EASY Meta-Programming with Rascal

Leveraging the Extract-Analyze-SYnthesize Paradigm

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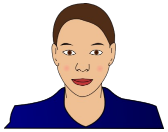
Cast of Our Heroes

- Alice, system administrator
- Bernd, forensic investigator
- Charlotte, financial engineer
- Daniel, multi-core specialist
- Elisabeth, model-driven engineering specialist

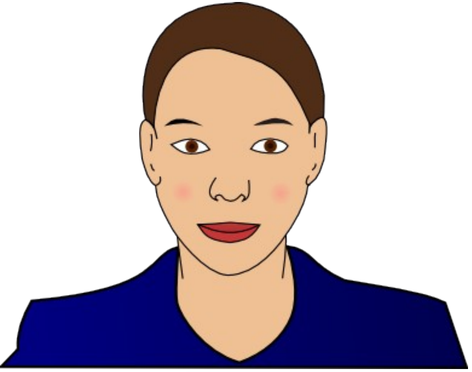


Meet Alice

- Alice is security administrator at a large online marketplace
- Objective: look for security breaches
- Solution:
  - Extract relevant information from system log files, e.g. failed login attempts in Secure Shell
  - Extract IP address, login name, frequency, …
  - Synthesize a security report

Meet Bernd

- Bernd: investigator at German forensic lab
- Objective: finding common patterns in confiscated digital information in many different formats. This is very labor intensive.
- Solution:
  - Design DERRICK a domain-specific language for this type of investigation
  - Extract data, analyze the used data formats and synthesize Java code to do the actual investigation



Meet Charlotte

- Charlotte works at a large financial institution in Paris
- Objective: connect legacy software to the web
- Solution:
    - extract call information from the legacy code, analyze it, and synthesize an overview of the call structure
    - Use entry points in the legacy code as entry points for the web interface
    - Automate these transformations

Meet Daniel

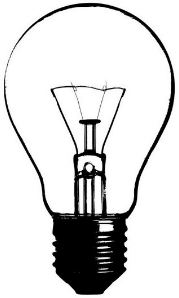
- Daniel is concurrency researcher at one of the largest hardware manufacturers worldwide
- Objective: leverage the potential of multi-core processors and find concurrency errors
- Solution:
  - extract concurrency-related facts from the code (e.g., thread creation, locking), analyze these facts and synthesize an abstract automaton
  - Analyze this automaton with third-party verification tools

Meet Elisabeth

- Elisabeth is software architect at an airplane manufacturer
- Objective: Model reliability of controller software
- Solution:
  - describe software architecture with UML and add reliability annotations
  - Extract reliability information and synthesize input for statistics tool
  - Generate executable code that takes reliability into account

