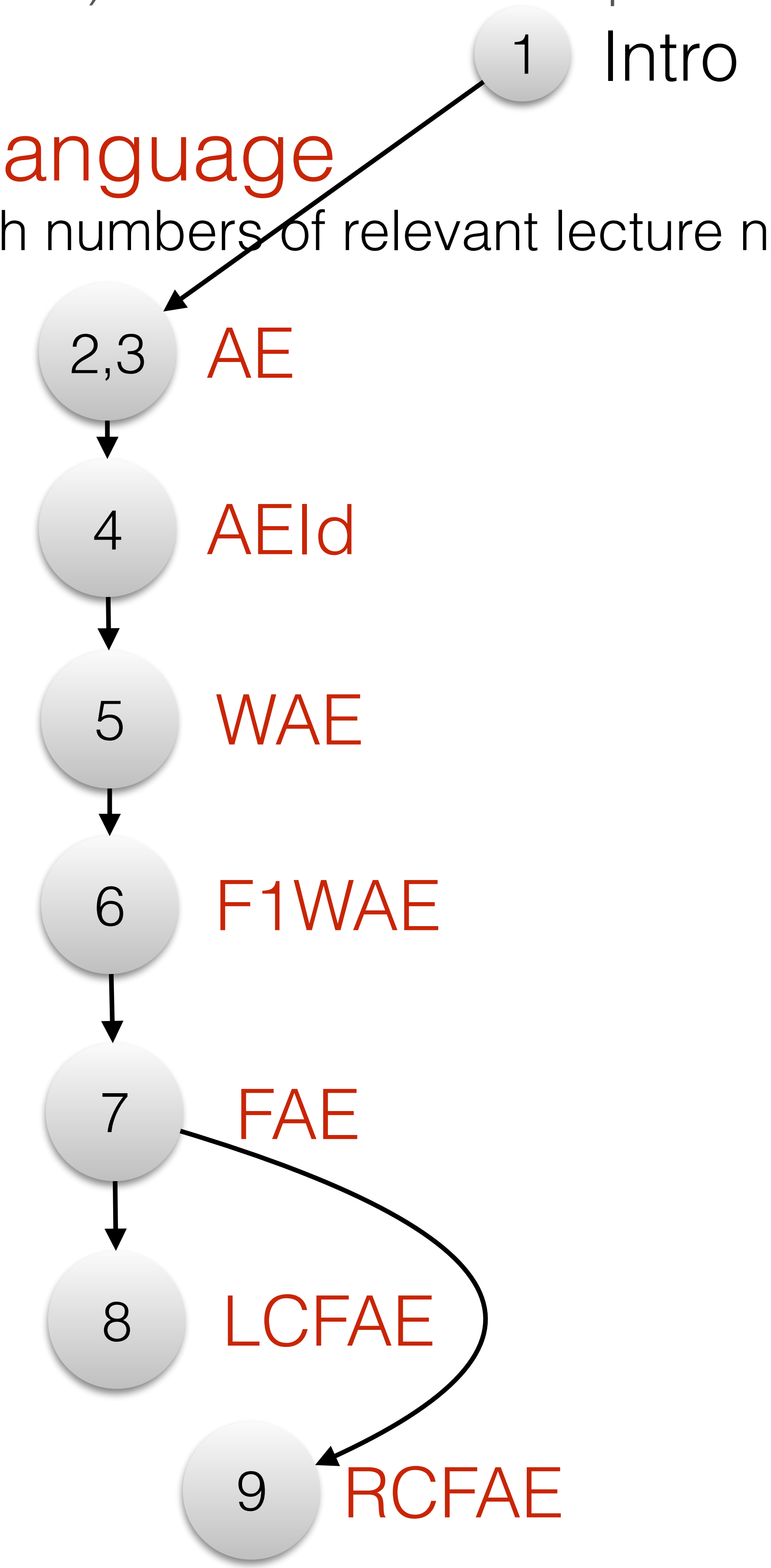
PL1 (SS 2020) — Overview of first part

→ = possible reading order



Language (with numbers of relevant lecture notes)		Concepts covered
1	Intro	
2,3	AE	Interpretation, Desugaring
4	AEId	Environments, Visitors (+ Currying)
5	WAE	Binding (+ Scope), Substitution
6	F1WAE	First-Order Functions, Static & Dynamic Scoping
7	FAE	Higher-Order Functions, Substitution- Vs. Environment-Based Interpreter, Closures (!)
8	LCFAE	Call-By-Name, Call-By-Need, Thunks
9	RCFAE	Recursion with `Letrec`

2,3 AE

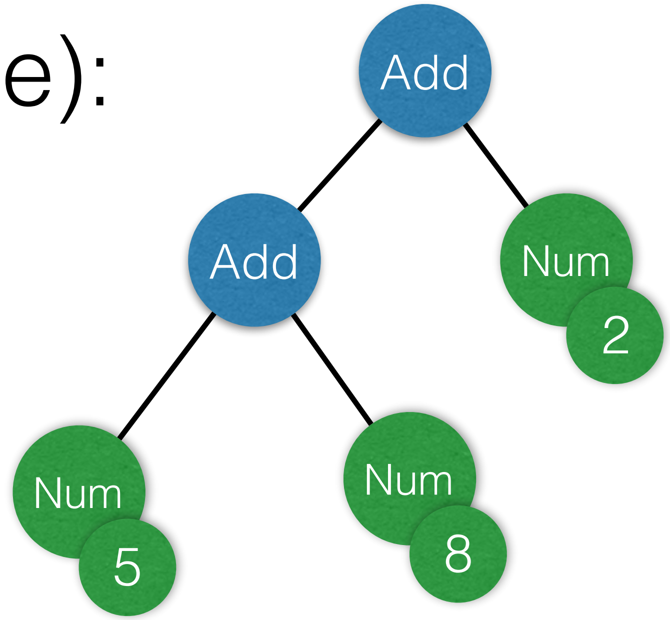
A formal language consists of:

- types of nodes, each with
- arity, and possibly
- other information (data)

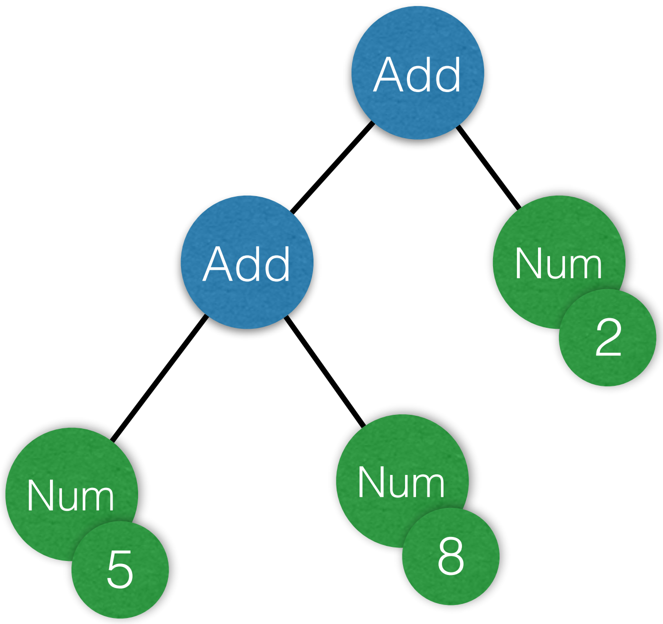
In AE, those are

- Num: arity 0, other data: a number
- Add: arity 2

An example term in tree form (Abstract Syntax Tree):



2,3 AE

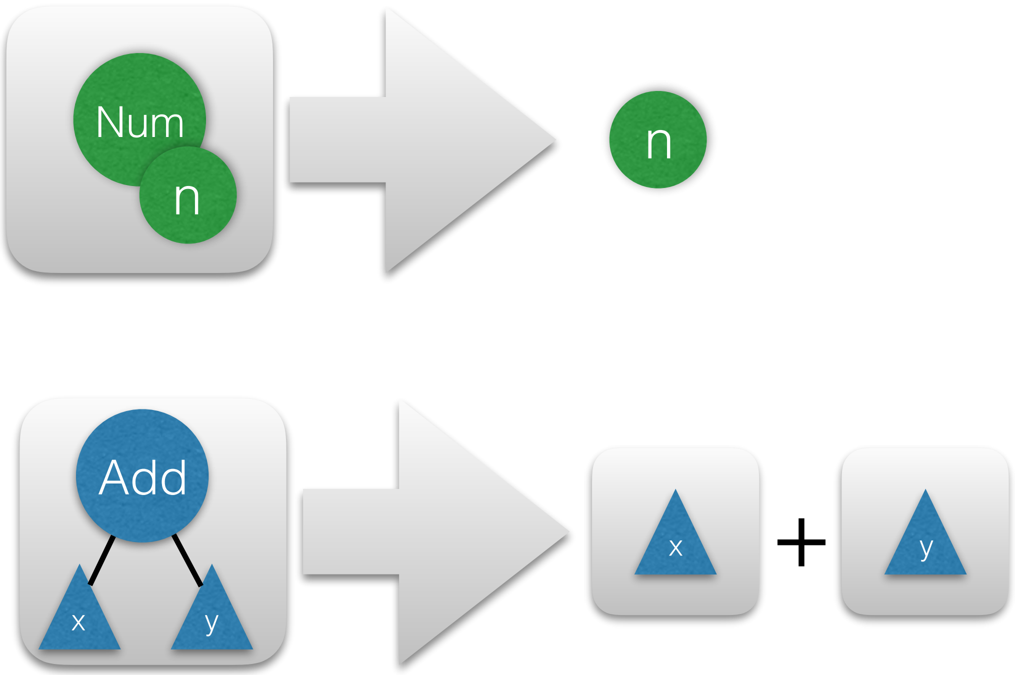


Interpretation: assigns a **value** to each term of the language

Example (Scala):

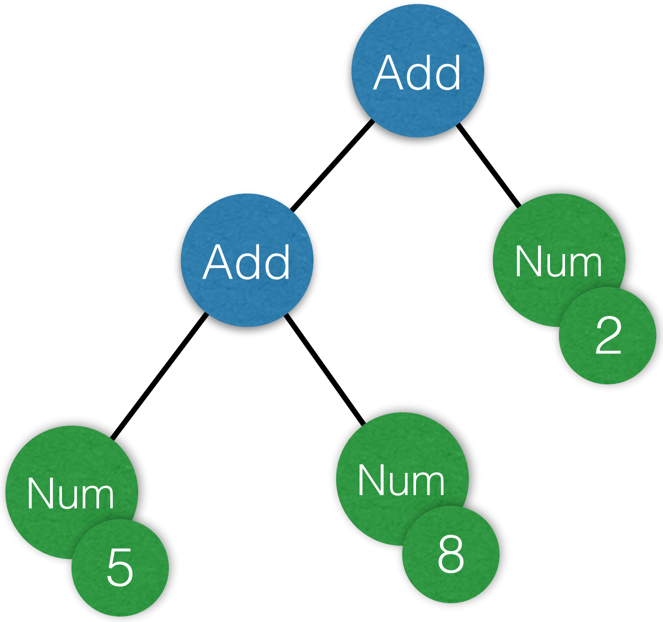
```
def eval(e: Exp): Int =
    e match {
      case Num(n) => n
      case Add(lhs, rhs) =>
        eval(lhs) + eval(rhs)
    }
```

visually:



2,3

AE



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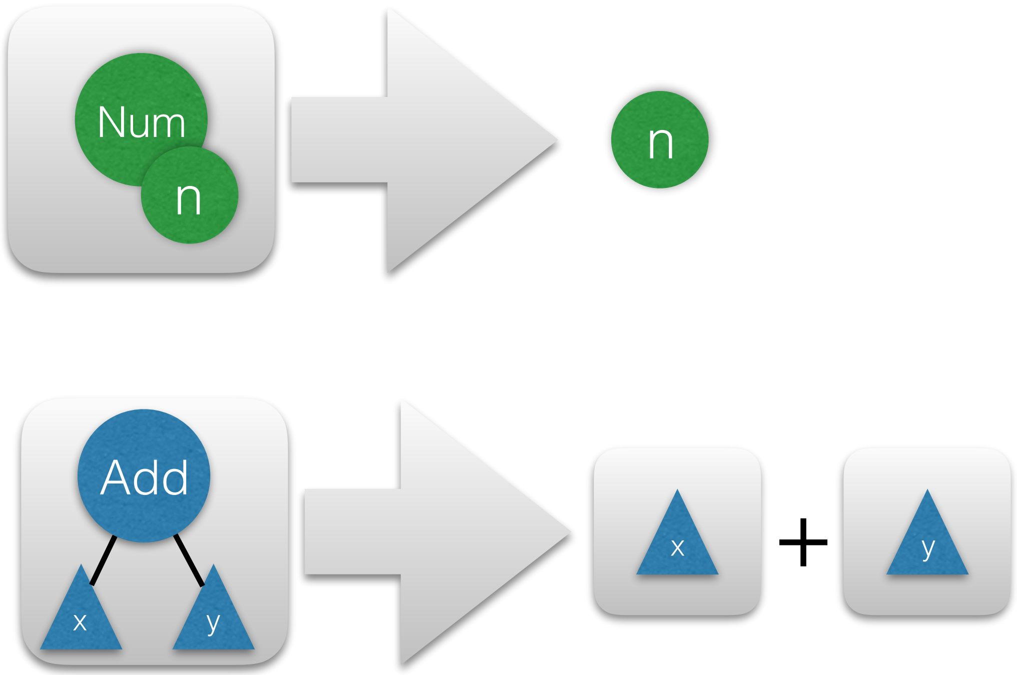
   case Add(lhs, rhs) =>
    eval(lhs) + eval(rhs)
  }
```

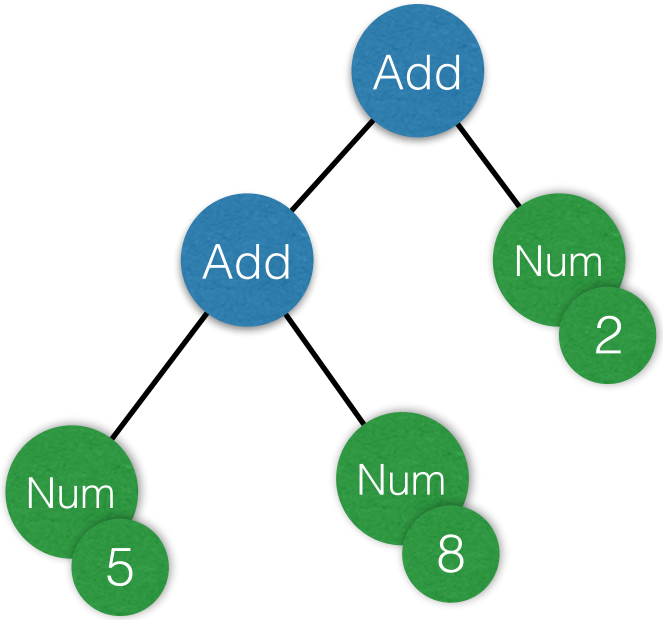
Matching on the
node type

visually:



2,3

AE



Interpretation: assigns a **value** to each term of the language

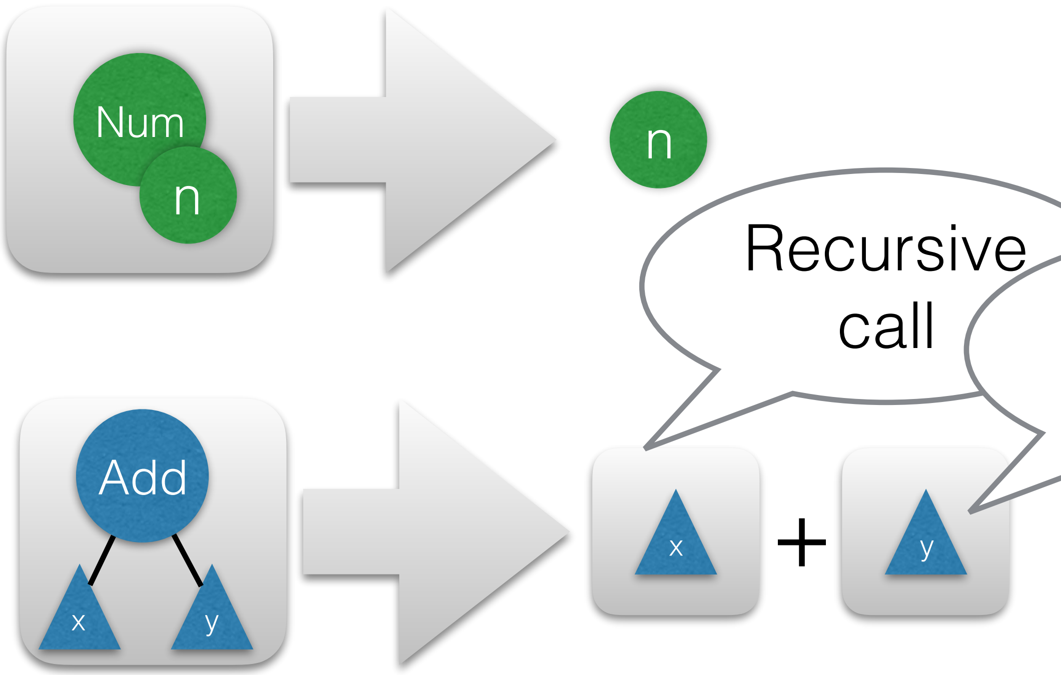
Example (Scala):

