EDAN65: Compilers, Lecture 09
More on Attribute Grammars

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This lecture

source code (text)

| Regular expressions | → | Lexical analyzer (scanner) |

tokens

| Context-free grammar | → | Syntactic analyzer (parser) |

AST (Abstract syntax tree)

| Attribute grammar | → | **Semantic analyzer** |

Visitors
Static aspects
Attribute grammars

Attributed AST

Intermediate code generator

intermediate code

Optimizer

intermediate code

Target code generator

target code

runtime system

activation records — stack

objects — garbage collection — heap

Interpreter

Virtual machine — code and data

machine

2

Attribute mechanisms

Intrinsic – given value when the AST is constructed (no equation)

Synthesized – the equation is in the same node as the attribute

Inherited – the equation is in an ancestor

Broadcasting – the equation holds for a complete subtree

Reference – the attribute can be a reference to an AST node.

Parameterized – the attribute can have parameters

NTA – the attribute is a "nonterminal" (a fresh node or subtree)

Collection * – the attribute is defined by a set of contributions, instead of by an equation.

Circular * – the attribute may depend on itself (solved using fixed-point iteration)

* Treated in this lecture

More examples of collection attributes

Example: uses of declaration

reversing references

```
...
IdDecl ::= <ID:String>;
IdUse ::= <ID:String>;
```
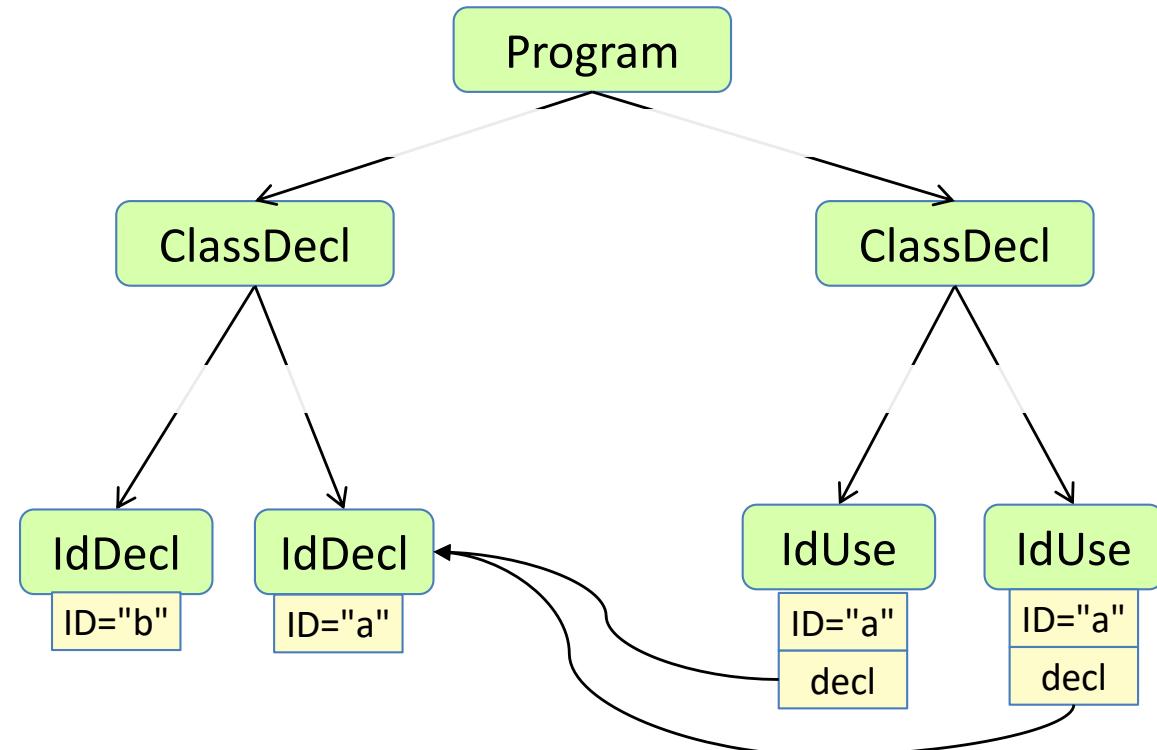
Example: uses of declaration
reversing references


```
...
IdDecl ::= <ID>;
IdUse ::= <ID>;
```

A "uses" attribute contains the collection of IdUses referring to the IdDecl

Program

ClassDecl   ClassDecl

IdDecl   IdDecl   IdUse   IdUse
ID="b"   ID="a"   ID="a"   ID="a"
uses= ∅   uses={□,□}   decl   decl
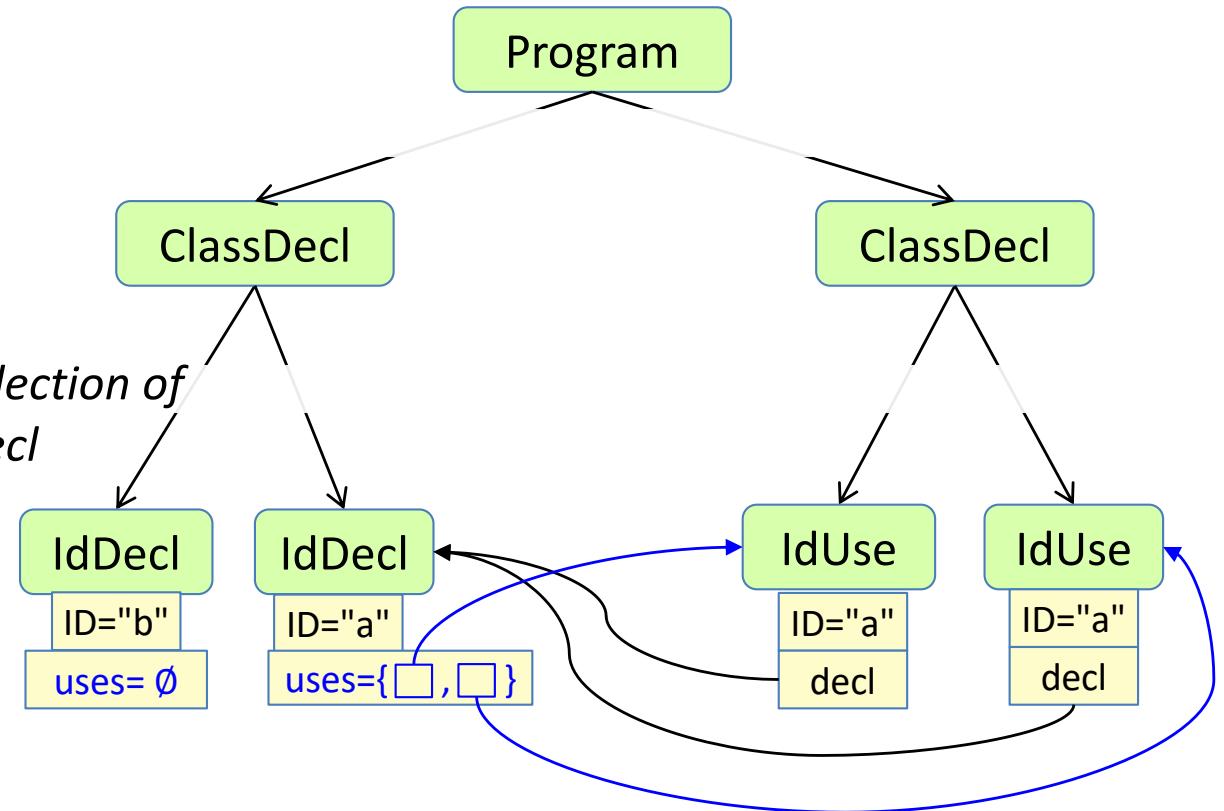
```
coll Set<IdUse> IdDecl.uses() [new HashSet<IdUse>()] with add;

IdUse contributes this
to IdDecl.uses()
for decl();
```

can skip because of defaults

Example: NPM metric

conditional count

```
ClassDecl ...
MethodDecl ...
ConstructorDecl ...
```


NPM – Number of Public Methods and constructors in a class

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Example: NPM metric
conditional count

```
ClassDecl ...
MethodDecl ...
ConstructorDecl ...
```

