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11. Program Transformation

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Roadmap

- Program Transformation
- Refactoring
- Aspect-Oriented Programming

Links

- **Program Transformation:**
  - http://swerl.tudelft.nl/bin/view/Pt
  - http://www.program-transformation.org/
- **Stratego:**
  - http://strategoxt.org/
- **TXL:**
  - http://www.txl.ca/
- **Refactoring:**
  - http://www.ibm.com/developerworks/library/os-ecref/
  - http://recoder.sourceforge.net/wiki/
  - http://www.refactory.com/RefactoringBrowser/
- **AOP:**
  - http://www.eclipse.org/aspectj/

Roadmap

- **Program Transformation**
  - Introduction
  - Stratego/XT
  - TXL
- Refactoring
- Aspect-Oriented Programming

Thanks to Eelco Visser and Martin Bravenboer for their kind permission to reuse and adapt selected material from their Program Transformation course.
http://swerl.tudelft.nl/bin/view/Pt

What is “program transformation”?

- *Program Transformation* is the process of transforming one program to another.

- Near synonyms:
  - Metaprogramming
  - Generative programming
  - Program synthesis
  - Program refinement
  - Program calculation

Applications of program transformation

- **Translation**
  - *Migration*
  - *Synthesis*
    - Refinement
    - Compilation
  - *Reverse Engineering*
    - Decompilation
    - Architecture Extraction
    - Visualization
  - *Program Analysis*
    - Control flow
    - Data flow

Translation — compilation

Tiger

```
function fact(n : int) : int =
  if n < 1 then 1
           else (n * fact(n - 1))
```

⇒

MIPS

```
fact:subu   $sp, $sp, 20
     sw     $fp, 8($sp)
     addiu  $fp, $sp, 20
     sw     $s2, -8($fp)
     sw     $ra, -4($fp)
     sw     $a0, 0($fp)
     move   $s2, $a1
     li     $t0, 1
     bge    $s2, $t0, c_0
     li     $v0, 1
     b      d_0
c_0: lw     $a0, ($fp)
     li     $t0, 1
     subu   $a1, $s2, $t0
     jal    fact_a_0
     mul    $v0, $s2, $v0
d_0: lw     $s2, -8($fp)
     lw     $ra, -4($fp)
     lw     $fp, 8($sp)
     addiu  $sp, $sp, 20
     jr     $ra
```

http://www.cs.uu.nl/docs/vakken/pt/slides/PT05-ProgramTransformation.pdf

Translation — migration from procedural to OO

```
type tree = {key: int, children: treelist}
type treelist = {hd: tree, tl: treelist}
function treeSize(t : tree) : int =
  if t = nil then 0 else 1 + listSize(t.children)
function listSize(ts : treelist) =
  if ts = nil then 0 else listSize(t.tl)
```

Tiger

⇓

```
class Tree {
  Int key;
  TreeList children;
  public Int size() {
    return 1 + children.size
  }
}
class TreeList { ... }
```

Java

http://www.cs.uu.nl/docs/vakken/pt/slides/PT05-ProgramTransformation.pdf

Rephrasing — desugaring regular expressions

```
Exp := Id
     | Id "(" {Exp ","}* ")"
     | Exp "+" Exp
     | ...
```

EBNF

⇒

```
Exp  := Id
     |  Id "(" Exps ")"
     |  Exp "+" Exp
     |  ...

Exps :=
     | Expp

Expp := Exp
     |  Expp "," Exp
```

BNF

http://www.cs.uu.nl/docs/vakken/pt/slides/PT05-ProgramTransformation.pdf

Rephrasing — partial evaluation

```
function power(x : int, n : int) : int =
  if n = 0 then 1
  else if even(n) then square(power(x, n/2))
  else (x * power(x, n - 1))
```

Tiger

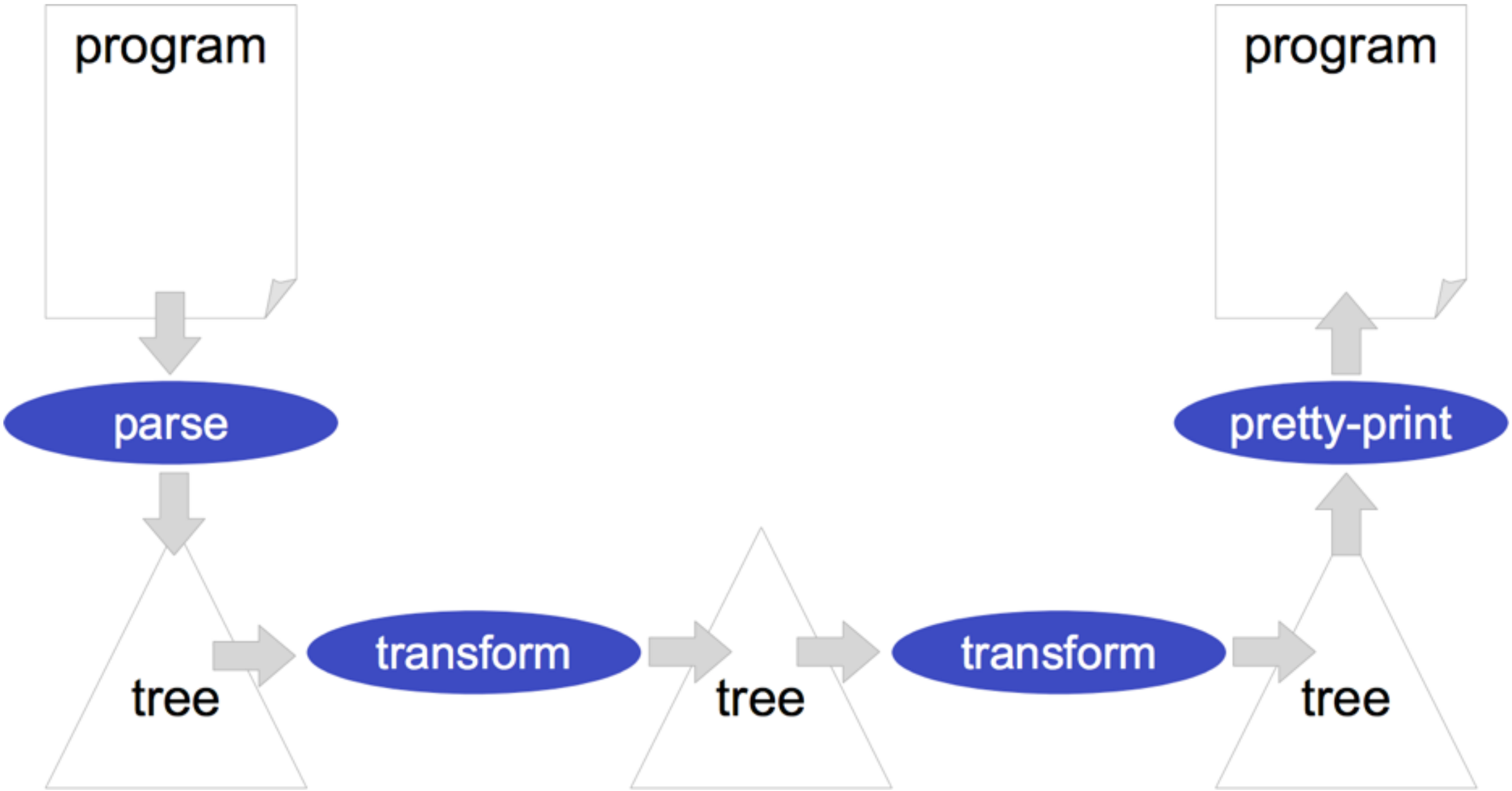
$\Downarrow$ `n = 5`

Tiger

```
function power5(x : int) : int =
  x * square(square(x))
```

http://www.cs.uu.nl/docs/vakken/pt/slides/PT05-ProgramTransformation.pdf

Transformation pipeline



http://losser.st-lab.cs.uu.nl/~mbravenb/PT05-Infrastructure.pdf

Roadmap

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  - TXL
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Stratego/XT

