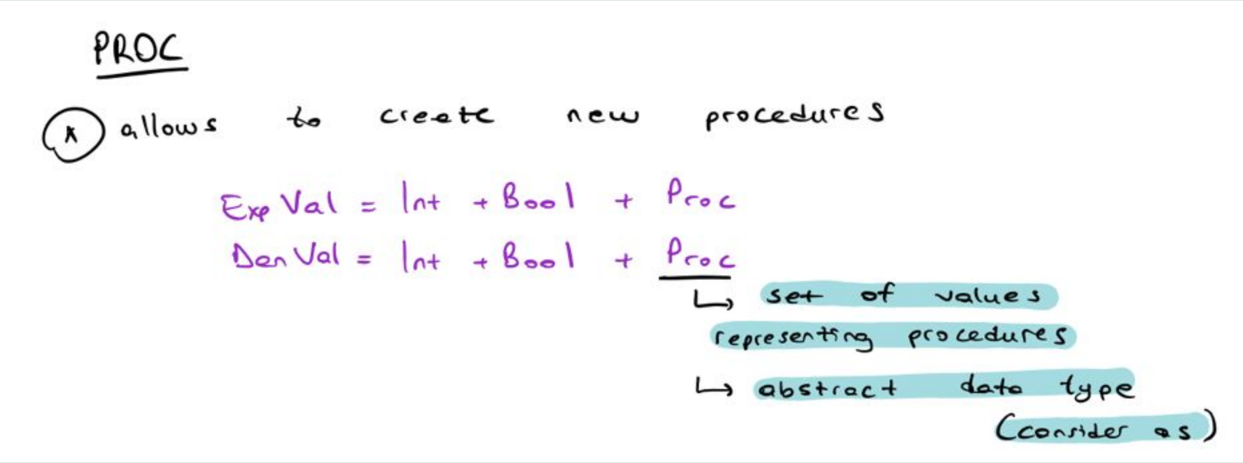
Lecture 13 – Review Proc

T. METIN SEZGIN

Review



PROC

allows to create new procedures

$$\text{ExpVal} = \text{Int} + \text{Bool} + \text{Proc}$$

$$\text{DenVal} = \text{Int} + \text{Bool} + \underline{\text{Proc}}$$

↳ set of values representing procedures

↳ abstract data type (consider as)

Review

add procedure

procedures

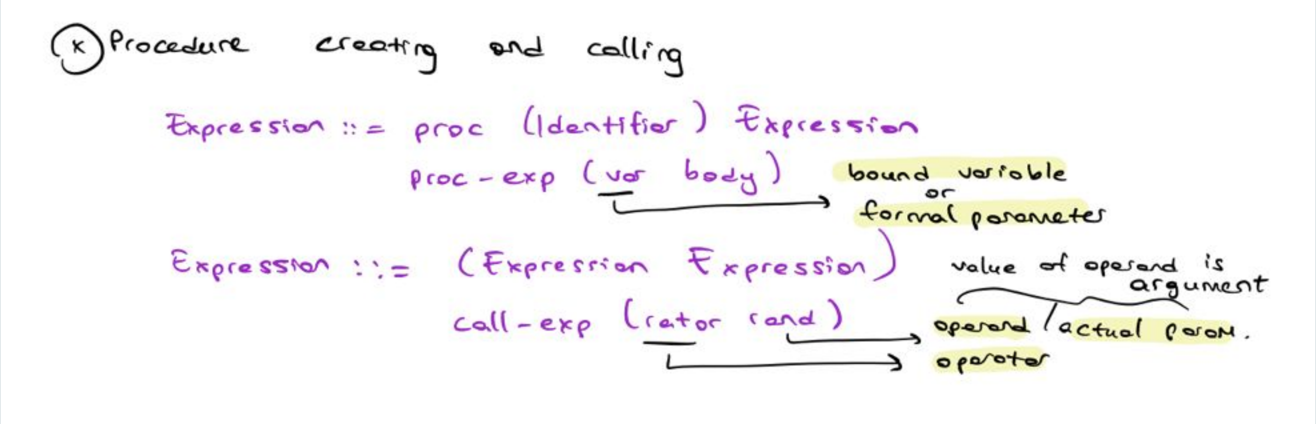
contains : variable (input)

: body – make references to existing variables in the environment

(first) : snapshot of its current environment called saved environment

Ecenaz Egri

Review



Ⓧ Procedure creating and calling

Expression ::= proc (Identifier) Expression

proc-exp (var body) → bound variable or formal parameter

Expression ::= (Expression Expression)

call-exp (rator rand) → operand / actual param. → operator

value of operand is argument

Sude Gungor

Syntax for constructing and calling procedures

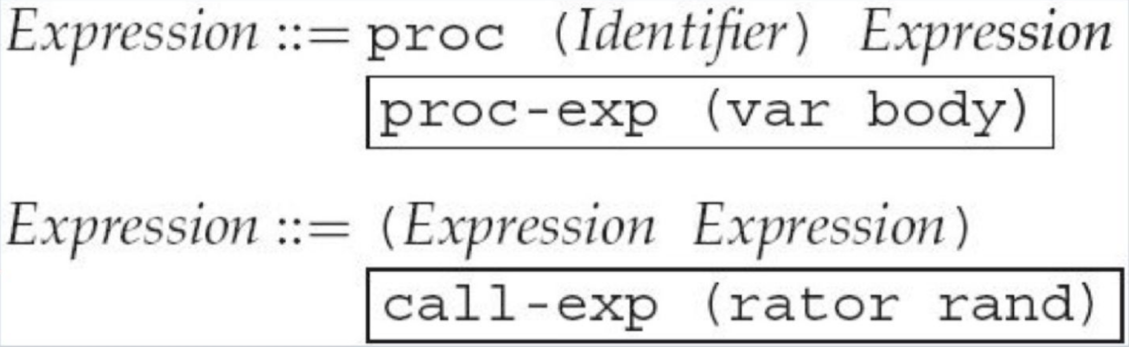
(proc (x) -(x,1) 5)

x	5

-(x,1) ↺

Procedure Application says:

- take my current environment
- extend my current environment with the input to my procedure assigned to the input to the procedure
- find the value of body with respect to that



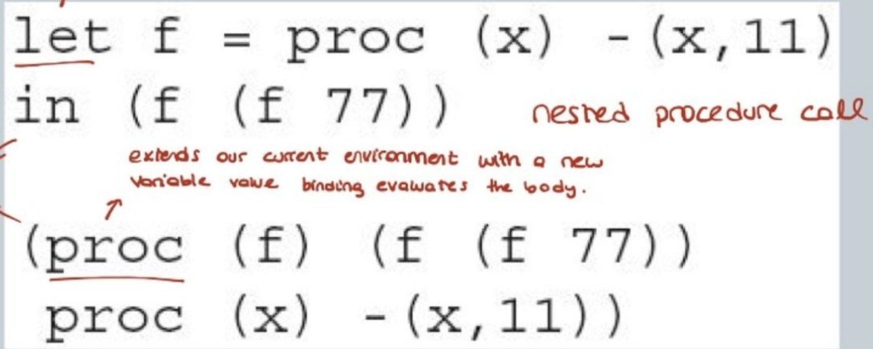
Expression ::= `proc` (*Identifier*) *Expression*

`proc-exp (var body)`

Expression ::= (*Expression* *Expression*)

`call-exp (rator rand)`

take extends our current environment for the new binding and evaluates the body.



```
let f = proc (x) -(x,11)
in (f (f 77))
```

nested procedure call

(let and proc)
These two expressions are equal

extends our current environment with a new variable value binding evaluates the body.

```
(proc (f) (f (f 77))
 proc (x) -(x,11))
```

Lecture 14
PROC

T. METIN SEZGIN

Announcements

- Exam on Sunday
- Extra office hours

LET is ex; long live PROC

- LET had its limitations
  - No procedures
- Define a language with procedures
  - Specification
    - Syntax
    - Semantics
  - Representation
  - Implementation

Expressed and Denoted values

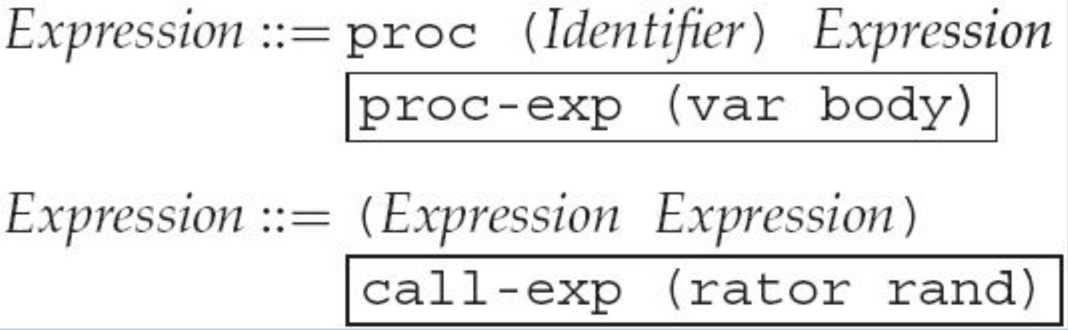
- Before

$$
\begin{aligned}
ExpVal &= Int + Bool \\
DenVal &= Int + Bool
\end{aligned}
$$

- After

$$
\begin{aligned}
ExpVal &= Int + Bool + Proc \\
DenVal &= Int + Bool + Proc
\end{aligned}
$$

Examples



Expression ::= `proc` (*Identifier*) *Expression*

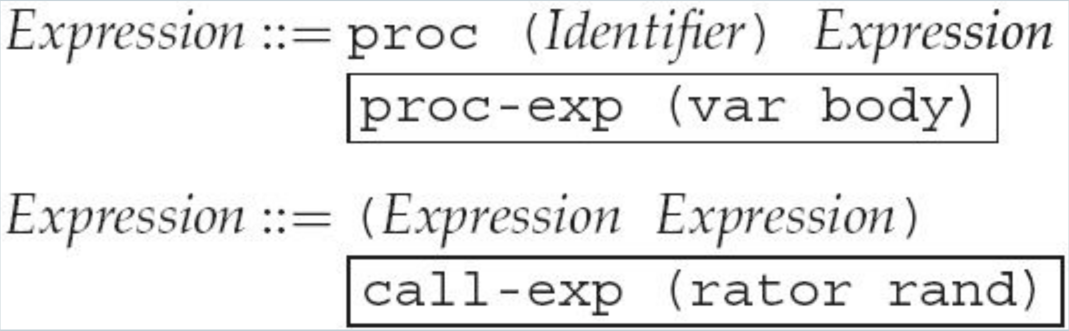
$\boxed{\texttt{proc-exp (var body)}}$

Expression ::= (*Expression* *Expression*)

$\boxed{\texttt{call-exp (rator rand)}}$

- Concepts
  - In definition
    - var
      - Bound variable (a.k.a. formal parameter)
  - In procedure call
    - Rand
      - Actual parameter (the value □ argument)
    - Rator
      - Operator