Program

ClassDecl — npm=1

ClassDecl — npm=2

MethodDecl

ConstructorDecl

Private
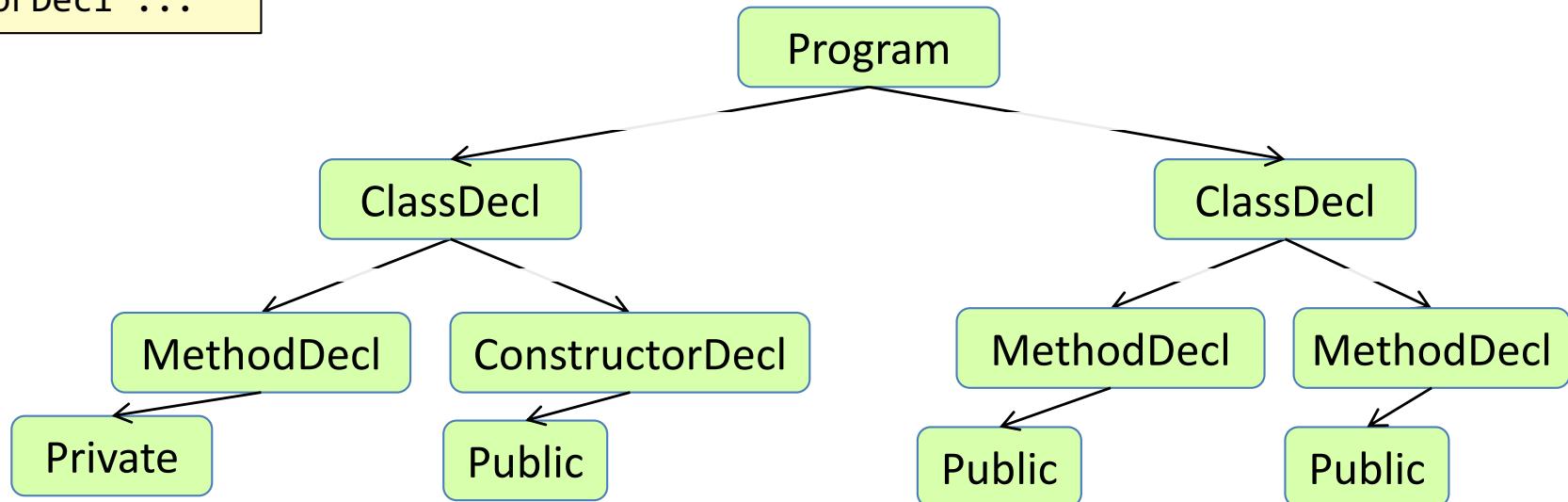
Public

MethodDecl

MethodDecl
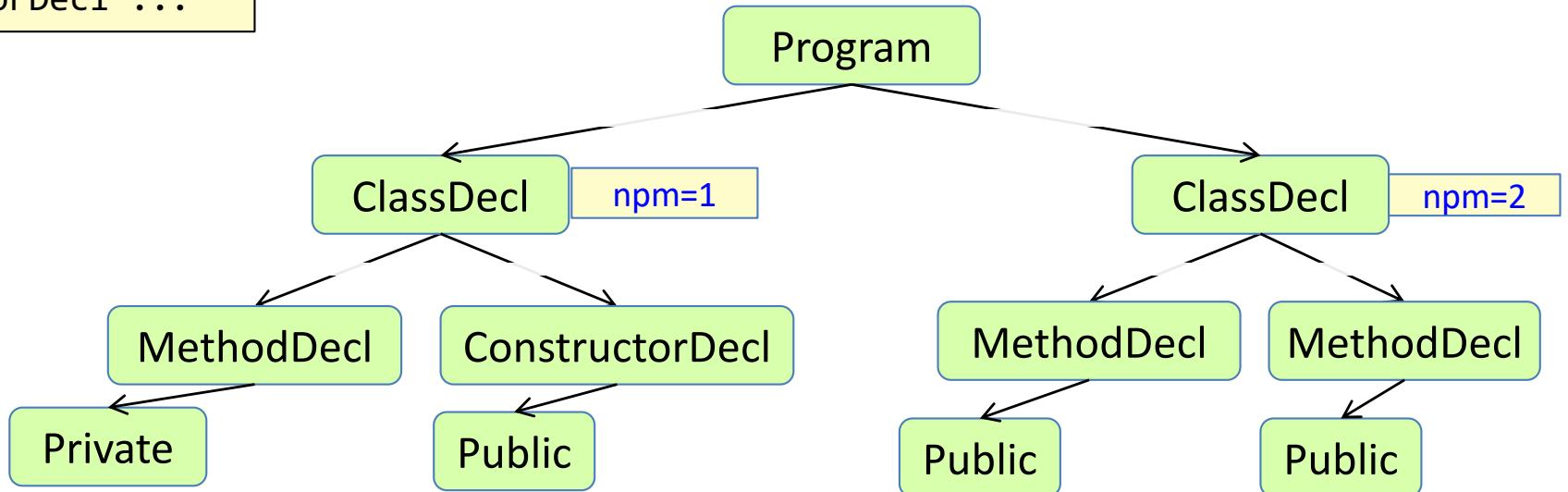
Public

Public

NPM – Number of Public Methods and constructors in a class

```
class Counter {
  int count = 0;
  void add(int i) { count += i; }
}
```

can skip because of defaults

coll Counter ClassDecl.npm () [new Counter()] with add root ClassDecl;

MethodDecl contributes 1 when isPublic() to ClassDecl.npm();
ConstructorDecl contributes 1 when isPublic() to ClassDecl.npm();

Circular attributes

# Circular attributes
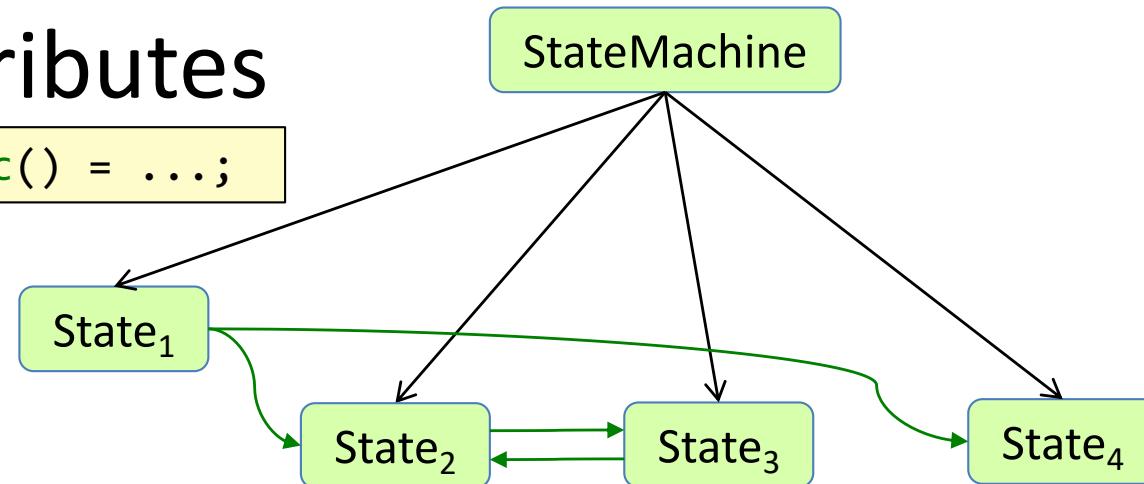
```
syn Set<State> State.succ() = ...;
```

What states are reachable
from state k?

Circular attributes

```
syn Set<State> State.succ() = ...;
```

What states are reachable
from state k?

StateMachine

State$_1$

reachable={2,3,4}

State$_2$

reachable={2,3}

State$_3$

reachable={2,3}
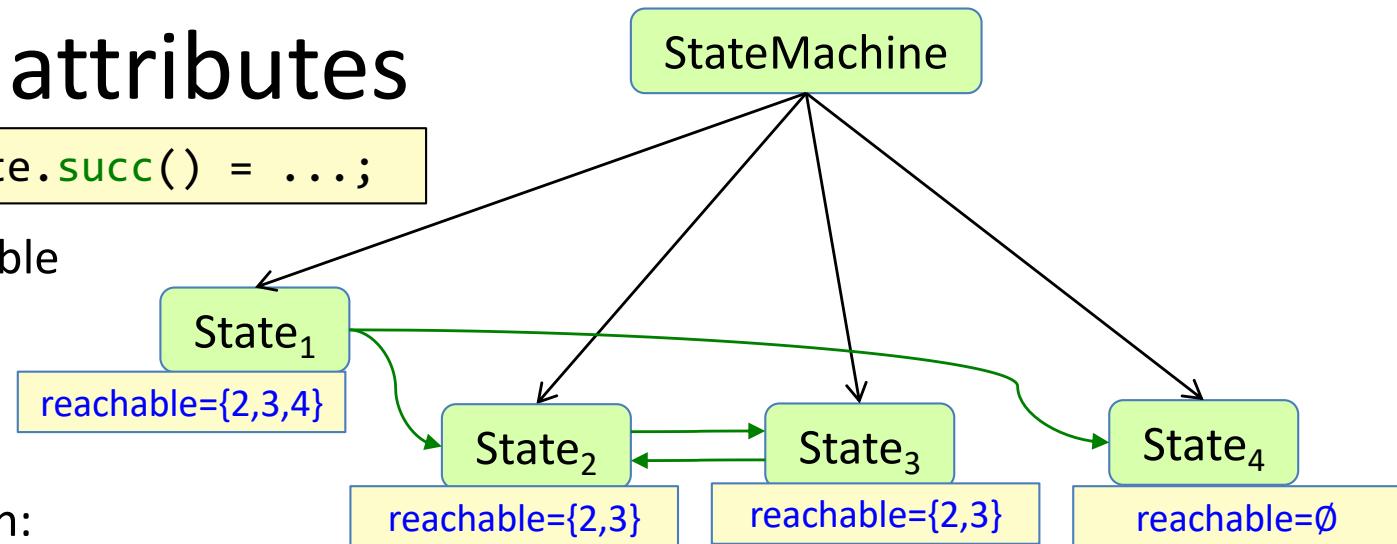
State$_4$

reachable=Ø

Mathematical definition:

$$reachable_k = succ_k \cup \bigcup_{s_j \in succ_k} reachable_j$$

Implementation using a circular attribute

```
syn Set<State> State.reachable() circular [new HashSet<State>()] {
  HashSet<State> result = new HashSet<State>();
  result.addAll(succ());
  for (State s : succ())
    result.addAll(s.reachable());
  return result;
}
```

A circular attribute may depend (transitively) on itself.

Circular attributes - termination

Does this computation terminate?

Implementation using a circular attribute

```
syn Set<State> State.reachable() circular [new HashSet<State>()] {
  HashSet<State> result = new HashSet<State>();
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  return result;
}
```

A circular attribute may depend (transitively) on itself.

Circular attributes - termination

Does this computation terminate?

Yes!
The values (sets of states) can be arranged in a lattice.
The lattice is of finite height (the number of states is finite).
The equations are monotonic: they use set union.

Warning! JastAdd does not check this property. If you use non-monotonic equations or values that can grow unbounded, you might get nontermination.