```
def eval(e:              =
  e mat
    case
    case   dd(lhs, rhs)  =>
      eval(lhs) + eval(rhs)
  }
```

Recursive call

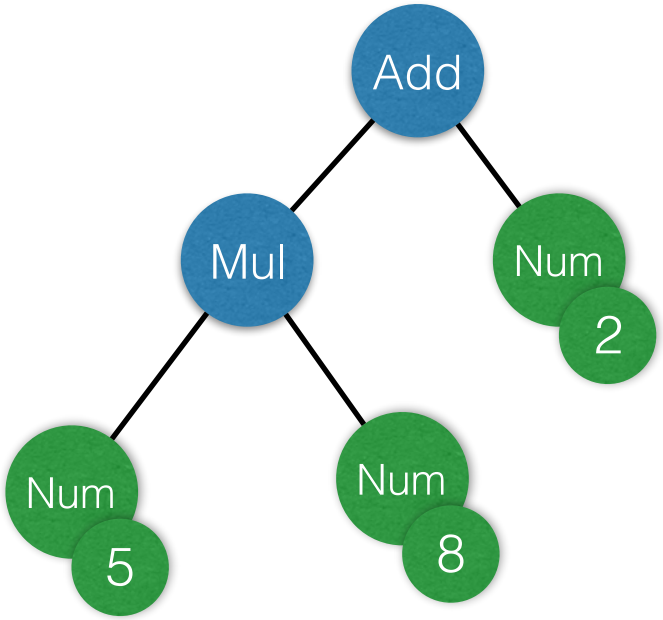
Recursive call

…ally:



2,3

AE

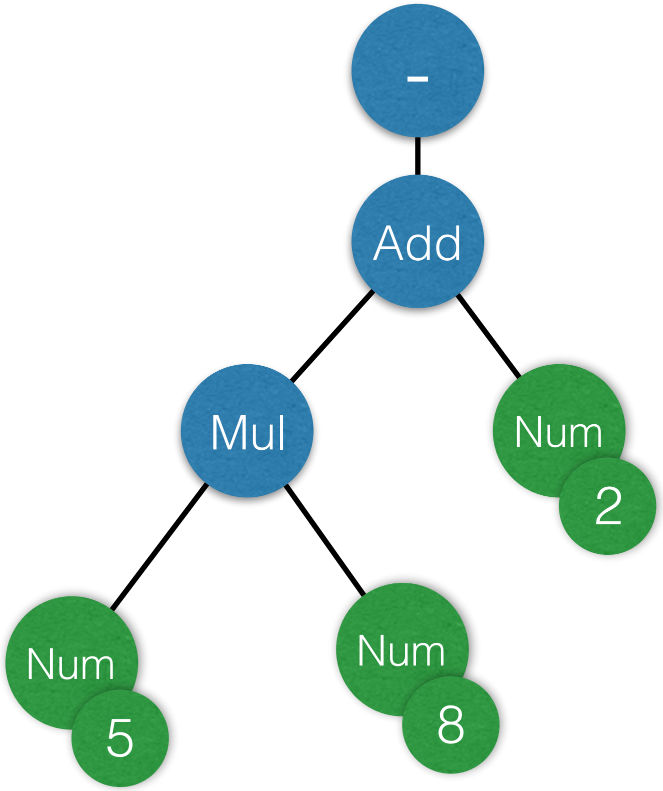


Mul

We add a new node type for multiplication

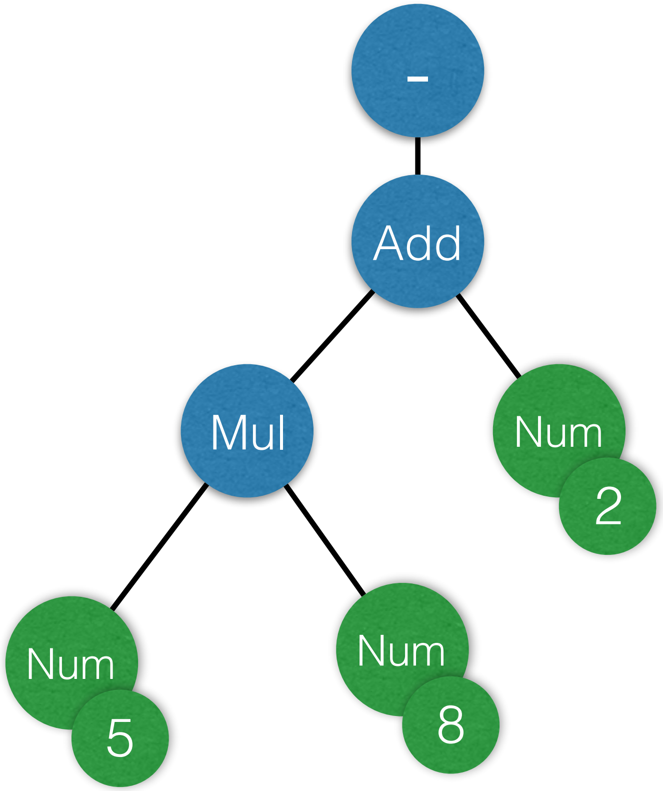
2,3

AE



Then we add another new node type for unary minus

2,3 AE

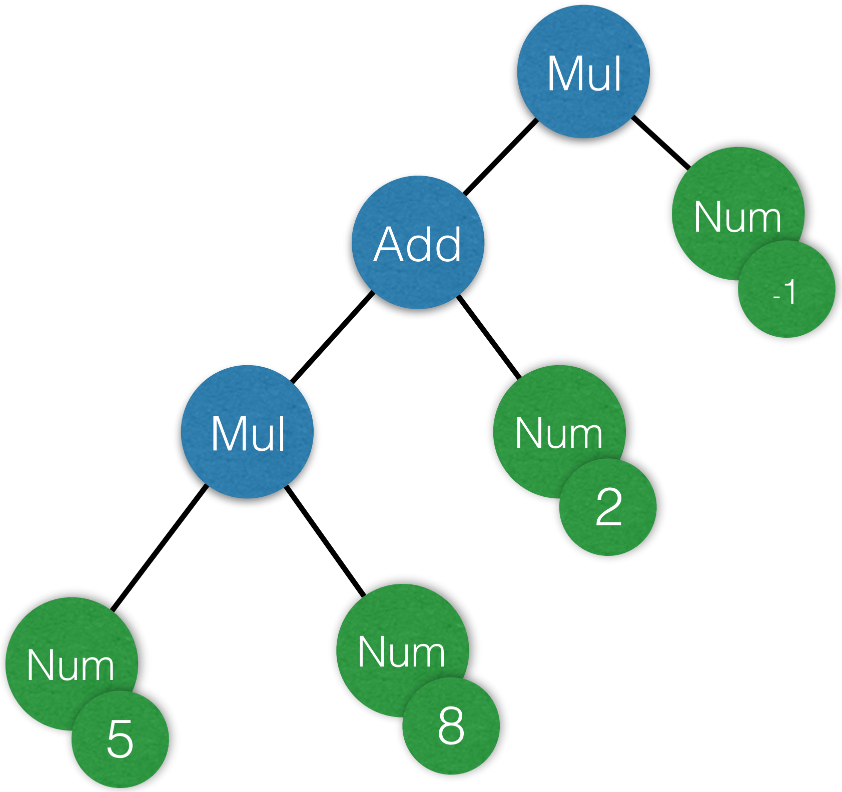


But we do not really need a new node type for this.

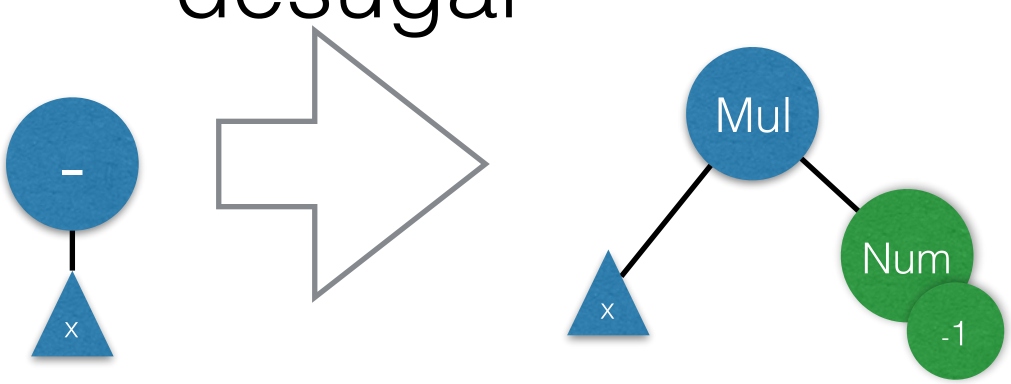
<u>Desugaring</u>: transforms the AST to eliminate a node type

1. Semantics must stay the same.
2. Ideally we do not want to look into the child nodes for this.

2,3 AE



desugar



Desugaring: transforms the AST to eliminate a node type

1. Semantics must stay the same.
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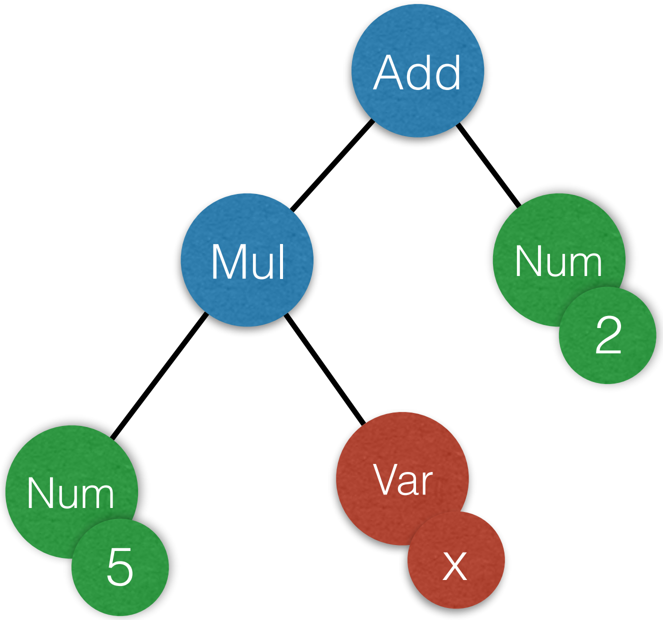