Syntax for constructing and calling procedures

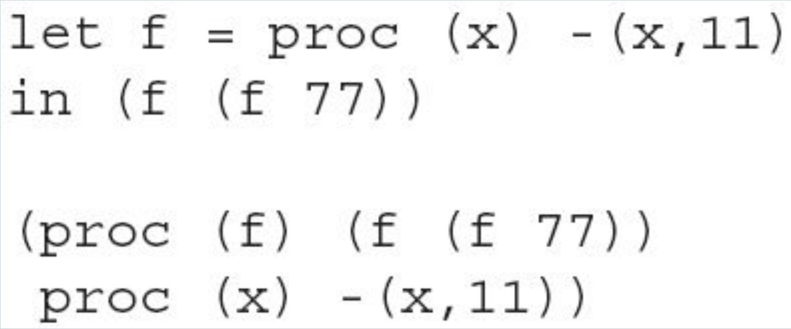


Expression ::= proc (*Identifier*) *Expression*

proc-exp (var body)

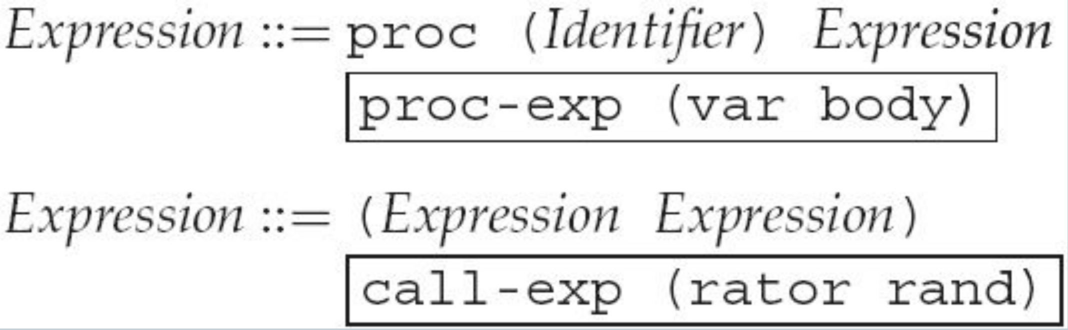
Expression ::= (*Expression* *Expression*)

call-exp (rator rand)



```
let f = proc (x) -(x,11)
in (f (f 77))

(proc (f) (f (f 77))
 proc (x) -(x,11))
```

Syntax for constructing and calling procedures

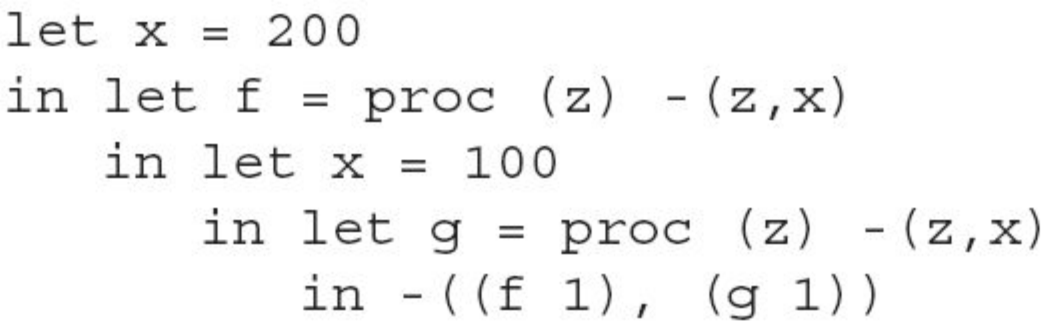


Expression ::= `proc` (*Identifier*) *Expression*

$\boxed{\texttt{proc-exp (var body)}}$

Expression ::= (*Expression* *Expression*)

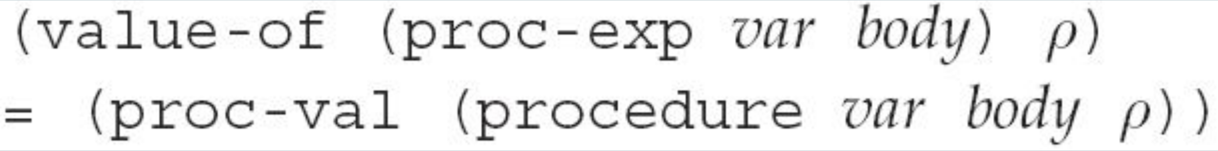
$\boxed{\texttt{call-exp (rator rand)}}$



```
let x = 200
in let f = proc (z) -(z,x)
   in let x = 100
      in let g = proc (z) -(z,x)
         in -((f 1), (g 1))
```