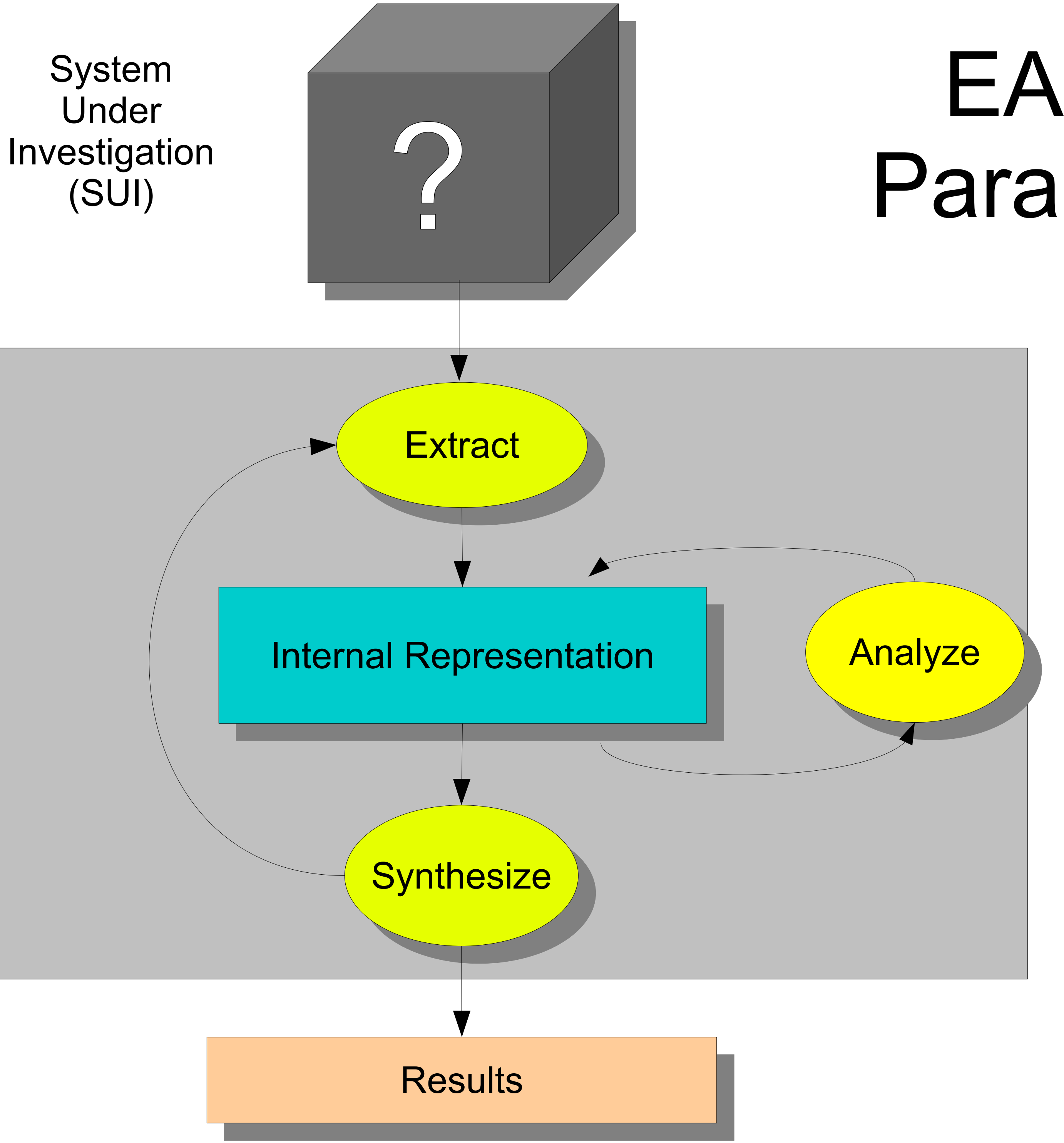
What are their *Technical Challenges*?

- How to parse source code/data files/models?
- How to extract facts from them?
- How to perform computations on these facts?
- How to generate new source code (trafo, refactor, compile)?
- How to synthesize visualizations, charts?



EASY: Extract-Analyze-SYnthesize Paradigm

EASY Paradigm



System
Under
Investigation
(SUI)

?

Extract

Internal Representation

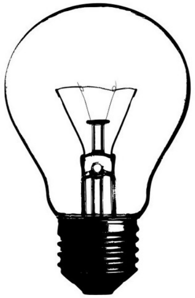
Analyze

Synthesize

Results

Why a new Language?