Implementation using a circular attribute

```
syn Set<State> State.reachable() circular [new HashSet<State>()] {
  HashSet<State> result = new HashSet<State>();
  result.addAll(succ());
  for (State s : succ())
    result.addAll(s.reachable());
  return result;
}
```

A circular attribute may depend (transitively) on itself.   13

Useful lattice types

Set lattice
Start with the empty set.
Use the UNION operator.
Make sure there is a finite set
of possible values in a set.
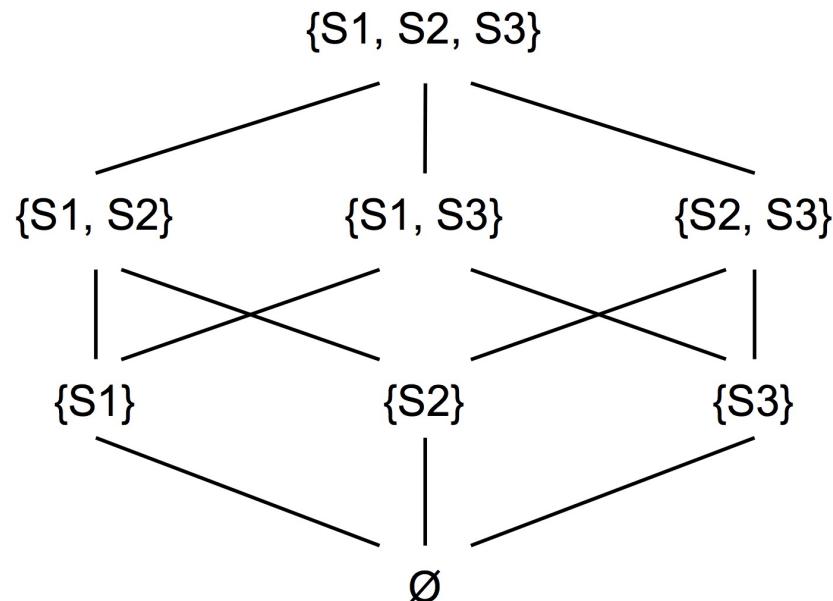
Boolean lattices
The lattice is of finite height:
only two possible elements

{S1, S2, S3}

{S1, S2}   {S1, S3}   {S2, S3}

{S1}   {S2}   {S3}

Ø

TRUE   FALSE

FALSE   TRUE

Start with FALSE   Start with TRUE
Use the OR operator   Use the AND operator

Circular attributes – beware of externally visible side effects!

It is ok to use local side effects:

```
syn Set<State> State.reachable() circular [new HashSet<State>()] {
  HashSet<State> result = new HashSet<State>();
  for (State s : succ()) {
    result.add(s);
    result.addAll(s.reachable());
  }
  return result;
}
```

Only the local object is changed. There are no externally visible side effects. This is fine!

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Circular attributes – beware of externally visible side effects!

It is ok to use local side effects:

```
syn Set<State> State.reachable() circular [new HashSet<State>()] {
  HashSet<State> result = new HashSet<State>();
  for (State s : succ()) {
    result.add(s);
    result.addAll(s.reachable());
  }
  return result;
}
```

Only the local object is changed. There are no externally visible side effects. This is fine!

Warning! If you by mistake change the value of an attribute, e.g.

```
... s.reachable().add(...) ...
```

JastAdd does not detect this error, and inconsistent attribution may result.

There are many fixed-point problems in compilers and program analysis tools

There are many fixed-point problems in compilers and program analysis tools

- Cyclic class hierarchy: find out if a class inherits from itself

- Definite assignment: find out if every variable is guaranteed to have been assigned a value before it is used.

- Call graph analysis: for example, find methods that are never called (dead code)

- Data flow analysis: for example, find variables that are never used (dead code)

- Nullable, FIRST, and FOLLOW (if your "compiler" is actually a parser generator)

- ...

Program analysis

compute program properties

to find compile-time errors
to generate code
to optimize code
to find probable bugs
to support interactive tooling
to measure quality
...

Program analysis

compute program properties

to find compile-time errors
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...

Static

on the source code
or on compiled code

the analysis holds for all possible
program runs

many extend basic analyses like
name and type analysis

Dynamic

on a running program

analysis of one particular run

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Example static analyses

name-analysis.jrag

type-analysis.jrag

Example static analyses

name-analysis.jrag

type-analysis.jrag

control-flow.jrag

What are the possible successors of a given statement?
Are there statements that are unreachable in a method?

data-flow.jrag

What statements affect the value of a variable at a given point?
Are there statements that are unnecessary in the method?

call-graph.jrag

What methods are called by a given method?
Are there methods that are never called?

metrics.jrag

Compute some useful metrics of a method,
class or program.

....jrag

Modular extension in JastAdd

Base language

Abstract grammar

*.ast

*.jrag

Basic analysis

JastAdd

*.java
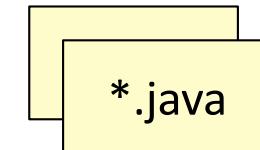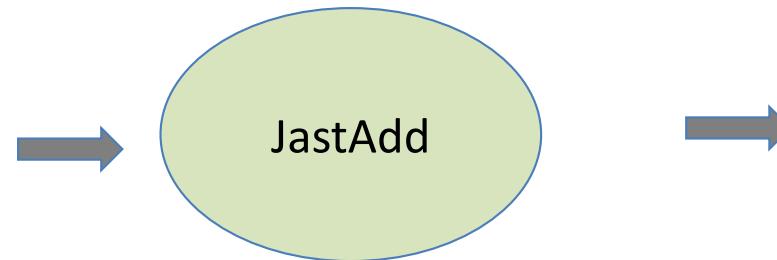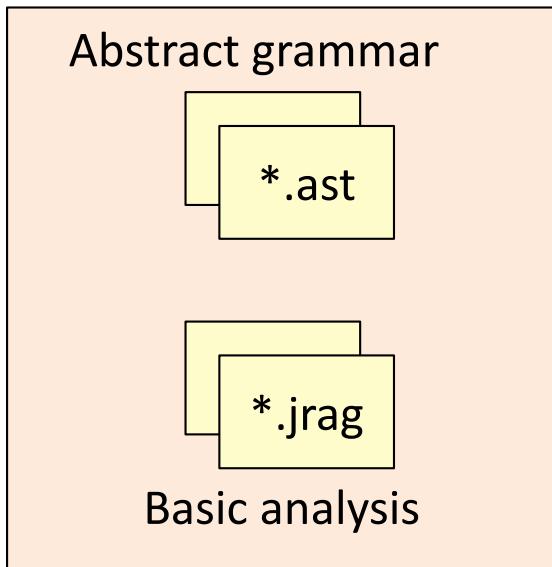
Generated
AST classes

Modular extension in JastAdd
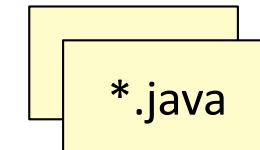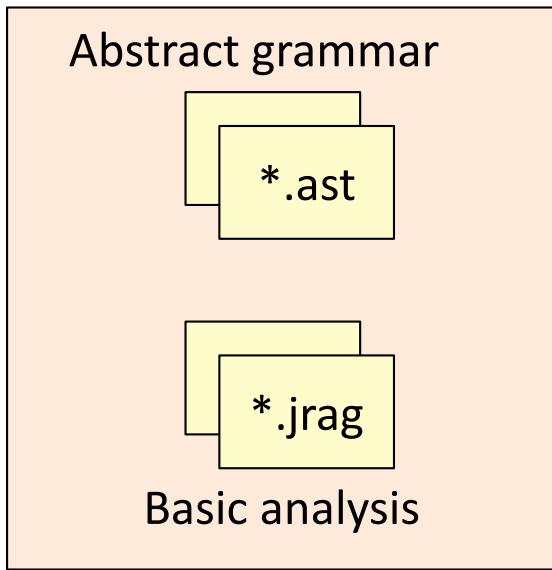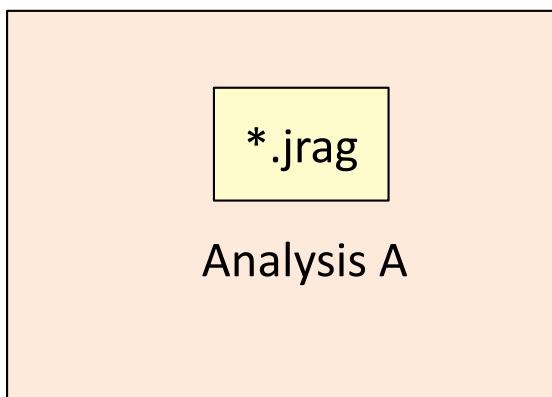
Base language

