Rscript: a Relational Approach to Program and System Understanding

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Structure of Presentation

- Background and context
- About program understanding
- Roadmap: Rscript

Background

Application areas

Domain-specific languages

Software renovation

- System understanding
- System transformation

This talk

Technology

ASF+SDF Meta-Environment
Generalized LR parsing
(Compiled) term rewriting

ToolBus coordination architecture
Code Generators

Foundations

Formal languages
Term rewriting

Relational calculus

Process Algebra
Module algebra

Compilation is a mature area

- Some new developments
  - just-in-time compilation
  - energy-aware code generation
- Many research results are not yet used widely
  - interprocedural pointer analysis
  - slicing
- Why don't we just apply all these techniques to understanding and restructuring?

Compilation is a mature area

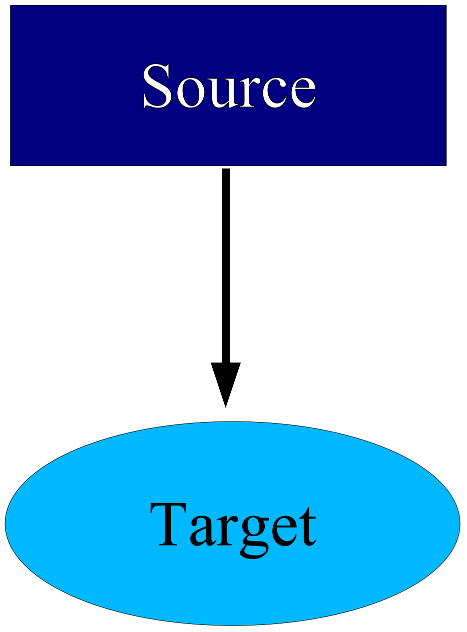
- ... of course, we do just that, but ...
- there is a mismatch between
  - standard compilation techniques and
  - the needs for understanding and restructuring

Compilation is ...

- A well-defined process with well-defined input, output and constraints
- Input: source program in a fixed language with well-defined syntax and semantics
- Output: a fixed target language with well-defined syntax and semantics
- Constraints are known (correctness, performance)
- A batch-like process

Compilation is ...

Single,
well defined,
source



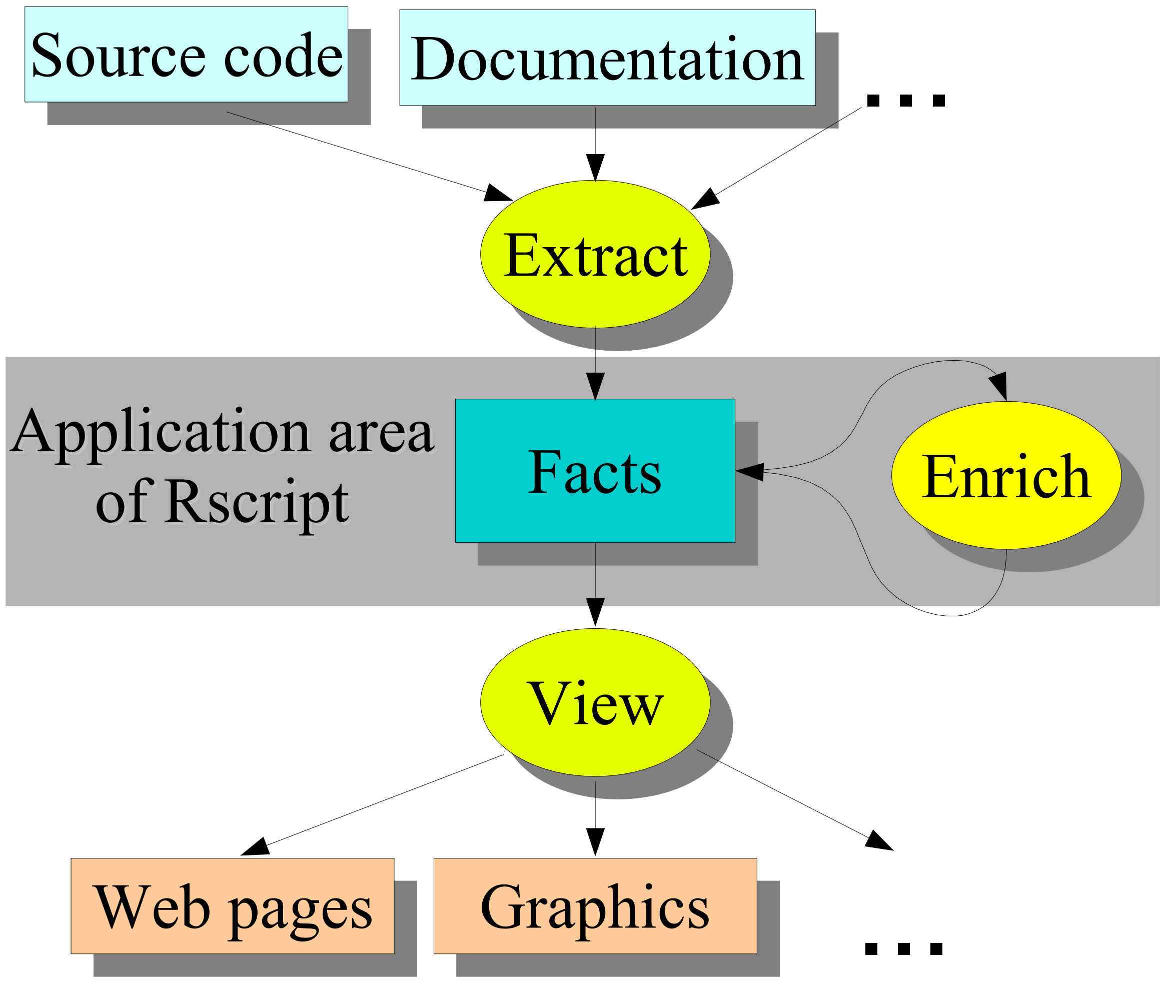
A batch-like process with
clear constraints

