

# Introduction to Software Language Engineering using Rascal



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CWI



Rascal = Functional  
Metaprogramming  
language



Rascal = Functional  
Metaprogramming  
language

- Immutable variables
- Higher order functions
- Static safety, with local type inference



Rascal = Functional  
Metaprogramming

???



**WIKIPEDIA**  
The Free Encyclopedia

## Metaprogramming

From Wikipedia, the free encyclopedia

**Metaprogramming** is a programming technique in which computer programs have the ability to treat other programs as their data. It means that a program can be designed to read, generate, analyze or transform other programs [...]



# Rascal = Functional Metaprogramming

- “Code as data”
- Program that generates/analyzes other programs
- Syntax definitions and parsing
- Pattern matching and rewriting mechanisms
- Visiting / traversal of Tree structure

# Rascal can be used for...

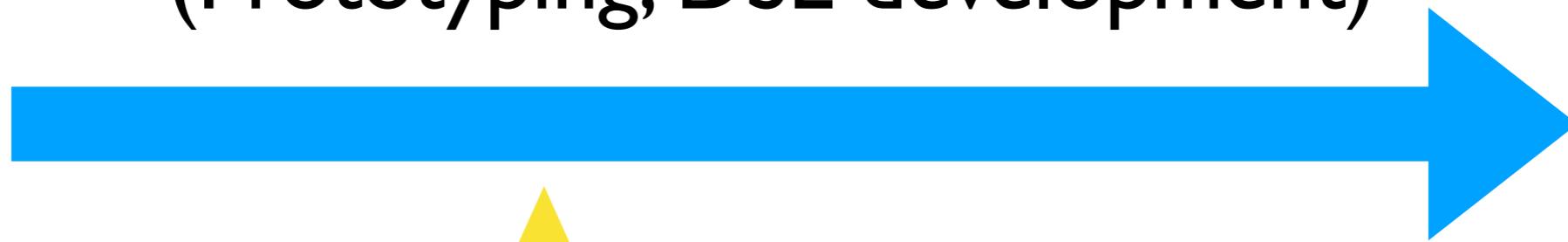
Forward Engineering  
(Prototyping, DSL development)



Backward Engineering  
(Analysis, detectors, renovations)

# Rascal can be used for...

Forward Engineering  
(Prototyping, DSL development)



This is our focus in this course



Backward Engineering  
(Analysis, detectors, renovations)

Why learn yet another  
new language?



Java

Grep

ANTLR

awk



# Basic concepts

# Functional immutability with an imperative syntax

- All data is immutable
- Can write code that looks like ‘mutating variables’

# Functional immutability with an imperative syntax

- All data is immutable

# Common Data Types

- e.g. Sets, Lists, Maps, Tuples and Relations
- Can all be used in comprehensions

# Sets

- Unordered sequence of values
- Elements are all of the same static type
- All elements are distinct
- Allows all sorts of powerful operations like comprehensions, difference, slicing, etc..
- `import Set;` for convenient functions on sets
- See: <http://docs.rascal-mpl.org/unstable/Rascal/#Values-Set>

# Lists

- Ordered sequence of values
- Elements are all of the same static type
- Allows for duplicate entries
- Allows all sorts of powerful operations like comprehensions, difference, slicing, etc..
- `import List;` for convenient functions on sets
- See: <http://docs.rascal-mpl.org/unstable/Rascal/#Values-List>

# Tuples

- Ordered sequence of elements
- Tuples are fixed sized
- Elements may be of different types
- Each element can have a label
- See: <http://docs.rascal-mpl.org/unstable/Rascal/#Values-Tuple>

# Relations

- All elements have the same static tuple type
- Set of Tuples
- Next to the set operations allows for composition, joining, transitive closure, etc
- `import Relation;` for convenient functions on relations
- See: <http://docs.rascal-mpl.org/unstable/Rascal/#Values-Relation>

# Source Locations

- Provide a uniform way to represent files on local or remote storage
- Can have different schemes
  - file:///
  - project://
  - http://
  - etc ...
- Can contain text location markers
- See: <http://docs.rascal-mpl.org/unstable/Rascal/#Values-Location>

# String templates

- Easy way to “generate” strings
- Often used for source-to-source transformation

