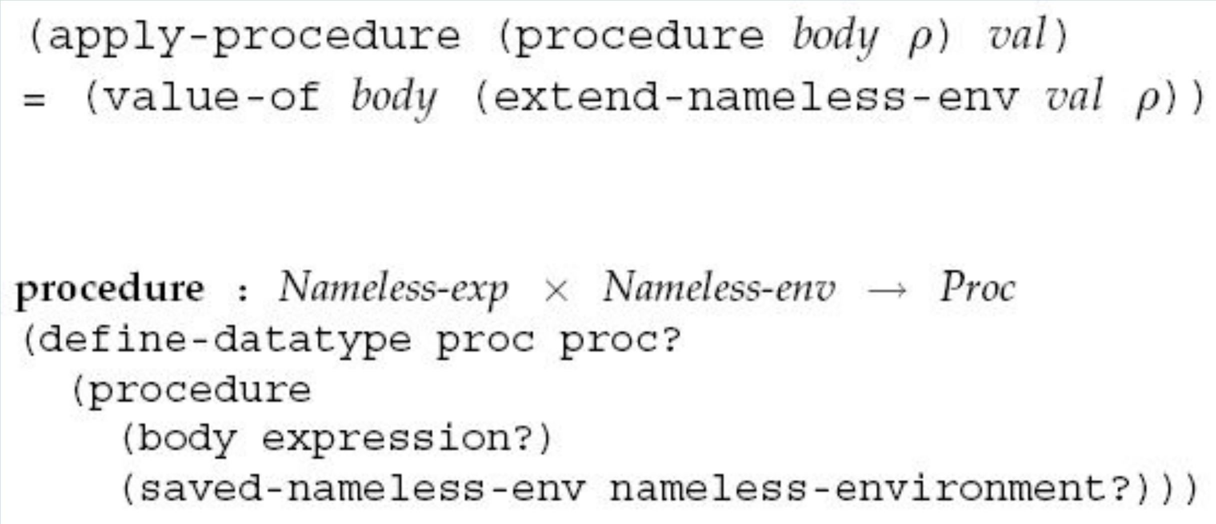
extend-nameless-env : *ExpVal* × *Nameless-env* → *Nameless-env*

```
(define extend-nameless-env
  (lambda (val nameless-env)
    (cons val nameless-env)))
```

apply-nameless-env : *Nameless-env* × *Lexaddr* → *ExpVal*

```
(define apply-nameless-env
  (lambda (nameless-env n)
    (list-ref nameless-env n)))
```

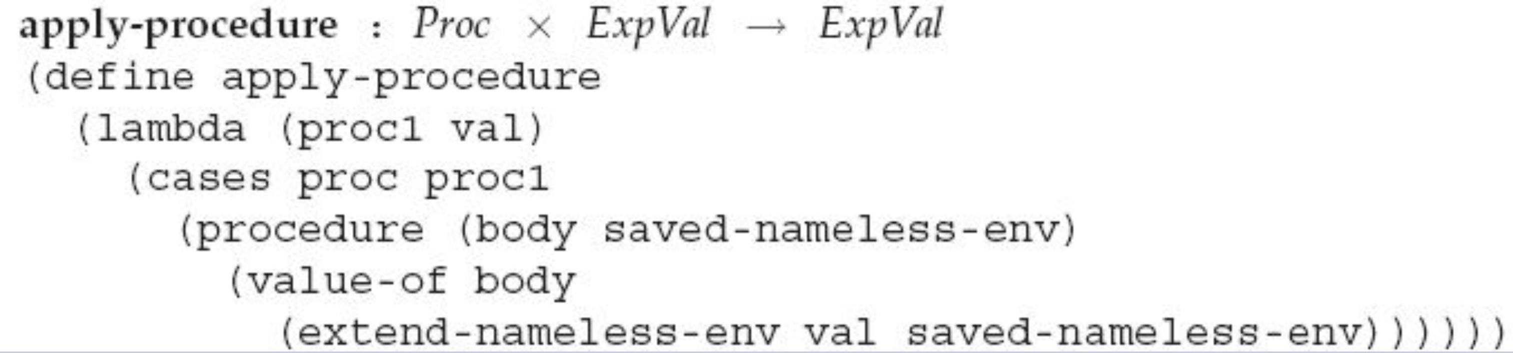
Procedure specification and implementation



```
(apply-procedure (procedure body ρ) val)
= (value-of body (extend-nameless-env val ρ))
```