Single,
well
defined,
target

Understanding is ...

- An exploration process with as input
  - system artifacts (source, documentation, tests, ...)
  - implicit knowledge of its designers or maintainers
- There is no clear target language
- An interactive process:
  - Extract elementary facts
  - Abstract to get derived facts needed for analysis
  - View derived facts through visualization or browsing

Extract-Enrich-View Paradigm



Examples of understanding problems

- Which programs call each others?
- Which programs use which databases?
- If we change this database record, which programs are affected?
- Which programs are more complex than others?
- How much code clones exist in the code?

Examples of the results of understanding

- Textual reports indicating properties of system parts (complexity, use of certain utilities, ...)
- Same, but in hyperlinked format
- Graphs (call graphs, use def graphs for databases)
- More sophisticated visualizations

Other aspects of Understanding

- Systems consist of several source languages
- Analysis techniques over multiple language => a language-independent analysis framework is needed
- A very close link to the source text is needed

Related approaches

- Generic dataflow frameworks exist but are not used widely
- Relations have been used for querying of software (Rigi, GROK, RPA, ...)
  - All based on untyped, binary, relation algebra
  - Mostly used for architectural, coarse grain, queries

Relation-based analysis

- What happens if we use relations for fine grain software analysis (ex: find uninitialized variables)
- What happens if we use a relational calculus (as opposed to the relational algebra approaches)?
- What happens if we use term rewriting as basic computational mechanism?
  - relations can represent graphs in the rewriting world
- Could yield a unifying framework for analysis and transformation

Roadmap

- Rscript in a nutshell
- Example 1: call graph analysis
- Example 2: component structure
- Example 3: Java analysis
- Example 4: a toy language
- A vizualization experiment

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Rscript in a Nutshell

- Basic types: `bool`, `int`, `str`, `loc` (text location in specific file with comparison operators)
- Sets, relations and associated operations (domain, range, inverse, projection, ...)
- Comprehensions
- User-defined types
- Fully typed
- Functions and sets of equations over the above

Rscript: examples

- Set: {3, 5, 7}
  - type: set[int]
- Set: {"y", "x","z"}
  - type: set[str]
- Relation: {<"y",3>, <"x",3>, <"z", 5>}
  - type: rel[str,int]

Rscript: examples

- rel[str,int] U = {<"y",3>, <"x",3>, <"z", 5>}
- int Usize = #U
  - 3
- rel[int,str] Uinv = inv(U)
  - {<3, "y">, <3, "x">, <5, "z">}
- set[str] Udom = domain(U)
  - {"y", "x", "z"}

domain:
all elements in lhs of pairs
range:
all elements in rhs of pairs
carrier:
all elements in lhs or rhs of pairs