# Pattern Matching

- Determines whether pattern matches a given value
- One of Rascal's most powerful features
- Can bind matches to local variables
- Can be used in many places
- May result in multiple matches so employs local backtracking
- See <http://docs.rascal-mpl.org/unstable/RascalConcepts/#RascalConcepts-PatternMatching>

# Different types of matching

type-based matching

```
int x := 3;
```

structural matching

```
event(x, y) := event("a", "b");
```

anti-matching

```
event("c", "d") !:= event("a", "b");
```

list matching

```
[*x, 1, *y] := [5, 6, 1, 1, 1, 3, 4];
```

set matching

```
{1, *x} := {4, 5, 6, 1, 2, 3};
```

deep matching

```
/transition(e, "idle") := ast;  
/state(x, _, /transition(_, x)) := ast;
```

element matching

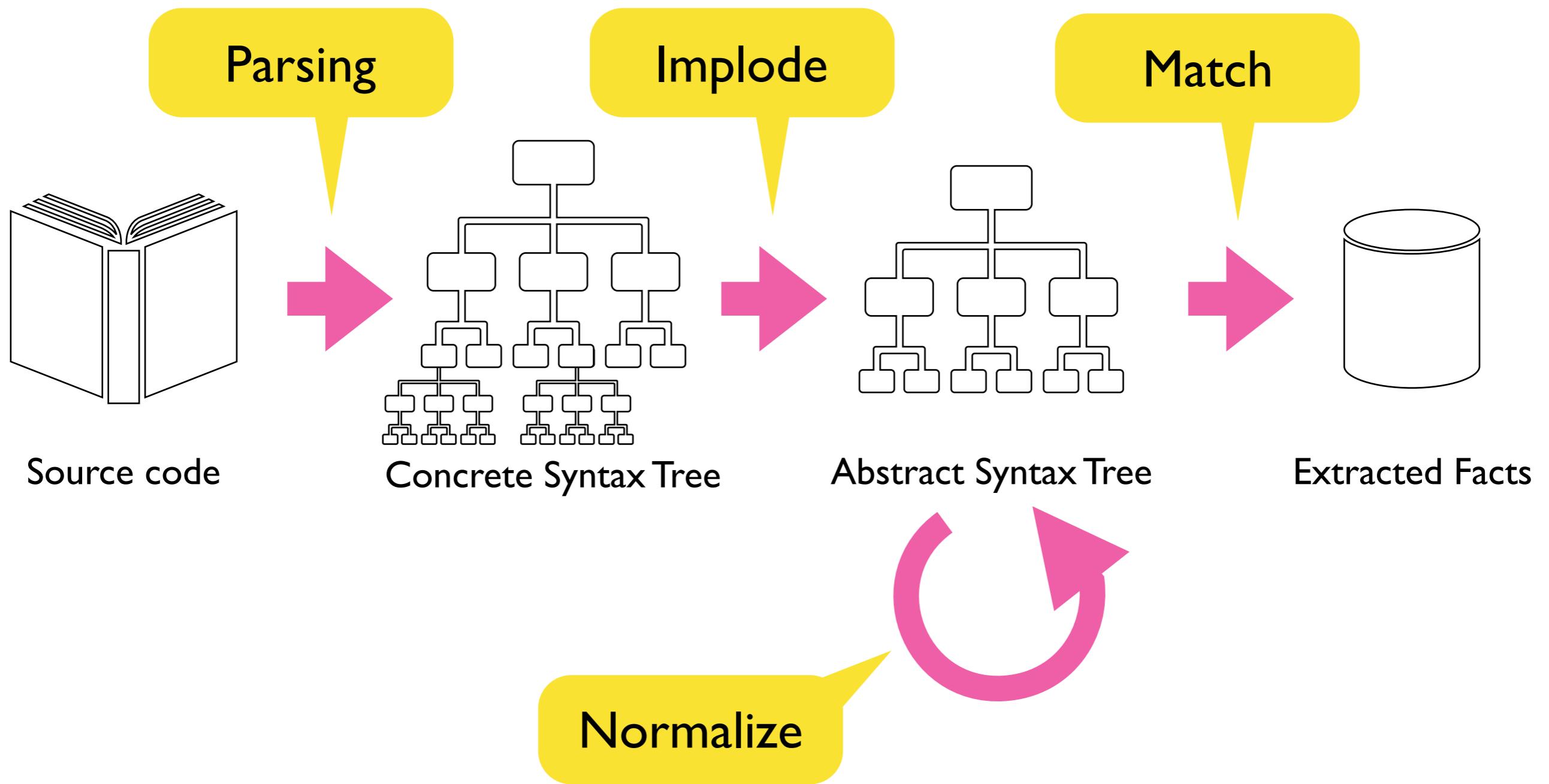
```
3 ← {1,2,3}  
int x ← {1,2,3}
```

regular expressions

```
/[A-Za-z]*/ := "09090aap noot mies"
```

# Tools for Language Engineering

# Extracting facts using parsing



Describes all possible strings which can be produced

```
start syntax Program = "begin" Stat* "end";  
  
syntax Statement+  
= "if" Nonterminal "Stat*" "else" Stat* "fi"  
| Id  
| "while" Expression "do" Stat* "od"  
;  
  
syntax Expression  
= Id  
| "(" Expression ")"  
| left Expression "*" Expression  
| right Expression "+" Expression  
Terminal  
  
lex Layout characters [-9\-\-]*;  
  
layout Whitespace = [\t\n\r]*;
```

# Abstract Syntax

(— ADT)

Same information as concrete tree but more abstract

```
data Program = program(list[Stat] stats);
```

Abstract Data Type

```
: [Stat] \tr, list[Stat] \f)
```

```
| assign(str id, Expr val)
```

```
| \while(Expr cons, list[Stat] body)
```

```
;
```

Escape for keywords

```
= id(str name)
```

```
| mult(Expr lhs, Expr rhs)
```

```
| add(Expr lhs, Expr rhs)
```

```
;
```

# Extracting information from an Abstract Syntax Tree

- Use Pattern Matching
  - Match on structure
  - Match on values
  - Deep matching