> ***Stratego***

—A language for specifying program transformations

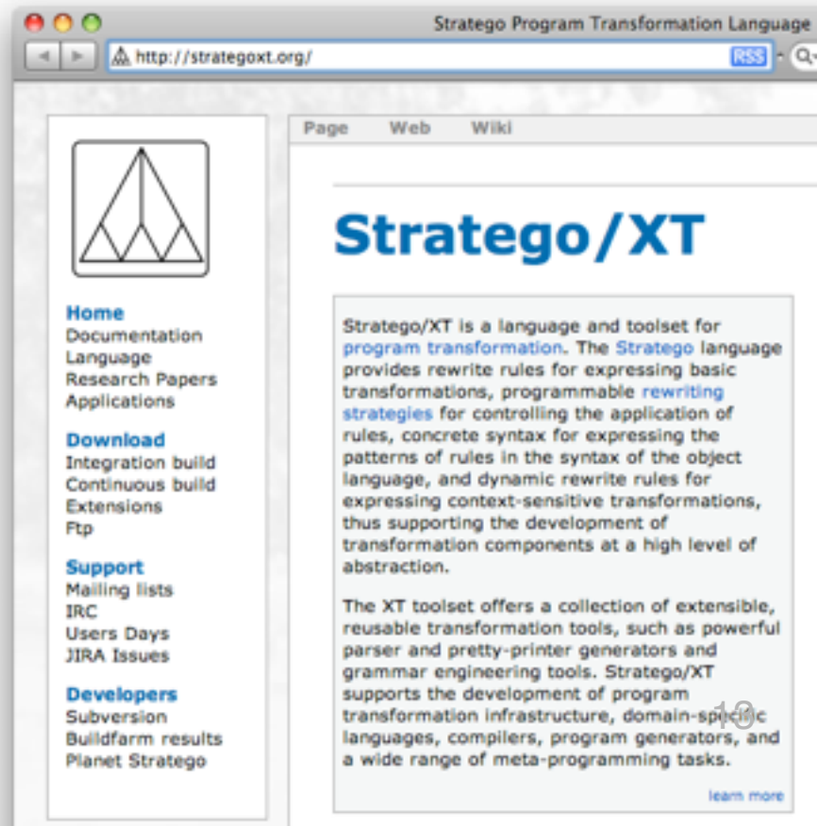
- *term rewriting rules*
- *programmable rewriting strategies*
- *pattern-matching against syntax of object language*
- *context-sensitive transformations*

> ***XT***

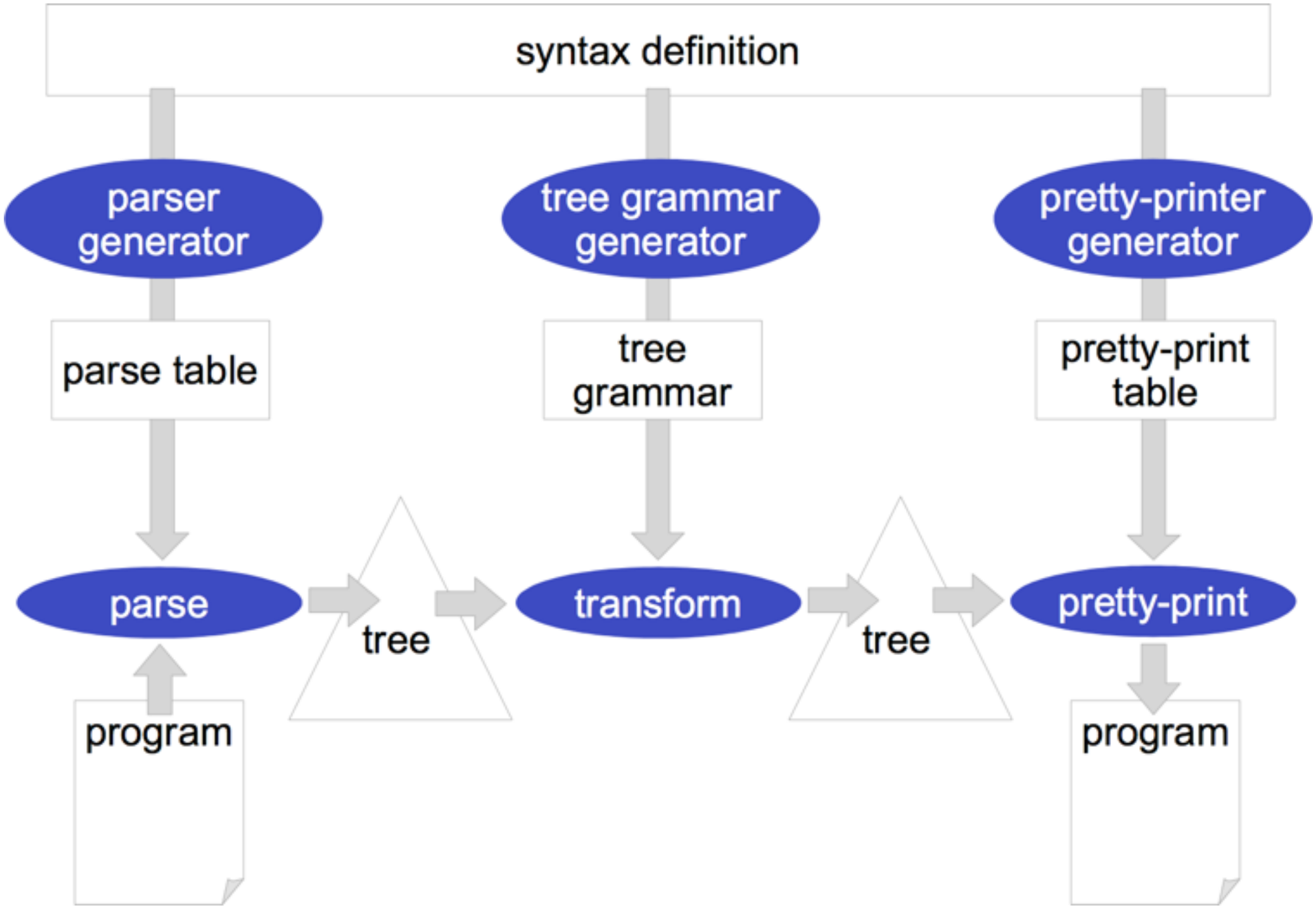
—A collection of transformation tools

- *parser and pretty printer generators*
- *grammar engineering tools*

http://strategoxt.org/



Stratego/XT



http://losser.st-lab.cs.uu.nl/~mbravenb/PT05-Infrastructure.pdf

Parsing

Rules translate *terms* to *terms*

Stratego parses any context-free language using Scannerless Generalized LR Parsing

File: Exp.sdf

```
module Exp
exports
  context-free start-symbols Exp
  sorts Id IntConst Exp

  lexical syntax
    [\ \t\n]  -> LAYOUT
    [a-zA-Z]+ -> Id
    [0-9]+    -> IntConst

  context-free syntax
    Id         -> Exp {cons("Var")}
    IntConst   -> Exp {cons("Int")}

    "(" Exp ")" -> Exp   {bracket}

    Exp "*"  Exp -> Exp  {left, cons("Mul")}
    Exp "/"  Exp -> Exp  {left, cons("Div")}
    Exp "%"  Exp -> Exp  {left, cons("Mod")}

    Exp "+"  Exp -> Exp  {left, cons("Plus")}
    Exp "-"  Exp -> Exp  {left, cons("Minus")}

  context-free priorities
    {left:
      Exp "*"  Exp -> Exp
      Exp "/"  Exp -> Exp
      Exp "%"  Exp -> Exp
    }
  > {left:
      Exp "+"  Exp -> Exp
      Exp "-"  Exp -> Exp
    }
```

Testing

File: Exp.testsuite

```
testsuite Exp
topsort Exp

test eg1 parse
 "1 + 2 * (3 + 4) * 3 - 1"
->
Minus(
  Plus(
    Int("1")
  , Mul(
      Mul(Int("2"), Plus(Int("3"), Int("4")))
    , Int("3")
    )
  )
, Int("1")
)
```

Running tests

```
pack-sdf -i Exp.sdf -o Exp.def
  including ./Exp.sdf

sdf2table -i Exp.def -o Exp.tbl -m Exp
SdfChecker:error: Main module not defined
--- Main

parse-unit -i Exp.testsuite -p Exp.tbl
-------------------------------------------------------------
executing testsuite Exp with 1 tests
-------------------------------------------------------------
* OK   : test 1 (eg1 parse)
-------------------------------------------------------------
results testsuite Exp
successes : 1
failures  : 0
-------------------------------------------------------------
```

Pack the definitions

Generate the parse table

Run the tests

Interpretation example

File: ExpEval.str

```
module ExpEval

imports libstratego-lib
imports Exp

rules
 convert : Int(x) -> <string-to-int>(x)
 eval : Plus(m,n) -> <add>(m,n)
 eval : Minus(m,n) -> <subt>(m,n)
 eval : Mul(m,n) -> <mul>(m,n)
 eval : Div(m,n) -> <div>(m,n)
 eval : Mod(m,n) -> <mod>(m,n)

strategies
 main = io-wrap(innermost(convert <+ eval))
```

File: ultimate-question.txt

```
1 + 2 * (3 + 4) * 3 - 1
```

Stratego separates the specification of *rules* (transformations) from *strategies* (traversals). In principle, both are reusable.