Abstract grammar

*.ast

*.jrag

Basic analysis

JastAdd

*.java

Generated
AST classes

*.jrag

Analysis A

New analysis A

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Modular extension in JastAdd
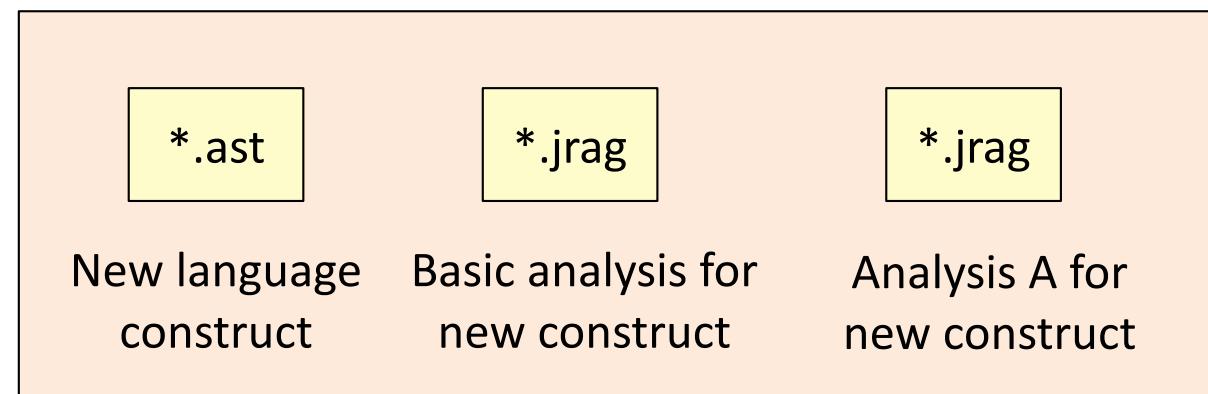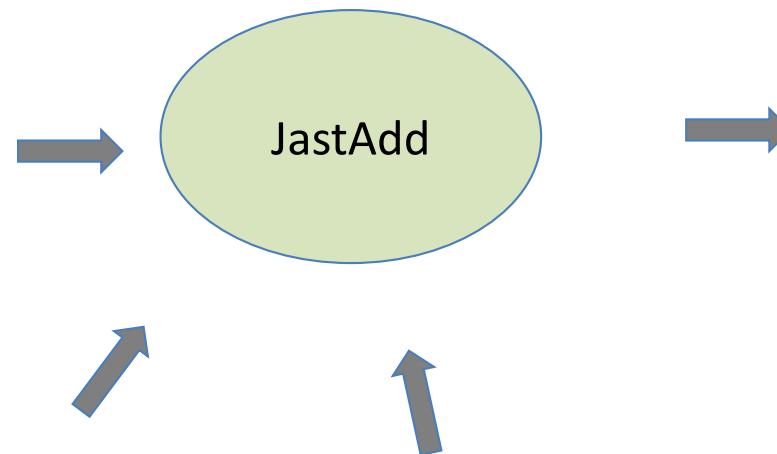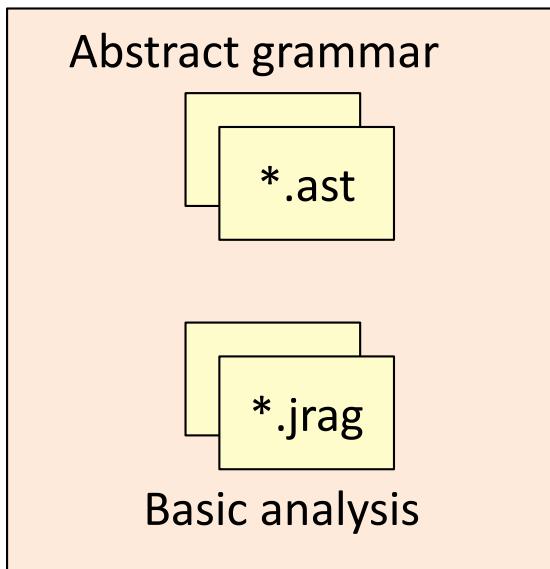
Think declaratively!

Think declaratively!

subtree   context
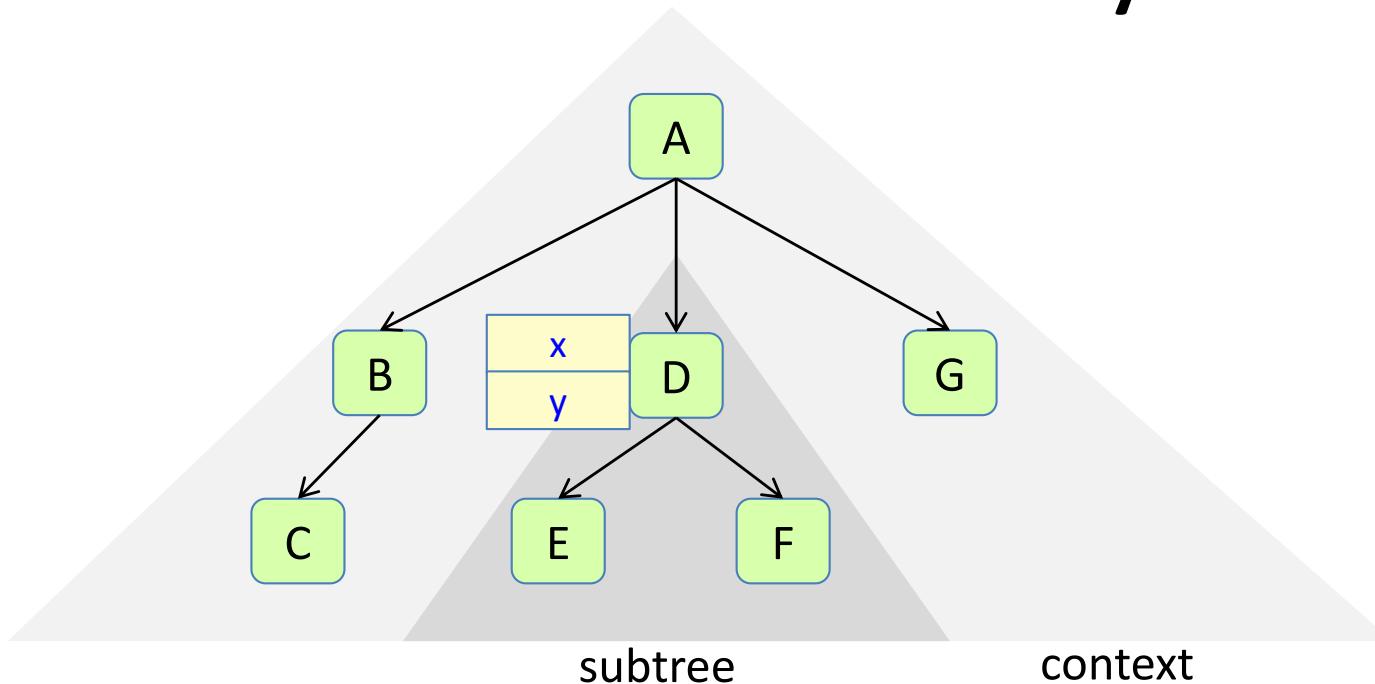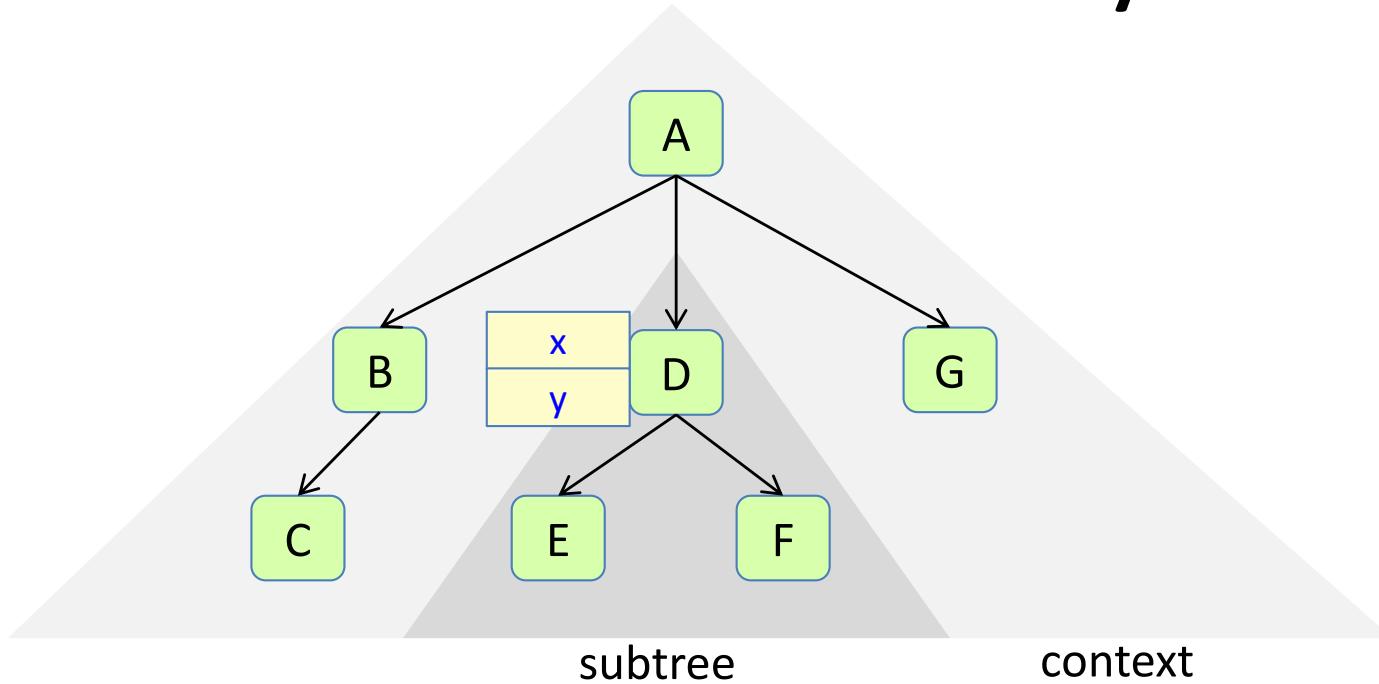
- What is the property you would like to compute? Declare as an attribute.
- What other properties would allow you to easily define its value? Declare as more attributes.
- Make an attribute *synthesized* if it depends on information in the subtree of the node.
- Make an attribute *inherited* if it *only* depends on the context (nodes outside the subtree).
- Don't think about the order of computation.

Review of attribute mechanisms

Intrinsic
Synthesized
Inherited
Broadcasting
Reference
Parameterized
NTA
Collection
Circular

Intrinsic attribute

A ::= B
B ::= <x:int>

A

B

x
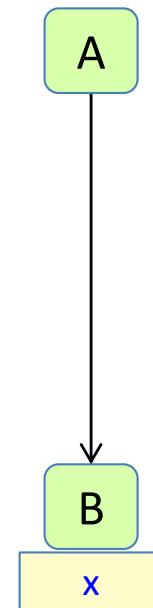
Defined in abstract grammar.
Given value when AST is constructed.