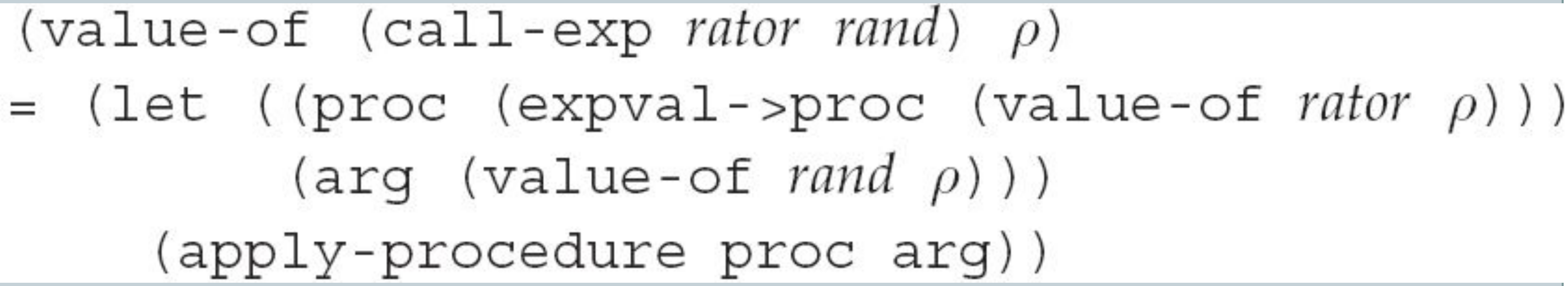
The interface for PROC

- Procedures have
  - Constructor □ **procedure**



```
(value-of (proc-exp var body) ρ)
= (proc-val (procedure var body ρ))
```

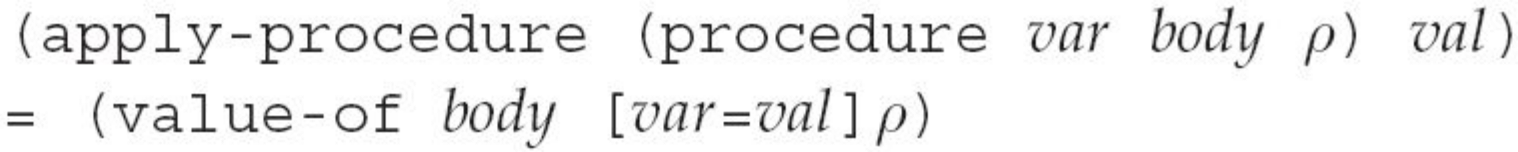
  - Observer □ **apply-procedure**



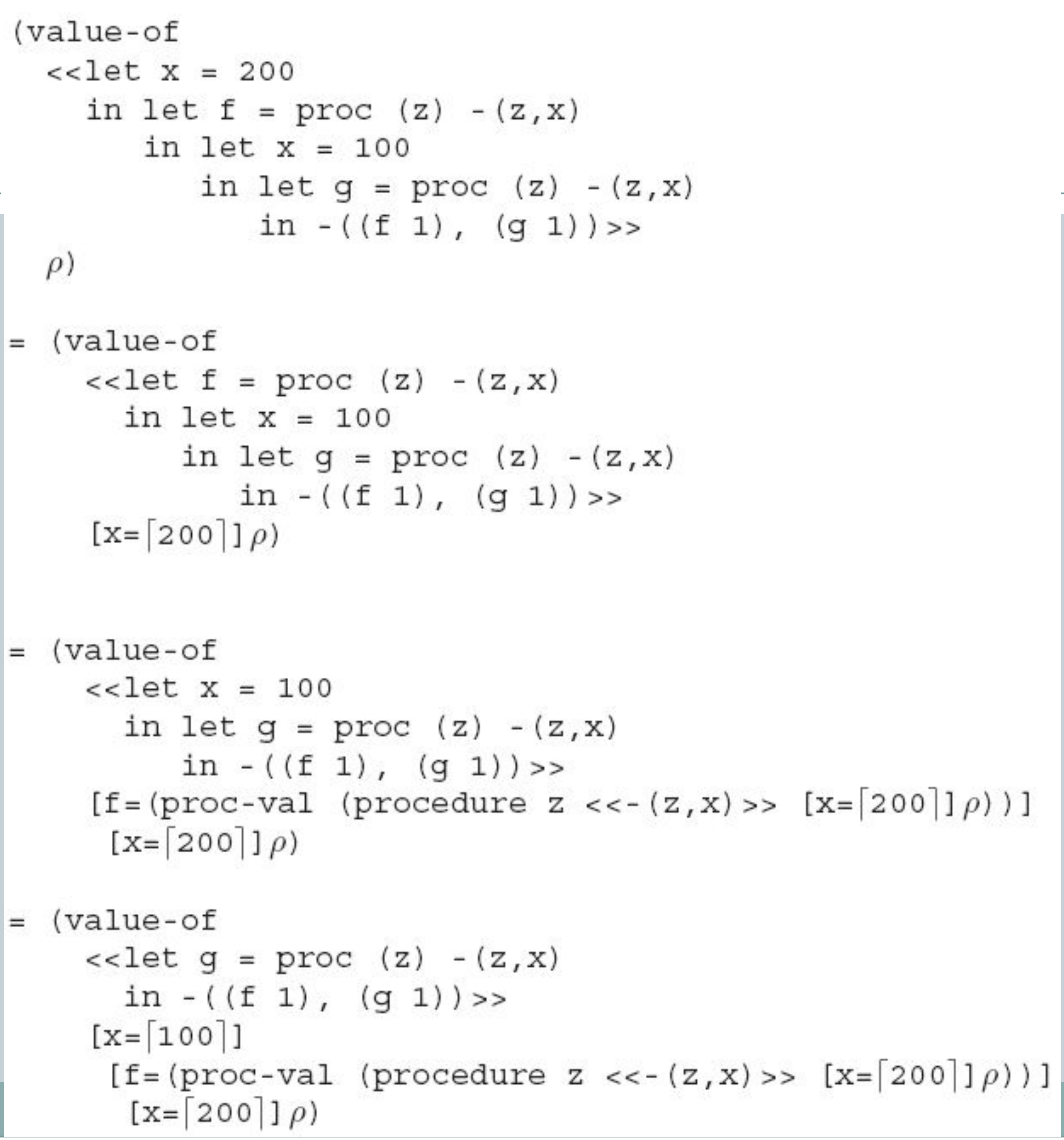
```
(value-of (call-exp rator rand) ρ)
= (let ((proc (expval->proc (value-of rator ρ)))
        (arg (value-of rand ρ)))
    (apply-procedure proc arg))
```