Strategies

A *strategy* determines how a set of rewrite rules will be used to traverse and transform a term.

- innermost
- top down
- bottom up
- repeat
- …

Running the transformation

```
sdf2rtg -i Exp.def -o Exp.rtg -m Exp
SdfChecker:error: Main module not defined
--- Main
```

Generate regular tree grammar

```
rtg2sig -i Exp.rtg -o Exp.str
```

Generate signature

```
strc -i ExpEval.str -la stratego-lib
[ strc | info ] Compiling 'ExpEval.str'
[ strc | info ] Front-end succeeded          : [user/system] = [0.56s/0.05s]
[ strc | info ] Optimization succeeded -O 2 : [user/system] = [0.00s/0.00s]
[ strc | info ] Back-end succeeded           : [user/system] = [0.16s/0.01s]
 gcc -I /usr/local/strategoxt/include -I /usr/local/strategoxt/include -I /usr/local/strategoxt/
include -Wall -Wno-unused-label -Wno-unused-variable -Wno-unused-function -Wno-unused-parameter -
DSIZEOF_VOID_P=4 -DSIZEOF_LONG=4 -DSIZEOF_INT=4 -c ExpEval.c  -fno-common -DPIC -o .libs/ExpEval.o
 gcc -I /usr/local/strategoxt/include -I /usr/local/strategoxt/include -I /usr/local/strategoxt/
include -Wall -Wno-unused-label -Wno-unused-variable -Wno-unused-function -Wno-unused-parameter -
DSIZEOF_VOID_P=4 -DSIZEOF_LONG=4 -DSIZEOF_INT=4 -c ExpEval.c -o ExpEval.o >/dev/null 2>&1
gcc .libs/ExpEval.o -o ExpEval -bind_at_load  -L/usr/local/strategoxt/lib /usr/local/strategoxt/lib/
libstratego-lib.dylib /usr/local/strategoxt/lib/libstratego-lib-native.dylib /usr/local/strategoxt/
lib/libstratego-runtime.dylib -lm /usr/local/strategoxt/lib/libATerm.dylib
[ strc | info ] C compilation succeeded     : [user/system] = [0.31s/0.36s]
[ strc | info ] Compilation succeeded       : [user/system] = [1.03s/0.42s]
```

Compile to C

```
sglri -p Exp.tbl -i ultimate-question.txt | ./ExpEval
42
```

Parse and transform

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  - Stratego/XT
  - **TXL**
- Refactoring
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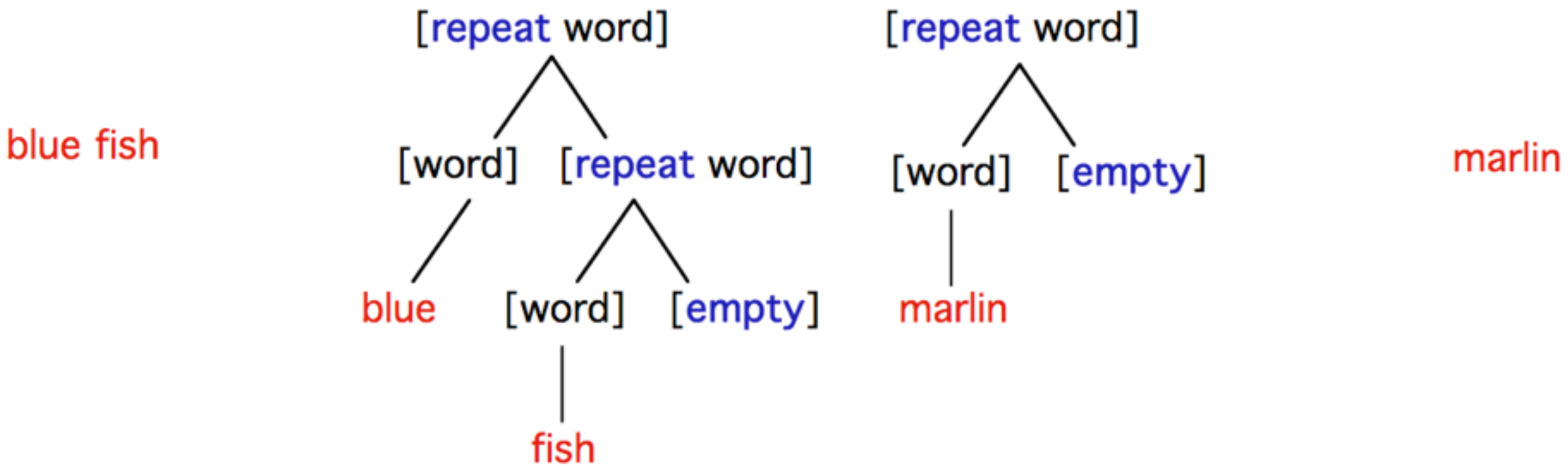
The TXL paradigm: *parse, transform, unparse*



http://www.txl.ca/docs/TXLintro.pdf

TXL programs

Base grammar	*defines tokens and non-terminals*
Grammar overrides	*extend and modify types from grammar*
Transformation rules	*rooted set of rules and functions*

Expression example

File: Question.Txl

```
% Part I.  Syntax specification
define program
        [expression]
end define

define expression
        [expression] + [term]
    |   [expression] - [term]
    |   [term]
end define

define term
        [term] * [primary]
    |   [term] / [primary]
    |   [primary]
end define

define primary
        [number]
    |   ( [expression] )
end define
```

```
% Part 2.  Transformation rules
rule main
    replace [expression]
        E [expression]
    construct NewE [expression]
        E [resolveAddition]
          [resolveSubtraction]
          [resolveMultiplication]
          [resolveDivision]
          [resolveBracketedExpressions]
    where not
        NewE [= E]
    by
        NewE
end rule

rule resolveAddition
    replace [expression]
        N1 [number] + N2 [number]
    by
        N1 [+ N2]
end rule
...

rule resolveBracketedExpressions
    replace [primary]
        ( N [number] )
    by
        N
end rule
```

Running the example

File: Ultimate.Question

```
1 + 2 * (3 + 4) * 3 - 1
```

```
txl Ultimate.Question
TXL v10.5d (1.7.08) (c)1988-2008 Queen's University at Kingston
Compiling Question.Txl ...
Parsing Ultimate.Question ...
Transforming ...
42
```

Example: TIL — a tiny imperative language

```
// Find all factors of a given input number
var n;
write "Input n please";
read n;
write "The factors of n are";
var f;
f := 2;
while n != 1 do
    while (n / f) * f = n do
        write f;
        n := n / f;
    end
    f := f + 1;
end
```

File: factors.til

http://www.program-transformation.org/Sts/TILChairmarks

TIL Grammar

File: TIL.Grm

```
% Keywords of TIL
keys
    var if then else while
    do for read write
end keys

% Compound tokens
compounds
    :=  !=
end compounds

% Commenting convention
comments
    //
end comments
```

All TXL parsers are also pretty-printers if the grammar includes formatting cues

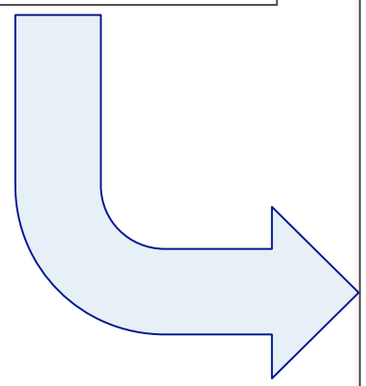
```
define program
    [statement*]
end define

define statement
        [declaration]
    |   [assignment_statement]
    |   [if_statement]
    |   [while_statement]
    |   [for_statement]
    |   [read_statement]
    |   [write_statement]
end define

% Untyped variables
define declaration
    'var [id] ;                         [NL]
end define

define assignment_statement
    [id] := [expression] ;              [NL]
end define

define if_statement
    'if [expression] 'then              [IN][NL]
        [statement*]                    [EX]
    [opt else_statement]
    'end                                [NL]
end define
...
```

