Announcements

1. Mid-semester evaluation
2. Lecture notes

Irem Karaca

Announcements

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```
Lecture 11: Let

Steps of Inventing a Language:
1 - grammar (syntax)
2 - behavior specification (scanning, parsing, evaluation) (eg: what
is +)
3 - data structures
4 - interpreter
```

Irem Karaca

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* values → things that our languege manipulate

* Expressed values: Possible values of exp. (Int and Bool in LET).
* Denoted values: " " " variables (Int and Bool too)

Eren Berke Demirbas

→ Expressed Values : values of all expressions. → (Int + bool)
→ Denoted Values : values of allowed assignments.

Erim Satar

Announcements

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* We specify meanings of expressions first.

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Let has 2 classes of Values

Expressed Values	Denoted Values
Possible values of expressions	All values that are allowed to be assigned to variables
Ex: [All numbers, booleans]	
ExpVal = Int + Bool	DenVal = Int + Bool

Eren Ceylan

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When writing a compiler / interpreter:

We are specifying interfaces for values (Int and Bool in this case)

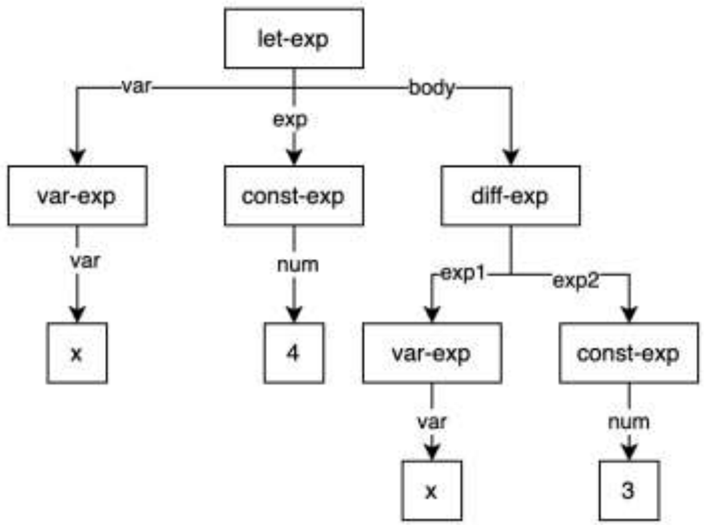
Constructors → num-val, bool-val

Observers: expval → num, expval → bool

Eren Ceylan

Quiz 4

Unparse the following abstract syntax tree.



Solution: The representation using LET language:

Let x = 4
    In -(x, 3)

But the implementation in Scheme:
(let ((x 4)) (- x 3))

Remember the Syntax for the LET language:

Program ::= *Expression*
`a-program (exp1)`

Expression ::= *Number*
`const-exp (num)`

Expression ::= `-(`*Expression* `,` *Expression*`)`
`diff-exp (exp1 exp2)`

Expression ::= `zero?` `(`*Expression*`)`
`zero?-exp (exp1)`

Expression ::= `if` *Expression* `then` *Expression* `else` *Expression*
`if-exp (exp1 exp2 exp3)`

Expression ::= *Identifier*
`var-exp (var)`

Expression ::= `let` *Identifier* `=` *Expression* `in` *Expression*
`let-exp (var exp1 body)`

Lecture 12
Let – Implementation

T. METIN SEZGIN

Specifying the behavior

- Programs

```
(value-of-program exp)
= (value-of exp [i=⌈1⌉,v=⌈5⌉,x=⌈10⌉])
```

- Expressions
  - Constructors

const-exp	$: Int \to Exp$
zero?-exp	$: Exp \to Exp$
if-exp	$: Exp \times Exp \times Exp \to Exp$
diff-exp	$: Exp \times Exp \to Exp$
var-exp	$: Var \to Exp$
let-exp	$: Var \times Exp \times Exp \to Exp$

```
(value-of (const-exp n) ρ) = (num-val n)
(value-of (var-exp var) ρ)  = (apply-env ρ var)
```