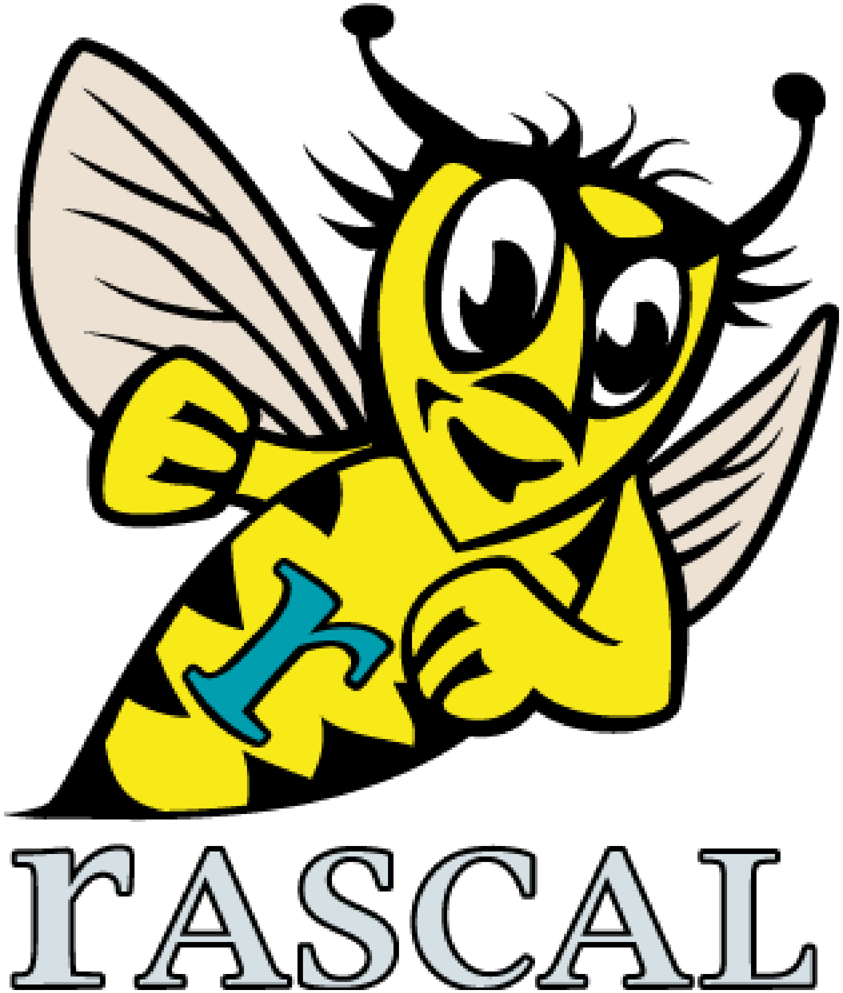
- No current technology spans the full range of EASY steps
- There are many fine technologies but they are
  - highly specialized with steep learning curves
  - hard to learn unintegrated technologies
  - not integrated with a standard IDE
  - hard to extend