The intuition behind application

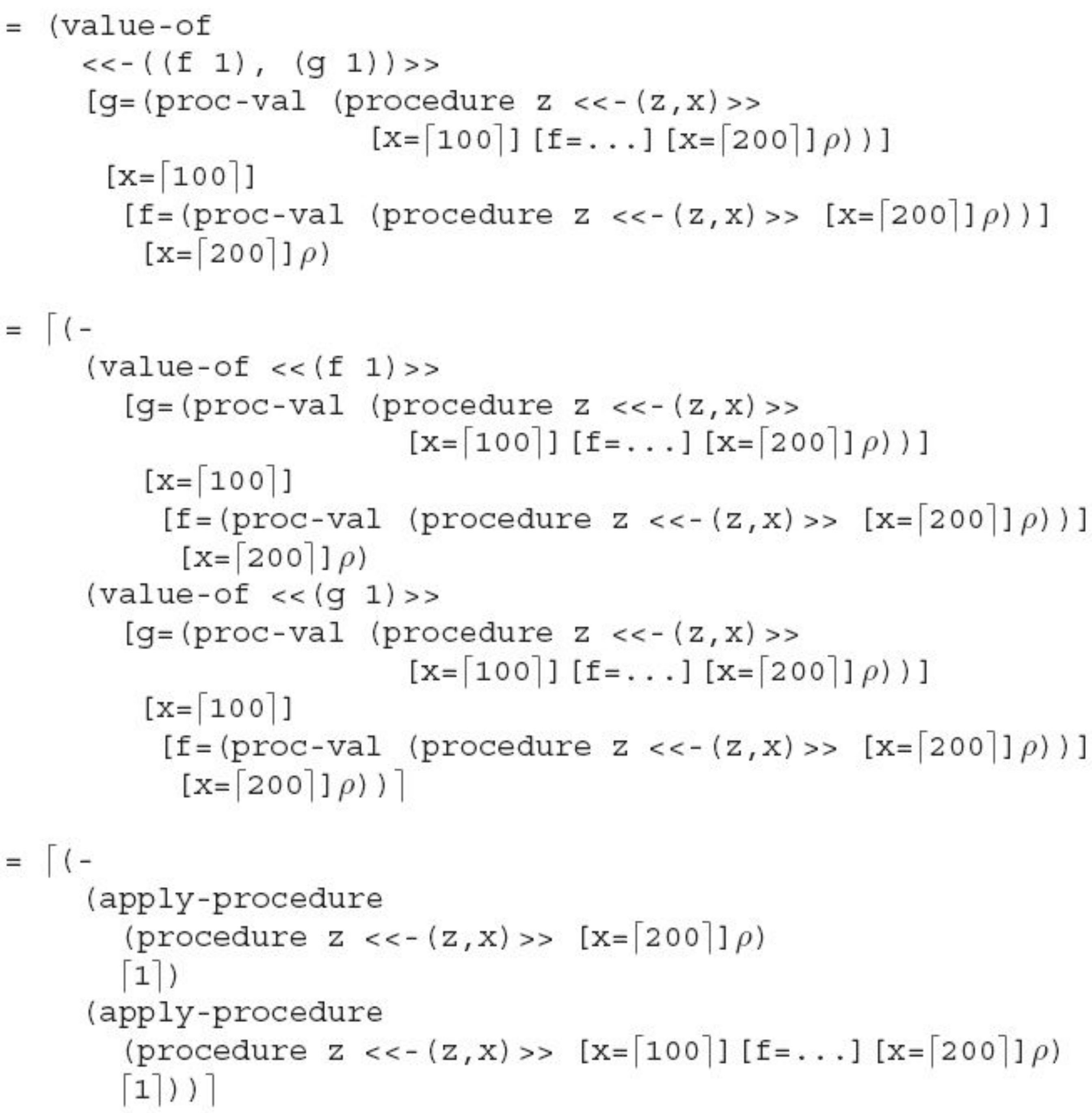
- Extend the environment
- Evaluate the body



```
(apply-procedure (procedure var body ρ) val)
= (value-of body [var=val]ρ)
```