Synthesized attribute

eq ... = ... getB.x ...   A

eq B.x = ...   B

syn x
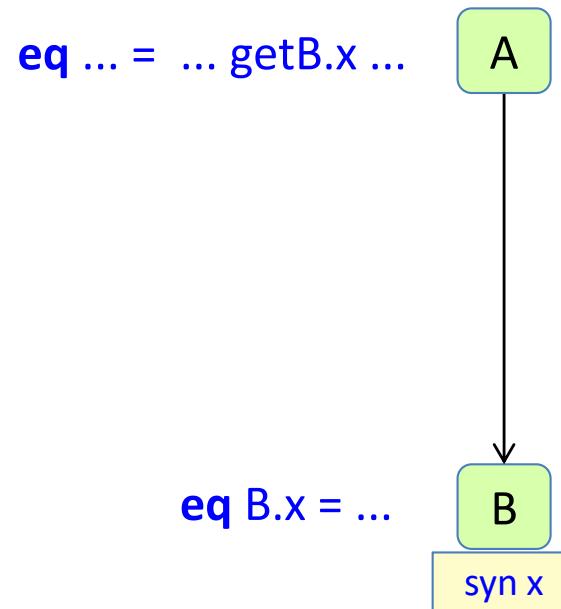
Define in the node itself. Use in parent.

Inherited attribute attribute

eq A.getB.x = ... A

eq ... = ... x ... B

inh x
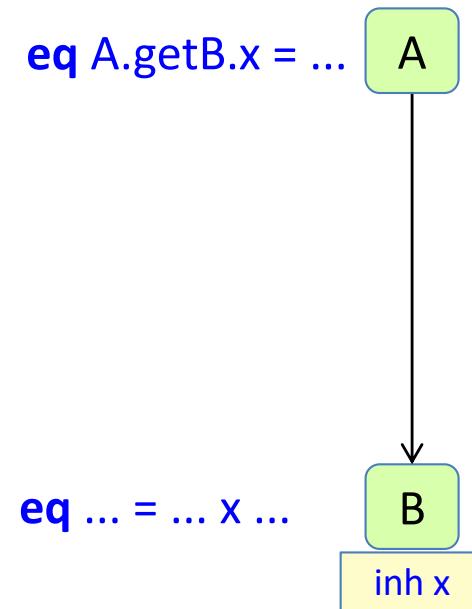
Use in the node itself. Define in a parent.

Broadcasting

eq A.getB.x = ...   A

B

eq ... = ... x ...   C

inh x
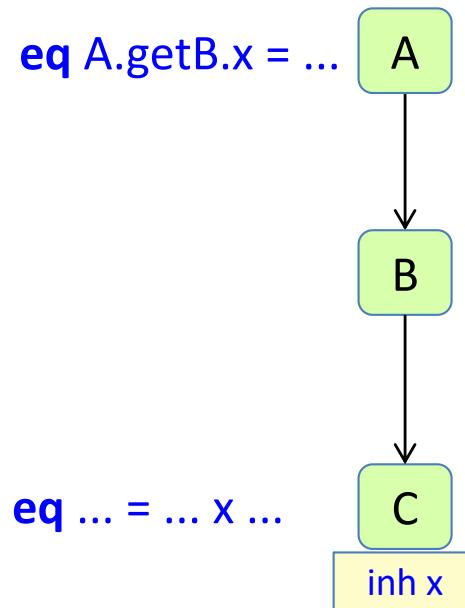
The definition does not have to be in the immediate parent.

Reference attributes

eq B.aC = …
eq … = … aC.x …
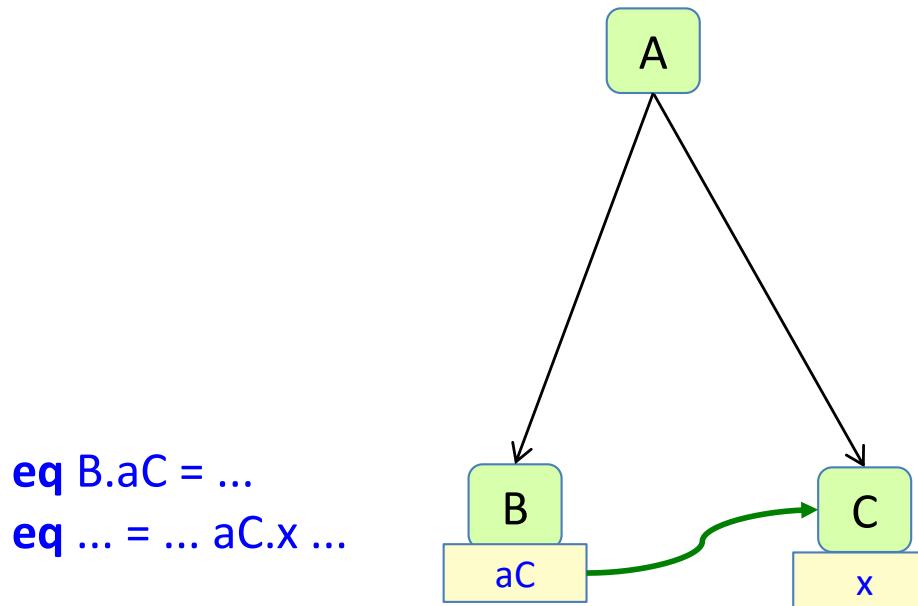
An attribute can be a reference to another node.
Attributes of that node can be accessed.

Parameterized attributes
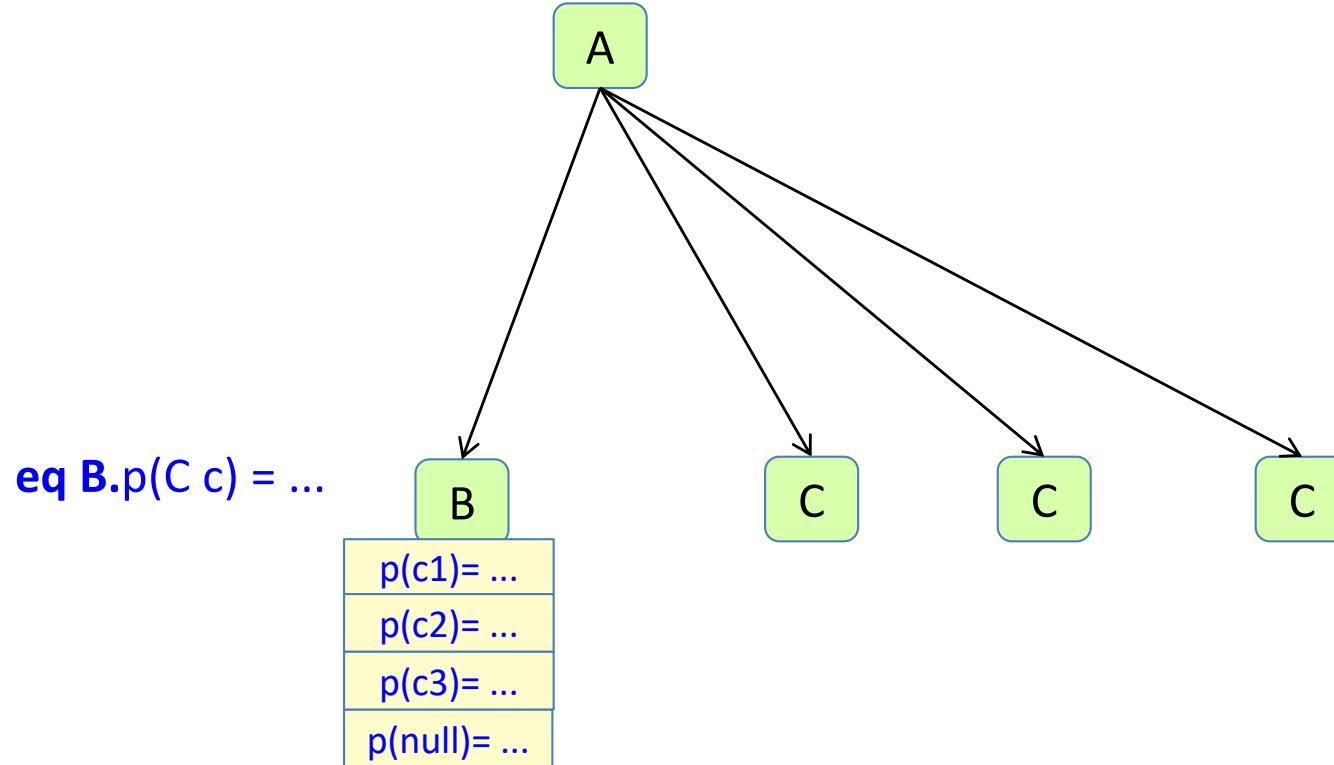
An attribute can have parameters.
There is one attribute instance for each possible parameter combination.

# Nonterminal attributes (NTAs)
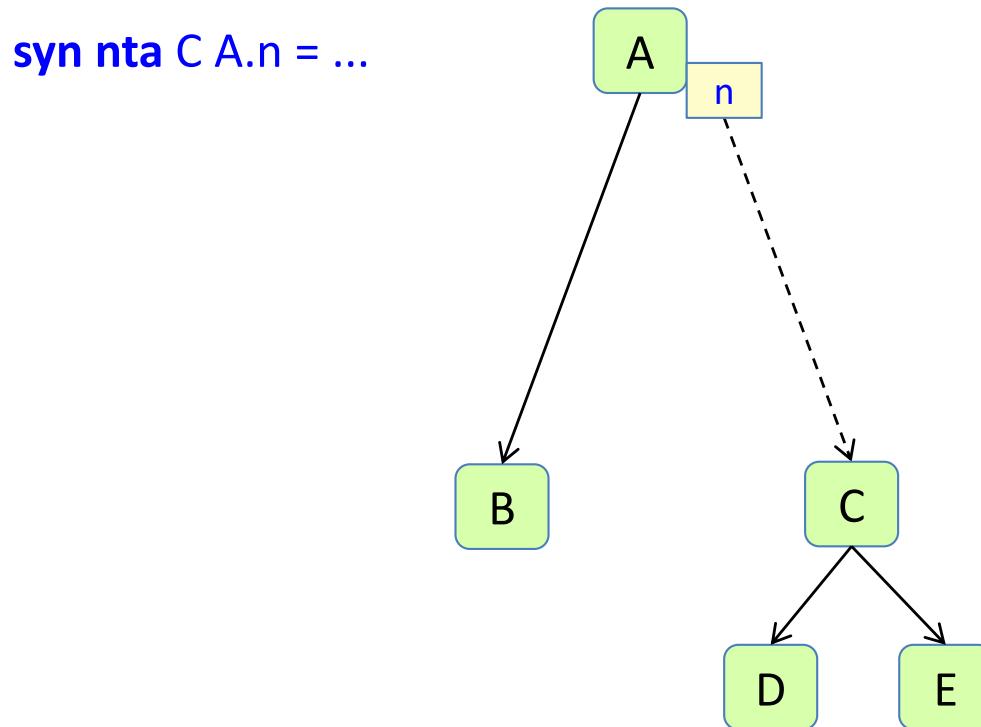
syn nta C A.n = …

An attribute can be a new fresh subtree.