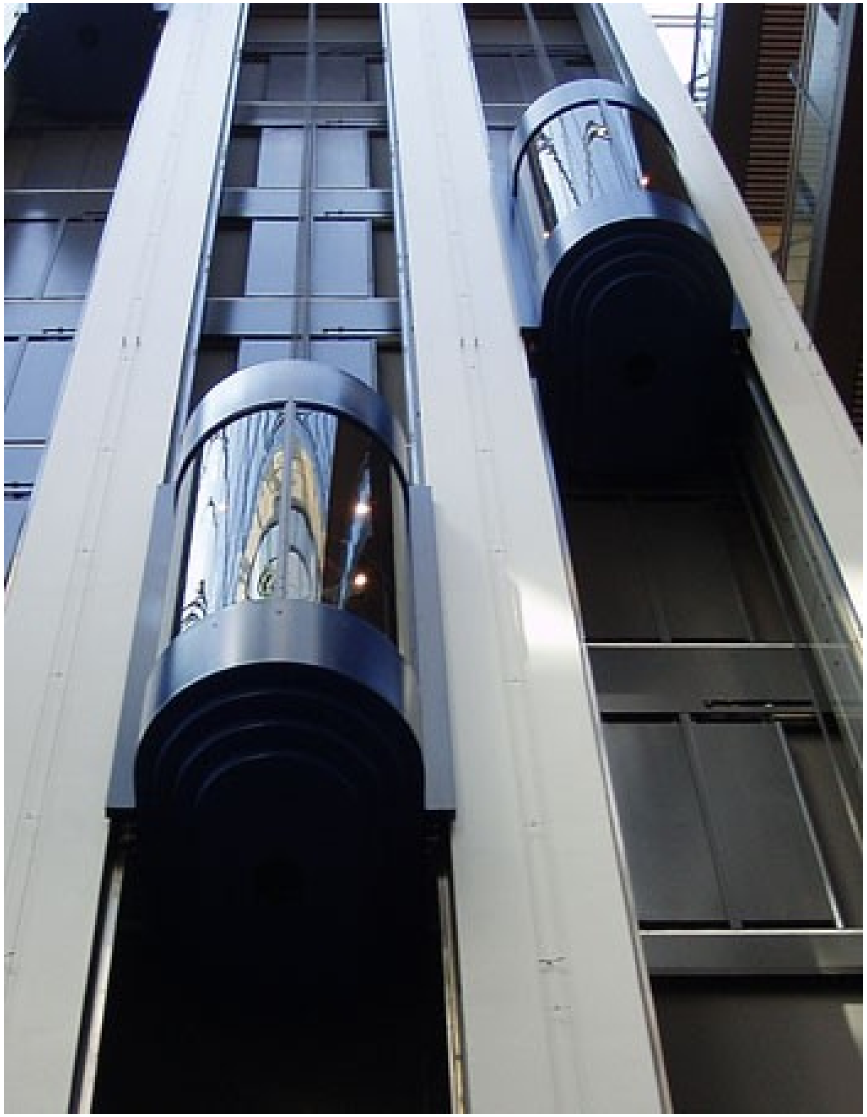
Goal

Keep all benefits of advanced (academic) tools and unify them in a **new**, **extensible**, **teachable** framework

Here comes Rascal to the Rescue



Rascal Elevator Pitch



Rascal Elevator Pitch

- Sophisticated built-in data types
- Immutable data
- Static safety
- Generic types
- Local type inference
- Pattern Matching
- Syntax definitions and parsing
- Concrete syntax
- Visiting/traversal
- Comprehensions
- Higher-order
- Familiar syntax
- Java and Eclipse integration
- Read-Eval-Print (REPL)


HOW EXCITING!! PLEASE TELL ME MORE!!

Rascal ...

- is a new language for meta-programming
- is based on *Syntax Analysis*, *Term Rewriting*, *Relational Calculus*
- extended super set (regarding features not syntax!) of ASF+SDF and Rscript
- relations used for sharing and merging of facts for different languages/modules
- embedded in the Eclipse IDE
- easily extensible with Java code

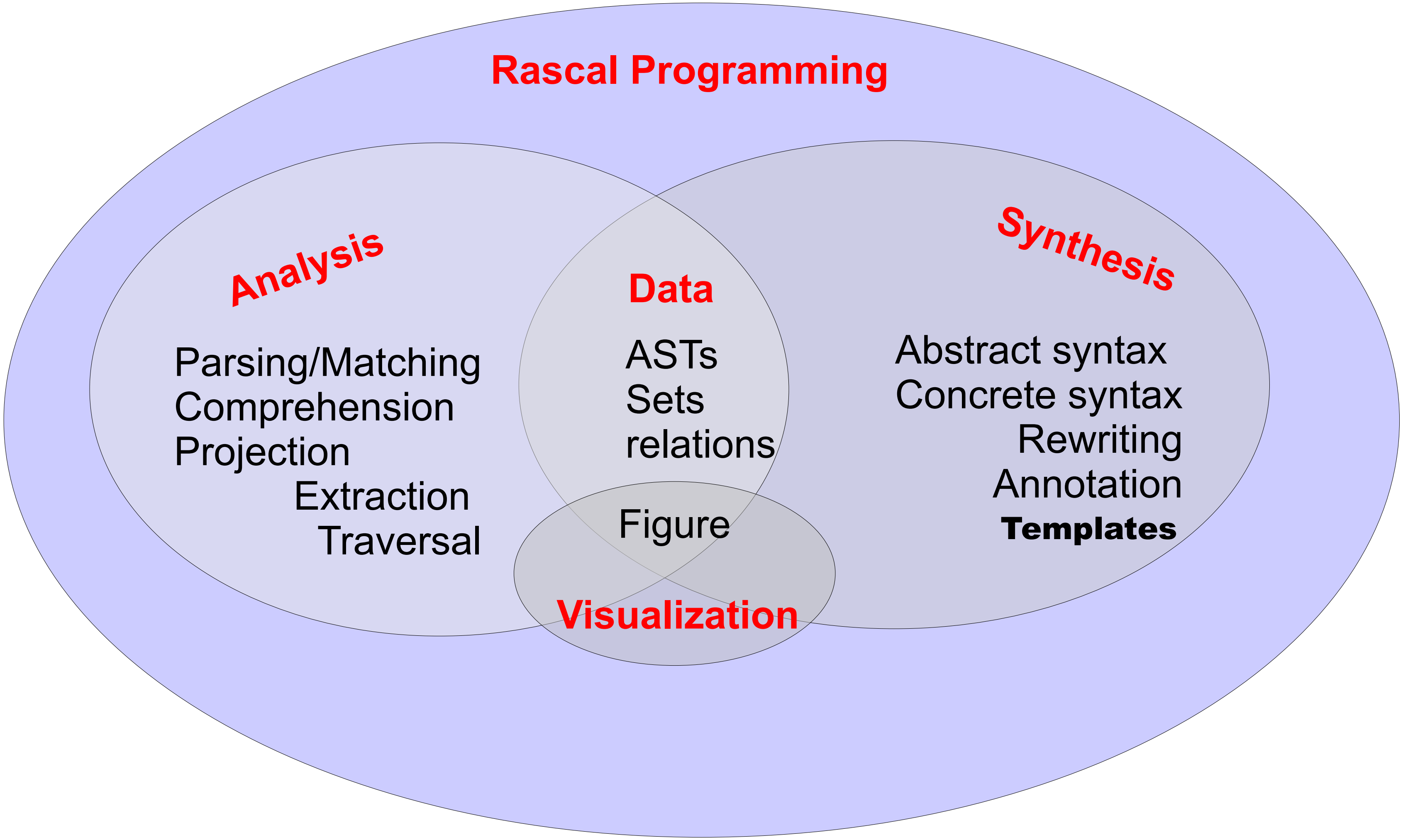
Rascal design based on ...