procedure : *Nameless-exp* × *Nameless-env* → *Proc*

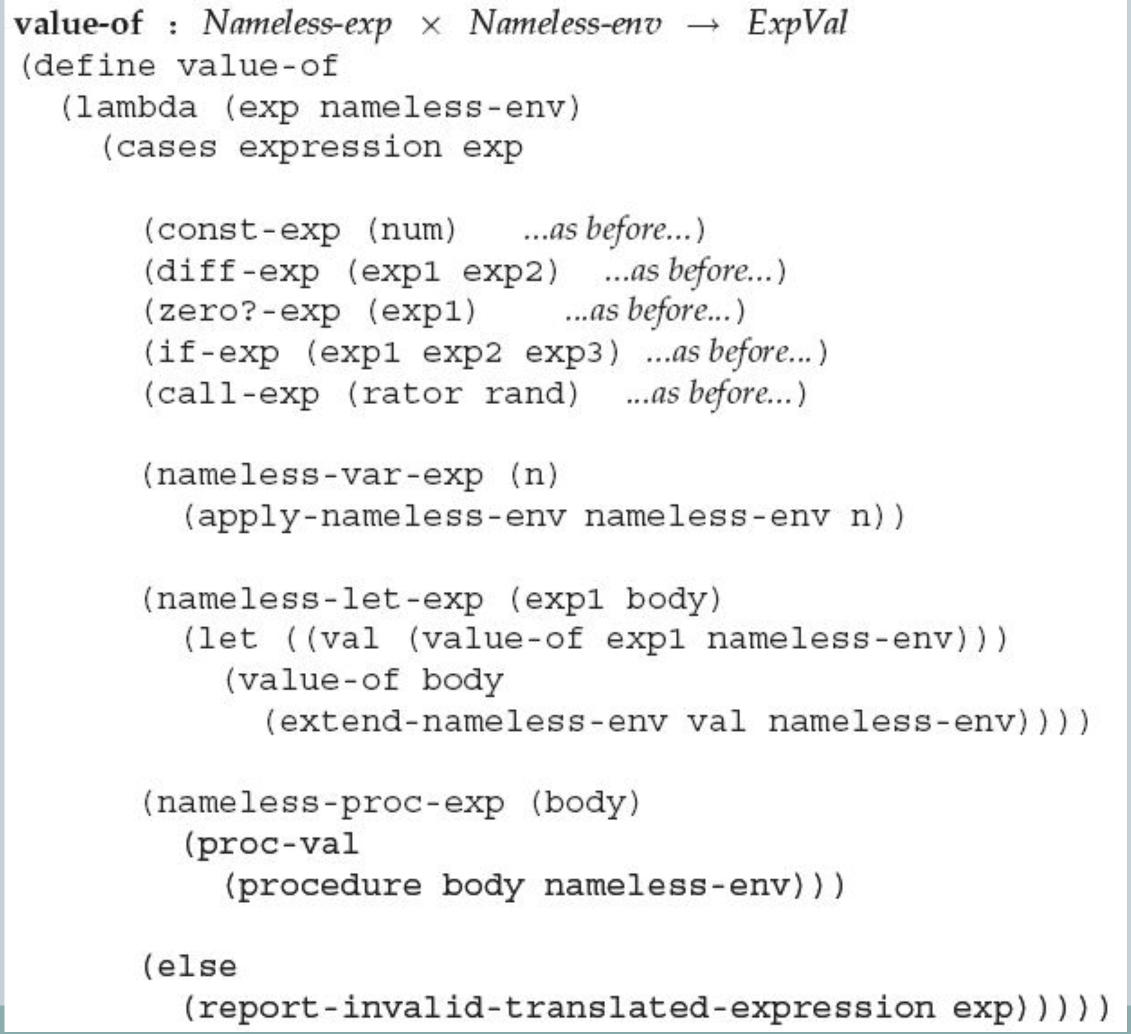
```
(define-datatype proc proc?
  (procedure
    (body expression?)
    (saved-nameless-env nameless-environment?)))
```



apply-procedure : *Proc* × *ExpVal* → *ExpVal*

```
(define apply-procedure
  (lambda (proc1 val)
    (cases proc proc1
      (procedure (body saved-nameless-env)
        (value-of body
          (extend-nameless-env val saved-nameless-env))))))
```

Interpreter for the new language

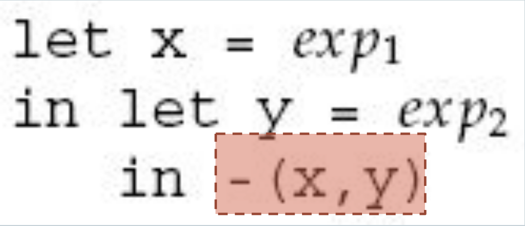


value-of : *Nameless-exp* × *Nameless-env* → *ExpVal*

```
(define value-of
  (lambda (exp nameless-env)
    (cases expression exp

      (const-exp (num)    ...as before...)
      (diff-exp (exp1 exp2)   ...as before...)
      (zero?-exp (exp1)     ...as before...)
      (if-exp (exp1 exp2 exp3) ...as before...)
      (call-exp (rator rand)   ...as before...)

      (nameless-var-exp (n)
        (apply-nameless-env nameless-env n))

      (nameless-let-exp (exp1 body)
        (let ((val (value-of exp1 nameless-env)))
          (value-of body
            (extend-nameless-env val nameless-env))))

      (nameless-proc-exp (body)
        (proc-val
          (procedure body nameless-env)))

      (else
        (report-invalid-translated-expression exp)))))
```

Quiz #9

1. Find the value
2. Draw the contours for the entire expression
3. Draw the environment diagram at the time of evaluation for the expression in the box



```
let x = exp1
in let y = exp2
   in -(x,y)
```