```
(value-of (diff-exp exp1 exp2) ρ)
= (num-val
    (-
      (expval->num (value-of exp1 ρ))
      (expval->num (value-of exp2 ρ))))
```

  - Observer

value-of	$: Exp \times Env \to ExpVal$

Specifying the behavior

- Programs

$$\texttt{(value-of-program } exp\texttt{)} = \texttt{(value-of } exp\ \texttt{[i=}\lceil 1\rceil\texttt{,v=}\lceil 5\rceil\texttt{,x=}\lceil 10\rceil\texttt{])}$$

- Expressions
  - Constructors

const-exp	: $Int \to Exp$
zero?-exp	: $Exp \to Exp$
if-exp	: $Exp \times Exp \times Exp \to Exp$
diff-exp	: $Exp \times Exp \to Exp$
var-exp	: $Var \to Exp$
let-exp	: $Var \times Exp \times Exp \to Exp$

$$\frac{\texttt{(value-of } exp_1\ \rho) = val_1}{\begin{array}{l}\texttt{(value-of (zero?-exp } exp_1\texttt{) } \rho\texttt{)} \\ = \begin{cases}\texttt{(bool-val \#t)} & \text{if } \texttt{(expval->num } val_1) = 0 \\ \texttt{(bool-val \#f)} & \text{if } \texttt{(expval->num } val_1) \neq 0\end{cases}\end{array}}$$

$$\frac{\texttt{(value-of } exp_1\ \rho) = val_1}{\begin{array}{l}\texttt{(value-of (if-exp } exp_1\ exp_2\ exp_3\texttt{) } \rho\texttt{)} \\ = \begin{cases}\texttt{(value-of } exp_2\ \rho\texttt{)} & \text{if } \texttt{(expval->bool } val_1) = \texttt{\#t} \\ \texttt{(value-of } exp_3\ \rho\texttt{)} & \text{if } \texttt{(expval->bool } val_1) = \texttt{\#f}\end{cases}\end{array}}$$

  - Observer

value-of : $Exp \times Env \to ExpVal$

Specifying the behavior

- Programs

$$\texttt{(value-of-program } exp\texttt{)} \\ = \texttt{(value-of } exp \texttt{ [i=}\lceil 1\rceil\texttt{,v=}\lceil 5\rceil\texttt{,x=}\lceil 10\rceil\texttt{])}$$

- Expressions
  - Constructors

const-exp	$: Int \to Exp$
zero?-exp	$: Exp \to Exp$
if-exp	$: Exp \times Exp \times Exp \to Exp$
diff-exp	$: Exp \times Exp \to Exp$
var-exp	$: Var \to Exp$
let-exp	$: Var \times Exp \times Exp \to Exp$

$$\frac{\texttt{(value-of } exp_1 \ \rho) = val_1}{\texttt{(value-of (let-exp } var \ exp_1 \ body\texttt{)} \ \rho\texttt{)} \\ = \texttt{(value-of } body \ [var = val_1]\rho\texttt{)}}$$

$$\texttt{(value-of (let-exp } var \ exp_1 \ body\texttt{)} \ \rho\texttt{)} \\ = \texttt{(value-of } body \ \texttt{[}var\texttt{=(value-of } exp_1 \ \rho\texttt{)]} \rho\texttt{)}$$

  - Observer

value-of	$: Exp \times Env \to ExpVal$

Behavior implementation

what we envision

Let $\rho =$ `[i=1,v=5,x=10]`.

```
(value-of
  <<-(-(x,3), -(v,i))>>
  ρ)

= ⌈(-
    ⌊(value-of <<-(x,3)>> ρ)⌋
    ⌊(value-of <<-(v,i)>> ρ)⌋)⌉

= ⌈(-
    (-
      ⌊(value-of <<x>> ρ)⌋
      ⌊(value-of <<3>> ρ)⌋)
    ⌊(value-of <<-(v,i)>> ρ)⌋)⌉

= ⌈(-
    (-
      10
      ⌊(value-of <<3>> ρ)⌋)
    (value-of <<-(v,i)>> ρ))⌉
```

```
= ⌈(-
    (-
      10
      3)
    ⌊(value-of <<-(v,i)>> ρ)⌋)⌉

= ⌈(-
    7
    ⌊(value-of <<-(v,i)>> ρ)⌋)⌉

= ⌈(-
    7
    (-
      ⌊(value-of <<v>> ρ)⌋
      ⌊(value-of <<i>> ρ)⌋))⌉

= ⌈(-
    7
    (-
      5
      ⌊(value-of <<i>> ρ)⌋))⌉
```

```
= ⌈(-
    7
    (-
      5
      1))⌉

= ⌈(-
    7
    4)⌉

= ⌈3⌉
```

Behavior implementation

what we envision

Let ρ = [x=⌈33⌉,y=⌈22⌉].