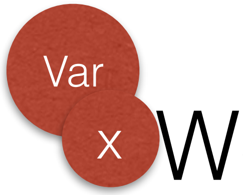
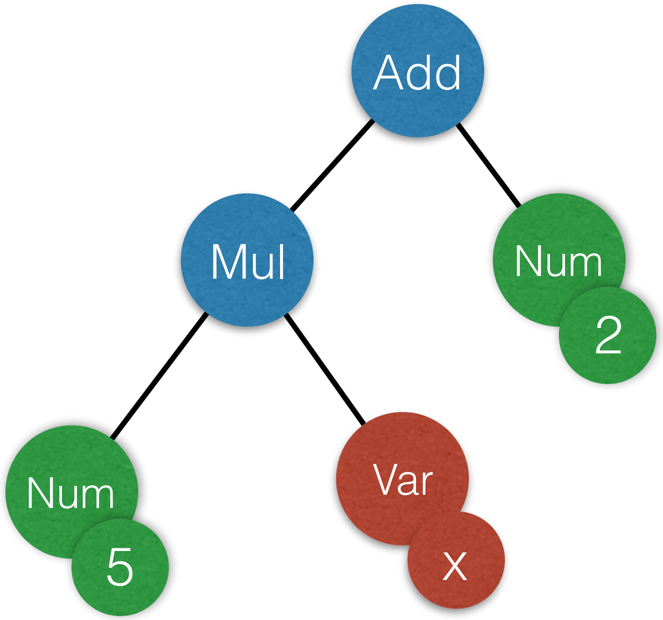
4 AEId

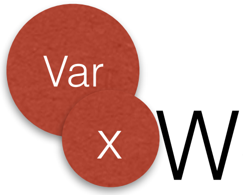




We add a new node for a new feature: **variables**

4 AEId





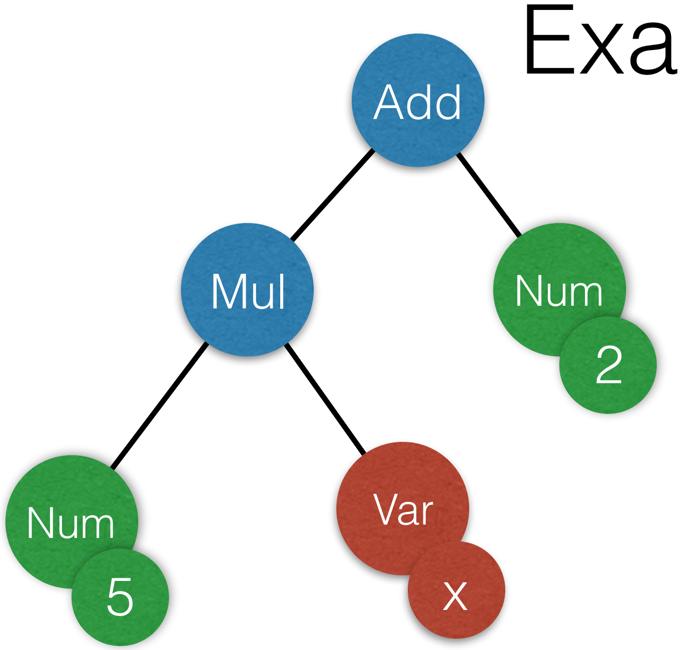
We add a new node for a new feature: **variables**

On its own, a term does not have meaning anymore.

We need to give the interpreter a map from variable names to values.
This map is called an environment.

4

AEId



Example environment:

x —> 8

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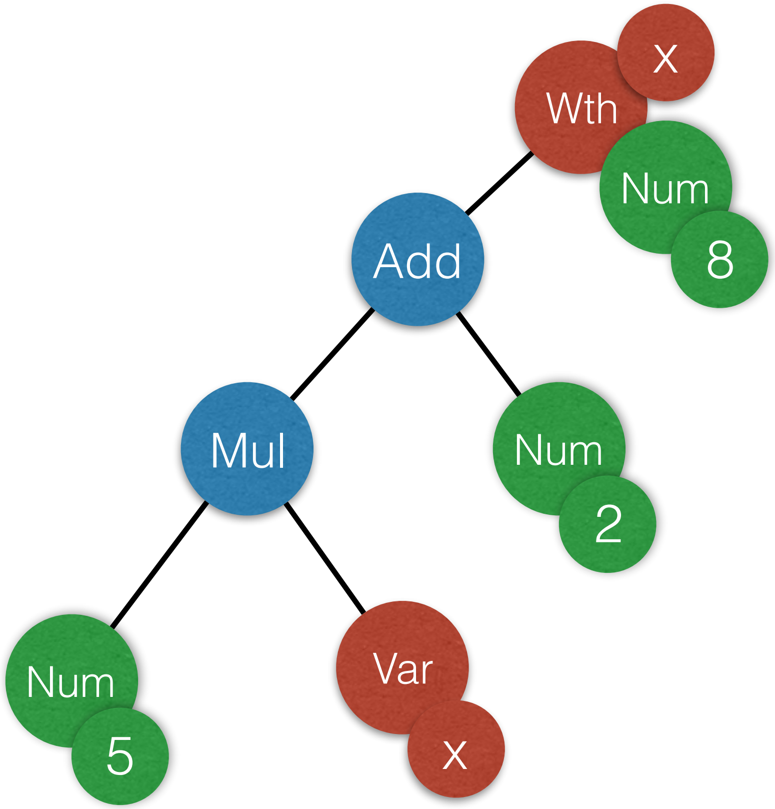
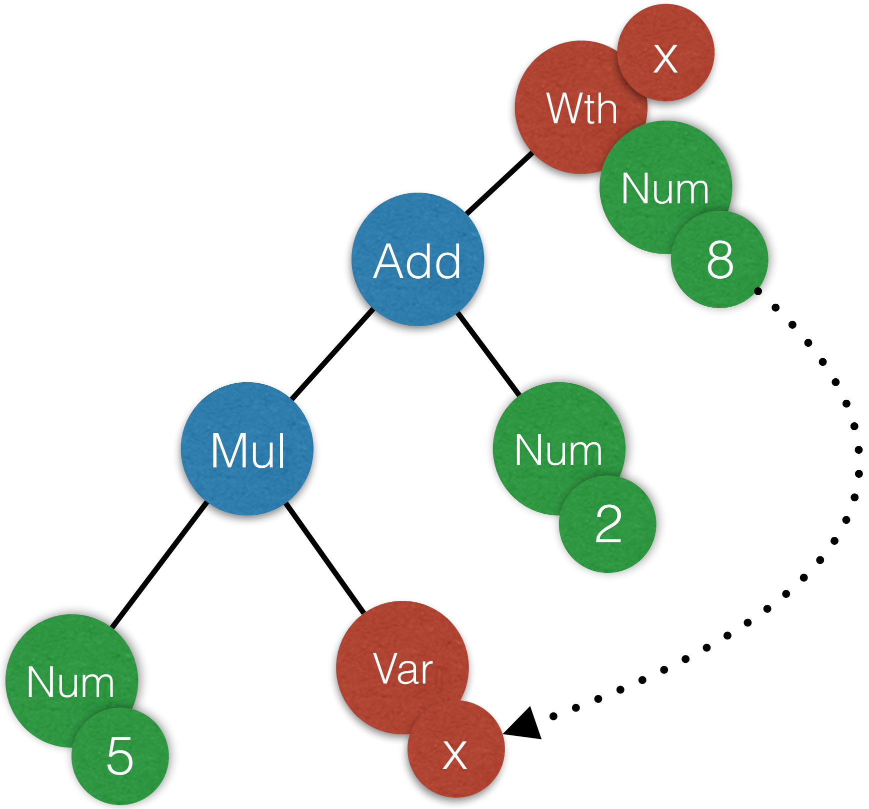
5 WAE



Wth

We add a new node for binding variables

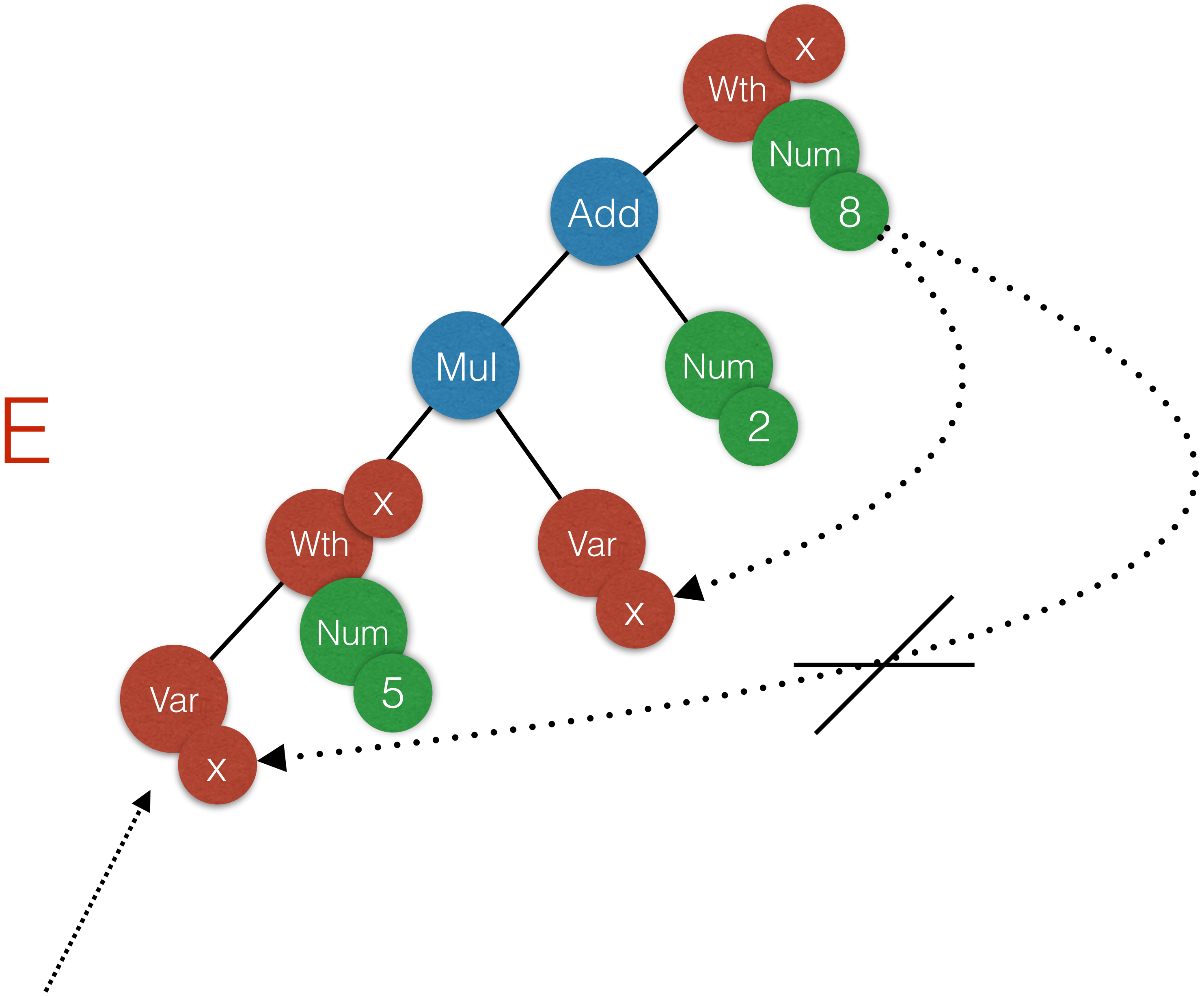
5 WAE



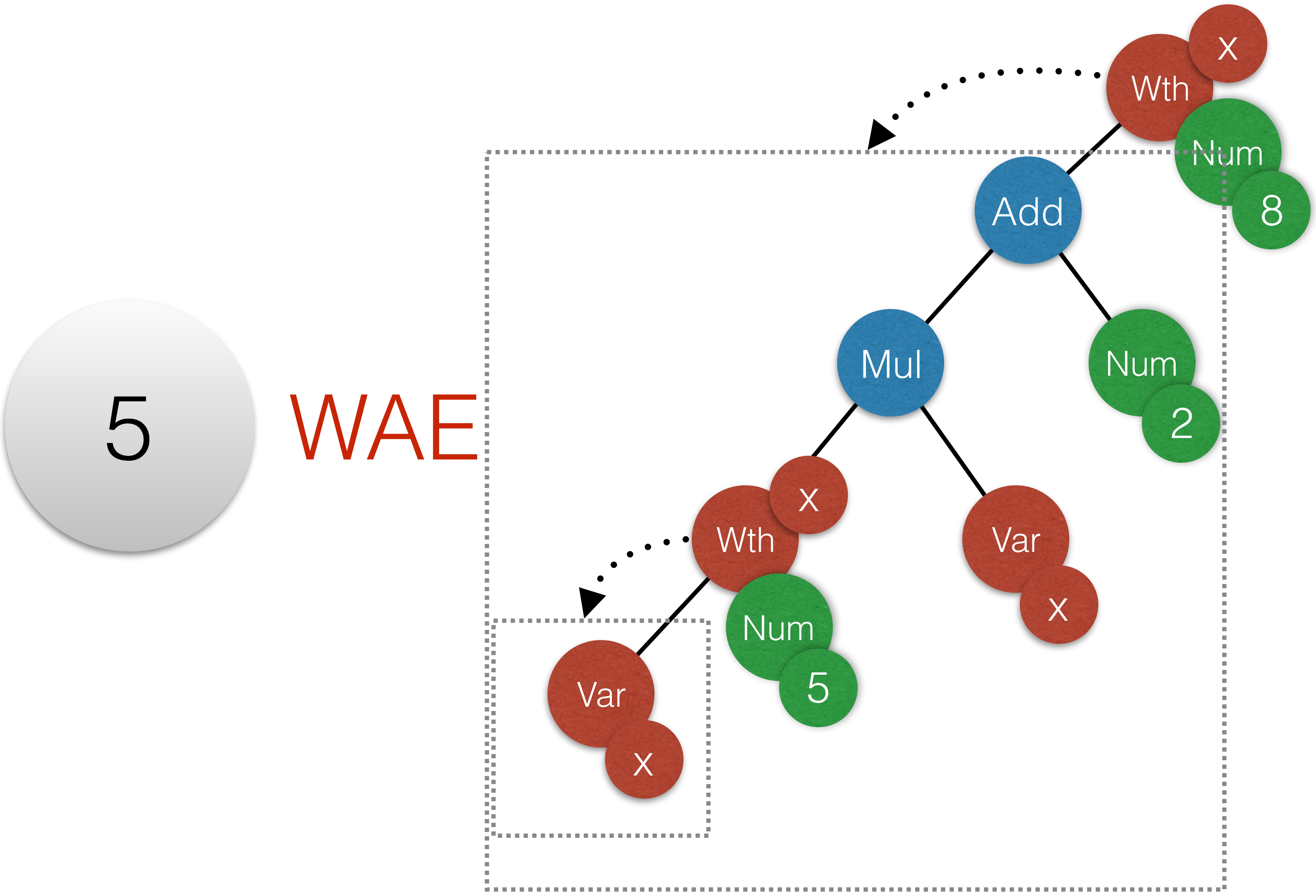
We add a new node for binding variables