- See <http://docs.rascal-mpl.org/unstable/RascalConcepts/#RascalConcepts-PatternMatching>

# Find all assigned variables

```
data Program = program(list[Decl] decls, list[Stat] stats);

data Stat
= \if(Expr cond, list[Stat] \tr, list[Stat] \f)
| assign(str id, Expr val)
| \while(Expr cons, list[Stat] body)
```

Iterate over all Stats in subtree

```
// find assigned identifiers
for (Stat s ← program.stats, assign(str id, Expr _) := s) {
    println("Found id: <id>");
}
```

Only match on ‘assign’

Wildcard

# Find all assigned variables

```
data Program = program(list[Decl] decls, list[Stat] stats);

data Stat
= \if(Expr cond, list[Stat] \tr, list[Stat] \f)
| assign(str id, Expr val)
| \while(Expr cons, list[Stat] body)
```

Direct iterate and match on ‘assign’

```
// find assigned identifiers
for (assign(str id, Expr _) ← program.stats) {
    println("Found id: <id>");
}
```

# Find all *nested* assigned variables

```
data Program = program(list[Decl] decls, list[Stat] stats);  
  
data Stat  
= \if(Expr cond, list[Stat] \tr, list[Stat] \f)  
| assign(str id, Expr val)  
| \while(Expr cons, list[Stat] body)
```

What if an assignment is nested?

# Find all *nested* assigned variables

```
data Program = program(list[Decl] decls, list[Stat] stats);

data Stat
= \if(Expr cond, list[Stat] \tr, list[Stat] \f)
| assign(str id, Expr val)
| \while(Expr cons, list[Stat] body)
```

Use a deep match

```
for (/assign(str id, Expr _) ← program) {
    println("Found id: <id>");
}
```

# Find the variable named “x”

```
data Program = program(list[Decl] decls, list[Stat] stats);  
  
data Stat  
= \if(Expr cond, list[Stat] \tr, list[Stat] \f)  
| assign(str id, Expr val)  
| \while(Expr cons, list[Stat] body)
```

Match on value

```
for (/assign("x", Expr expr) ← program) {  
    println("Expr assigned to x: <expr>");  
}
```

# Transforming an Abstract Syntax Tree

- Use visit-statement
  - reach all nodes
  - not composable
- See <http://docs.rascal-mpl.org/unstable/Rascal/#Expressions-Visit>