Parameterized nonterminal attribute

syn nta C A.n(String s) = ...
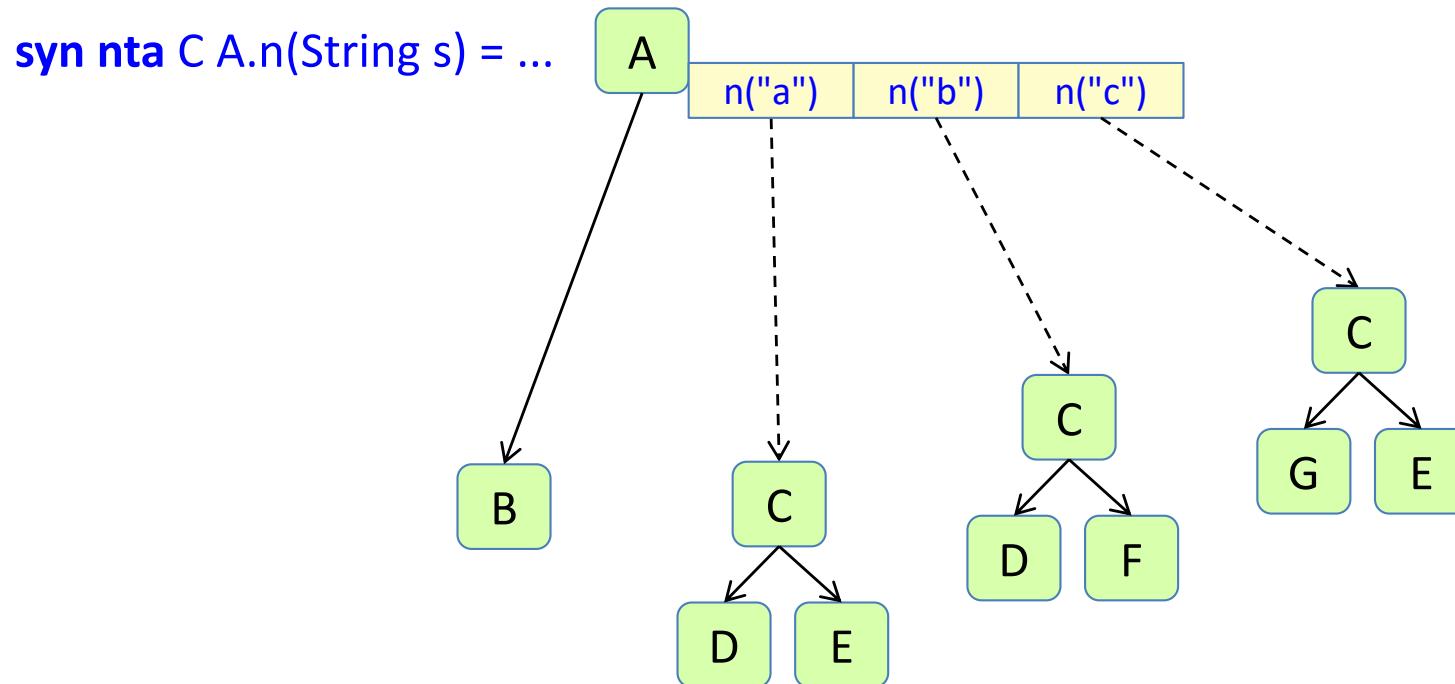
An NTA can be parameterized.

Collection attributes

coll Set A.c() [new HashSet()] with add   A   c = { ... }

B contributes x ...   B

x = ...

C

D   E   E contributes y ...

y = ...
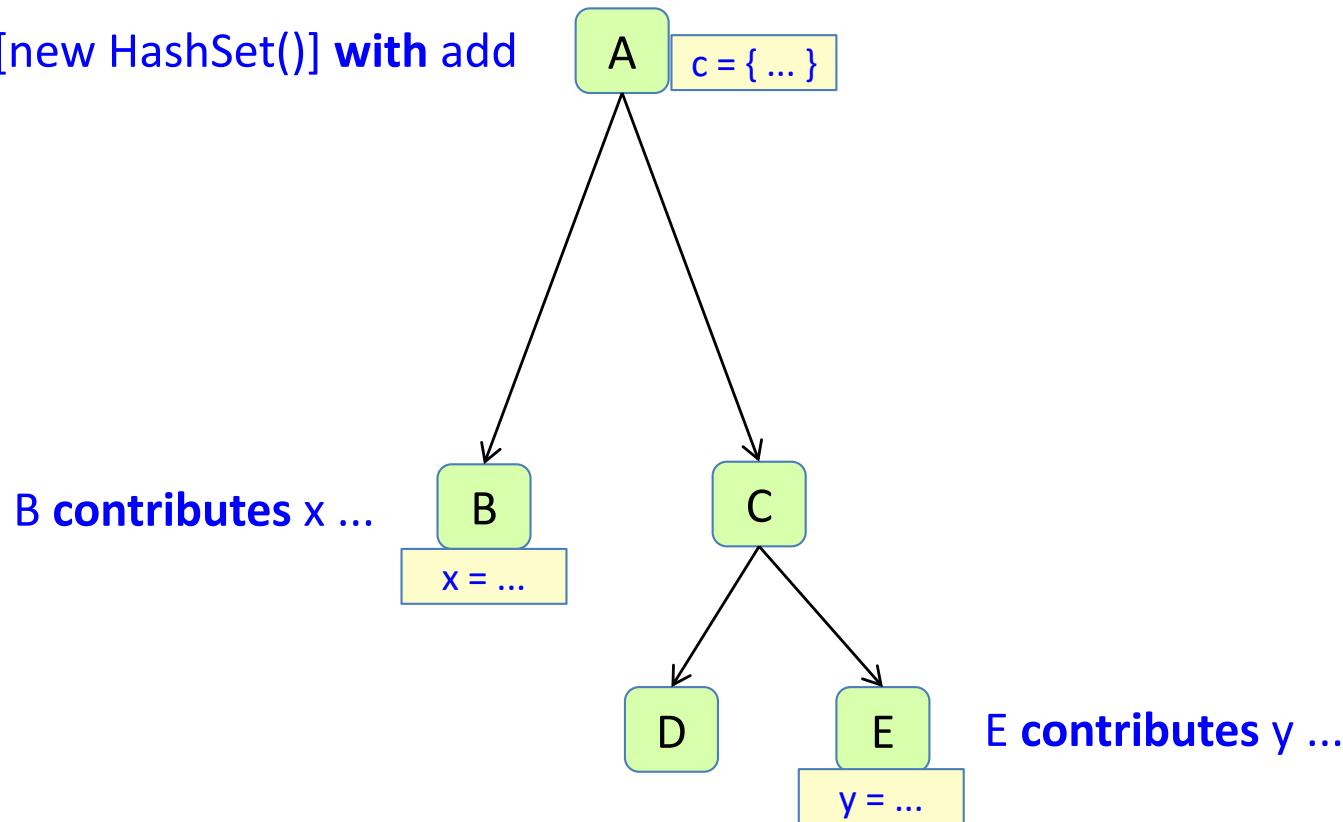
A collection is a combination of contributions.

Circular attributes
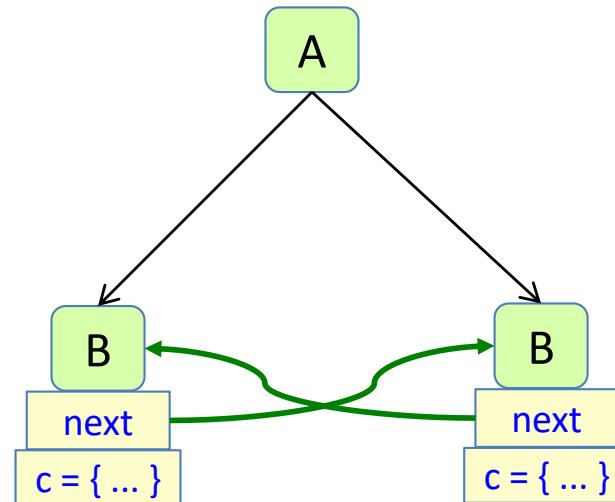
syn Set B.c() **circular** [new HashSet()] = ... next().c() ...;

A circular attribute depends (transitively) on itself.
The evaluation algorithm uses fixed point iteration.