Comprehensions

- Comprehensions: {Exp | Gen1, Gen2, ... }
  - A generator is an enumerator or a test
  - Enumerators: V : SetExp or <V1,V2> : RelExp
  - Tests: any predicate
  - consider all combinations of values in Gen1, Gen2,...
  - if some Gen_i is false, reject that combination
  - compute Exp for all legal combinations

Comprehensions

- {X | int X : {1,2,3,4,5}}
  - yields {1,2,3,4,5}
- {X | int X : {1,2,3,4,5}, X > 3}
  - yields {4,5}
- {<Y, X> | <int X, int Y> : {<1,10>,<2,20>}}
  - yields {<10,1>,<20,2>}

Functions

- rel[int, int] inv(rel[int,int] R) =
  { <Y, X> | <int X, int Y> : R }
  - inv({1,10>, <2,20>} yields {<10,1>,<20,2>}
- rel[&B, &A] inv(rel[&A, &B] R) =
  { <Y, X> | <&A X, &B Y> : R}
  - inv({<1,"a">, <2,"b">}) yields {<"a",1>,<"b",2>}

&A, &B indicate *any* type and are used to define polymorphic functions

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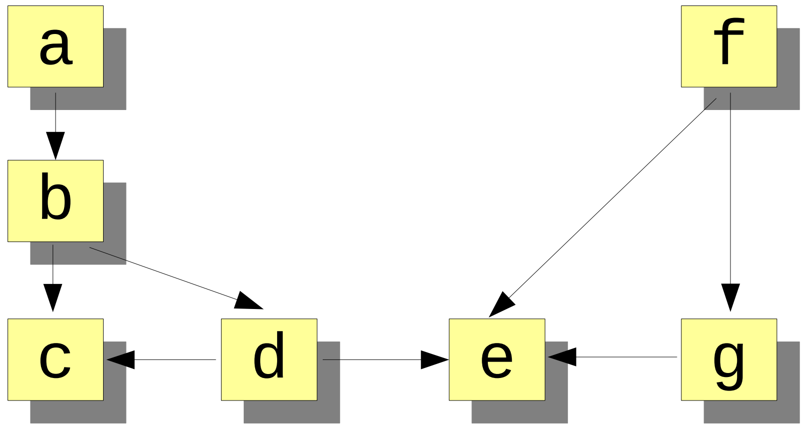
Analyzing the call structure of an application



```
rel[str, str] calls = {<"a", "b">, <"b", "c">, <"b", "d">, <"d", "c">,
                       <"d","e">, <"f", "e">, <"f", "g">, <"g", "e">}
```

Some questions

$$\begin{tikzcd}
a \arrow[d] & & & f \arrow[ddl] \arrow[dd] \\
b \arrow[d] \arrow[dr] & & & \\
c & d \arrow[l] \arrow[r] & e & g \arrow[l]
\end{tikzcd}$$

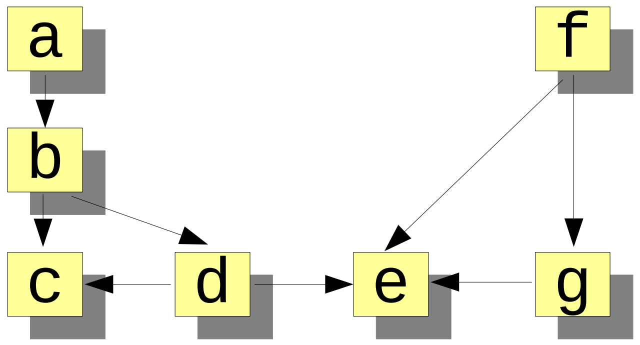
- How many calls are there?
  - int ncalls = # calls
  - 8

Number of elements

- How many procedures are there?
  - int nprocs = # carrier(calls)
  - 7

All elements in domain or range of a relations

Some questions


$$\begin{tikzcd}
a \arrow[d] & & & & f \arrow[dl] \arrow[d] \\
b \arrow[d] \arrow[dr] & & & & g \\
c & d \arrow[l] \arrow[r] & e & & g \arrow[ll]
\end{tikzcd}$$

- What are the entry points?
  - `set[str] entryPoints = top(calls)`
  - `{"a", "f"}`
- What are the leaves?
  - `set[str] bottomCalls = bottom(calls)`
  - `{"c", "e"}`

The *roots* of a relation (viewed as a graph)

The *leaves* of a relation (viewed as a graph)