An interpreter can produce a value from such a term by: substituting the value from evaluating the bound term for all **free** variables with the name

5 WAE

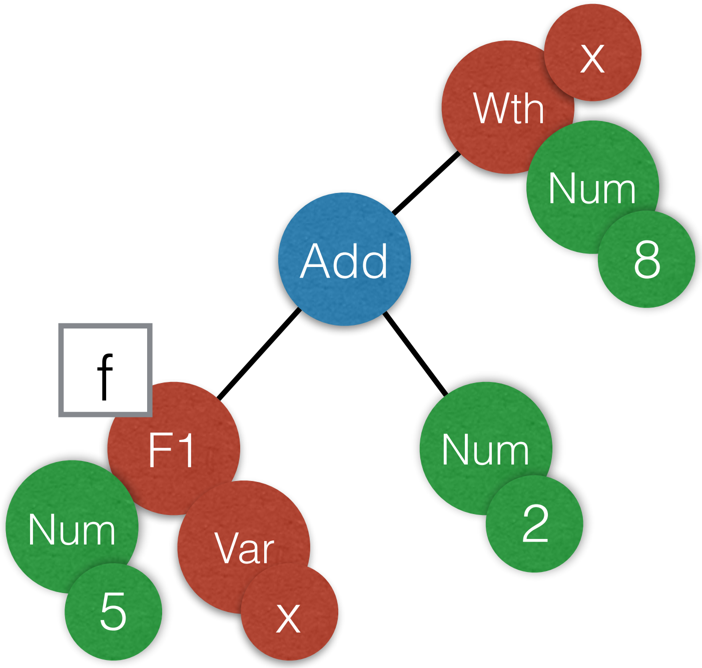


not free in the overall term



Static (lexical) scope

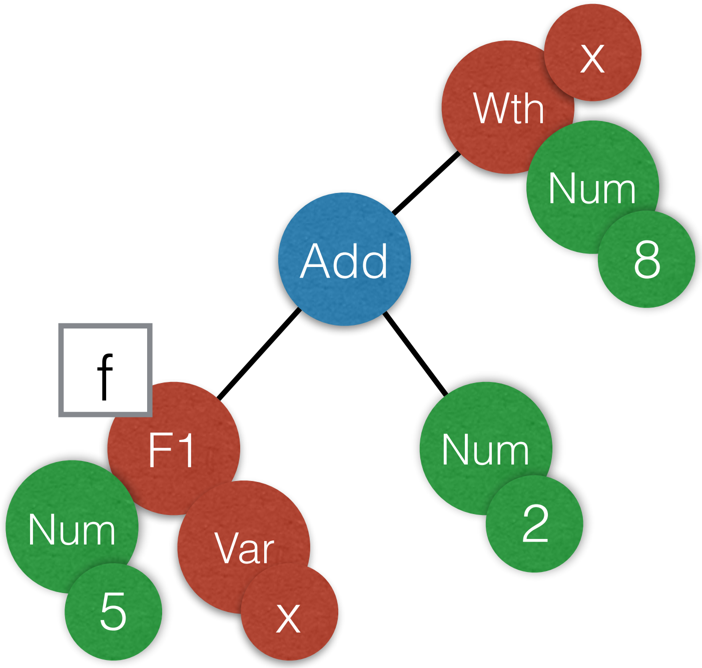
6 F1WAE



F1

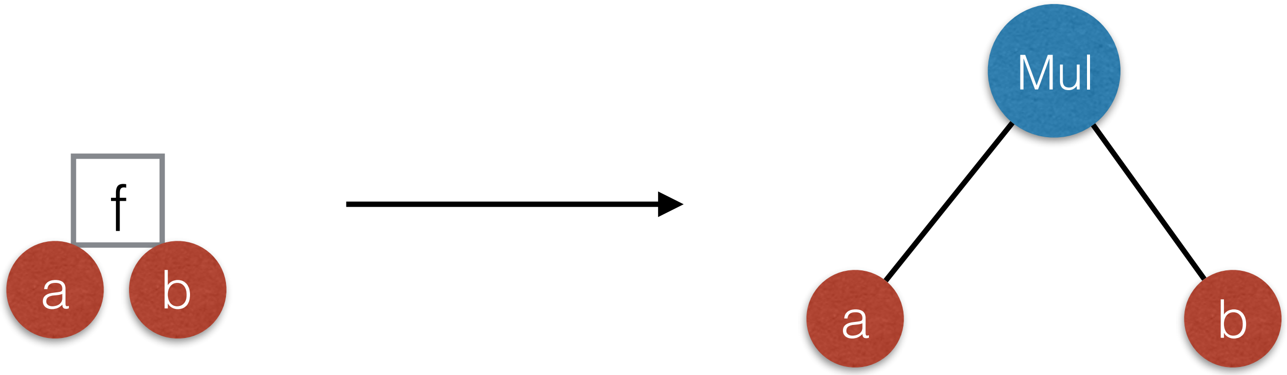
We add a new node for calling first-order functions

6 F1WAE

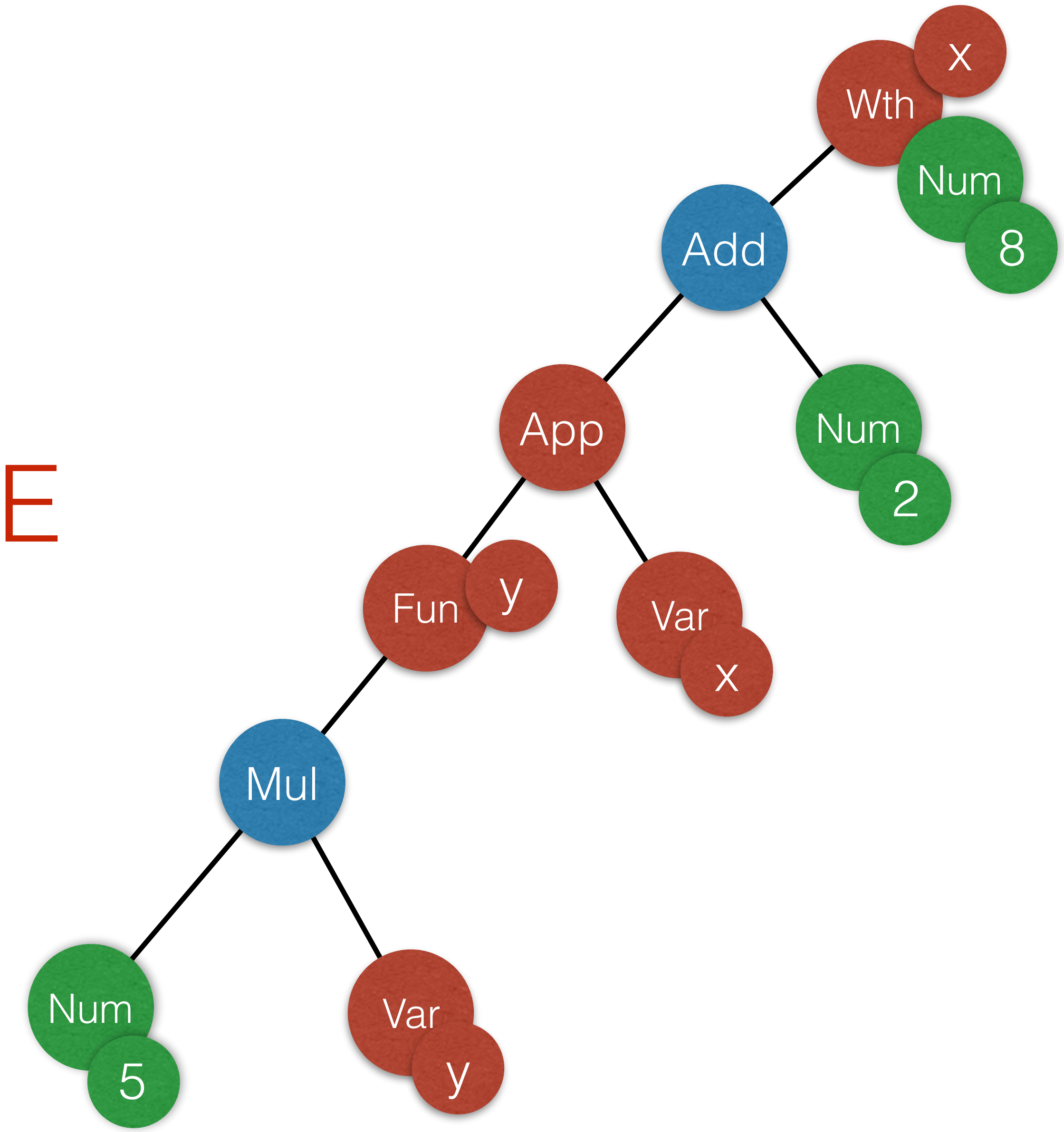


F1 We add a new node for calling first-order functions

We have a dictionary with an entry per function:



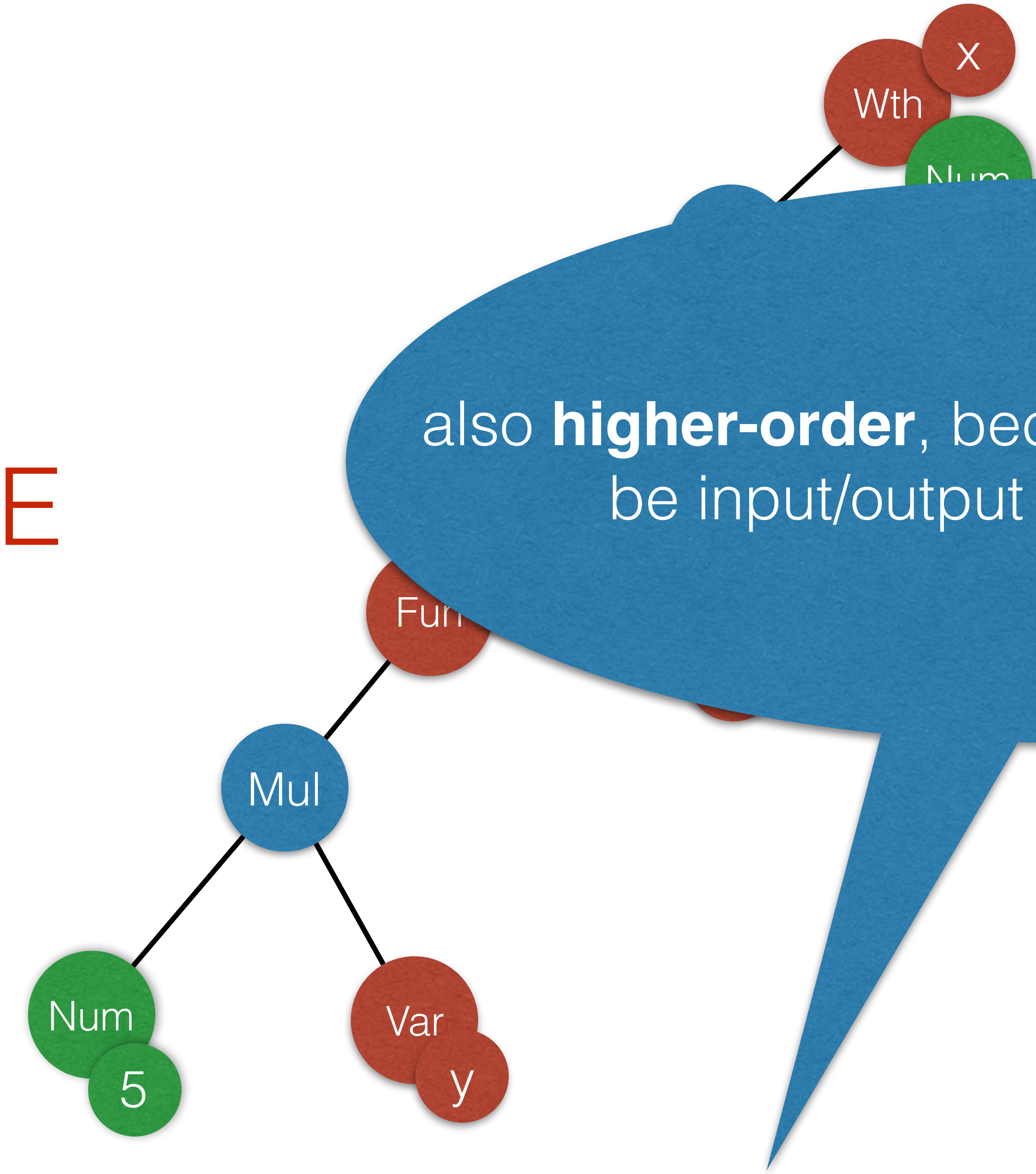
7 FAE



Fun Now we turn functions into **first-class** objects, that is, their definition happens locally in the AST

App Thus we also need a new node to call, or **apply**, them

7 FAE



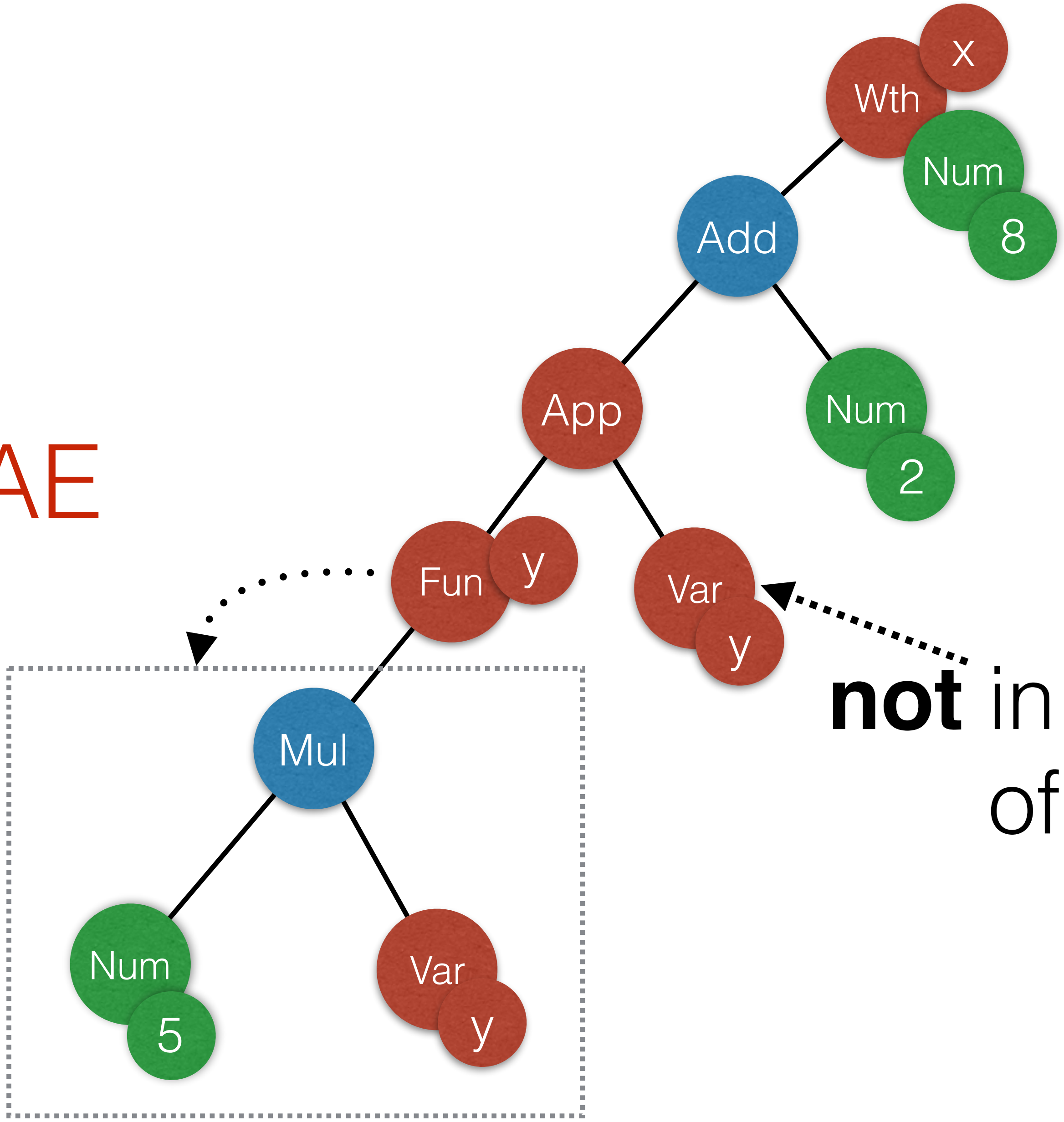
also **higher-order**, because functions can now be input/output of other functions