- **Principle of least surprise**
  - Familiar (Java-like) syntax
  - Imperative core
- **What you see is what you get**
  - No heuristics (or at least as few as possible)
  - *Explicit* preferred over *implicit*
- **Learnability**
  - Layered design
  - Low barrier to entry

Rascal provides

- Rich (immutable) data: lists, sets, maps, tuples, relations, ... with comprehensions and many operators
- Syntax definitions & parser generation
- Syntax trees, tree traversal
- Pattern matching (text, trees, lists, sets, ...) and pattern-directed invocation
- Code generation (string templates & trees)
- Java and Eclipse (IMP) integration

Bridging Gaps



Rascal Programming

Analysis

Parsing/Matching
Comprehension
Projection
Extraction
Traversal

Data

ASTs
Sets
relations

Synthesis

Abstract syntax
Concrete syntax
Rewriting
Annotation
Templates

Figure

Visualization

One-stop-shop

Cool parsers

Deal of the day:
Cheap type checkers

Fancy visualization

Just in: new modeling gadgets

Some Classical Examples

- Read-Eval-Print
- Hello
- Factorial
- ColoredTrees

Read-Eval-Print

```
rascal>1 + 1
int: 2

rascal>[1,2,3]
list[int]: [1,2,3]

rascal>[1,2,3] + [9,5,1]
list[int]:[1,2,3,9,5,1]
```

List concatenation

Read-Eval-Print

```
rascal>{1,2,3}
set[int]: {1,2,3}

rascal>{1,2,1}
set[int]: {1,2}

rascal>{1,2,3} + {9,5,1}
set[int]:{1,2,3,9,5}
```

Sets do not contain duplicates

Set union

Read-Eval-Print

Set comprehension

```
rascal>{i*i|i <- [1..10]}
set[int]: {1,4,9,16,25,36,...}

rascal>{i*i|i <- [1..10],t%2==0}
set[int]: {4,16,36,...}
```

Read-Eval-Print

String interpolation

```
rascal>import IO;
ok
rascal>for (i <- [1..10]) {
>>>>>>>  println("<i> * <i> = <i * i>");
>>>>>>>}
1 * 1 = 1
2 * 2 = 4
3 * 3 = 9
4 * 4 = 16
5 * 5 = 25
6 * 6 = 36
7 * 7 = 49
8 * 8 = 64
9 * 9 = 81
10 * 10 = 100
list[void]: []
```

Hello (on the command line)

```
rascal > import IO;
ok

rascal> println(“Hello, my first Rascal program”);
Hello, my first Rascal program
ok
```

Hello (as function in module)

```
module demo::basic::Hello
import IO;
public void hello() {
  println(“Hello, my first Rascal program”);
}
```

```
rascal > import demo::basic::Hello;
ok

rascal> hello();
Hello, my first Rascal program
ok
```

Factorial

```
module demo::Factorial
public int fac(int N){
  return N <= 0 ? 1 : N * fac(N - 1);
}
```

```
rascal> import demo::Factorial;
ok

rascal> fac(47);
int: 25862324151116818064296435515361197996
9197632389120000000000
```

