SimpliPy: A notional machine for learning Python

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Notional Machine for Sequential Python

Expressions

An expression is

- A **literal** like 35, True or “hello”
- An **identifier** like x, y, z
- A **compound expression** built using arithmetic and logical operators like
  - 1 + 2 + 3 * 4
  - x + 4 * y
  - x > 2

The Result Datatype

- Expressions are **Evaluated**.

- The result of evaluation is either a value or an error.

$$\mathrm{Res} = \mathrm{Val} + \mathrm{Error}$$

Expression Assignment

$a = 10$

$b =$ "Hello"

$c = x$

$d = -x$

$e = 5 + 10 * x - \frac{4}{2}$

Environments

Expressions are evaluated **in environments**

An environment is a finite function
from identifiers to values

$$\mathrm{Env} = \mathrm{Id} \rightharpoonup \mathrm{Val}$$

- $\{a \mapsto 6, b \mapsto 4, c \mapsto \mathrm{True}\}$
- ϕ denotes the empty environment

Lookup in an environment

$$\text{lookup} : \text{Id} \times \text{Env} \to \text{Res}$$

$$e = \{x \mapsto 20, y \mapsto 5\}$$

$$e : x = 20$$

$$e : y = 5$$

$$e : z = \text{error}$$

Updating an environment

$$e = \{x \mapsto 20, y \mapsto 5\}$$

$$e' = e[x := 10] = \{x \mapsto 10, y \mapsto 5\}$$

$$e'' = e'[z := 11] = \{x \mapsto 10, y \mapsto 5, z \mapsto 11\}$$

Expressions are evaluated in an Environment

$$\text{eval} : \text{Exp} \times \text{Env} \to \text{Res}$$

$$\text{eval}(x + y, \{x \mapsto 10, y \mapsto 5\}) = 15$$

$$\text{eval}(10, \{x \mapsto 100\}) = 10$$

$$\text{eval}(x + y, \{x \mapsto 10\}) = \text{error}$$

$$\text{eval}(x + y, \{x \mapsto 10, y \mapsto \text{"hello"}\}) = \text{error}$$

$$\text{eval}(x/y, \{x \mapsto 10, y \mapsto 0\}) = \text{error}$$

Instruction

An instruction is either

- An expression assignment, or
- `pass`

Program

- Location datatype

$$\mathrm{Loc} = [0..N]$$

- A program is a sequence of instruction

$$P = [0..N-1] \rightarrow \mathrm{Instr}$$

```
0  x = 5
1  pass
2  y = x + 10
3  y = 2
4
```

Static Analysis

- Certain properties of the program can be determined statically (without execution)

- Control Transfer Functions

- Control Flow Graphs

Control Transfer Functions: `next` and `err`

Partial function that maps a location to another location

- Control transfers to `next(i)` in case of **no** error.
- Control transfers to `err(i)` in case of error.

```
0
    x = 5
1
    pass
2
    y = x + 10
3
    y = 2
4
```

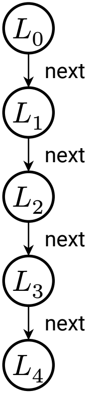
Loc	next	err
0	1	4
1	2	-
2	3	4
3	4	4
4	-	-

Control Flow Graph

- The set of control transfer functions represented as a graph.

```
x = 5
pass
y = x + 10
y = 2

```



Note that the `err` edges are omitted from the diagram for brevity.

Executing the program

- Static artefacts used in executing the program
- State
- Action (tick)
- Transitions (dynamics)

State of the Machine

- The machine is parametrized on the program P.

$$\mathrm{State} = \mathrm{Loc} \times \mathrm{Env}$$

Tranisitions of the Machine

$$(i, e) \xrightarrow{\text{tick}} (i', e')$$

Pass Transition

$$(i, e) \xrightarrow{\text{tick}} (\text{next}(i), e)$$

$$\text{if}$$

$$P_i ::= \text{pass}$$

Expression Assignment Transition

$$(i, e) \xrightarrow{\text{tick}} \begin{cases} (\text{next}(i), e') & \text{if res} \neq \text{error} \\ (\text{err}(i), e) & \text{if res} = \text{error} \end{cases}$$

$$\text{if}$$

$$P_i \Coloneqq \text{id} = \text{exp}$$

$$\text{where}$$

$$\text{res} = \text{eval}(\text{exp}, e)$$

$$e' = e[\text{id} := \text{res}]$$

Run of the Machine

```
x = 5
pass
y = x + 10
y = 2

```

Execution Diagram

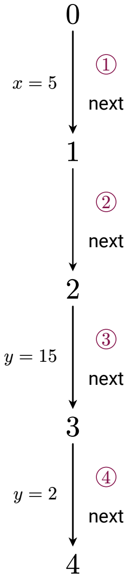
```python
x = 5
pass
y = x + 10
y = 2

```

Execution Diagram

```
0   x = 5
1   pass
2   y = x + 10
3   y = 2
4
```

$$e = \begin{cases} x \mapsto 5 & \textcircled{1} \\ \cancel{y \mapsto 15} & \textcircled{3} \\ y \mapsto 2 & \textcircled{4} \end{cases}$$



Example with error: Control Transfer Functions

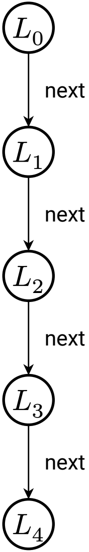
```
0  x = "Hello"
1  pass
2  y = x + 2
3  z = 5
4
```

Loc	next	err
0	1	4
1	2	-
2	3	4
3	4	4
4	-	-

Example with error: Control Flow Graph

```
x = "Hello"
pass
y = x + 2
z = 5

```



Example with error: Run of the machine

```
x = "Hello"
pass
y = x + 2
z = 5
```

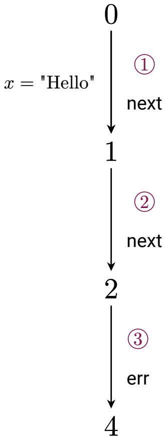
Example with error: Execution Diagram

```
x = "Hello"
pass
y = x + 2
z = 5

```

Example with error: Execution Diagram

```
0   x = "Hello"
1   pass
2   y = x + 2
3   z = 5
4
```



$$e = \{x \mapsto \text{"Hello"}$$ ①

Summary

- Expressions
- $\mathrm{Res} = \mathrm{Val} + \mathrm{Error}$
- Environments
- Evaluation
- Static Analysis
  - Control Transfer Functions (`next` and `err`)
  - Control Flow Graph
- State of the machine: (i, e)
- pass transition
- assignment expression transition
- Run of the machine
- Execution diagram