Fun Now we turn functions into **first-class** objects, that is, their definition happens locally in the AST

App Thus we also need a new node to call, or **apply**, them

7

FAE

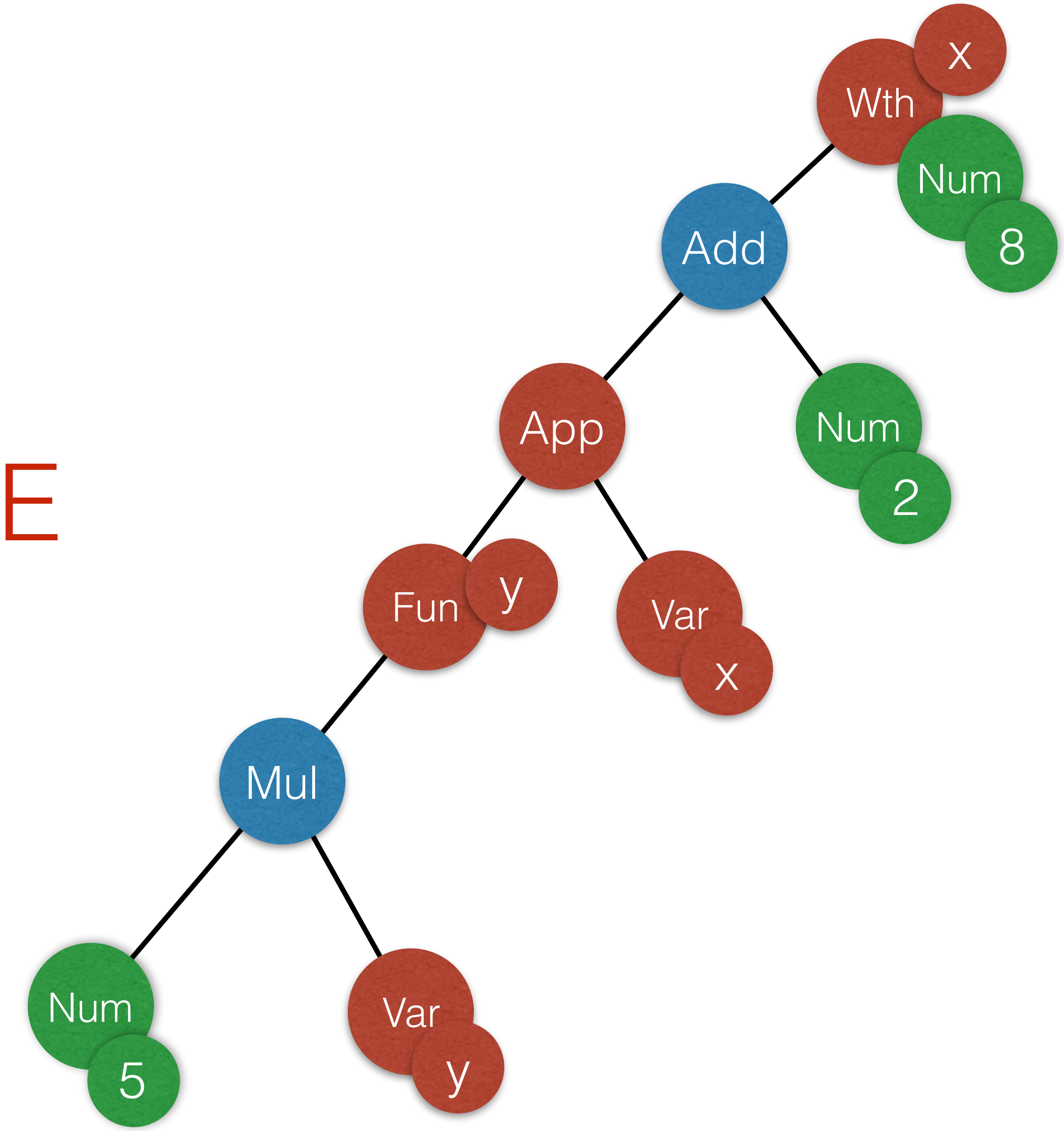


not in the static scope of the function

static scope of the function

7

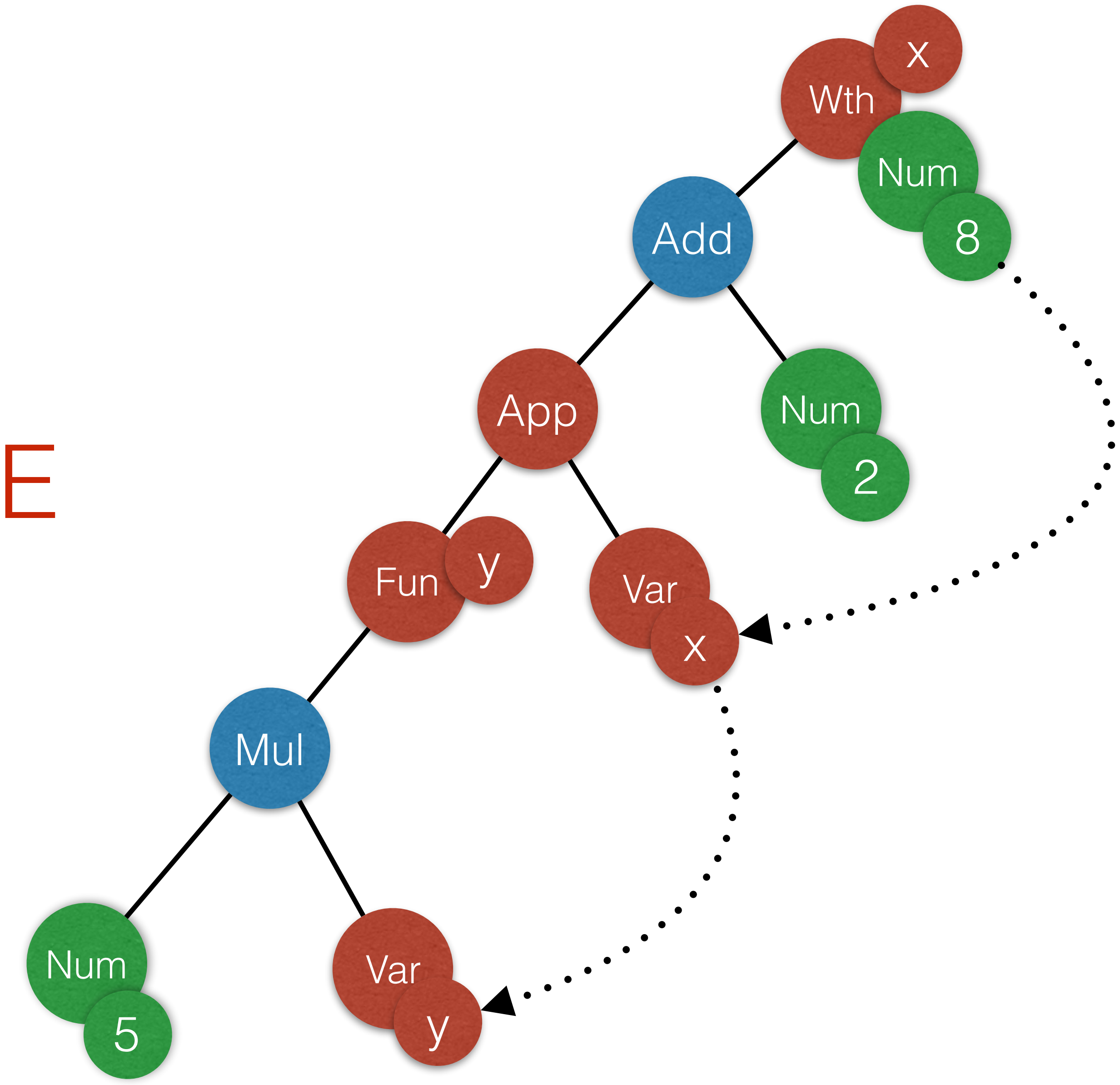
FAE



Two possible interpreters:
<u>substitution-based</u> and <u>environment-based</u>

7

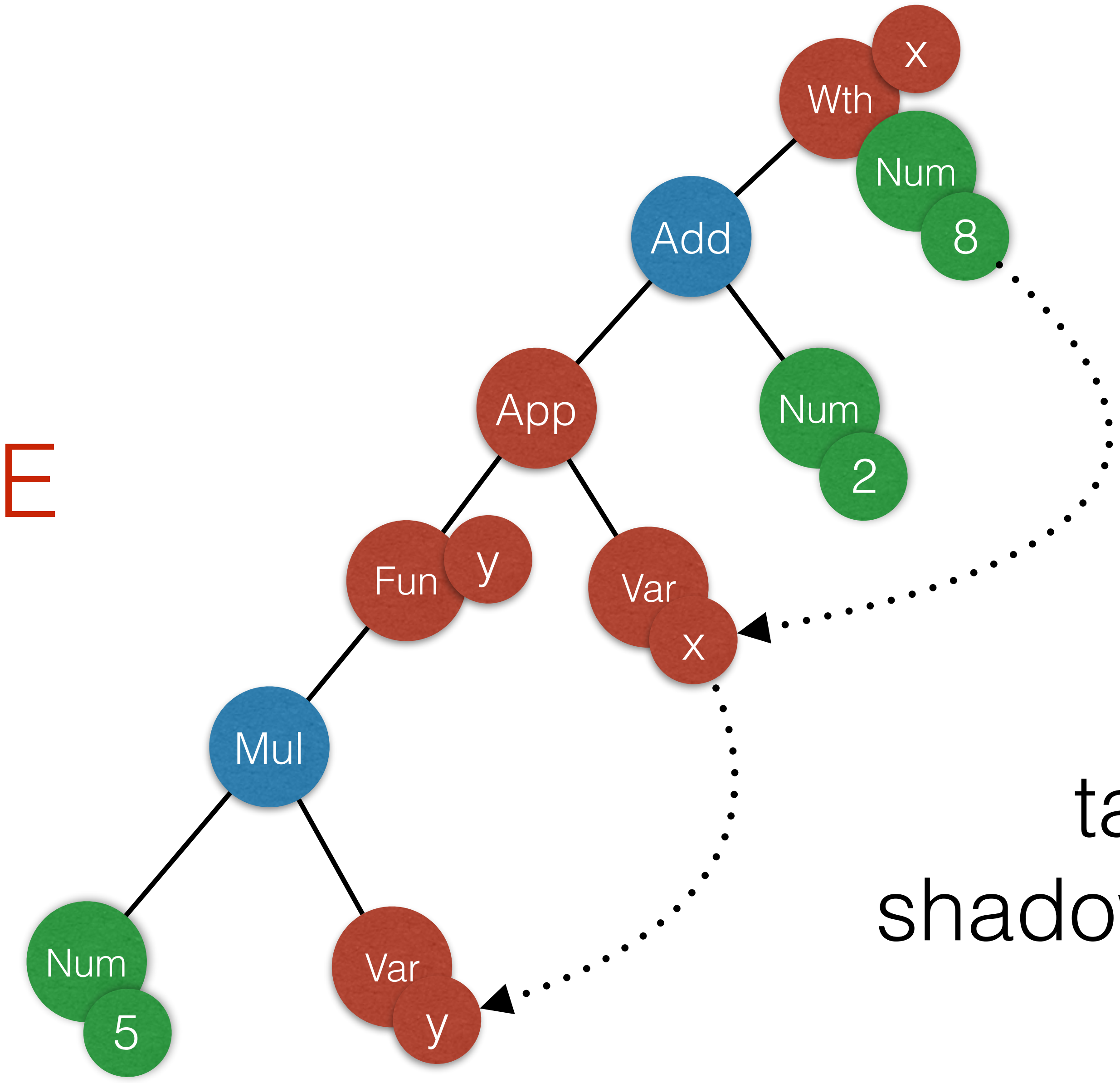
FAE



Substitution-based: just substitutes step-by-step

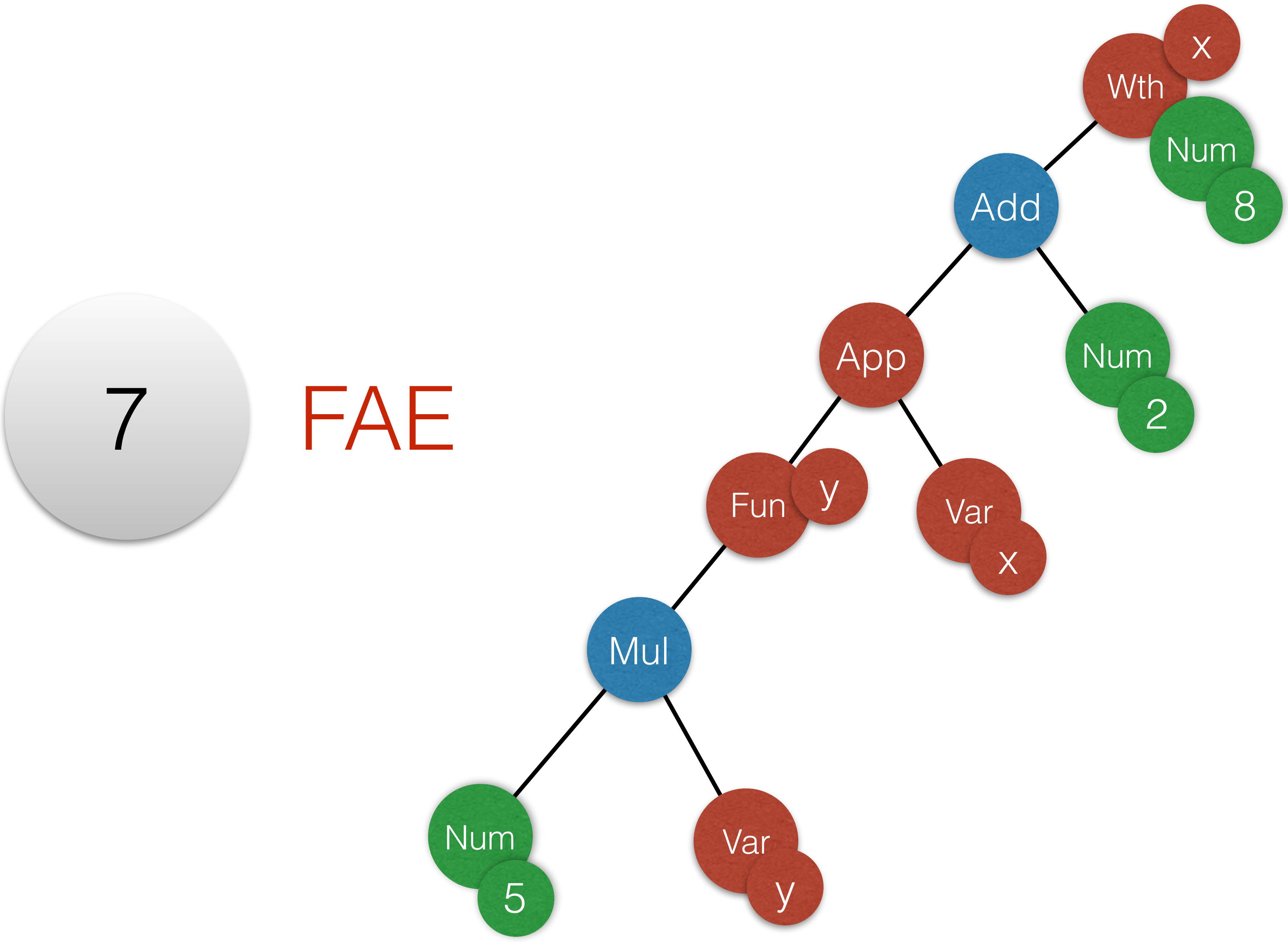
7

FAE



take care:
shadowed variables

Substitution-based: just substitutes step-by-step



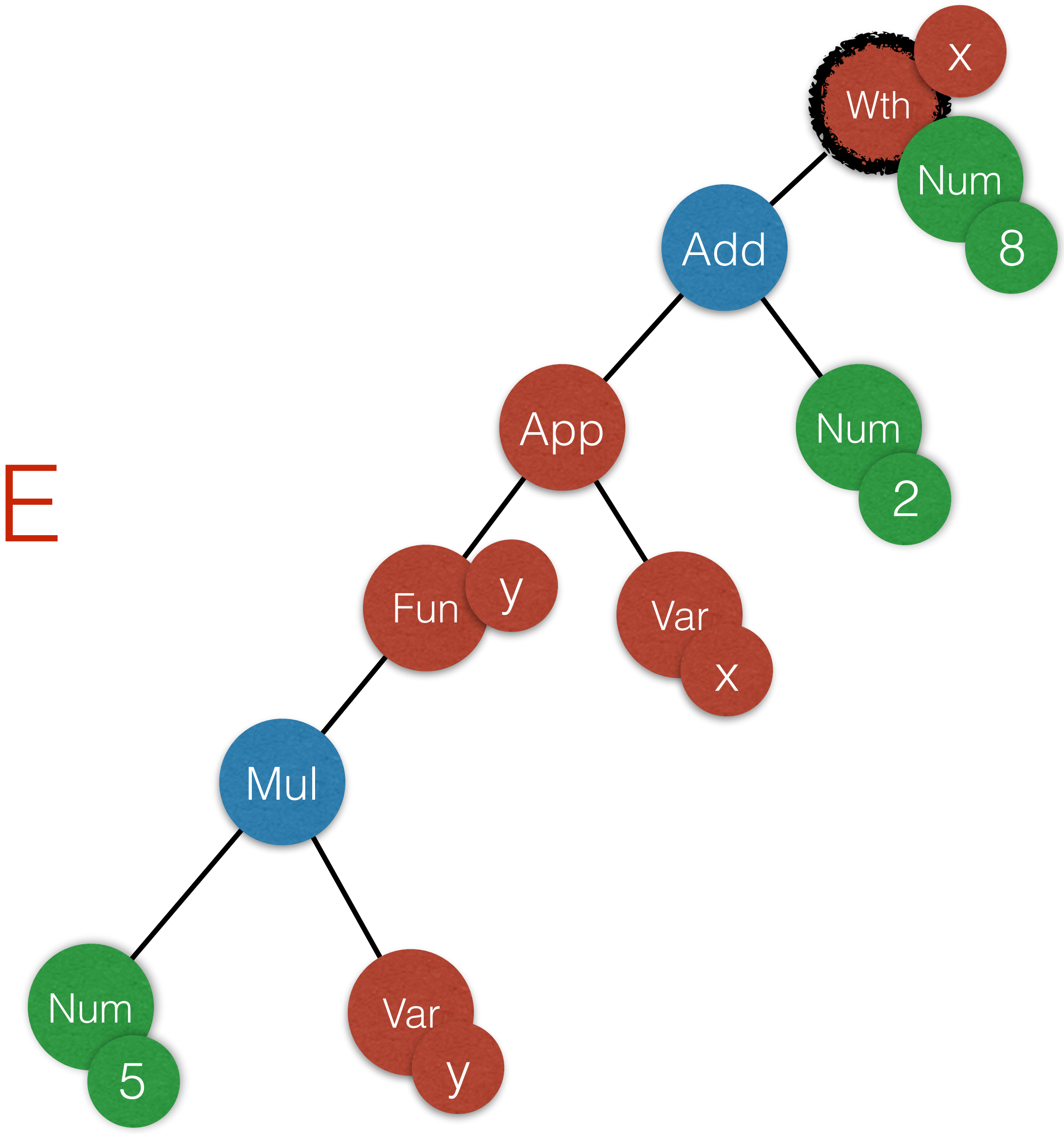
FAE

(empty)

Environment-based: carries along an environment

7

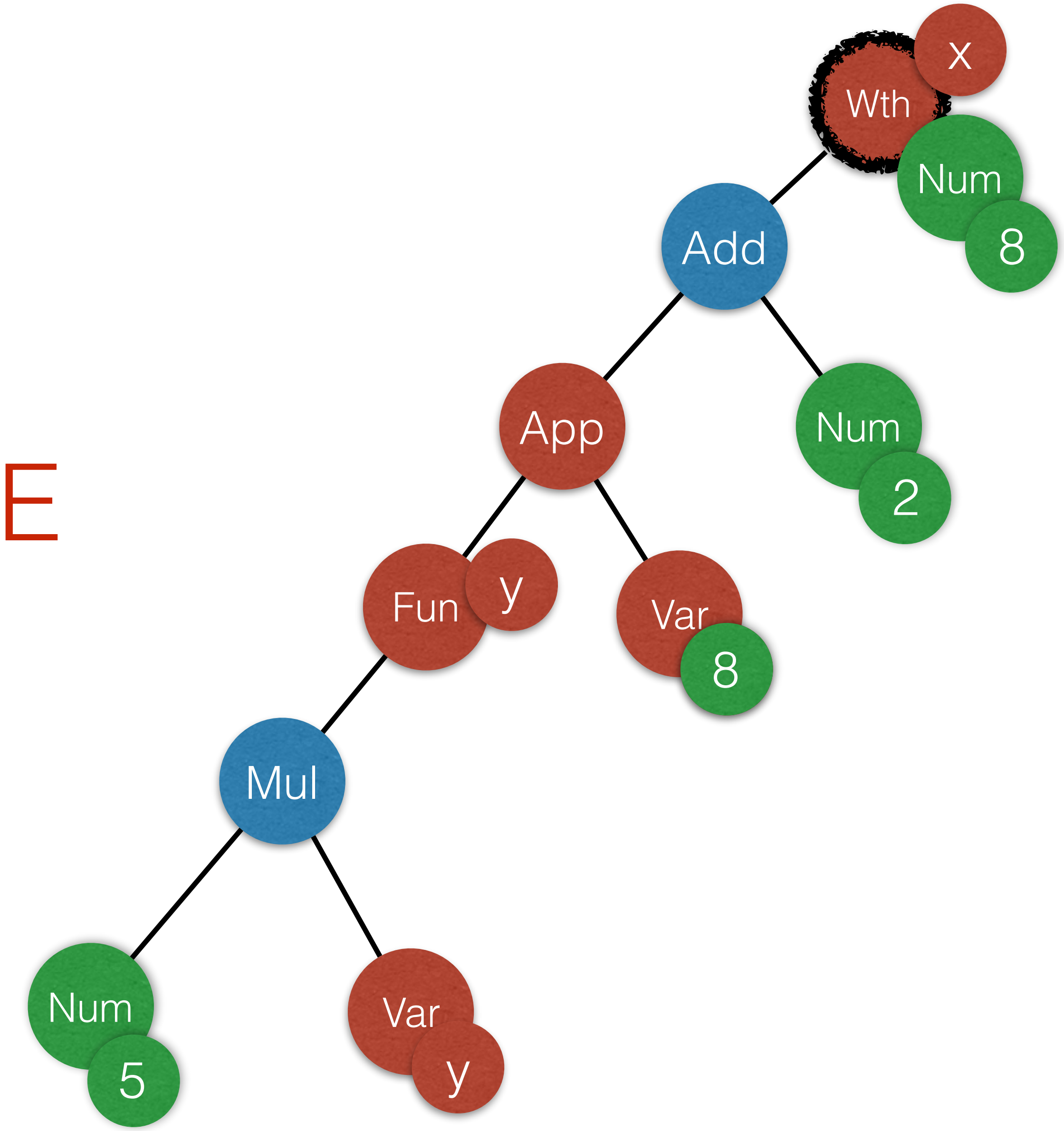
FAE



x —> 8

Environment-based: carries along an environment

FAE

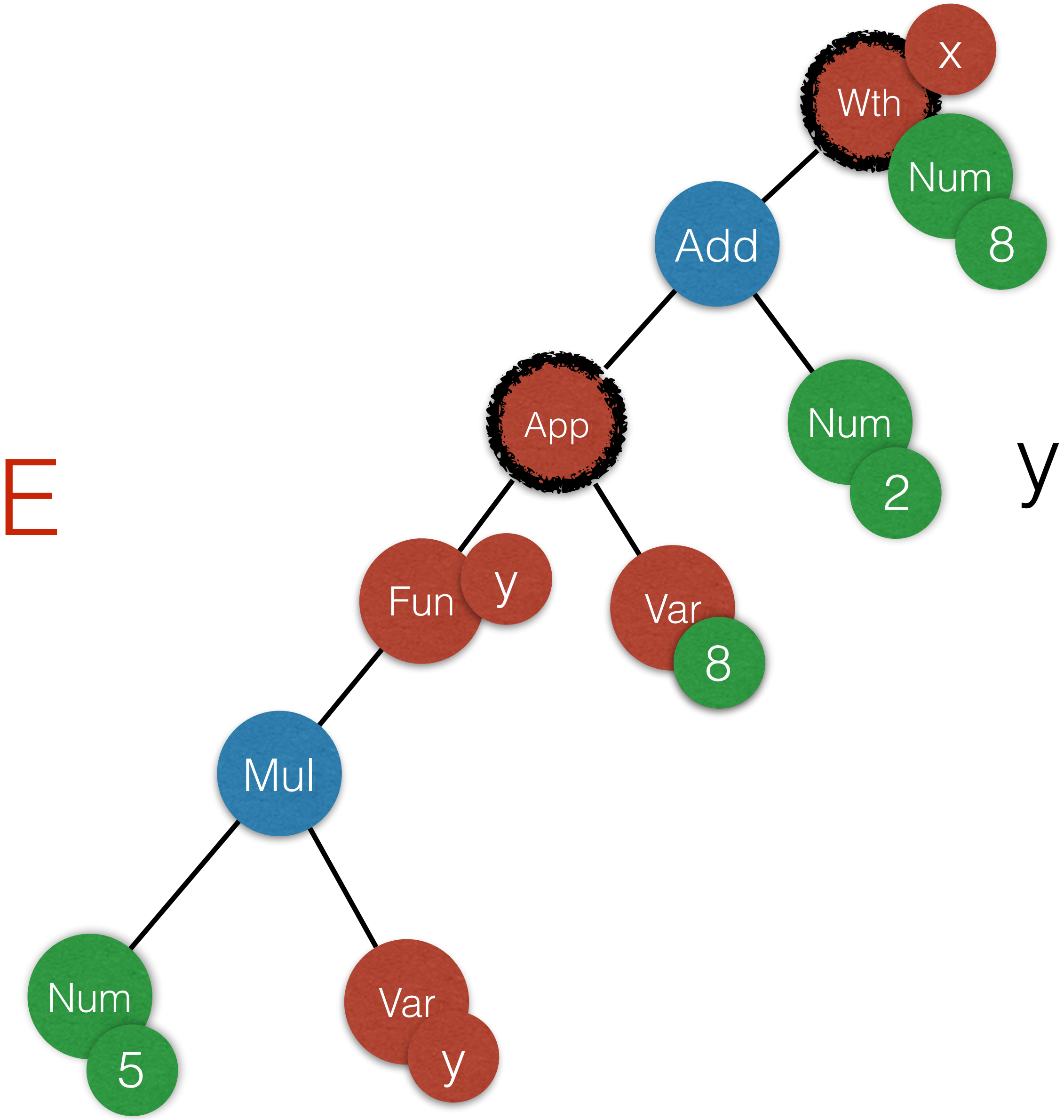