Pretty-printing TIL

```
include "TIL.Grm"
function main
    match [program]
        _ [program]
end function
```

File: TILparser.Txl

```
txl factors.til TILparser.Txl
```



```
var n;
write "Input n please";
read n;
write "The factors of n are";
var f;
f := 2;
while n != 1 do
    while (n / f) * f = n do
        write f;
        n := n / f;
    end
    f := f + 1;
end
```

Generating statistics

File: TILstats.Txl

```
include "TIL.Grm"

function main
    replace [program]
        Program [program]

    % Count each kind of statement we're interested in
    % by extracting all of each kind from the program

    construct Statements [statement*]
        _ [^ Program]
    construct StatementCount [number]
        _ [length Statements] [putp "Total: %"]

    construct Declarations [declaration*]
        _ [^ Program]
    construct DeclarationsCount [number]
        _ [length Declarations] [putp "Declarations: %”]
...
    by
        % nothing
end function
```

```
Total: 11
Declarations: 2
Assignments: 3
Ifs: 0
Whiles: 2
Fors: 0
Reads: 1
Writes: 3
```

Tracing

File: TILtrace.Txl

```
include "TIL.Grm"
...
redefine statement
        ...
    |    [traced_statement]
end redefine

define traced_statement
    [statement] [attr 'TRACED]
end define

rule main
replace [repeat statement]
        S [statement]
        Rest [repeat statement]
...
    by
        'write QuotedS;     'TRACED
        S                   'TRACED
        Rest
end rule

...
```

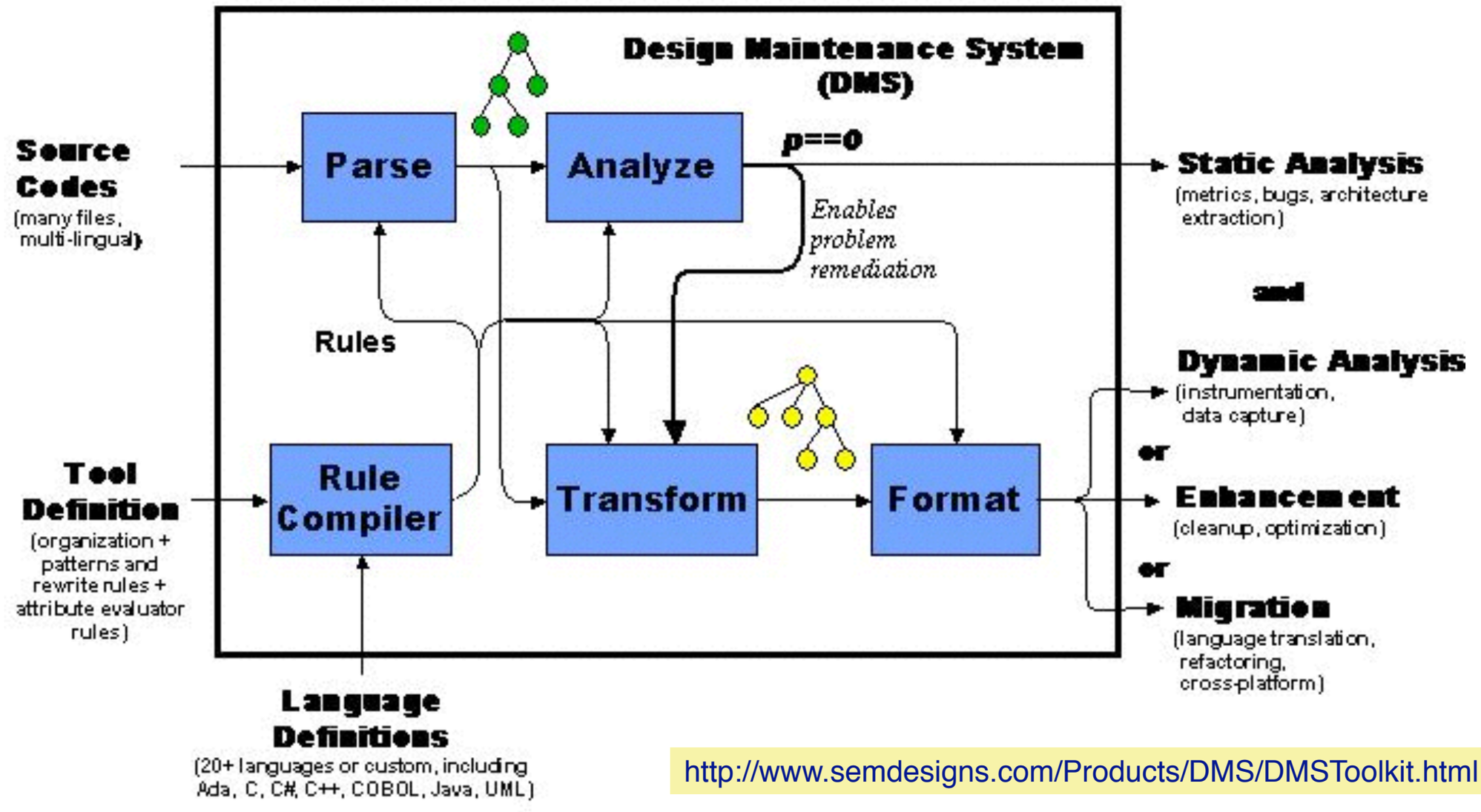
```
write "Trace: var n;";
var n;
write "Trace: write \"Input n please\";";
write "Input n please";
write "Trace: read n;";
read n;
...
```

TXL vs Stratego

Stratego	***TXL***
Scannerless GLR parsing	Agile parsing (top-down + bottom-up)
Reusable, generic traversal strategies	Fixed traversals
Separates rewrite rules from traversal strategies	Traversals part of rewrite rules
	

Commercial systems

"The DMS Software Reengineering Toolkit is a set of tools for automating customized source program analysis, modification or translation or generation of software systems, containing arbitrary mixtures of languages."



http://www.semdesigns.com/Products/DMS/DMSToolkit.html

Roadmap

- Program Transformation
- **Refactoring**
  - **Refactoring Engine and Code Critics**
  - Eclipse refactoring plugins
- Aspect-Oriented Programming

What is Refactoring?

> The process of *changing a software system* in such a way that it *does not alter the external behaviour* of the code, yet *improves its internal structure*.
>
> — Fowler, et al., Refactoring, 1999.