Types and Values

- Atomic: bool, num, int, real, str, loc (source code location), datetime
- Structured: list, set, map, tuple, rel (n-ary relation), abstract data type, parse tree
- Type system:
  - Types can be parameterized (polymorphism)
  - All function signatures are explicitly typed
  - Inside function bodies types can be inferred (local type inference)

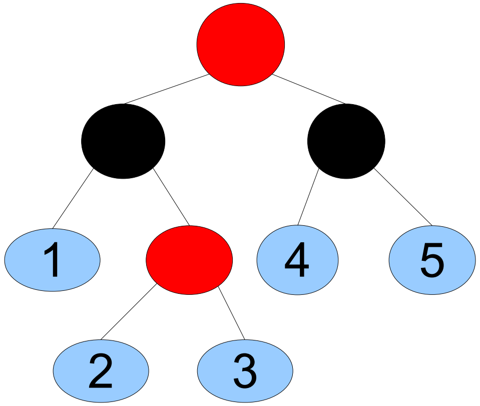
Type	**Example**
bool	true, false
int, real	1, 0, -1, 123, 1.023e20, -25.5
str	“abc”, “values is <x>”
loc	|file:///etc/passwd|
datetime	$2010-07-15T09:15:23.123+03:00
tuple[t_1, ..., t_n]	<1,2>, <“john”, 43, true>
list[t]	[], [1], [1,2,3], [true, 2, “abc”]
set[t]	{}, {1,3,5,7}, {“john”, 4.0}
rel[t_1, ..., t_n]	{<1,10,100>,<2,20,200>}
map[t, u]	(), (“a”:1, “b”:2,“c”:3)
node	f, add(x,y), g(“abc”,[2,3,4])

User-defined datastructures

- Named alternatives
  - name acts as constructor
  - can be used in patterns
- Named fields (access/update via . notation)
- All datastructures are a subtype of the standard type `node`
  - Permits very generic operations on data
- Parse trees resulting from parsing source code are represented by the datatype `Tree`

ColoredTrees: CTree

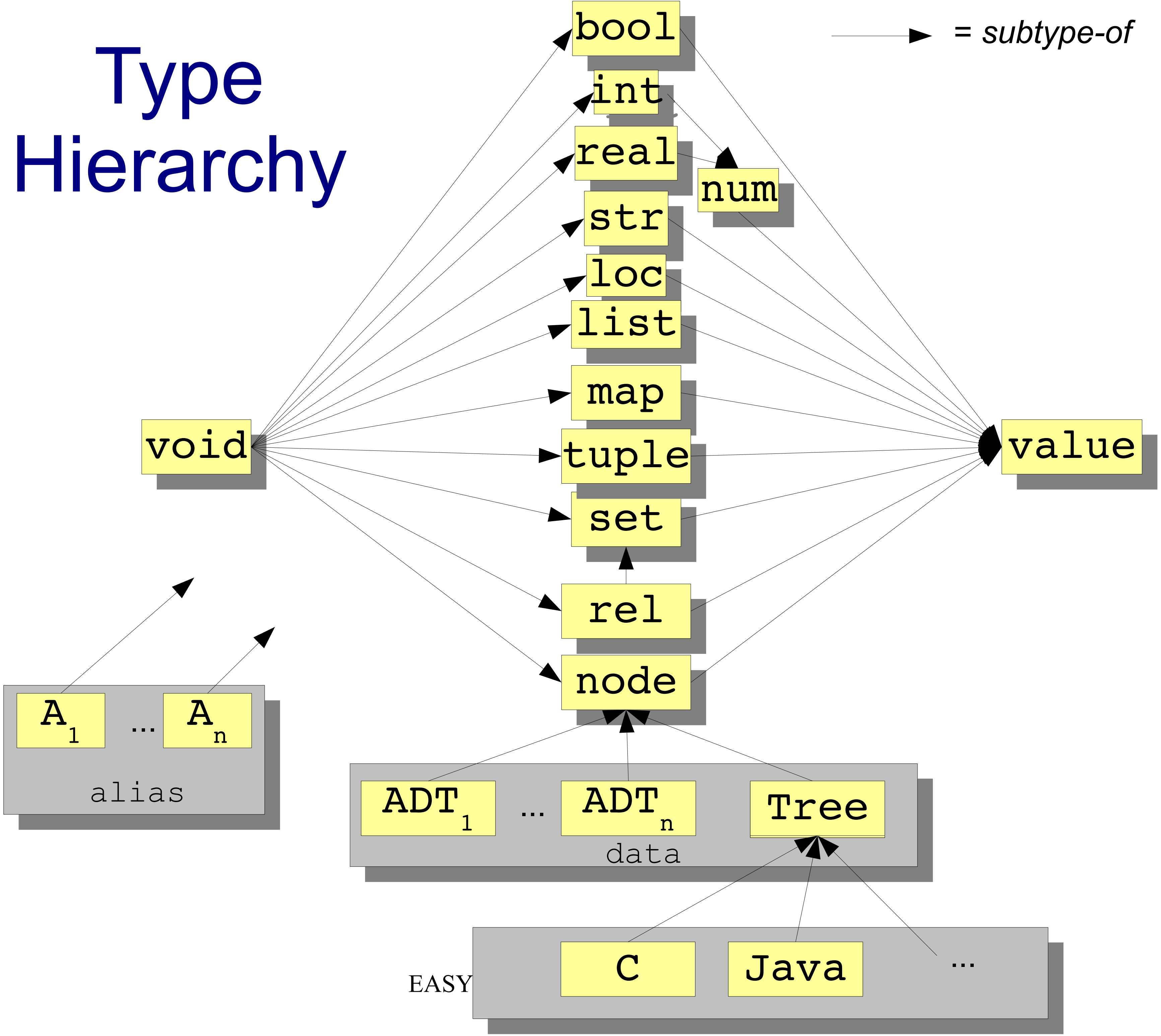
```
data CTree =  leaf(int N)
           |  red(CTree left, CTree right)
           |  black(Ctree left, Ctree right) ;

rb = red(black(leaf(1), red(leaf(2), leaf(3))),
         black(leaf(4), leaf(5)));
```