# Rename “x” to “y”

```
data Program = program(list[Decl] decls, list[Stat] stats);
```

```
data Stat
= \if(Expr cond, list[Stat] \tr, list[Stat] \f)
| assign(str id, Expr val)
| \while(Expr cons, list[Stat] body)
;
```

```
data Expr
= id(str name)
```

# Rename “x” to “y”

```
data Program = program(list[Decl] decls, list[Stat] stats);

data Stat
= \if(Expr cond, list[Stat] \tr, list[Stat] \f)
| assign(str id, Expr val)
| \while(Expr cons, list[Stat] body)
;

data Expr
= id(str name)
```

Visit all the nodes in the tree

Rewrite / replace node

```
p = visit(p, {
    case assign("x", Expr val) => assign("y", val)
    case id("x") => id("y")
})
```

Both assignment and use are replaced

# Visit strategies

- **top-down**: root to leafs (default)
- **top-down-break**: root to leafs but stop on case match
- **bottom-up**: leafs to root
- **bottom-up-break**: leafs to root but stop on case match
- **innermost**: bottom-up fix point (repeat until no more changes)
- **outermost**: top-down fix point

# Tips and Tricks

# Debugging Rascal

- Poor-mans debugging
  - Using `println` or `bprintln` (in comprehensions)
    - You need to import `IO` for this!
- Rich-mans debugging
  - Using the debugger
    - You have to open the debug perspective manually!

# Common errors

## Undeclared variable

- Forgetting to import a module, i.e.:
- Function is declared private

```
rascal>l = [1,2,3];
list[int]: [1,2,3]
rascal>size(l);
|prompt:///|(0,4,<1,0>,<1,4>): Undeclared variable: size
Advice: |http://tutor.rascal-mpl.org/Errors/Static/UndeclaredVariable.html|
```

- Solution for above example: `import List;`

# Common errors

## CallFailed

- Calling a function with the wrong arguments

```
void someFunc(str a) {  
    println(a);  
}
```

```
rascal>someFunc("a");  
a  
ok  
rascal>someFunc(2);  
lprompt:///|(9,1,<1,9>,<1,10>): CallFailed(  
  lprompt:///|(9,1,<1,9>,<1,10>),  
  [2])  
  at $root$(lprompt:///|(0,12,<1,0>,<1,12>))
```

# Common Error: Root cause analysis

- Slice your problem by
  - Importing the problematic module directly
  - Use ‘delta’-debugging (comment out 50% of the code and try to reimport, add 25% again and try again, etc)

Looking for how you can do  
stuff in Rascal?

# Looking for how you can do stuff in Rascal?

Browse and search the documentation

- <http://docs.rascal-mpl.org/unstable>
- Use the Tutor button in Eclipse

The screenshot shows a web browser window with the following details:

- Address Bar:** Not Secure | docs.rascal-mpl.org/unstable/Rascal/
- Toolbar:** Apps, Bookmarks, Save to Mendeley, Using Decision Ru..., Test voor internet..., Advice to new Pro...
- Search Bar:** Search ...
- Page Content:**
  - Rascal** (highlighted in red)
  - 1. Declarations**
    - 1.1. Module Declaration
    - 1.2. Import
    - 1.3. Program
    - 1.4. StaticTyping
    - 1.5. Algebraic Data Type
    - 1.6. Variable Declaration
    - 1.7. Function Declaration
    - 1.8. Syntax Definition
    - 1.9. Alias Declaration
    - 1.10. Annotation Declaration
    - 1.11. Tag Declaration
  - 2. Patterns**
- Right Panel:**
  - Rascal Language Reference**
  - Synopsis**: Reference manual for the Rascal meta-programming language.
  - Description**: Here we describe *all* features of the Rascal language in detail, for reference purposes.
    - **Declarations**: The entities that can be declared in Rascal programs.
    - **Patterns**: Patterns are a notation for pattern matching used to detect if a value has a certain shape,.
    - **Expressions**: The expressions available in Rascal.
    - **Statements**: All Rascal statements.
  - You can find more (accessible) information related to Rascal here:

# Looking for how you can do stuff in Rascal?

Take a look at the Rascal Cheatsheet:

**Rascal Cheat Sheet**

<http://www.rascal-mpl.org>  
<http://tutor.rascal-mpl.org>  
<https://github.com/cwi-swat/rascal>

**Modules**

```
module Example

import ParseTree;           // import
extend lang::std::Layout;   // "inherit"
```

**Declarations**

```
// Algebraic data types (ADT)
data Exp
    = var(str x)          // unary constructor
    | add(Exp l, Exp r); // binary constructor

data Person      // keyword parameter
    = person(int id, bool married=false);

alias Age = int; // type alias

anno loc Exp@location; // annotation

private real PI = 3.14; // variables

// Functions: signatures are lists of patterns
// May have keyword parameters.
void f(int x) { println(x); }      // block style
int inc(int x) = x+1;              // rewrite style
int inc0(int x) = x+1 when x == 0; // side condition
default int inc0(int x) = x;       // otherwise

// Test functions (invoke from console with :test)
test bool add() = 1+2 == 3;

// randomized test function
test bool comm(int x, int y) = x+y == y+x;

// Foreign function interface to Java
@javaClass{name.of.javaClass.with.Method}
java int method();
```

**Statements**

```
// Standard control-flow
if (E) S;
if (E) S; else S;
while (E) S;
do S; while(E);
continue; break;
return; return E;

// Loop over all bindings produce by patterns
for (i <- [0..10]) S; // Loop 10 times

fail;      // control backtracking
append E; // add to loop result list
```

**Context-free grammars**

```
start syntax Prog      // start symbol
= prog: Exp* exps     // production
| stats: {Stat ";"}* // separated list
| stats: {Stat ";"*}+ // one-or-more sep. list
| "private"? Func;   // optional
```

**Pattern-based switch-case**

```
switch (E) {
    case P: S; // do something
    case P => E // rewrite it
    default: S; // otherwise
}
```

**Traversal with visit; like switch, but matches at arbitrary depth of value**

```
visit (E) {
    case P: S; // do something
    case P => E // rewrite something
    case P => E when E
}
```

**insert E; // rewrite subject as statement**

**Strategies: bottom-up, innermost, outermost, top-down-break, bottom-up-break**

```
top-down visit (E) {}

try S; // pattern-based try-catch
catch P: S; // match to catch
finally S;

throw E; // throw values
```

**Fix-point equation solving;**

```
solve (out,ins) {
    out[b] = ( {} | it + ins[s] | s <- succ[b] );
    ins[b] = (out[b] - kill[b]) + gen[b];
};

x = 1; // assignment
nums[0] = 1; // subscript assignment
nums[1,3..10] = 2; // sliced (see below)
p.age = 31; // field assignment
ast@location = l; // annotation update
<p, a> = <"ed", 30>; // destrcuturing
```

**A op=E == A = A op E**

```
A += E; A -= E; A *= E;
A /= E; A &= E;
```



<https://github.com/cwi-swat/rascal-cheat-sheet/raw/master/sheet.pdf>

# Looking for how you can do stuff in Rascal?

Search on StackOverflow

<https://stackoverflow.com/questions/tagged/rascal>

The screenshot shows the Stack Overflow website with the URL <https://stackoverflow.com/questions/tagged/rascal> in the address bar. The page title is "Questions tagged [rascal]". A sidebar on the left includes links for Home, PUBLIC, Stack Overflow (selected), Tags, Users, and Jobs. A "Teams" section at the bottom left offers "Q&A for work". The main content area displays 314 questions, with sorting options: info, Newest, Frequent, Votes, Active, and unanswered. The first question listed is "how to use “IO actions” with list comprehension or mapper in Rascal?". To the right, there are sections for "BLOG" (with a link to the 2019 Developer Survey) and "FEATURED ON META" (with a link to the 2019 Developer Survey). At the bottom right, there's a "HOT META POSTS" section.

https://stackoverflow.com/questions/tagged/rascal

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1 how to use “IO actions” with list comprehension or mapper in Rascal?

BLOG

How the 2019 Stack Overflow Developer Survey Came to Be Your Last Chance...

FEATURED ON META

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HOT META POSTS

When logged in, pages from are now synonyms do not re

Please don't auto-subscribe to alerts

# Good luck!

- Next up: Lab session!
  - in 5114 .0035C
  - Rascal Wax-on, Wax-off tutorial