Intermezzo: Top

- The roots of a relation viewed as a graph
- `top({<1,2>,<1,3>,<2,4>,<3,4>})` yields `{1}`
- Consists of all elements that occur on the lhs but not on the rhs of a tuple

-
  ```
  set[&T] top(rel[&T, &T] R) =
            domain(R) \ range(R)
  ```

Intermezzo: Bottom

- The leaves of a relation viewed as a graph
- `bottom({<1,2>,<1,3>,<2,4>,<3,4>})` yields `{4}`
- Consists of all elements that occur on the rhs but not on the lhs of a tuple

-
  ```
  set[&T] bottom(rel[&T, &T] R) =
            range(R) \ domain(R)
  ```

Some questions

$$\begin{tikzcd}
a \arrow[d] & & & f \arrow[ddl] \arrow[dd] \\
b \arrow[d] \arrow[dr] & & & \\
c & d \arrow[l] \arrow[r] & e & g \arrow[l]
\end{tikzcd}$$

- What are the indirect calls between procedures?
  - rel[str,str] closureCalls = calls+
  - {<"a", "b">, <"b", "c">, <"b", "d">, <"d", "c">, <"d","e">, <"f", "e">, <"f", "g">, <"g", "e">, <"a", "c">, <"a", "d">, <"b", "e">, <"a", "e">}
- What are the calls from entry point a?
  - set[str] calledFromA = closureCalls["a"]
  - {"b", "c", "d", "e"}

The image of domain value “a”

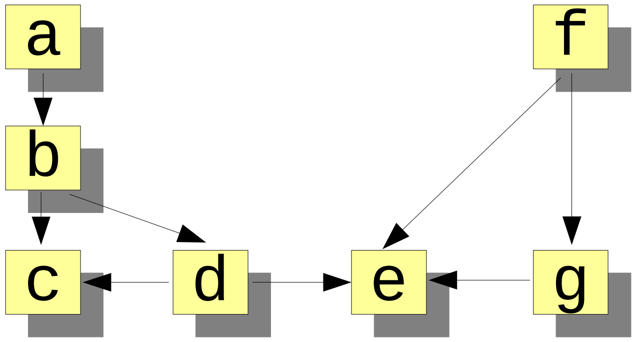
Intermezzo: right image

- Right-image of a relation: all elements that have a given value as left element (resembles array access)
- Notation: relation followed by [Value]
- Ex. Rel = {<1,10>,<2,20>,<1,11>,<3,30>,<2,21>}
- Rel[1] yields {10,11}
- Rel[{1,2}] yields {10, 11, 20, 21}

Intermezzo: left image

- Left-image of a relation: all elements that have a given value as right element
- Notation: relation followed by [-,Value]
- Ex. Rel = {<1,10>,<2,20>,<1,11>,<3,30>,<2,21>}
- Rel[-,10] yields {1}
- Rel[-,{10,20}] yields {1,2}

Some questions



- What are the calls to procedure e?
  - set[str] callsToE = closureCalls[-,"e"]
  - {"a", "b", "d", "f", "g"}

The domain of image value "e"