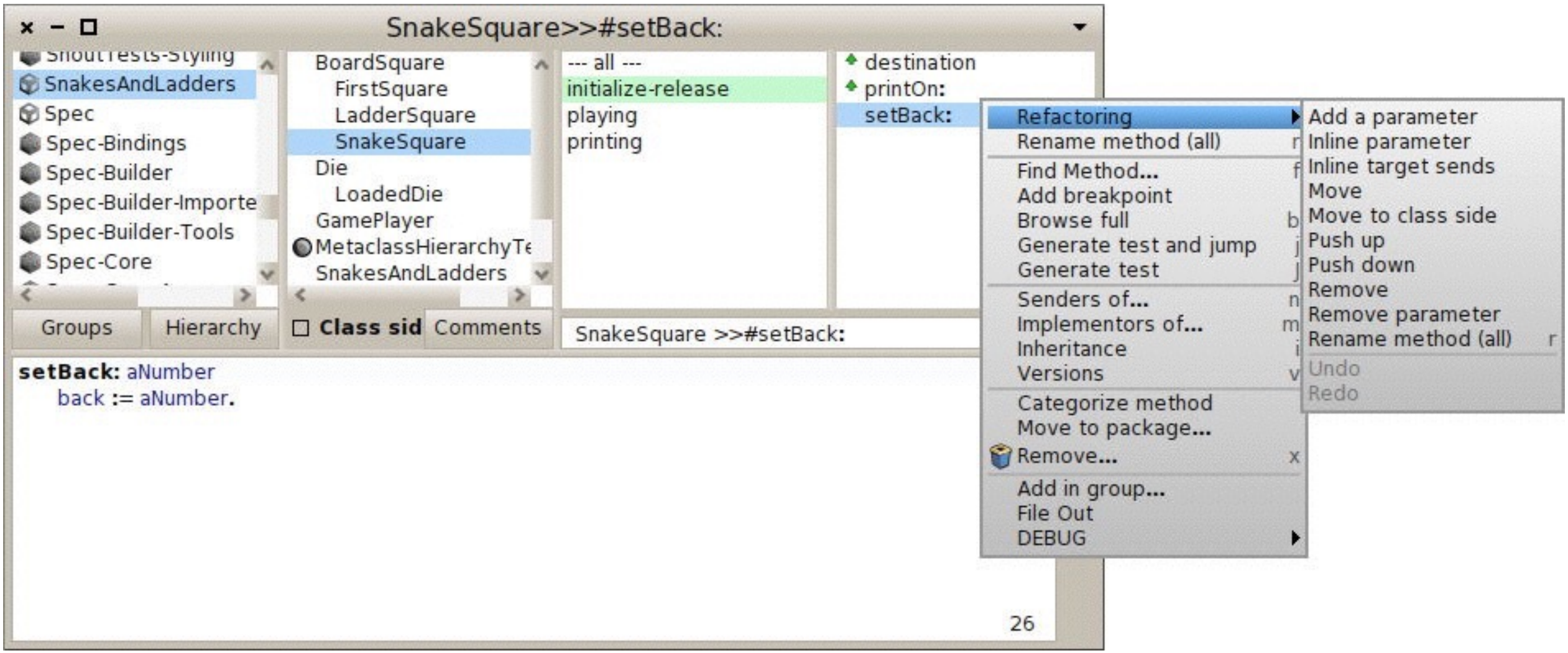
Rename Method — manual steps

- Do it yourself approach:
  - —Check that no method with the new name already exists in any subclass or superclass.
  - —Browse all the implementers (method definitions)
  - —Browse all the senders (method invocations)
  - —Edit and rename all implementers
  - —Edit and rename all senders
  - —Remove all implementers
  - —Test
- Automated refactoring is better !

Rename Method

- Rename Method (method, new name)
- Preconditions
  - —No method with the new name already exists in any subclass or superclass.
  - —No methods with same signature as method outside the inheritance hierarchy of method
- PostConditions
  - —method has new name
  - —relevant methods in the inheritance hierarchy have new name
  - —invocations of changed method are updated to new name
- Other Considerations
  - —Typed/Dynamically Typed Languages => Scope of the renaming

The Refactoring Browser



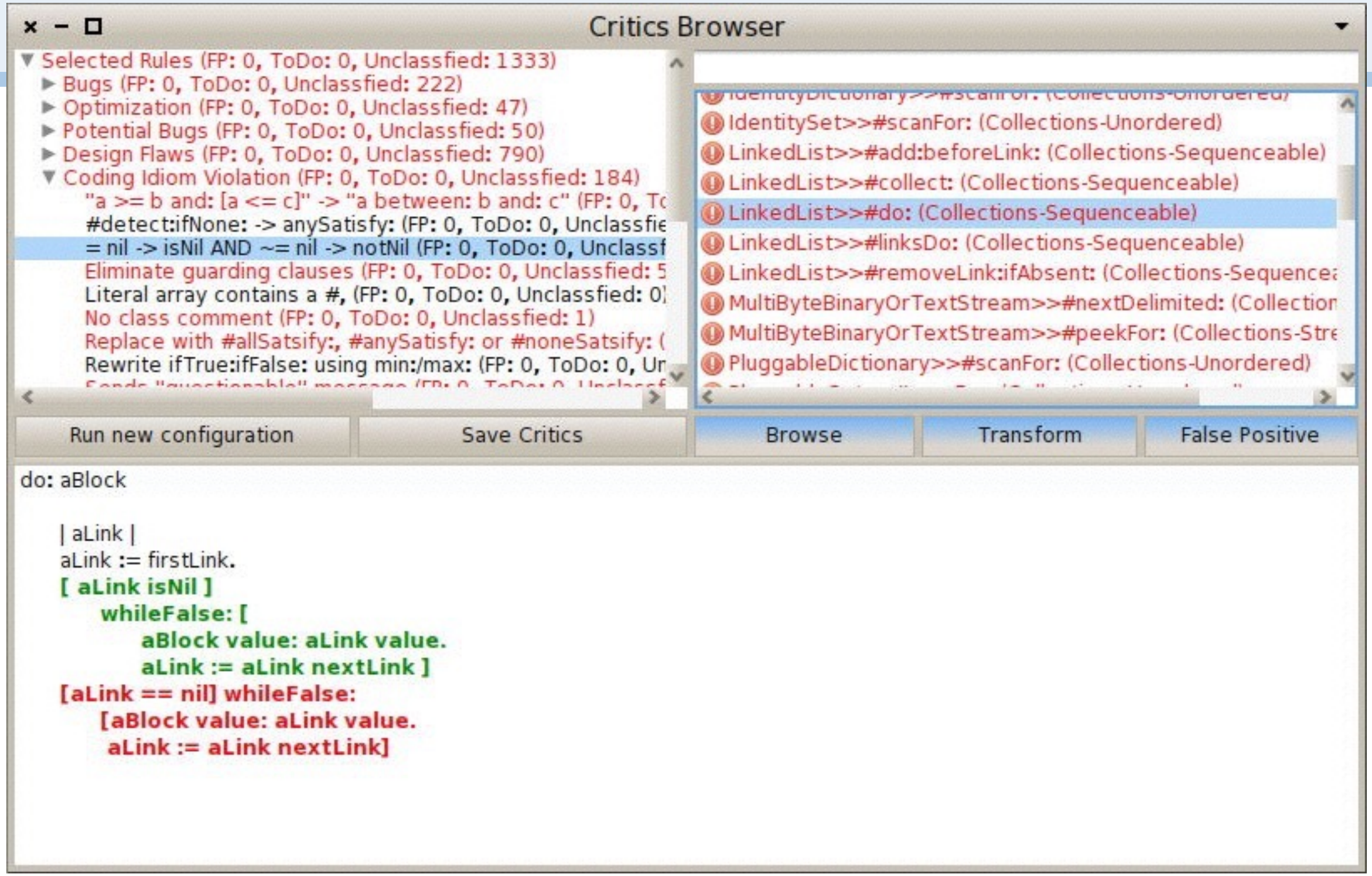
Typical Refactorings

Class Refactorings	Method Refactorings	Attribute Refactorings
add (sub)class to hierarchy	add method to class	add variable to class
rename class	rename method	rename variable
remove class	remove method	remove variable
	push method down	push variable down
	push method up	pull variable up
	add parameter to method	create accessors
	move method to component	abstract variable
	extract code in new method	

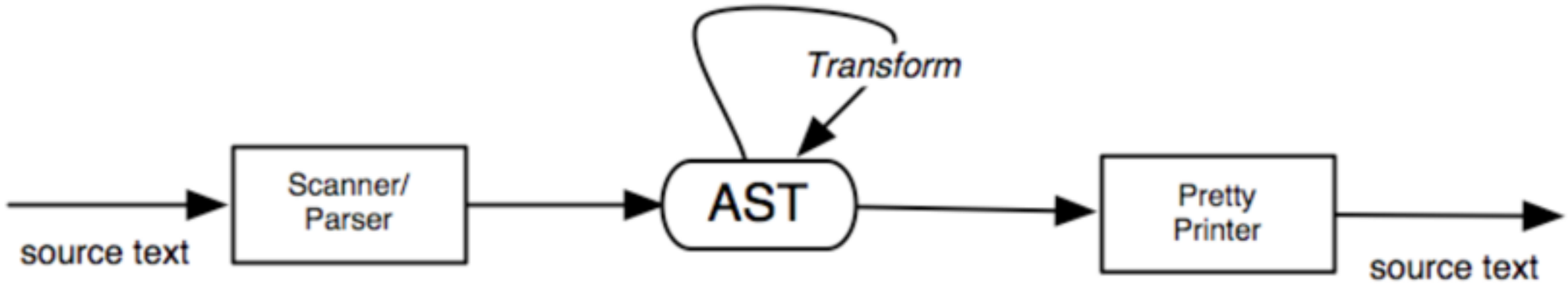
Bill Opdyke, "Refactoring Object-Oriented Frameworks," Ph.D. thesis, University of Illinois, 1992.

Don Roberts, "Practical Analysis for Refactoring," Ph.D. thesis, University of Illinois, 1999.