Attribute grammar systems

| System	Developed at	Characteristics	Example applications
JastAdd	Lund University, Sweden http://jastadd.org	Generates Java	• Java compiler *ExtendJ* (Lund U) • Modelica compiler *OCT – Optimica Compiler Toolkit* (Modelon AB) • AspectJ compiler *abc*, built as extension to ExtendJ (U. of Oxford, McGill U.) • Java bytecode analysis framework *Soot*, uses ExtendJ as its frontend (McGill U., Paderborn U.)
Silver	University of Minnesota, USA http://melt.cs.umn.edu/silver/	Generative system	• Java compiler (*ableJ*, U. of Minnesota) • C compiler (*ableC*, U. of Minnesota) • Promela compiler (U. of Minnesota)
Kiama	Macquarie University, Australia https://bitbucket.org/inkytonik/kiama	Scala library	
JavaRAG	Lund University, Sweden https://bitbucket.org/javarag/javarag/	Java library	
RACR	Technical University of Dresden, Germany https://github.com/christoff-buerger/racr	Scheme library	
uuagc	University of Utrecht, The Netherlands https://hackage.haskell.org/package/uuagc	Generates Haskell	

Compiler structure

Traditional pass-oriented

Passes compute data in explicit order

P1 → P2 → P3 → P4

read and write
use visitors

Global symbol table

A

B   x / y   D   G

C   E   F
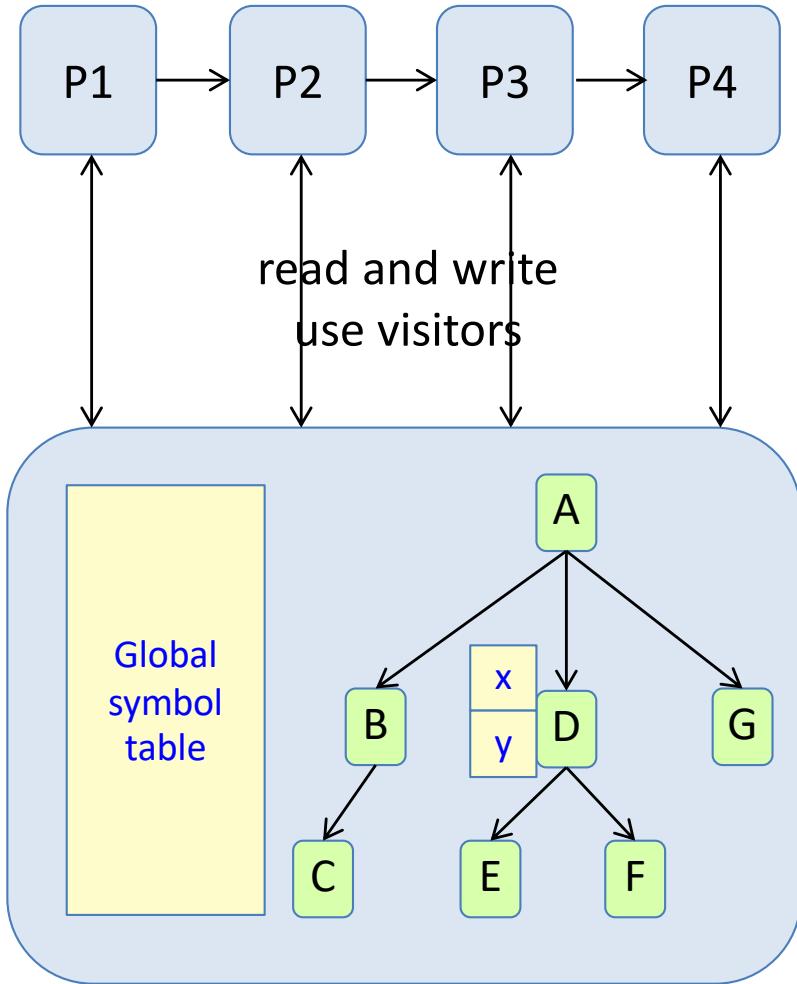
Example: OpenJDK Java compiler (javac).
http://openjdk.java.net/groups/compiler/doc/compilation-overview/

Attribute grammar

Attribute evaluation order is implicit.

Main

only read

A

x B   s / t   D   u G

C   E   F v

y z
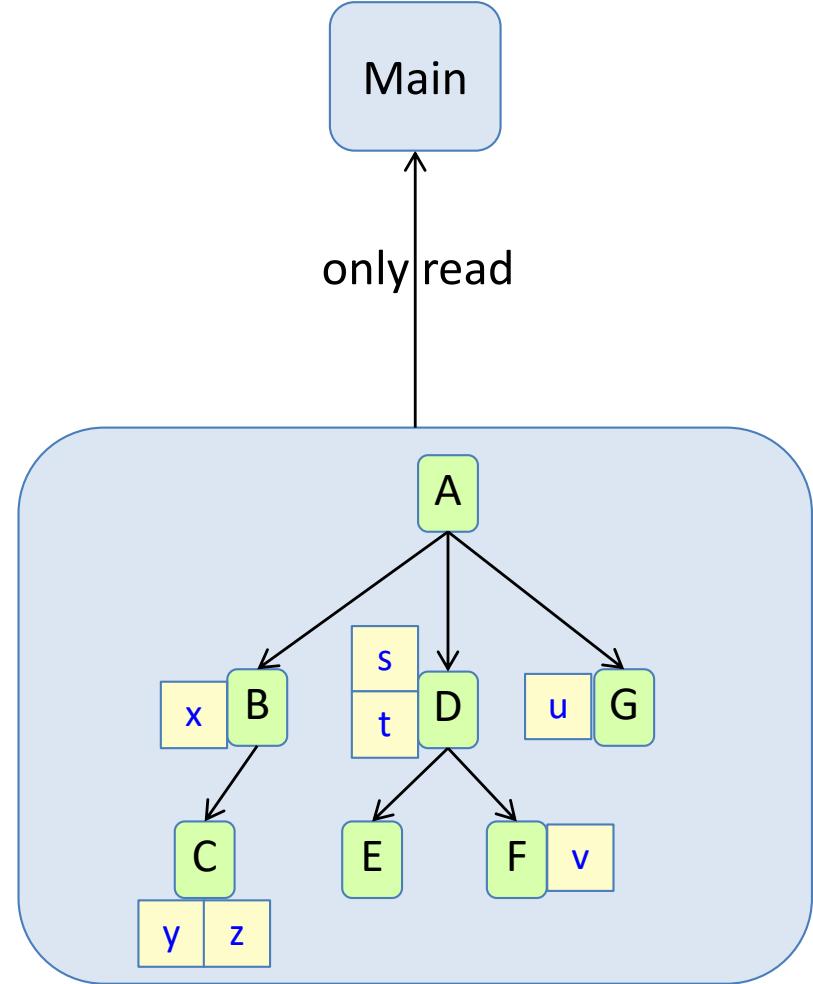
Example: ExtendJ Java compiler
http://extendj.org

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# The Interpreter design pattern

The interpreter design pattern

Commonly used for many computations in a compiler.
Here explained using Ordinary OO. Modularize using AOP or Visitors.