x —> 8

Environment-based: carries along an environment

7

FAE



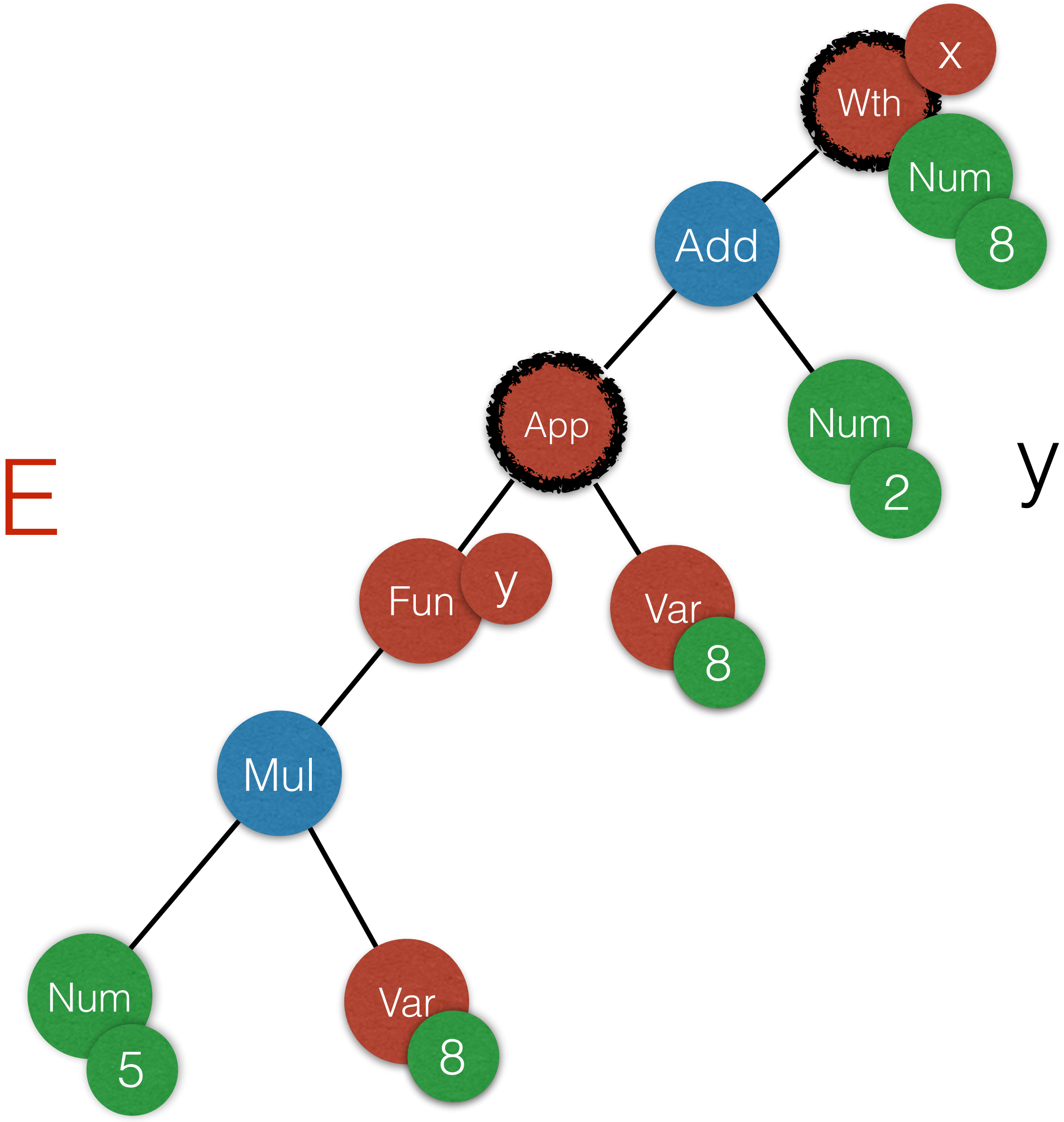
x —> 8

y —> 8, x —> 8

Environment-based: carries along an environment

7

FAE



x —> 8

y —> 8, x —> 8

Environment-based: carries along an environment

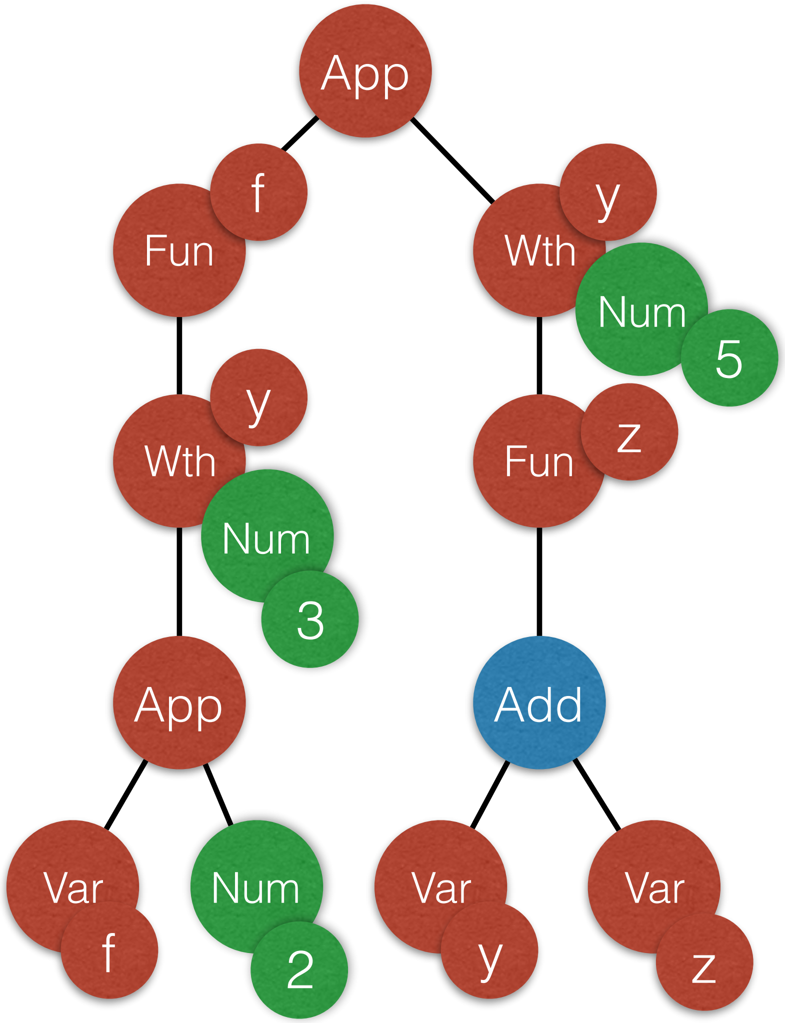
7 FAE

Note: Values can now also be functions, not just numbers!

But how exactly should they be represented?

7

FAE



Note: Values can now also be functions, not just numbers!

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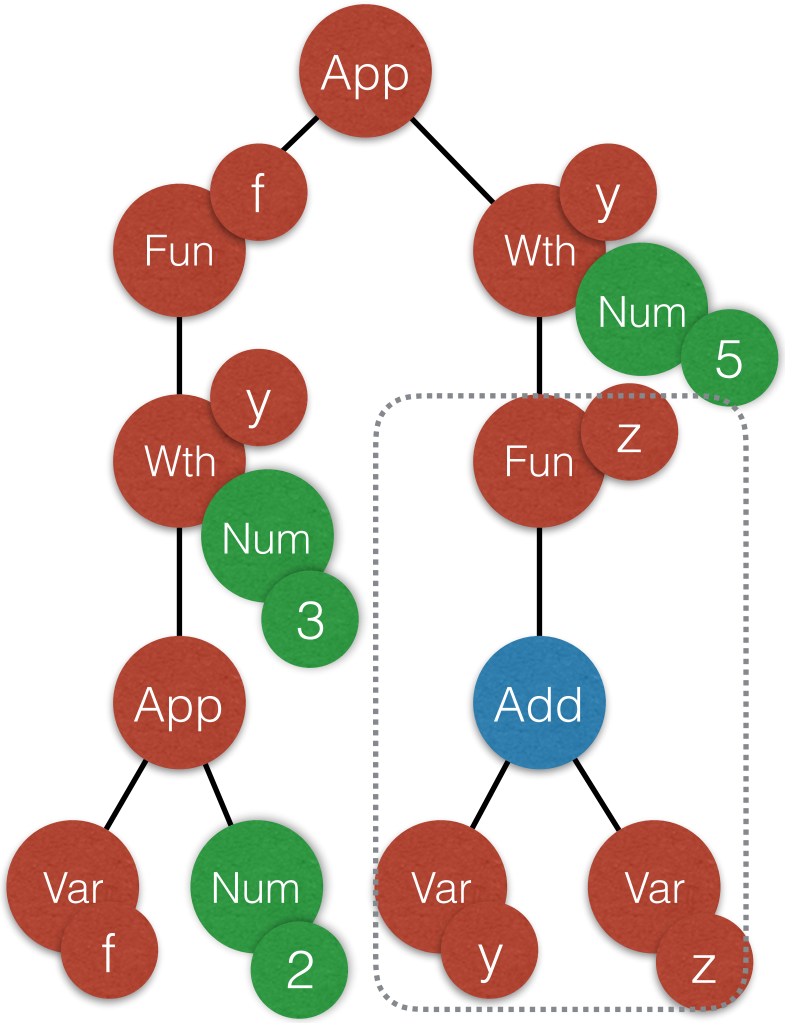
FAE



First idea:
value = term

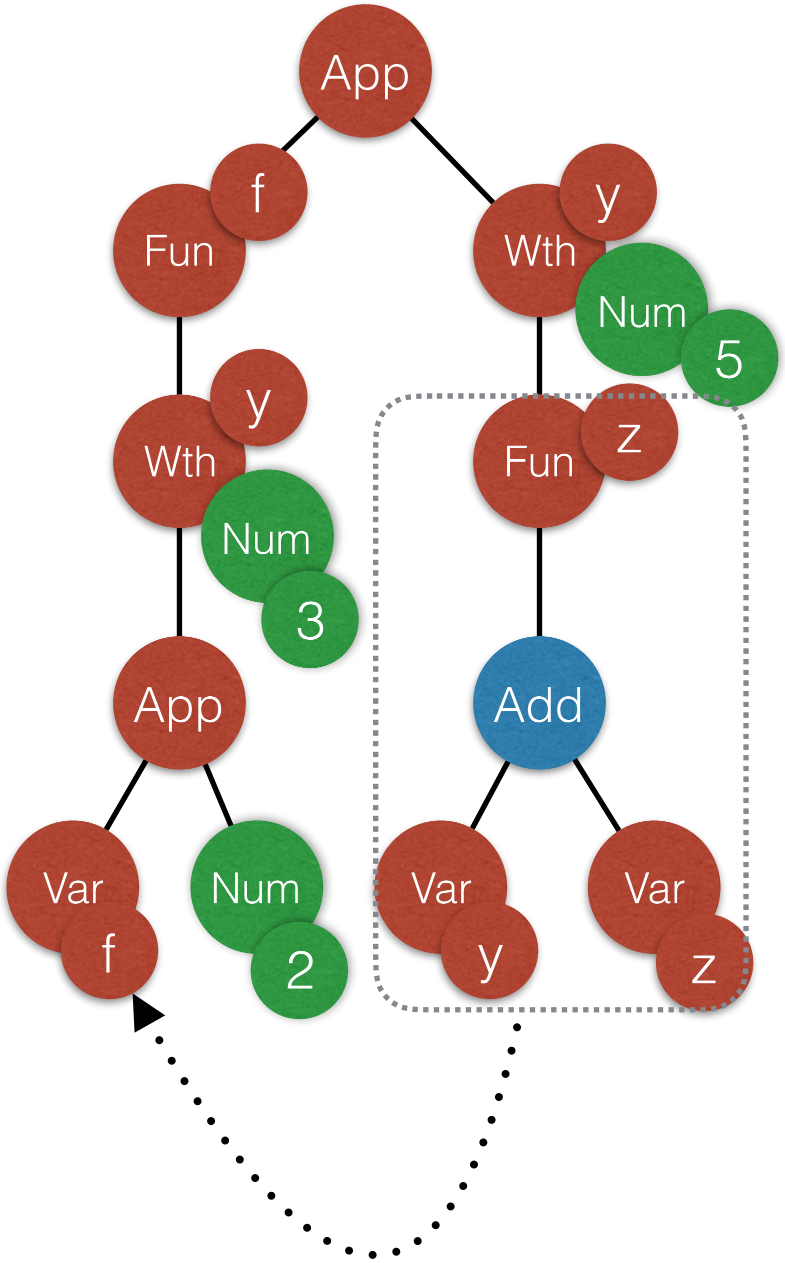
Note: Values can now also be functions, not just numbers!

But how exactly should they be represented as values?

7 FAE

Problem: we then have an environment assignment:

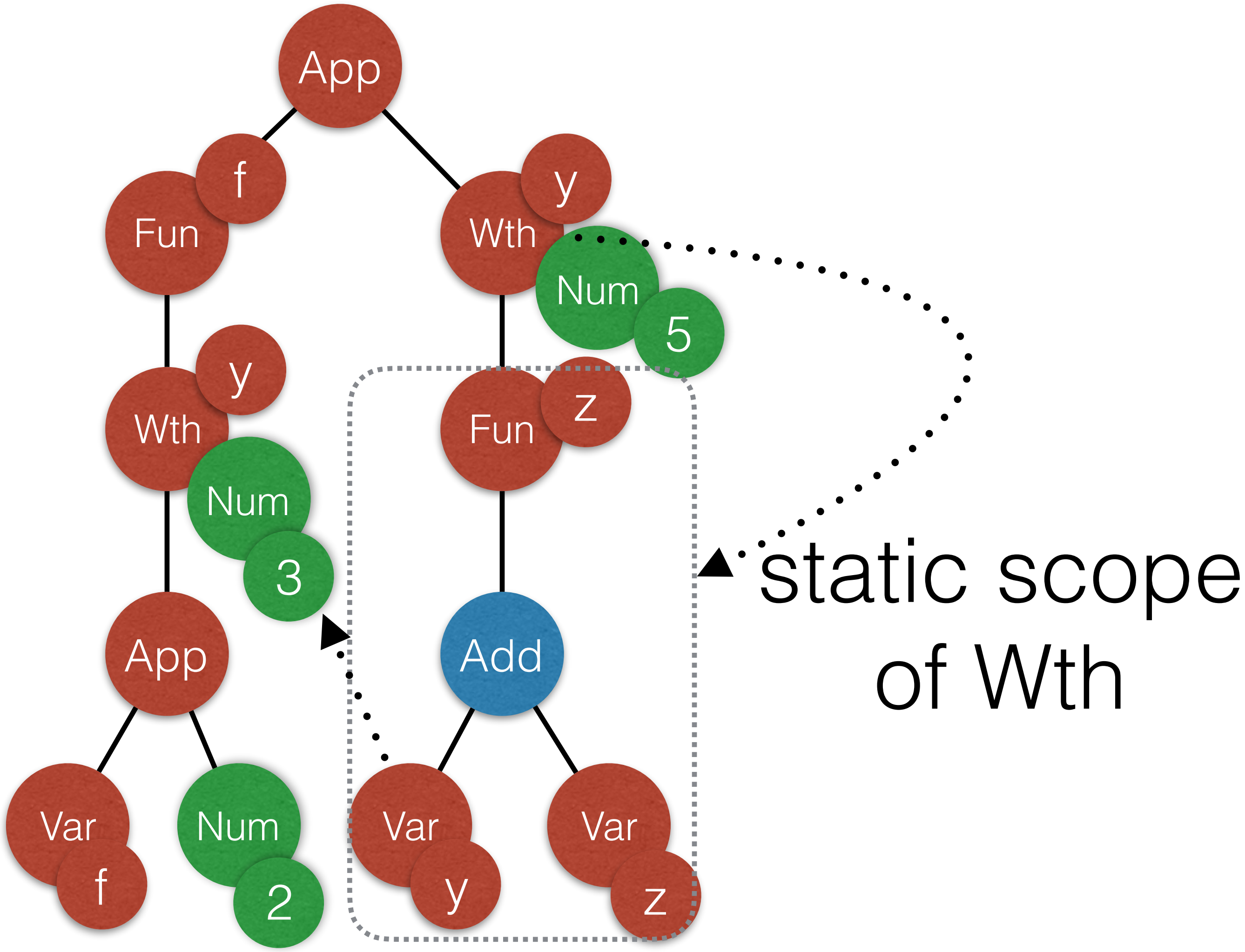
f —> Fun(z, Add(y, z))