Code Critic — search for common errors



Refactoring Engine — matching trees

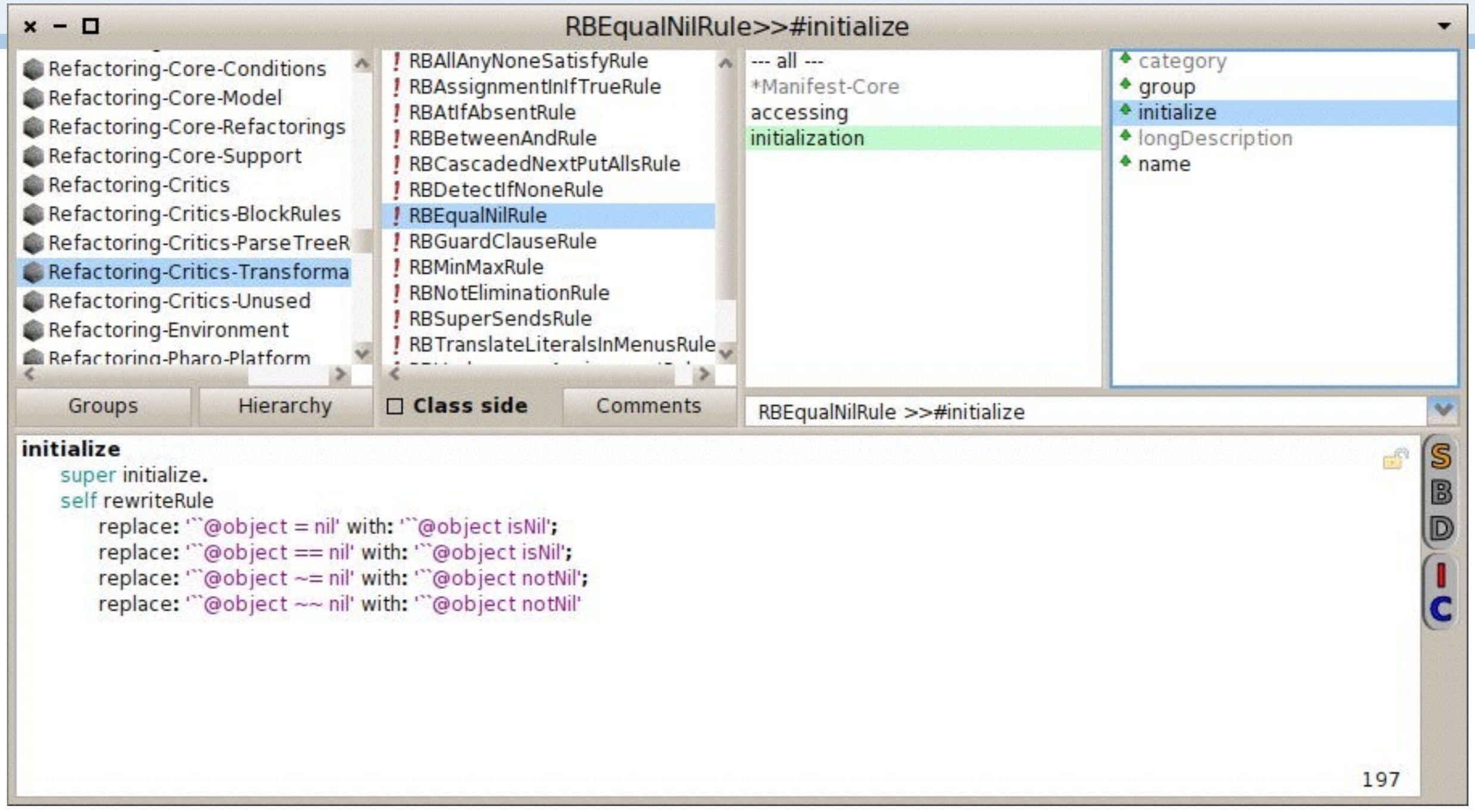


NB: All metavariables start with `

Syntax	Type
`	recurse
@	list
.	statement
#	literal

``@object halt	recursively match send of halt
`@.Statements	match list of statements
Class `@message: `@args	match all sends to Class

Rewrite rules



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- **Refactoring**
  - Refactoring Engine and Code Critics
  - **Eclipse refactoring plugins**
- Aspect-Oriented Programming

A workbench action delegate

When the workbench action proxy is triggered by the user, it delegates to an instance of this class.

```
package astexampleplugin.actions;
...
import org.eclipse.ui.IWorkbenchWindowActionDelegate;

public class ChangeAction implements IWorkbenchWindowActionDelegate {
    ...
    public void run( IAction action ) {
        for ( ICompilationUnit cu : this.classes ) {
            try {
                ...
                parser.setSource( cu );
                ...
                CompilationUnit ast = (CompilationUnit)parser.createAST( null );
                ...
                StackVisitor visitor = new StackVisitor( ast.getAST() );
                ast.accept( visitor );
                ...

            } catch ...
        }
    }
    ...
}
```

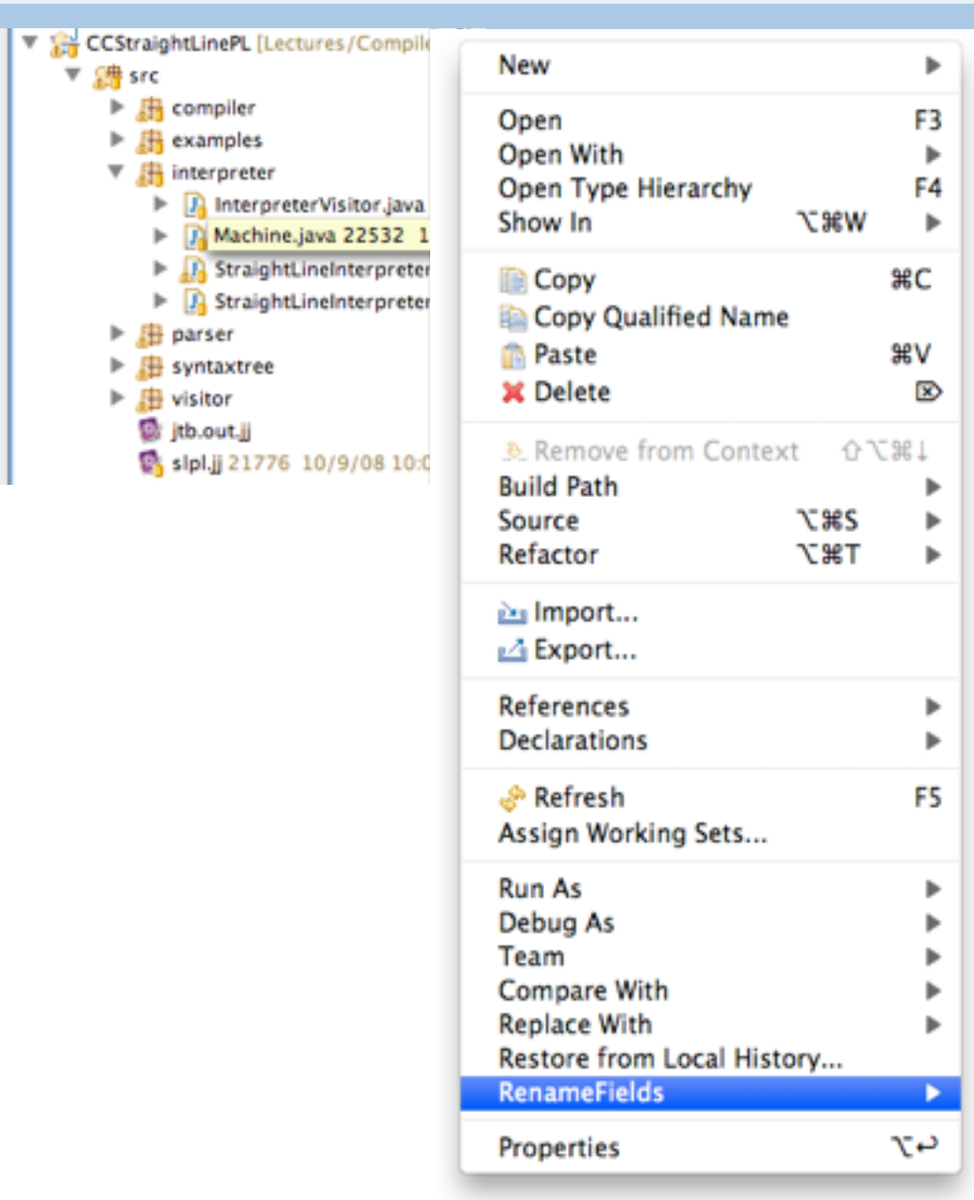
http://help.eclipse.org/ganymede/index.jsp?topic=/org.eclipse.jdt.doc.isv/guide/jdt_api_manip.htm

A field renaming visitor

```
package astexampleplugin.ast;
...
import org.eclipse.jdt.core.dom.ASTVisitor;

public class StackVisitor extends ASTVisitor {

    private static final String PREFIX = "_";
    ...
    public boolean visit(FieldDeclaration field){
        ...
    }

    public boolean visit(FieldAccess fieldAccess){
        String oldName = fieldAccess.getName().toString();
        String newName = this.fields.get( oldName );
        if(newName == null){
            newName = PREFIX + oldName;
            this.fields.put( oldName , newName );
        }
        fieldAccess.setName( this.ast.newSimpleName( newName ) );
        return true;
    }
}
```

The visitor simply implements the visit method for field declarations and accesses, and prepends an underscore.