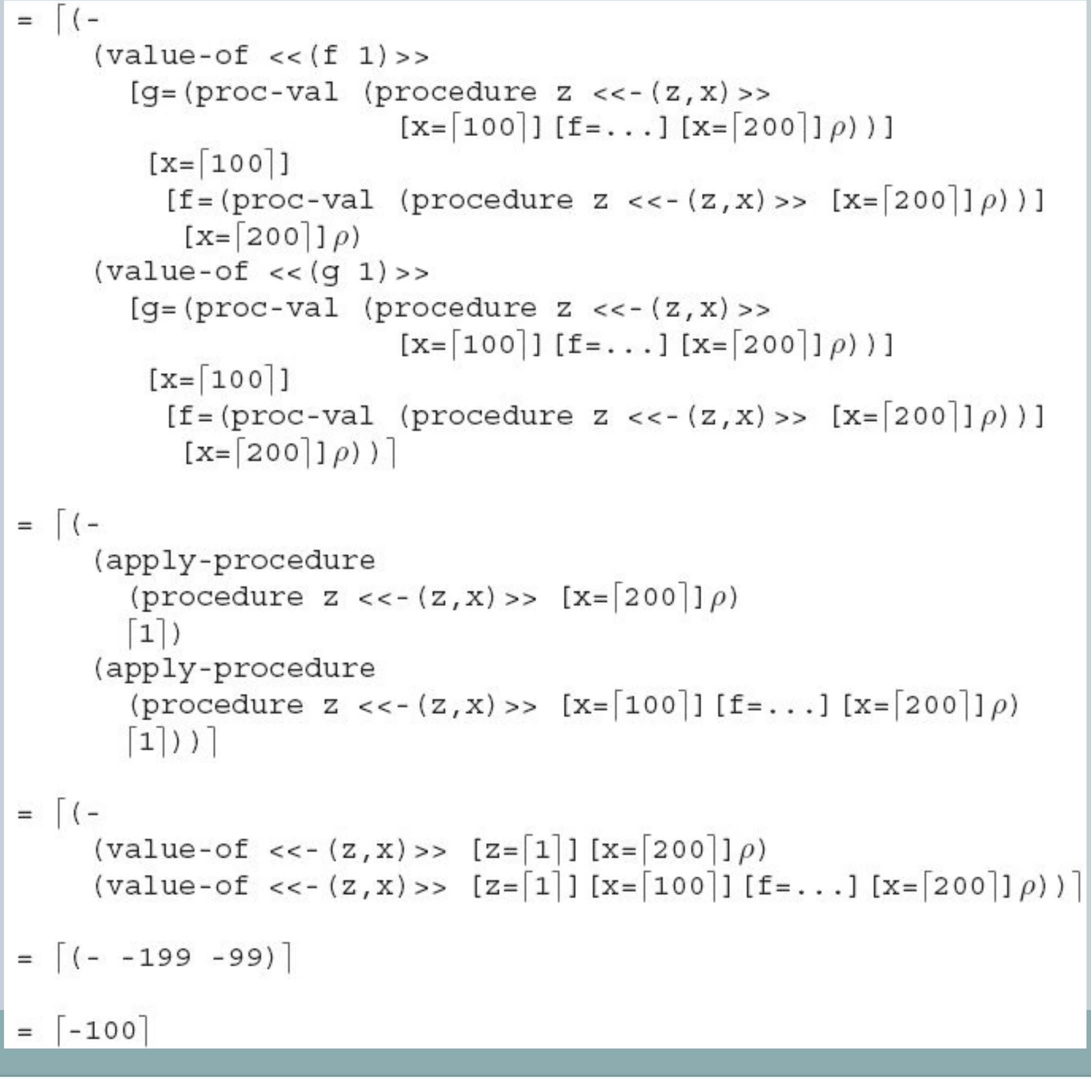


```
(value-of
  <<let x = 200
    in let f = proc (z) -(z,x)
       in let x = 100
          in let g = proc (z) -(z,x)
             in -((f 1), (g 1))>>
  ρ)

= (value-of
    <<let f = proc (z) -(z,x)
      in let x = 100
         in let g = proc (z) -(z,x)
            in -((f 1), (g 1))>>
    [x=⌈200⌉]ρ)


= (value-of
    <<let x = 100
      in let g = proc (z) -(z,x)
         in -((f 1), (g 1))>>
    [f=(proc-val (procedure z <<-(z,x)>> [x=⌈200⌉]ρ))]
     [x=⌈200⌉]ρ)

= (value-of
    <<let g = proc (z) -(z,x)
      in -((f 1), (g 1))>>
    [x=⌈100⌉]
     [f=(proc-val (procedure z <<-(z,x)>> [x=⌈200⌉]ρ))]
      [x=⌈200⌉]ρ)
```