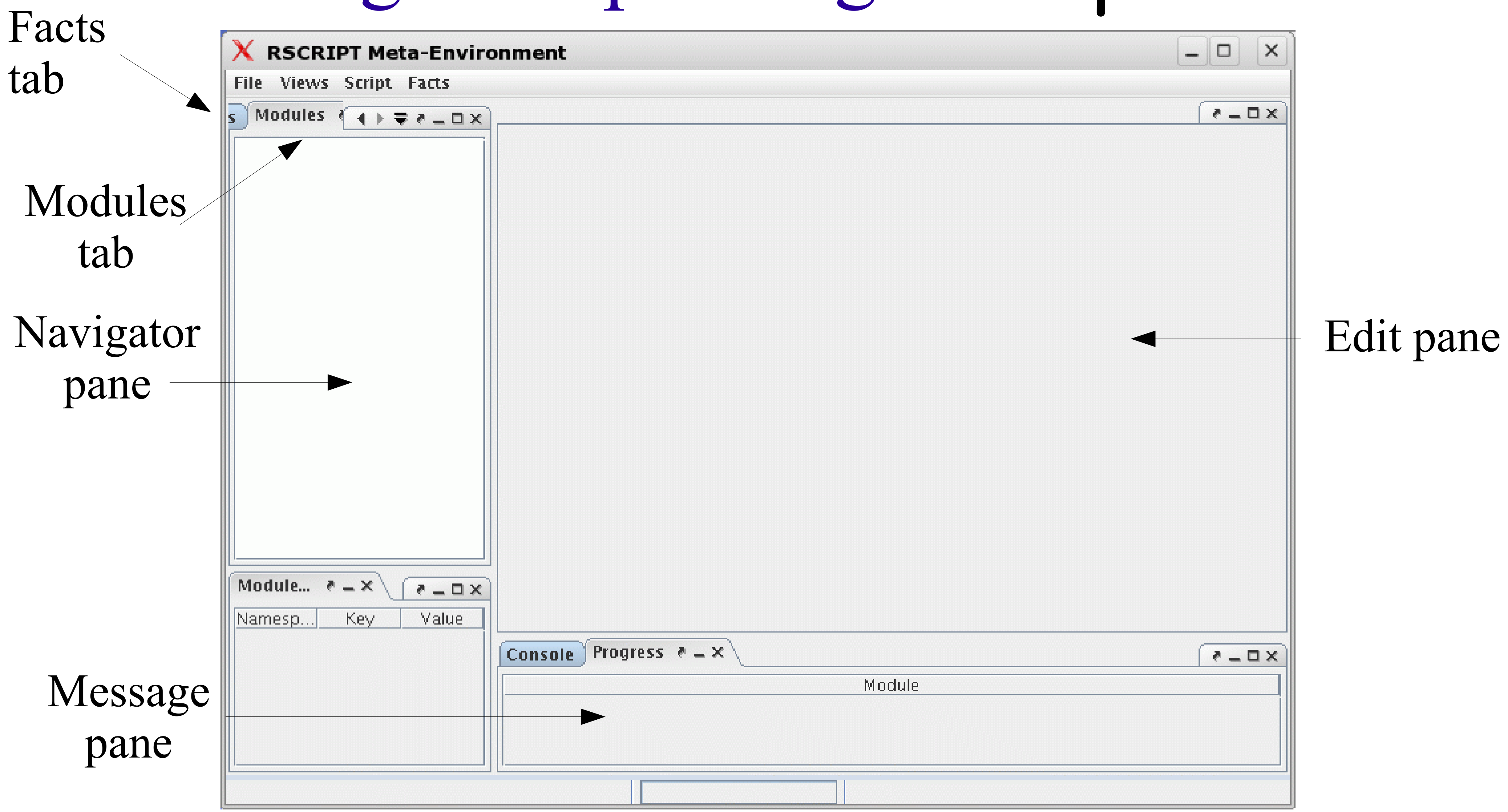
Some questions

$$\begin{tikzcd}
a \arrow[d] & & & f \arrow[ddl] \arrow[dd] \\
b \arrow[d] \arrow[dr] & & & \\
c & d \arrow[l] \arrow[r] & e & g \arrow[l]
\end{tikzcd}$$

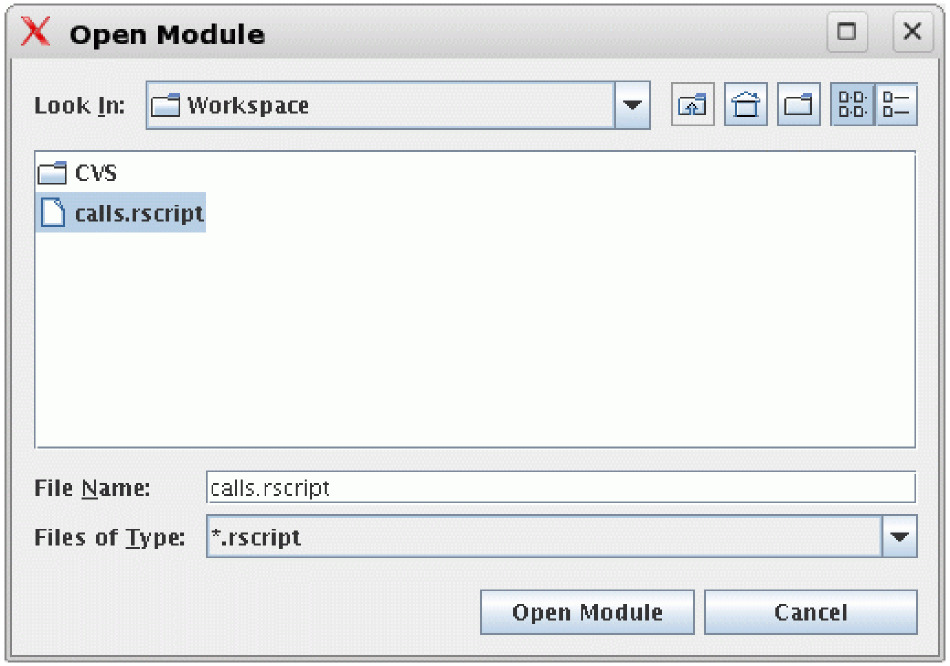
- What are the calls from entry point `f`?
  - `set[str] calledFromF = closureCalls["f"]`
  - `{"e", "g"}`
- What are the common procedures?
  - `set[str] commonProcs = calledFromA inter calledFromF`
  - `{"e"}`