Renaming fields



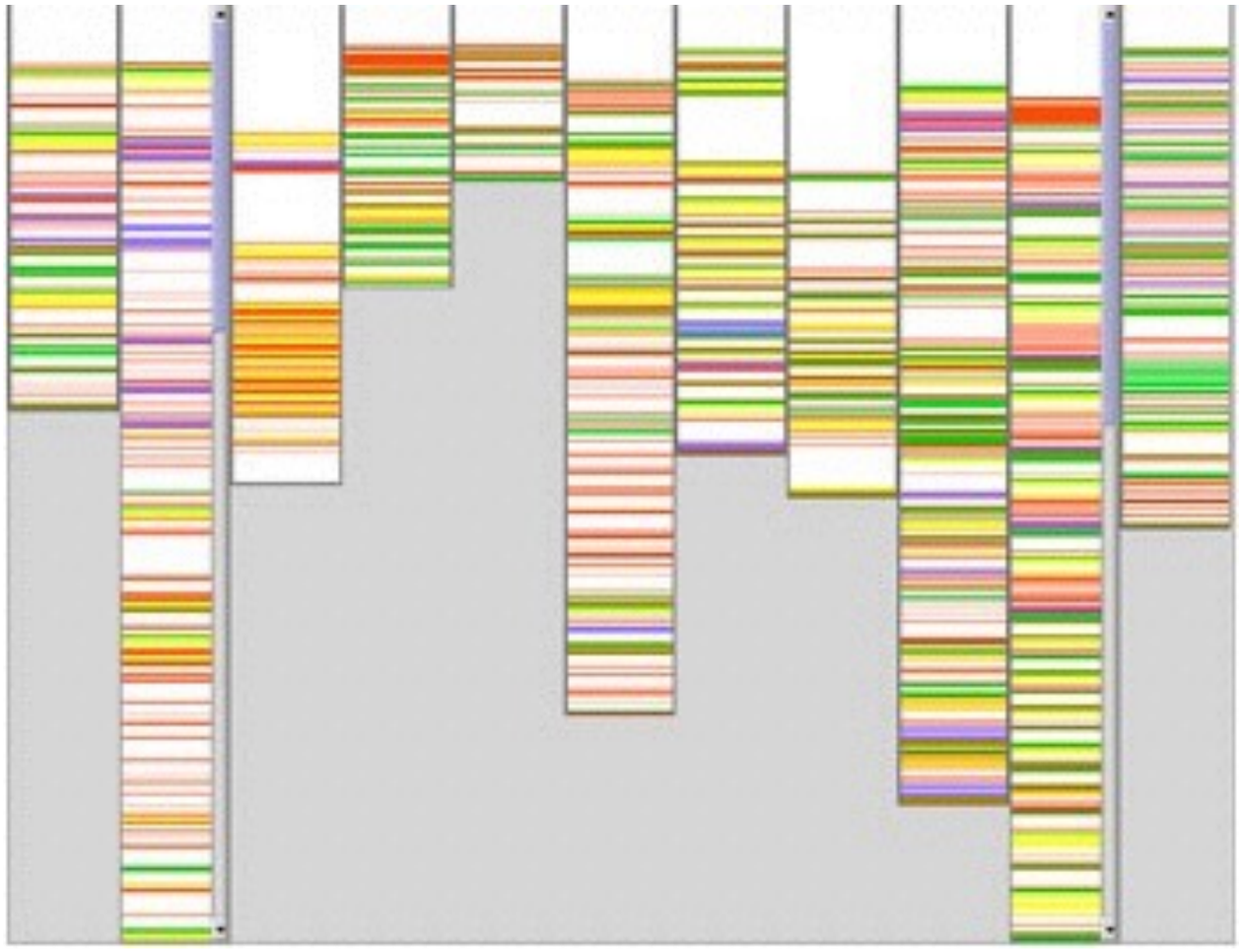

```
public class Machine {
    private Hashtable<String,Integer> store;    // current this.values of variables
    private StringBuffer output;                // print stream so far
    private int value;                          // result of current expression
    private Vector<Integer> vlist;              // list of expressions computed

    public Machine() {
        this.store = new Hashtable<String,Integer>();
        this.output = new StringBuffer();
        this.setValue(0);
        this.vlist = new Vector<Integer>();
    }
```

```
public class Machine {
    private Hashtable<String,Integer> _store;   // current this.values of variables
    private StringBuffer _output;               // print stream so far
    private int _value;                         // result of current expression
    private Vector<Integer> _vlist;             // list of expressions computed

    public Machine() {
        this._store = new Hashtable<String,Integer>();
        this._output = new StringBuffer();
        this.setValue(0);
        this._vlist = new Vector<Integer>();
    }
```

Roadmap

- Program Transformation
- Refactoring
- **Aspect-Oriented Programming**

Problem: cross-cutting concerns



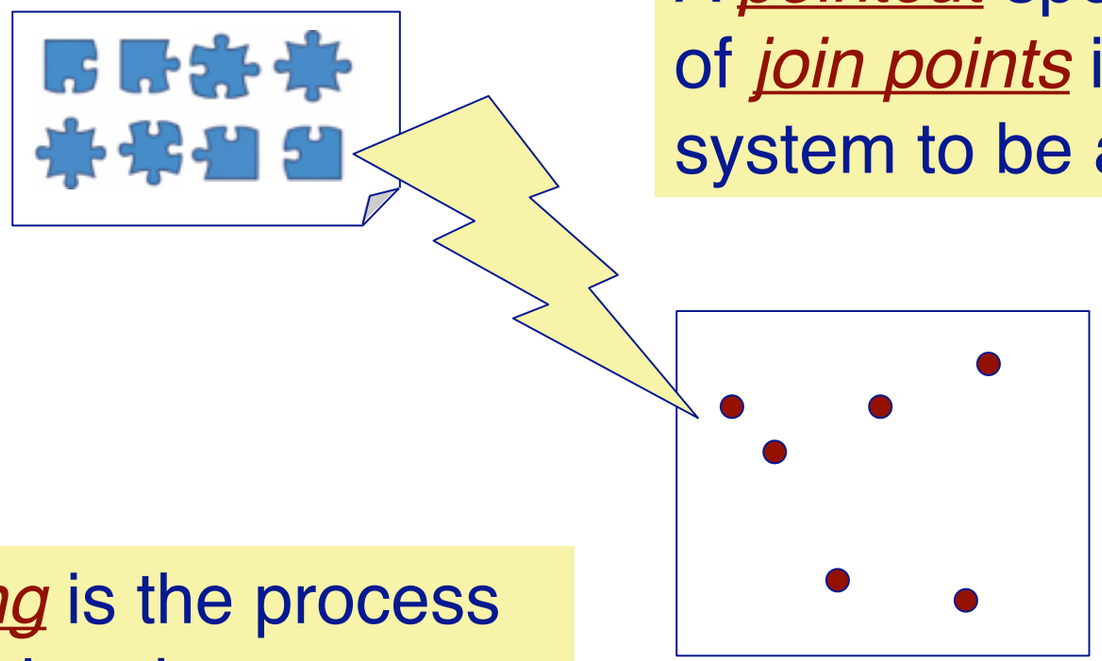
Certain features (like logging, persistence and security), cannot usually be encapsulated as classes. They *cross-cut* code of the system.

"Identifying Cross-Cutting Concerns in Embedded C Code", Bruntink, van Deursen, Tourwé

Aspect-Oriented Programming

AOP improves modularity by supporting the separation of cross-cutting concerns.