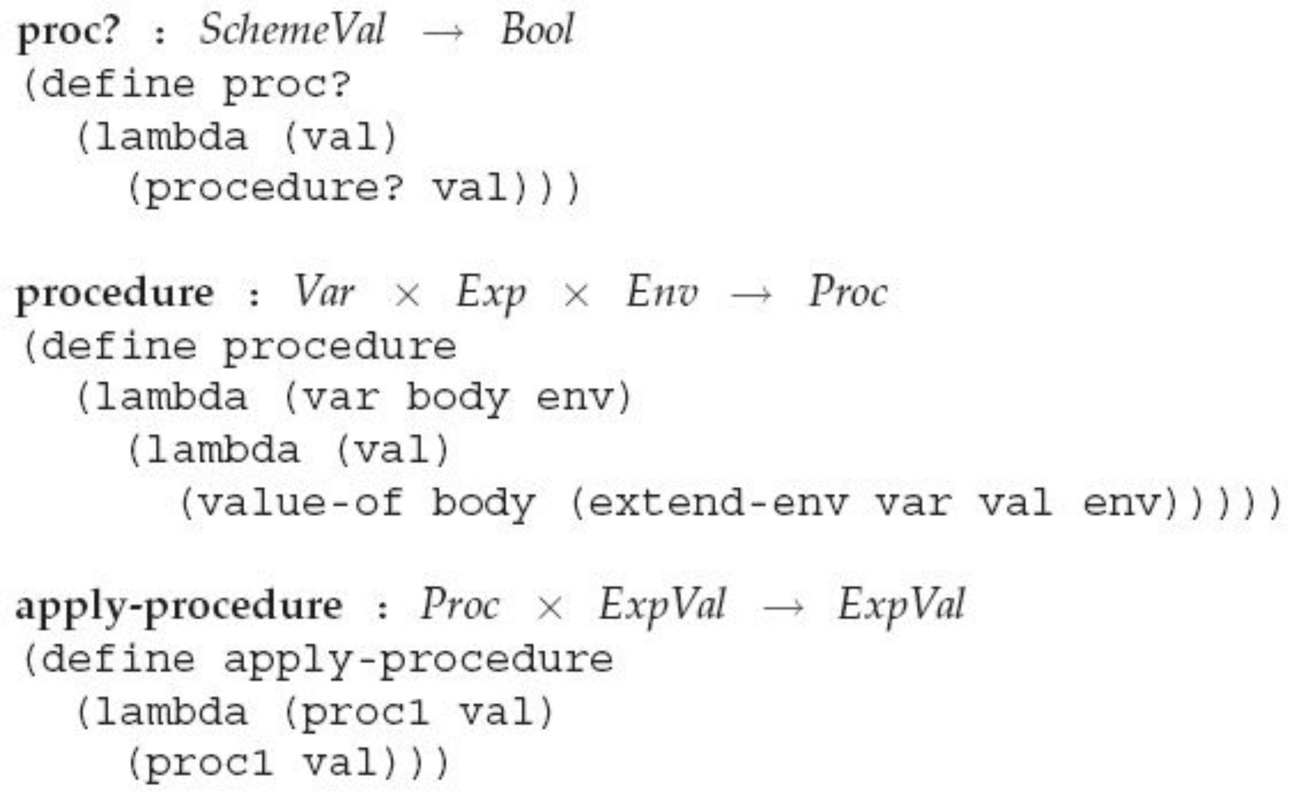
```
= (value-of
    <<-((f 1), (g 1))>>
    [g=(proc-val (procedure z <<-(z,x)>>
                      [x=⌈100⌉] [f=...] [x=⌈200⌉]ρ))]
     [x=⌈100⌉]
      [f=(proc-val (procedure z <<-(z,x)>> [x=⌈200⌉]ρ))]
       [x=⌈200⌉]ρ)

= ⌈(-
    (value-of <<(f 1)>>
      [g=(proc-val (procedure z <<-(z,x)>>
                        [x=⌈100⌉] [f=...] [x=⌈200⌉]ρ))]
       [x=⌈100⌉]
        [f=(proc-val (procedure z <<-(z,x)>> [x=⌈200⌉]ρ))]
         [x=⌈200⌉]ρ)
    (value-of <<(g 1)>>
      [g=(proc-val (procedure z <<-(z,x)>>
                        [x=⌈100⌉] [f=...] [x=⌈200⌉]ρ))]
       [x=⌈100⌉]
        [f=(proc-val (procedure z <<-(z,x)>> [x=⌈200⌉]ρ))]
         [x=⌈200⌉]ρ))⌉

= ⌈(-
    (apply-procedure
      (procedure z <<-(z,x)>> [x=⌈200⌉]ρ)
      ⌈1⌉)
    (apply-procedure
      (procedure z <<-(z,x)>> [x=⌈100⌉] [f=...] [x=⌈200⌉]ρ)
      ⌈1⌉))⌉
```

An example



```
= ⌈(-
    (value-of <<(f 1)>>
      [g=(proc-val (procedure z <<-(z,x)>>
                     [x=⌈100⌉] [f=...] [x=⌈200⌉]ρ))]
       [x=⌈100⌉]
        [f=(proc-val (procedure z <<-(z,x)>> [x=⌈200⌉]ρ))]
         [x=⌈200⌉]ρ)
    (value-of <<(g 1)>>
      [g=(proc-val (procedure z <<-(z,x)>>
                     [x=⌈100⌉] [f=...] [x=⌈200⌉]ρ))]
       [x=⌈100⌉]
        [f=(proc-val (procedure z <<-(z,x)>> [x=⌈200⌉]ρ))]
         [x=⌈200⌉]ρ))⌉

= ⌈(-
    (apply-procedure
      (procedure z <<-(z,x)>> [x=⌈200⌉]ρ)
      ⌈1⌉)
    (apply-procedure
      (procedure z <<-(z,x)>> [x=⌈100⌉] [f=...] [x=⌈200⌉]ρ)
      ⌈1⌉))⌉

= ⌈(-
    (value-of <<-(z,x)>> [z=⌈1⌉] [x=⌈200⌉]ρ)
    (value-of <<-(z,x)>> [z=⌈1⌉] [x=⌈100⌉] [f=...] [x=⌈200⌉]ρ))⌉

= ⌈(- -199 -99)⌉

= ⌈-100⌉
```

Implementation



proc? : *SchemeVal* → *Bool*

```
(define proc?
  (lambda (val)
    (procedure? val)))
```