So this term gets inserted in place of f.

7

FAE

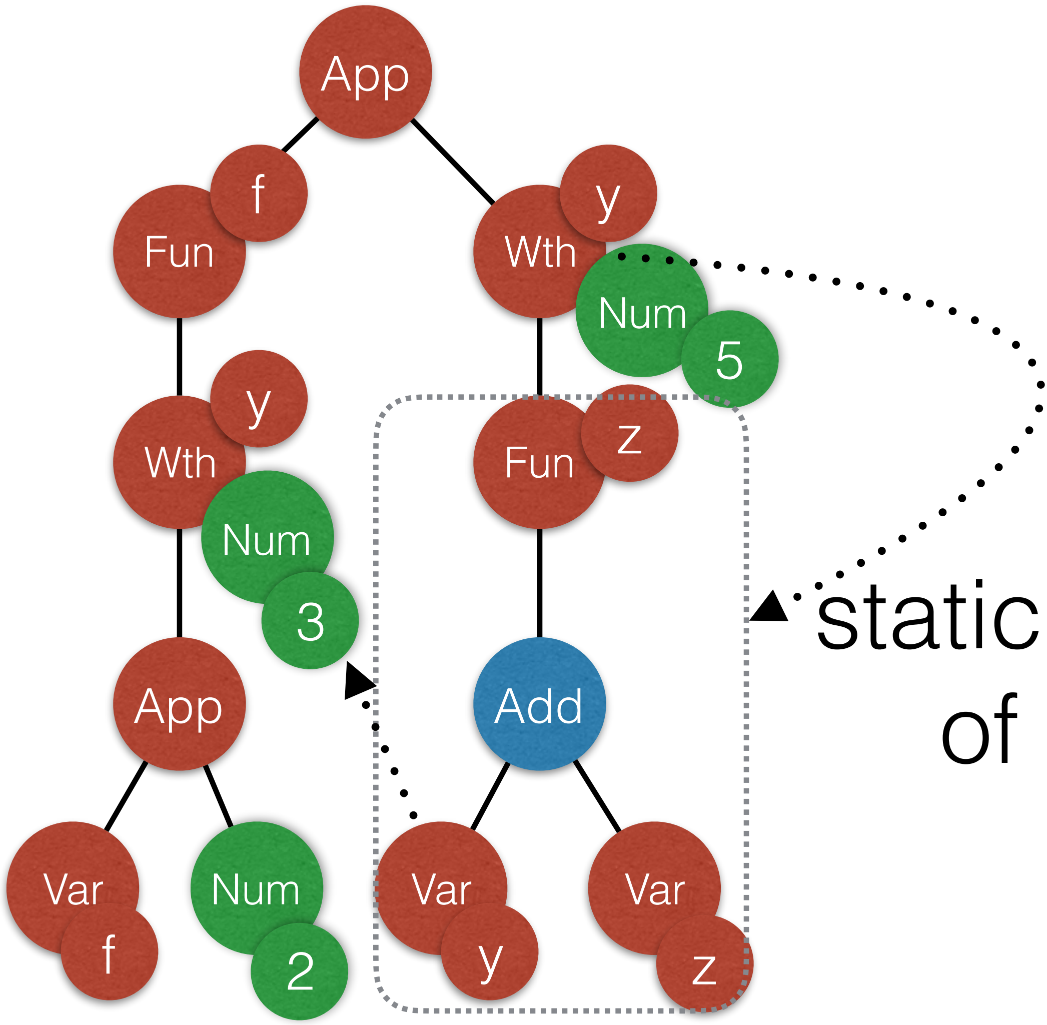


static scope of Wth

In effect, y is bound outside of the static scope.
=> We have a violation of static scoping!

7

FAE



static scope of Wth

Underlying problem:

The function term alone does not reflect **all** the knowledge of the evaluation. Thus it does not really qualify as a value.

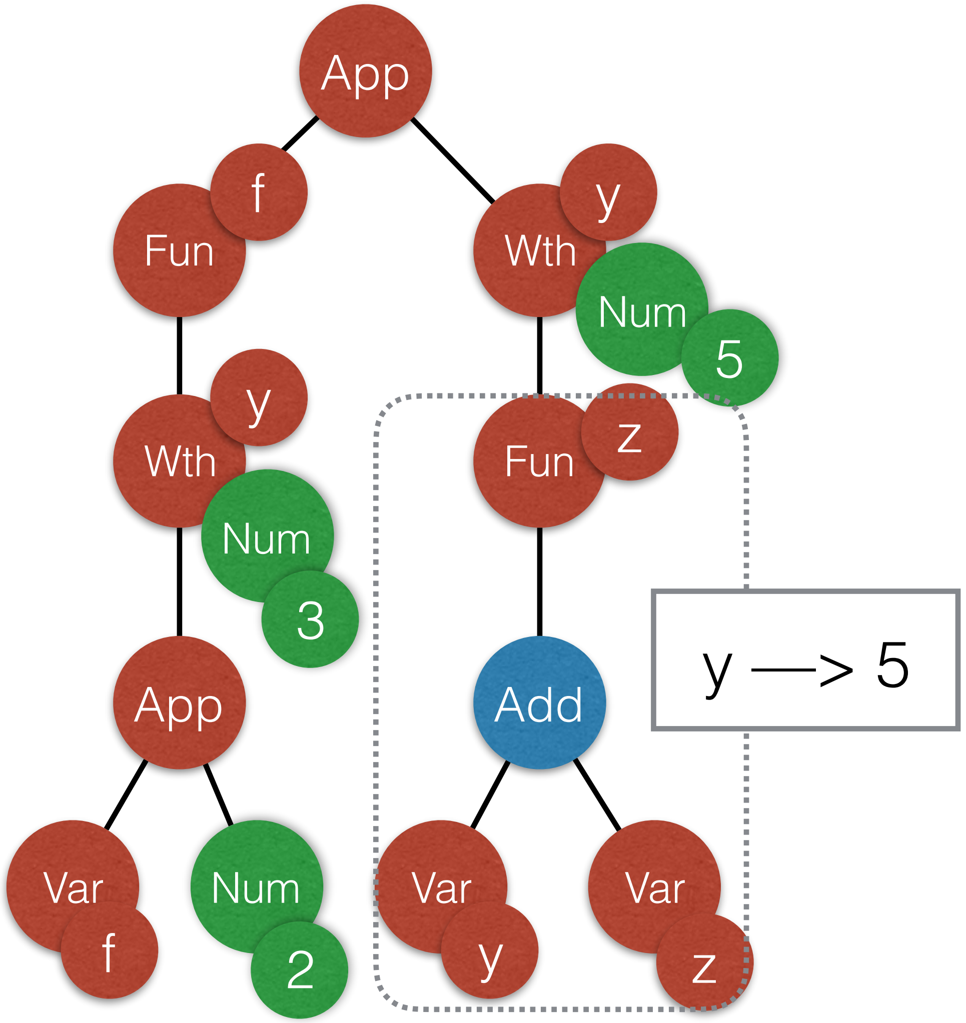
The remaining knowledge is in the environment!
With this in mind, the solution is rather straightforward:

7

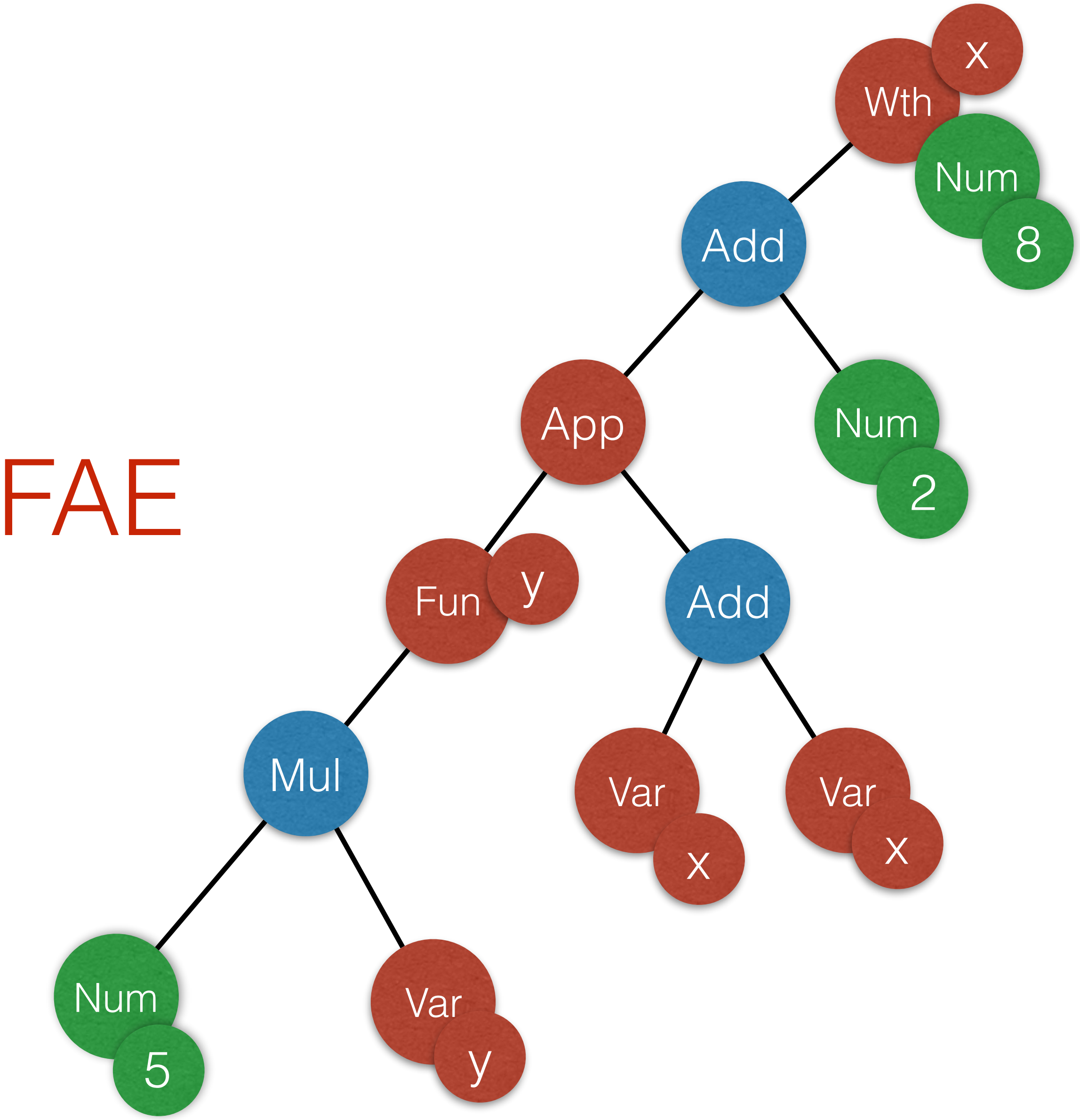
FAE

Solution: value = term together with environment at the time the term is evaluated

f —>
Closure(
Fun(z, Add(y, z)),
(y —> 5))



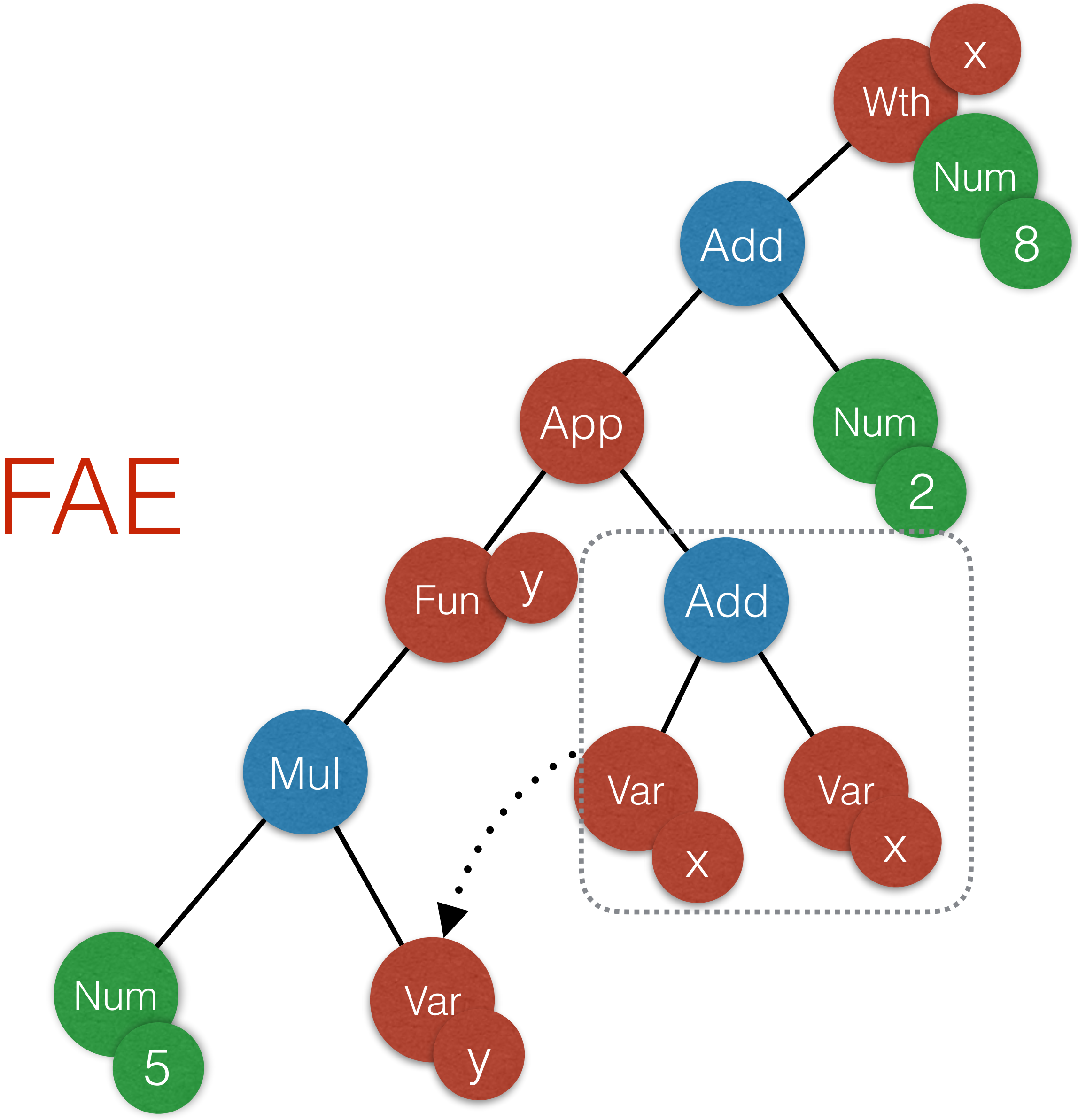
8 LCFAE



Same node types, but the Fun node is now evaluated differently, namely **call-by-name**

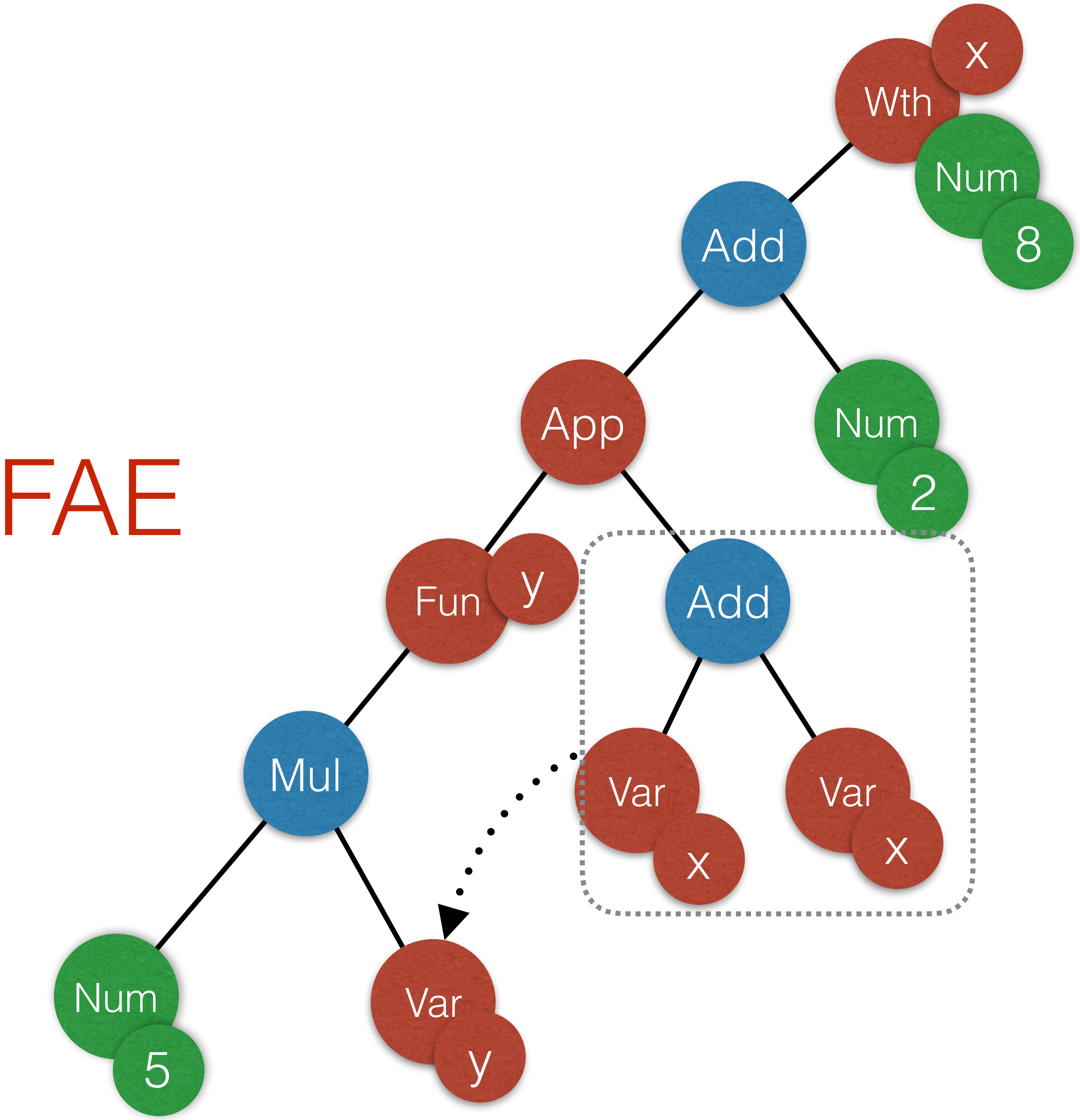