An *aspect* packages cross-cutting concerns



A *pointcut* specifies a set of *join points* in the target system to be affected

Weaving is the process of applying the aspect to the target system

Canonical example — logging

```
package tjp;

public class Demo {
 static Demo d;
 public static void main(String[] args){
  new Demo().go();
 }
 void go(){
  d = new Demo();
  d.foo(1,d);
  System.out.println(d.bar(new Integer(3)));
 }
 void foo(int i, Object o){
  System.out.println("Demo.foo(" + i + ", " + o + ")\n");
 }
 String bar (Integer j){
  System.out.println("Demo.bar(" + j + ")\n");
  return "Demo.bar(" + j  + ")";
 }
}
```

```
Demo.foo(1, tjp.Demo@939b78e)
Demo.bar(3)
Demo.bar(3)
```

http://www.eclipse.org/aspectj/downloads.php

A logging aspect

Intercept execution within control flow of `Demo.go()`

Identify all methods within `Demo`

```
aspect GetInfo {

 pointcut goCut(): cflow(this(Demo) && execution(void go()));

 pointcut demoExecs(): within(Demo) && execution(* *(..));

 Object around(): demoExecs() && !execution(* go()) && goCut() {
  ...
 }

...
}
```

Wrap all methods except `Demo.go()`

A logging aspect

```
aspect GetInfo {
 ...
 Object around(): demoExecs() && !execution(* go()) && goCut() {
  println("Intercepted message: " +
    thisJoinPointStaticPart.getSignature().getName());
  println("in class: " +
    thisJoinPointStaticPart.getSigna
  printParameters(thisJoinPoint);
  println("Running original method:
  Object result = proceed();
  println("  result: " + result );
  return result;
 }
 ...
}
```

```
Intercepted message: foo
in class: tjp.Demo
Arguments:
  0. i : int = 1
  1. o : java.lang.Object = tjp.Demo@c0b76fa
Running original method:

Demo.foo(1, tjp.Demo@c0b76fa)
  result: null
Intercepted message: bar
in class: tjp.Demo
Arguments:
  0. j : java.lang.Integer = 3
Running original method:

Demo.bar(3)
  result: Demo.bar(3)
Demo.bar(3)
```

Making classes visitable with aspects

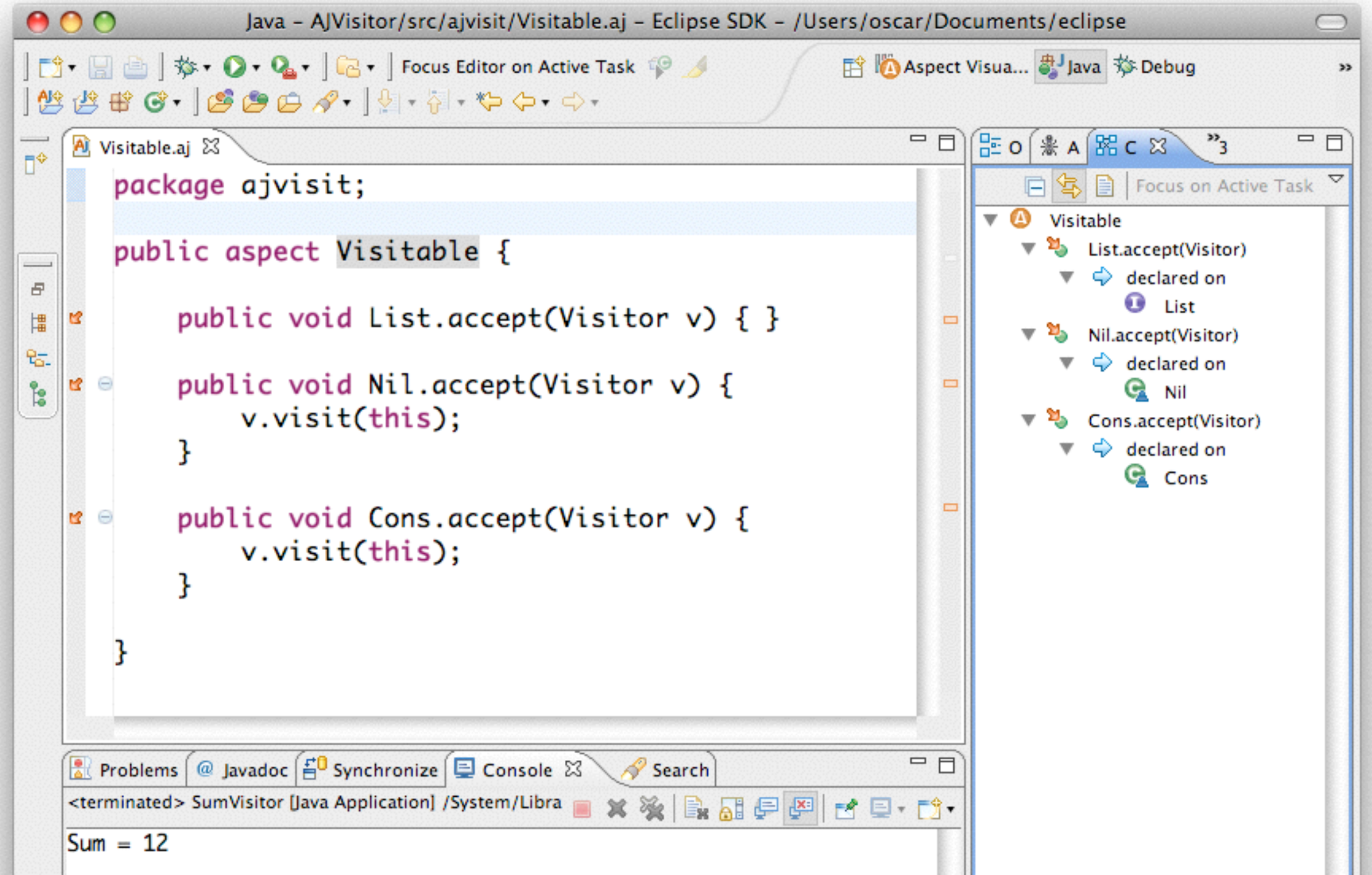
```
public class SumVisitor implements Visitor {
 int sum = 0;
 public void visit(Nil l) { }

 public void visit(Cons l) {
  sum = sum + l.head;
  l.tail.accept(this);
 }

 public static void main(String[] args) {
  List l = new Cons(5, new Cons(4,
        new Cons(3, new Nil())));
  SumVisitor sv = new SumVisitor();
  l.accept(sv);
  System.out.println("Sum = " + sv.sum);
 }
}
public interface Visitor {
 void visit(Nil l);
 void visit(Cons l);
}
```

We want to write this

```
public interface List {}
public class Nil implements List {}
public class Cons implements List {
 int head;
 List tail;
 Cons(int head, List tail) {
  this.head = head;
  this.tail = tail;
 }
}
```

But we are stuck with this …

AspectJ


Java – AJVisitor/src/ajvisit/Visitable.aj – Eclipse SDK – /Users/oscar/Documents/eclipse
Focus Editor on Active Task
Aspect Visua...
Java
Debug
Visitable.aj
package ajvisit;
public aspect Visitable {
public void List.accept(Visitor v) { }
public void Nil.accept(Visitor v) {
v.visit(this);
}
public void Cons.accept(Visitor v) {
v.visit(this);
}
}
Focus on Active Task
Visitable
List.accept(Visitor)
declared on
List
Nil.accept(Visitor)
declared on
Nil
Cons.accept(Visitor)
declared on
Cons
Problems
Javadoc
Synchronize
Console
Search
<terminated> SumVisitor [Java Application] /System/Libra
Sum = 12

With aspects, who needs visitors?

This would be even cleaner

```
public class SumList {
 public static void main(String[] args) {
  List l = new Cons(5, new Cons(4, new Cons(3, new Nil())));
  System.out.println("Sum = " + l.sum());
 }
}
```

The missing method is just an aspect

```
public aspect Summable {
 public int List.sum() {
  return 0;
 }
 public int Nil.sum() {
  return 0;
 }
 public int Cons.sum() {
  return head + tail.sum();
 }
}
```

What you should know!

- *What are typical program transformations?*
- *What is the typical architecture of a PT system?*
- *What is the role of term rewriting in PT systems?*
- *How does TXL differ from Stratego/XT?*
- *How does the Refactoring Engine use metavariables to encode rewrite rules?*
- *Why can't aspects be encapsulated as classes?*
- *What is the difference between a pointcut and a join point?*

Can you answer these questions?

- *How does program transformation differ from metaprogramming?*
- *In what way is optimization a form of PT?*
- *What special care should be taken when pretty-printing a transformed program?*
- *How would you encode typical refactorings like “push method up” using a PT system like TXL?*
- *How could you use a PT system to implement AOP?*