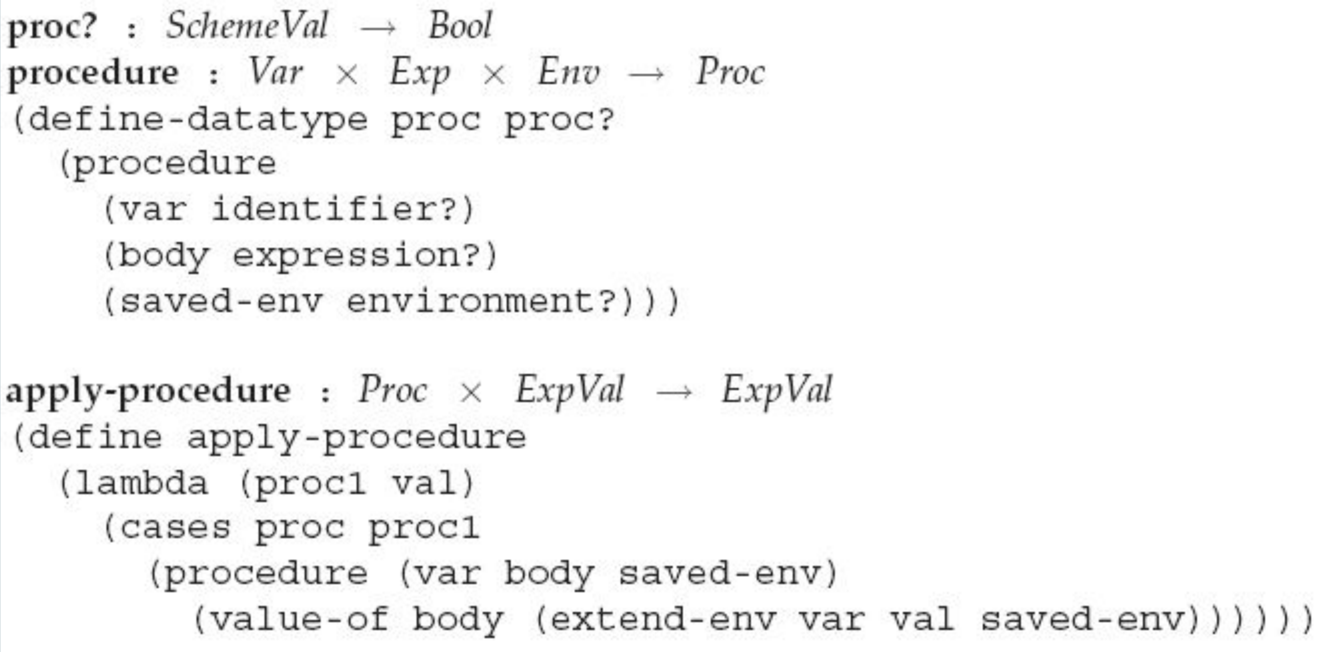
procedure : *Var* × *Exp* × *Env* → *Proc*

```
(define procedure
  (lambda (var body env)
    (lambda (val)
      (value-of body (extend-env var val env)))))
```

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

```
(define apply-procedure
  (lambda (proc1 val)
    (proc1 val)))
```

Alternative implementation



proc? : *SchemeVal* → *Bool*

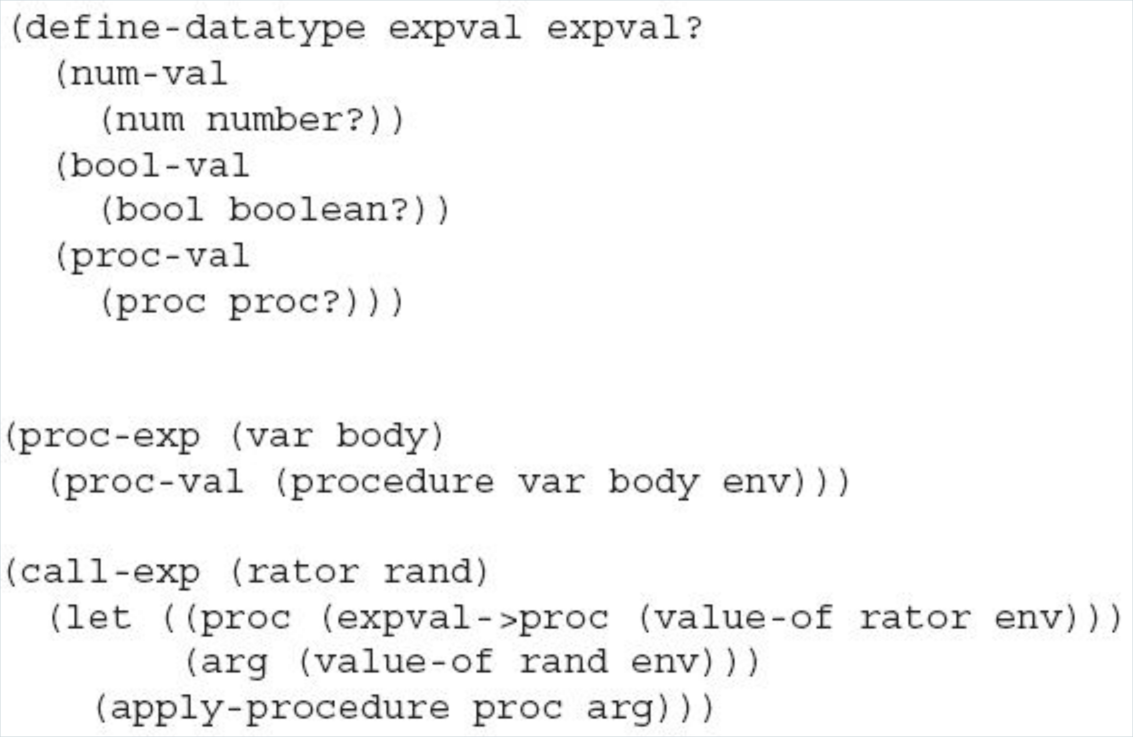
procedure : *Var* × *Exp* × *Env* → *Proc*

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

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

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

Other changes to the interpreter



```
(define-datatype expval expval?
  (num-val
    (num number?))
  (bool-val
    (bool boolean?))
  (proc-val
    (proc proc?)))


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

(call-exp (rator rand)
  (let ((proc (expval->proc (value-of rator env)))
        (arg (value-of rand env)))
    (apply-procedure proc arg)))
```