Intersection

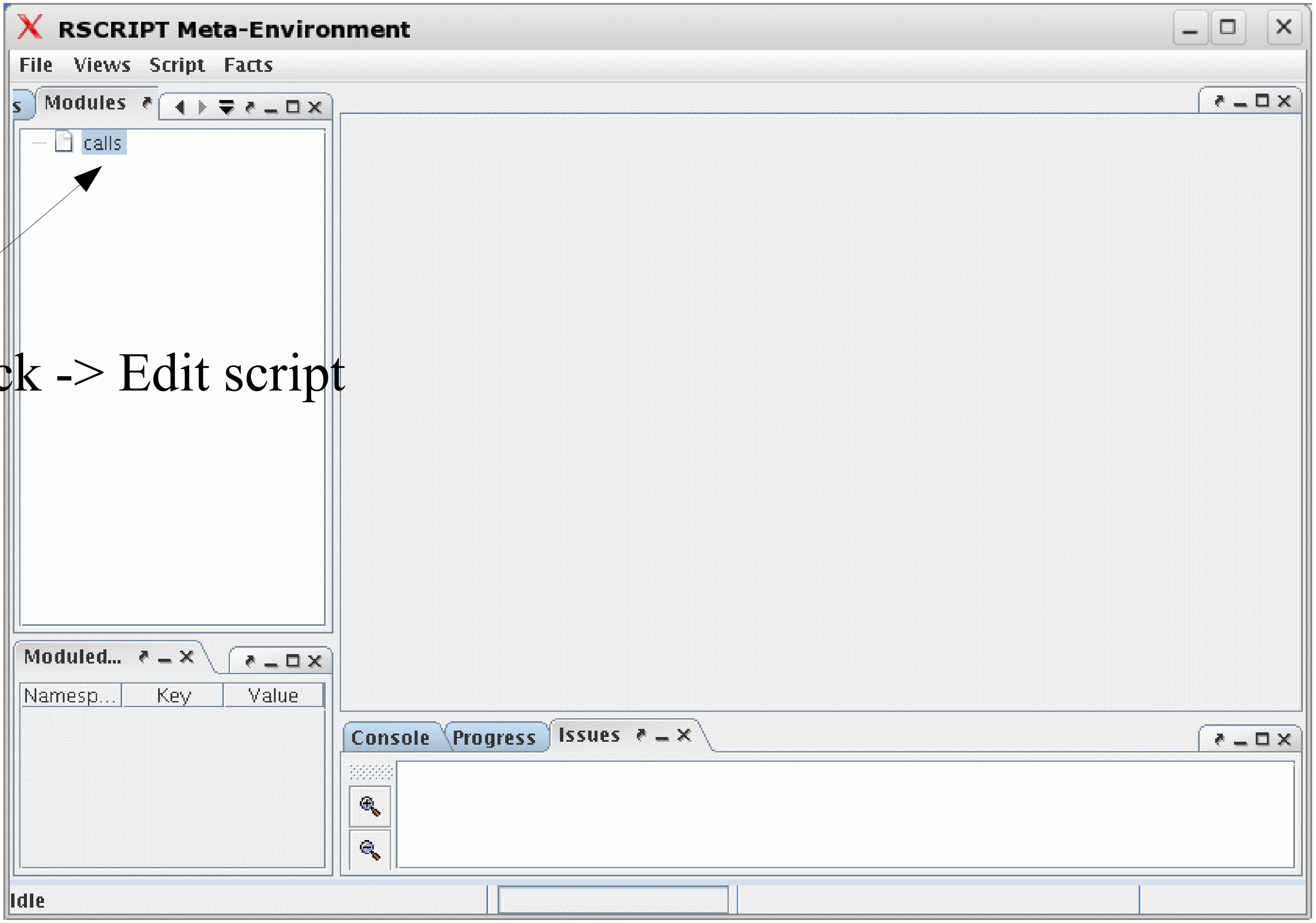
Running Rscript using rscript-meta



Script -> Open...