Abstract Syntax

```
data STAT = asgStat(Id name, EXP exp)
          | ifStat(EXP exp,list[STAT] thenpart,
                           list[STAT] elsepart)
          | whileStat(EXP exp, list[STAT] body)
          ;
```

Type Hierarchy



→ = *subtype-of*

bool

int

real

num

str

loc

list

map

void

tuple

value

set

rel

node

A_1 … A_n

alias

ADT_1 … ADT_n Tree

data

C Java …

Pattern matching

Given a pattern and a value:

- Determine whether the pattern matches the value
- If so, bind any variables occurring in the pattern to corresponding subparts of the value

Pattern matching

Pattern matching is used in:

- Explicit match operator Pattern := Value
- Switch: matching controls case selection
- Visit: matching controls visit of tree nodes

* **Function calls: matching controls dynamic dispatch**

Patterns

Regular: Grep/Perl like regular expressions

```
/^<before:\W*><word:\w+><after:.*$>/
```

Abstract: match data types

```
whileStat(Exp, Stats*)
```

Concrete: match parse trees

```
` while <Exp> do <Stats*> od `
```

Regular Patterns

```
rascal>/[a-z]+/ := "abc"
bool: true

rascal>/rac/ := "abracadabra";
bool: true

rascal>/^rac/ := "abracadabra";
bool: false

rascal>/rac$/ := "abracadabra";
bool: false
```

Regular Patterns

```
rascal>if(/\W<x:[a-z]+>/ := "12abc34")
          println("x = <x>");
ok
```

- Matches non-word characters (`\W`) followed by one or more letters.
- Binds text matched by `[a-z]+` to variable `x`. (Is only available in the body of the if statement)
- Prints: `abc`.
- Regular patterns are tricky (in any language)!