Intent: Given a language, define a representation for its grammar along with an interpreter that uses the representation to interpret sentences in the language.
[Gamma, Helm, Johnson, Vlissides, 1994]
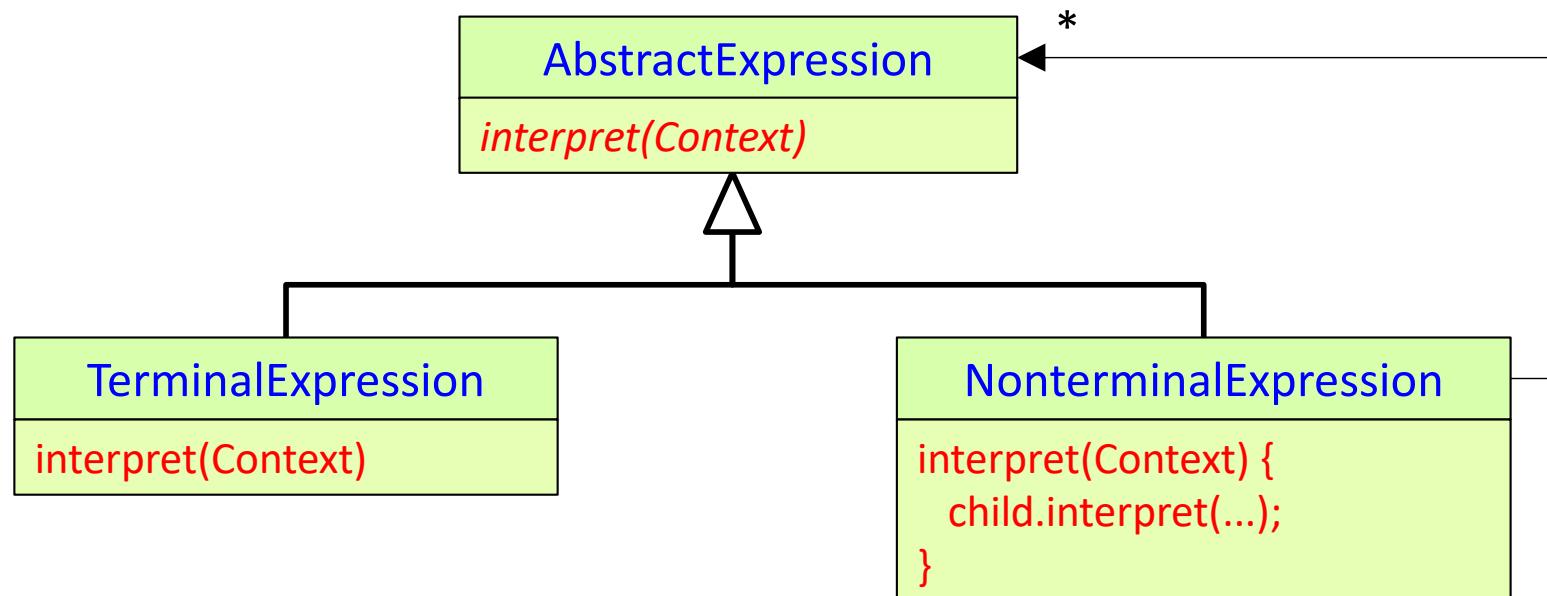
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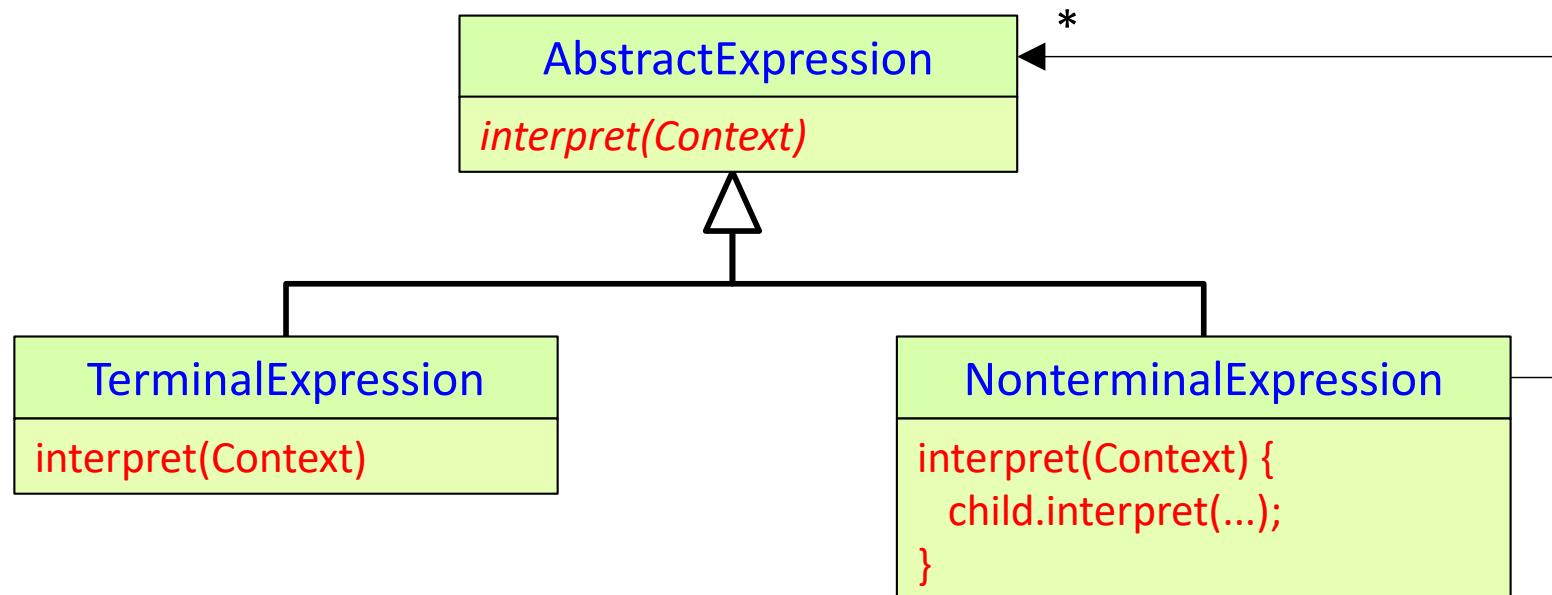
AbstractExpression, TerminalExpression, NonterminalExpression,
interpret, and Context are just ROLES in the pattern.
In our programs, we will use our own names.

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Example use of Interpreter
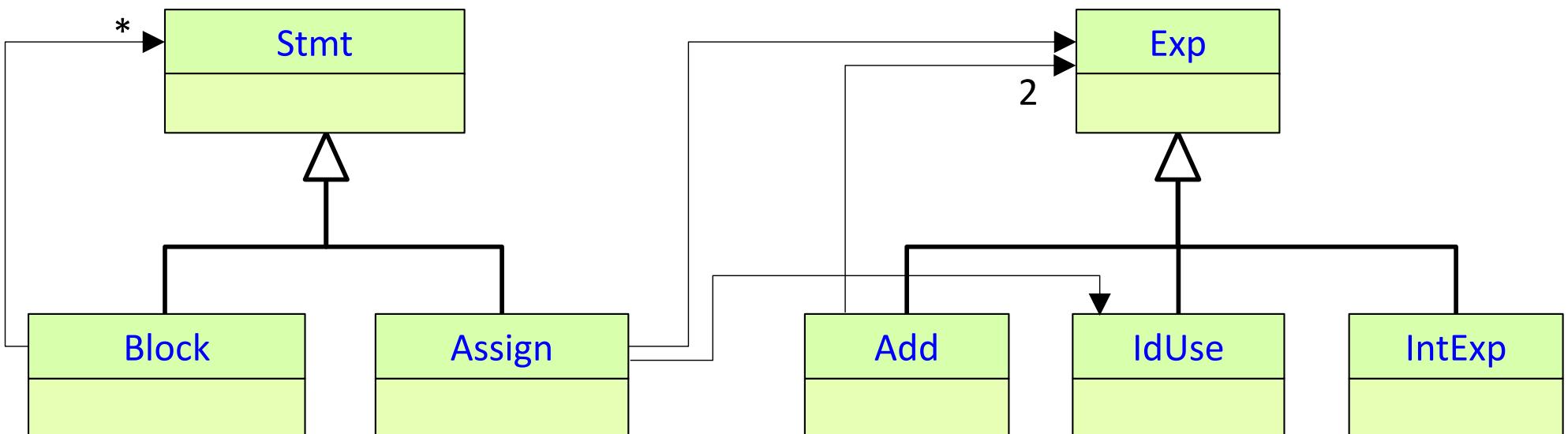
```
abstract Stmt;
Block : Stmt ::= Stmt*;
Assign : Stmt ::= IdUse Exp;
abstract Exp;
Add : Exp ::= Left:Exp Right:Exp;
IdUse : Exp ::= <ID>;
IntExp : Exp ::= <INT>;
```

Example use of Interpreter

abstract Stmt;
Block : Stmt ::= Stmt*;
Assign : Stmt ::= IdUse Exp;
abstract Exp;
Add : Exp ::= Left:Exp Right:Exp;
IdUse : Exp ::= <ID>;
IntExp : Exp ::= <INT>;

Pattern roles:
    context: *vars*
    interpret: *execute, value*
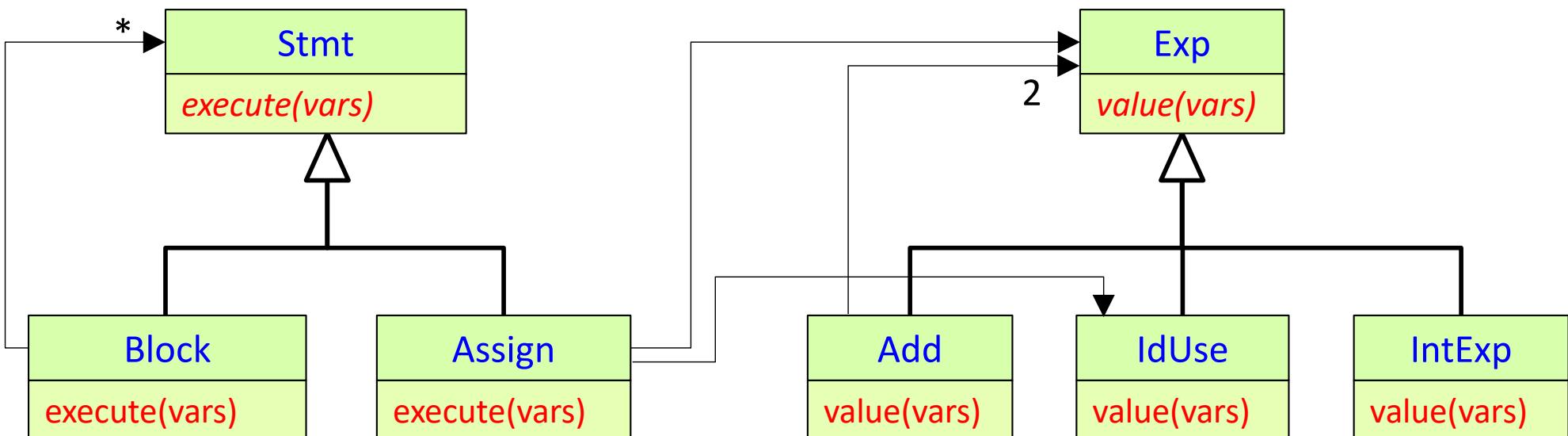
vars	a map String -> Value, keeping track of the current values of variables
execute	executes a Stmt, changing and using the vars map
value	executes an Exp and returns its value, making use of the vars map

Example implementation using JastAdd aspects

```
abstract Stmt;
Block : Stmt ::= Stmt*;
Assign : Stmt ::= IdUse Exp;
abstract Exp;
Add : Exp ::= Left:Exp Right:Exp;
IdUse : Exp ::= <ID>;
IntExp : Exp ::= <INT>;
```

```
aspect Interpreter {
  abstract void Stmt.execute(Map<String, Integer> vars);

  void Block.execute(Map<String, Integer> vars) {
    for (Stmt s : getStmts()) { s.execute(vars); }
  }
  void Assign.execute(Map<String, Integer> vars) {
    int value = getExp().value(vars);
    vars.put(getIdExp().getID(), value);
  }

  abstract int Exp.value(Map<String, Integer> vars);

  int Add.value(Map<String, Integer> vars) {
    return getLeft().value(vars) + getRight().value(vars);
  }
  int IdUse.value(Map<String, Integer> vars) {
    return vars.get(getID());
  }
  int IntExp.value(Map<String, Integer> vars) {
    return String.parseInt(getINT());
  }
}
```

Summary questions:

- Give examples of properties that can be computed using collection attributes.
- What is a circular attribute?
- How is a circular attribute evaluated?
- How can you know if the evaluation of a circular attribute will terminate?
- Give examples of properties that can be computed using circular attributes.
- How does the Interpreter design pattern work?