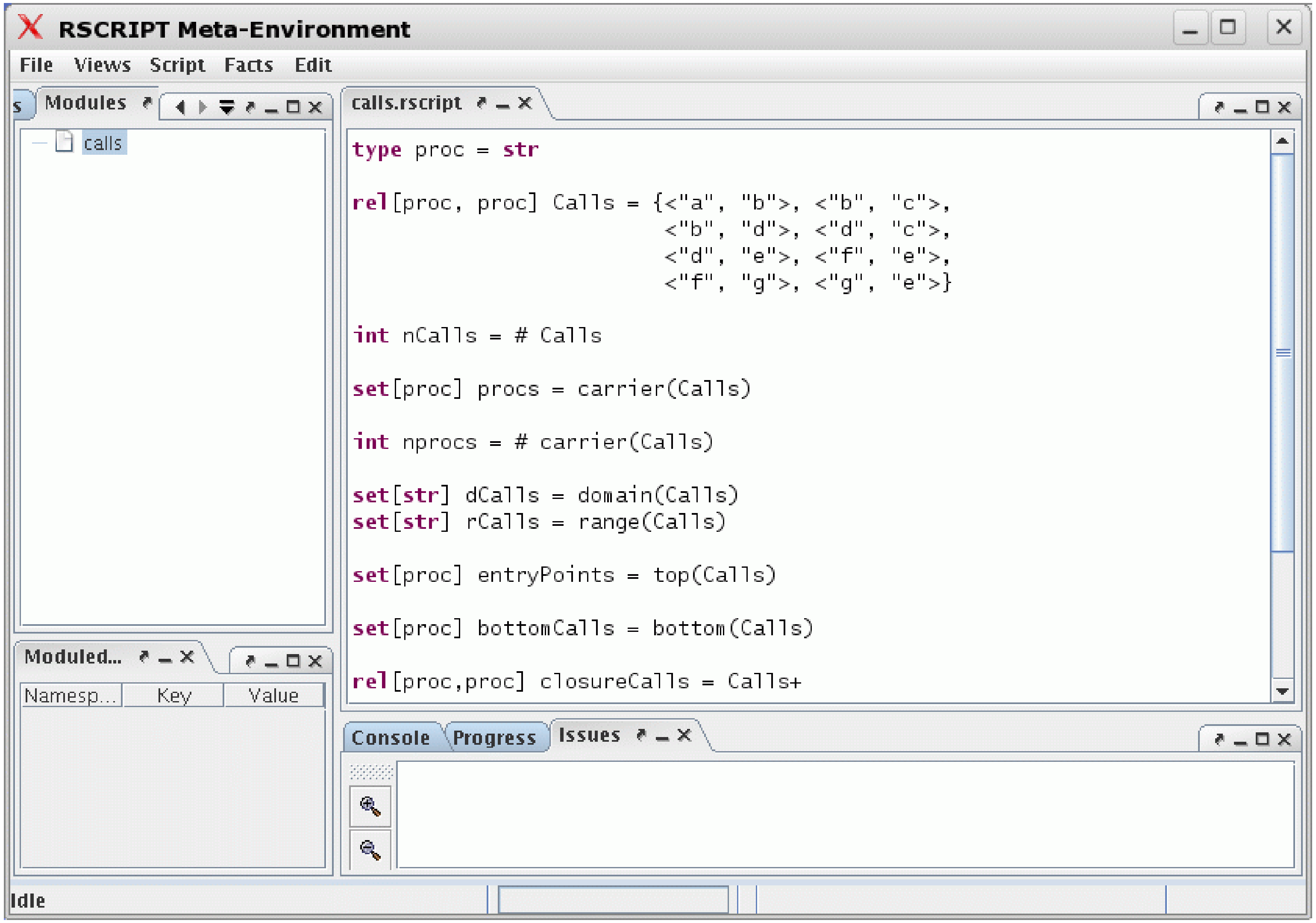

Open Module
Look In: Workspace
CVS
calls.rscript
File Name: calls.rscript
Files of Type: *.rscript
Open Module
Cancel