Patterns

Abstract/Concrete patterns support:

- List matching: [P1, ..., Pn]
- Set matching: {P1, ..., Pn}
- Named subpatterns: N:P
- Anti-patterns: !P
- Descendant: /N

Can be combined/nested in arbitrary ways

List Matching

```
rascal> L = [1, 2, 3, 1, 2];
list[int]: [1,2,3,1,2]

rascal> [X*, 3, X] := L;
bool: true

rascal> X;
Error: X is undefined

rascal> if([X*, 3, X] := L) println("X = <X>");
X = [1, 2]
ok
```

List pattern

X* is a list variable and abbreviates list[int] X

X is bound but has limited scope

List matching provides **associative** (A) matching

Set Matching

```
rascal> S = {1, 2, 3, 4, 5};
set[int]: {1,2,3,4,5}


rascal> {3, Y*} := S;
bool: true


rascal> if({3, Y*} := S) println("Y = <Y>");
Y = {5,4,2,1}
ok
```

Set pattern

Y* is a set variable
and abbreviates
`set[int] Y`

Set matching provides
associative, **commutative**, **identity** (ACI) matching

Note

- List and Set matching are non-unitary
- E.g., [L*, M*] := [1, 2] has three solutions:
  - L == [ ],   M == [1,2]
  - L == [1],   M == [2]
  - L == [1,2], M == [ ]
- In boolean expressions, matching, etc. solutions are generated when failure occurs later on (local backtracking)

Descendant Matching

```
whileStat(_, /ifStat(_,_,_))
```

Match a while statement
that contains an if statement
at arbitrary depth

Enumerators and Tests

- Enumerate the elements in a value
- Tests determine properties of a value
- Enumerators and tests are used in comprehensions

*** And in if, for, while, etc.**

Enumerators

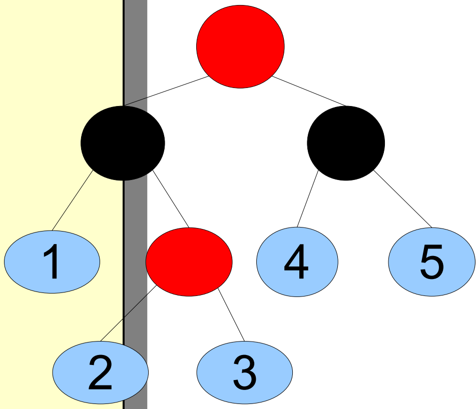
- Elements of a list or set
- The tuples in a relation
- The key/value pairs in a map
- The elements in a datastructure (in various orders!)

```
int x <- { 1, 3, 5, 7, 11 }
int x <- [ 1 .. 10 ]
asgStat(Id name, _) <- P
```

Comprehensions

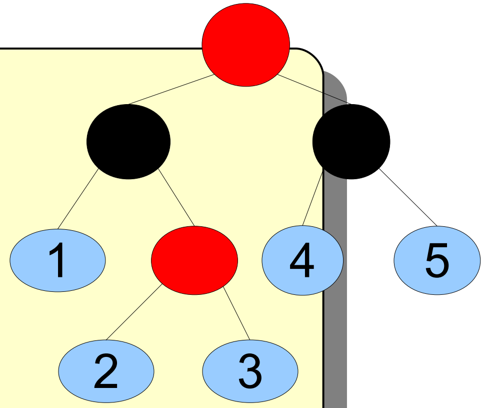
- Comprehensions for lists, sets and maps
- Enumerators generate values; tests filter them

```
rascal> {n * n | int n ← [1 .. 10], n % 3 == 0};
set[int]: {9, 36, 81}

rascal> [ n | /leaf(int n) ← rb ];
list[int]: [1,2,3,4,5]

rascal> {name | /asgStat(id name, _) ← P};
{ ... }
```



Control structures

- Combinations of enumerators and tests drive the control structures
- for, while, all, one



```
rascal> for(/int n ← rb, n > 3){ println(n);}
4
5
ok
rascal> for(/asgStat(Id name, _) ← P, size(name)>10){
    println(name);
}
...
```

Counting words in a string

```
public int countWords(str S){
  int count = 0;
  for(/[a-zA-Z0-9]+/ := S){
      count += 1;
  }
  return count;
}
```

Iterates over all matches

`countWords(` "'Twas brillig, and the slithy toves" `) => 6`

Switching

- A **switch** does a top-level case distinction

```
switch (P){
case whileStat(EXP Exp, Stats*):
     println("A while statement");
case ifStat(Exp, Stats1*, Stat2*):
     println("An if statement");
}
```

Every switch is a code smell, you can also use functions dispatched by patterns

Enough!

- Ok, that was quite a lot of information
- Rascal is for Meta-Programming
  - Code analysis
  - Code transformation
  - Code generation
  - Code visualization
- It is a normal programming language
- Learn it using the Tutor view and the Console