(or alternatively **call-by-need**, which is the same with caching)

LCFAE



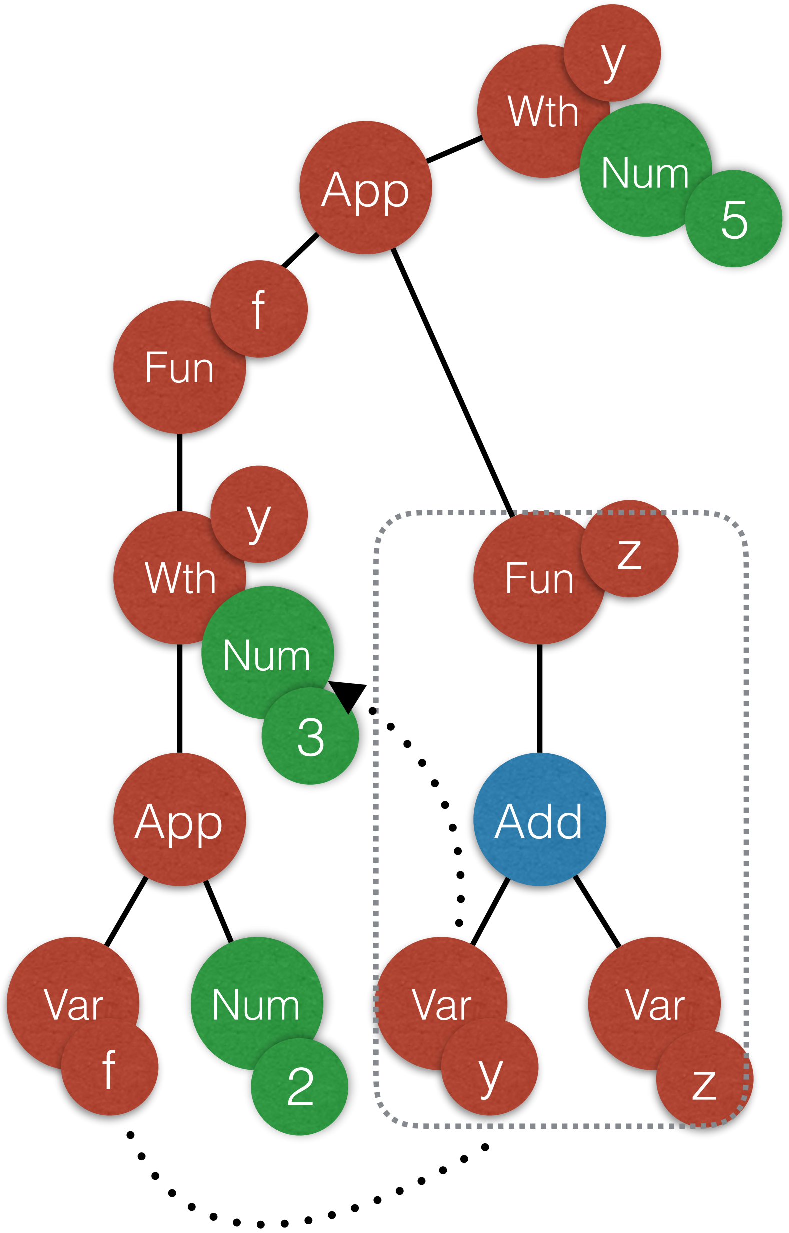
substitution-based interpreter:
the argument is not evaluated, but copied entirely

LCFAE



What does this mean for environment-based interpretation?

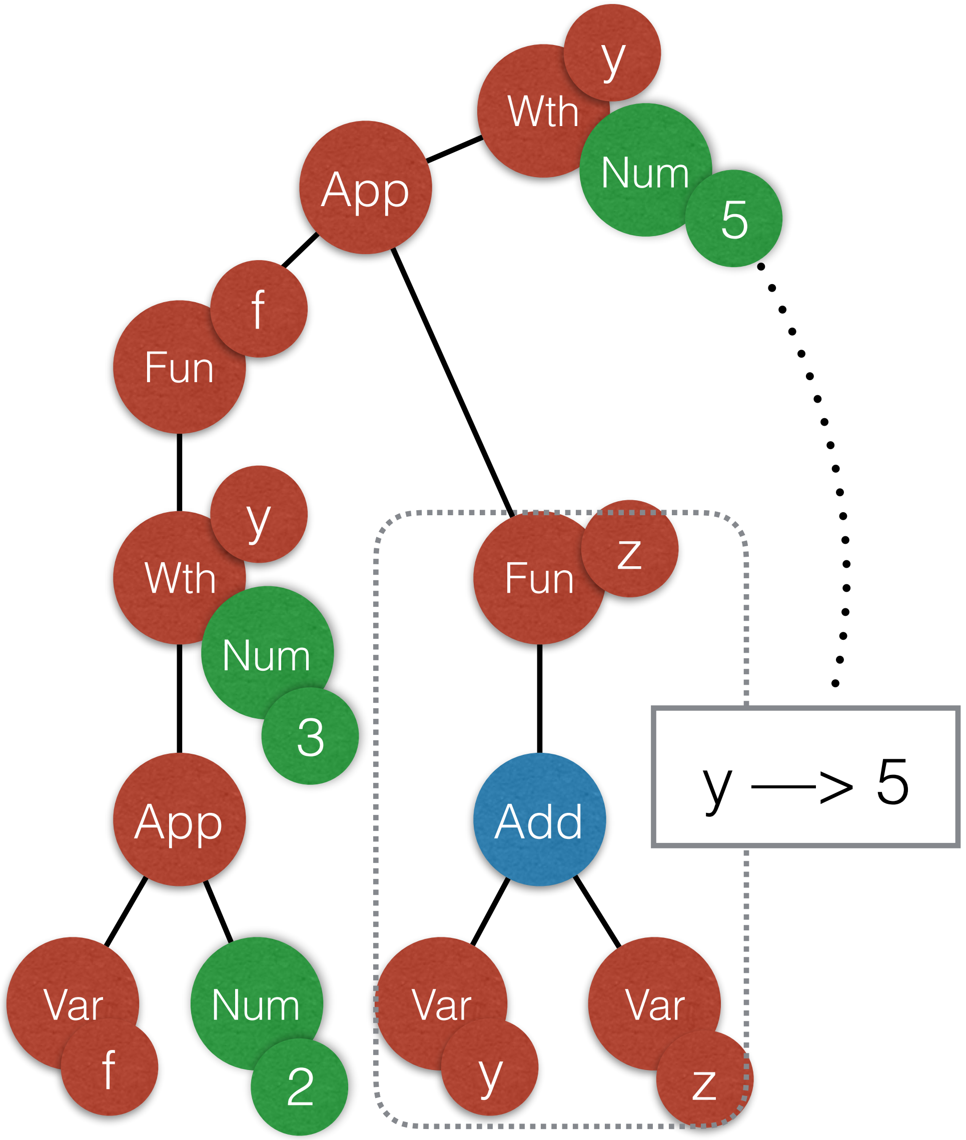
8 LCFAE



We can’t just use *values* for the right-hand sides, because we don’t evaluate unless necessary.

But when we just use terms, we run into a similar problem as with first-class functions under call-by-value, violating static scoping!

8 LCFAE

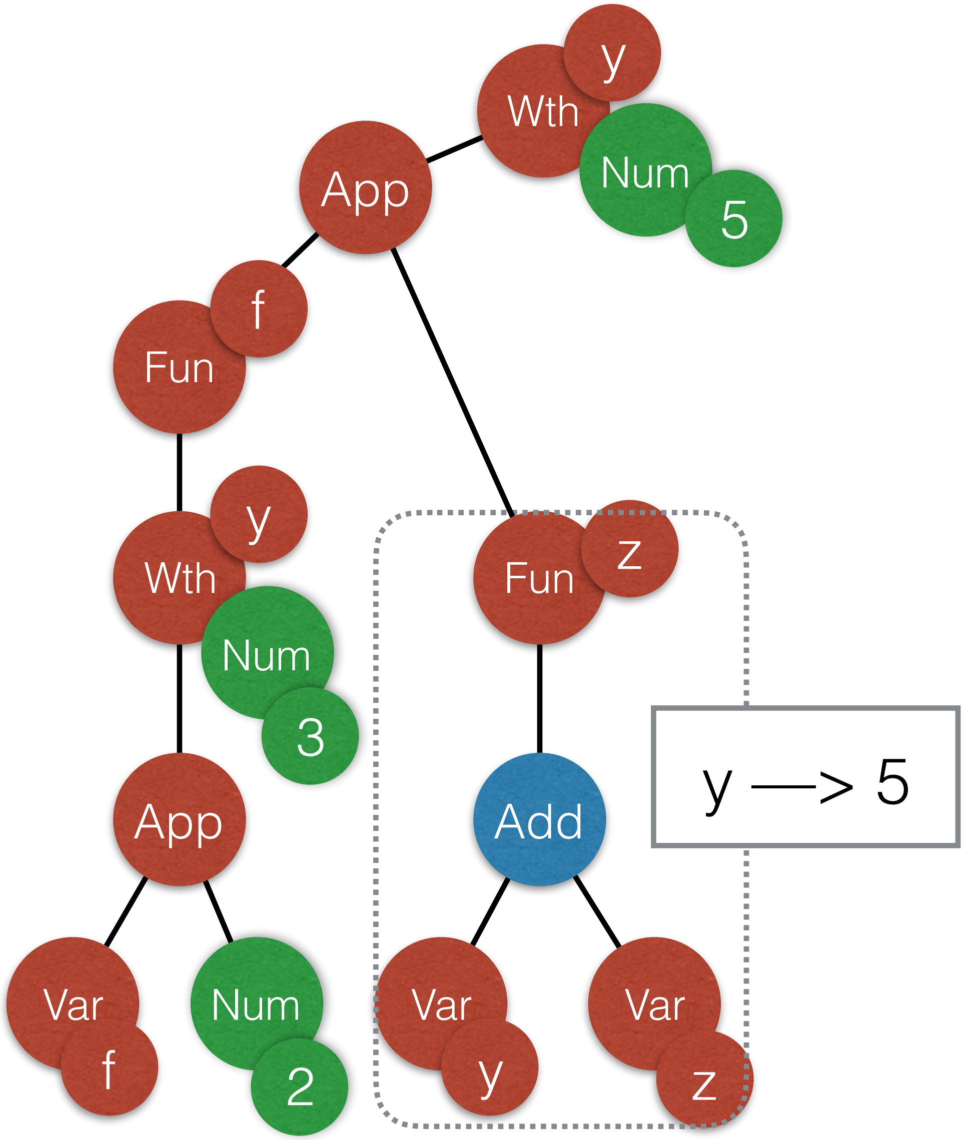


Again, the underlying problem is
that we ”threw away” the environment!

8 LCFAE

Solution: rhs = term together with environment at the time the term is copied

f —>
Thunk(
Fun(z, Add(y, z)),
(y —> Num(5)))



Wth
y
Num
5
App
Fun
f
Wth
y
Num
3
App
Var
f
Num
2
Fun
z
Add
Var
y
Var
z
y —> 5