```
(value-of
  <<if zero?(-(x,11)) then -(y,2) else -(y,4)>>
  ρ)

= (if (expval->bool (value-of <<zero?(-(x,11))>> ρ))
    (value-of <<-(y,2)>> ρ)
    (value-of <<-(y,4)>> ρ))

= (if (expval->bool (bool-val #f))
    (value-of <<-(y,2)>> ρ)
    (value-of <<-(y,4)>> ρ))

= (if #f
    (value-of <<-(y,2)>> ρ)
    (value-of <<-(y,4)>> ρ))

= (value-of <<-(y,4)>> ρ)

= ⌈18⌉
```

Nugget

Intro to implementation

It all revolves around **`value-of`**

The Interpreter

run : *String* → *ExpVal*

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

value-of-program : *Program* → *ExpVal*

```
(define value-of-program
  (lambda (pgm)
    (cases program pgm
      (a-program (exp1)
        (value-of exp1 (init-env))))))
```

The Interpreter

value-of : $Exp \times Env \to ExpVal$

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

$$\boxed{\texttt{(value-of (const-exp } n\texttt{) } \rho\texttt{)} = n}$$

```
      (const-exp (num) (num-val num))
```

$$\boxed{\texttt{(value-of (var-exp } var\texttt{) } \rho\texttt{)} = \texttt{(apply-env } \rho\ var\texttt{)}}$$

```
      (var-exp (var) (apply-env env var))
```

$$\boxed{\begin{array}{l}\texttt{(value-of (diff-exp } exp_1\ exp_2\texttt{) } \rho\texttt{)} = \\ \quad \lceil \texttt{(- } \lfloor \texttt{(value-of } exp_1\ \rho\texttt{)} \rfloor\ \lfloor \texttt{(value-of } exp_2\ \rho\texttt{)} \rfloor \texttt{)} \rceil\end{array}}$$

```
      (diff-exp (exp1 exp2)
        (let ((val1 (value-of exp1 env))
              (val2 (value-of exp2 env)))
          (let ((num1 (expval->num val1))
                (num2 (expval->num val2)))
            (num-val
              (- num1 num2)))))
```

$$\boxed{\dfrac{\texttt{(value-of } exp_1\ \rho\texttt{)} = val_1}{\begin{array}{l}\texttt{(value-of (zero?-exp } exp_1\texttt{) } \rho\texttt{)} \\ \quad = \begin{cases}\texttt{(bool-val \#t)} & \text{if } \texttt{(expval->num } val_1\texttt{)} = 0 \\ \texttt{(bool-val \#f)} & \text{if } \texttt{(expval->num } val_1\texttt{)} \neq 0\end{cases}\end{array}}}$$

```
      (zero?-exp (exp1)
        (let ((val1 (value-of exp1 env)))
          (let ((num1 (expval->num val1)))
            (if (zero? num1)
              (bool-val #t)
              (bool-val #f)))))
```

$$\boxed{\dfrac{\texttt{(value-of } exp_1\ \rho\texttt{)} = val_1}{\begin{array}{l}\texttt{(value-of (if-exp } exp_1\ exp_2\ exp_3\texttt{) } \rho\texttt{)} \\ \quad = \begin{cases}\texttt{(value-of } exp_2\ \rho\texttt{)} & \text{if } \texttt{(expval->bool } val_1\texttt{)} = \texttt{\#t} \\ \texttt{(value-of } exp_3\ \rho\texttt{)} & \text{if } \texttt{(expval->bool } val_1\texttt{)} = \texttt{\#f}\end{cases}\end{array}}}$$

```
      (if-exp (exp1 exp2 exp3)
        (let ((val1 (value-of exp1 env)))
          (if (expval->bool val1)
            (value-of exp2 env)
            (value-of exp3 env))))
```

$$\boxed{\dfrac{\texttt{(value-of } exp_1\ \rho\texttt{)} = val_1}{\begin{array}{l}\texttt{(value-of (let-exp } var\ exp_1\ body\texttt{) } \rho\texttt{)} \\ \quad = \texttt{(value-of } body\ [var = val_1]\rho\texttt{)}\end{array}}}$$

```
      (let-exp (var exp1 body)
        (let ((val1 (value-of exp1 env)))
          (value-of body
            (extend-env var val1 env)))))))
```