File calls has been opened



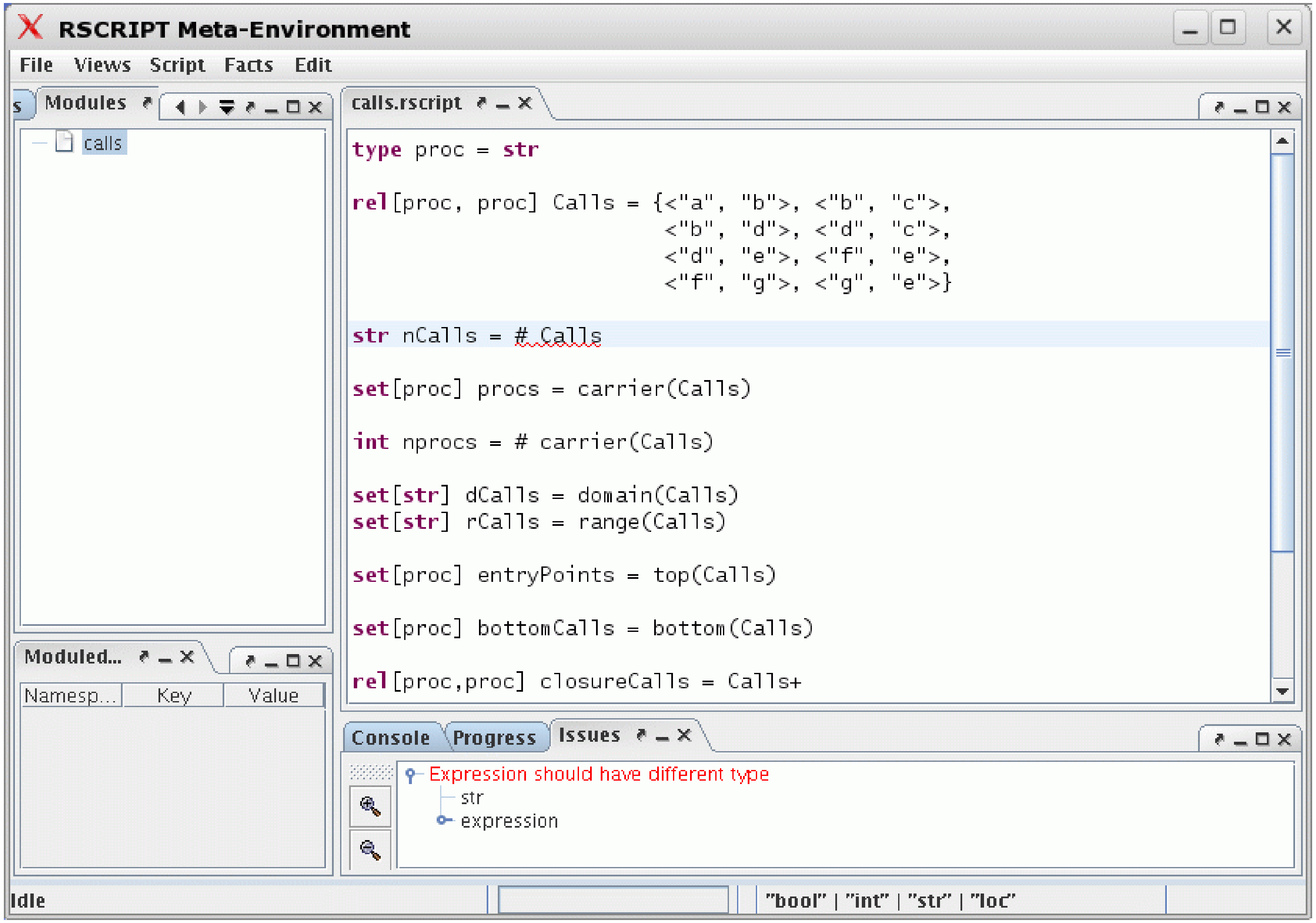
Right click -> Edit script

Editing calls.rscript



```
type proc = str

rel[proc, proc] Calls = {<"a", "b">, <"b", "c">,
                         <"b", "d">, <"d", "c">,
                         <"d", "e">, <"f", "e">,
                         <"f", "g">, <"g", "e">}

int nCalls = # Calls

set[proc] procs = carrier(Calls)

int nprocs = # carrier(Calls)

set[str] dCalls = domain(Calls)
set[str] rCalls = range(Calls)

set[proc] entryPoints = top(Calls)

set[proc] bottomCalls = bottom(Calls)

rel[proc,proc] closureCalls = Calls+
```

Making errors ...



```
type proc = str

rel[proc, proc] Calls = {<"a", "b">, <"b", "c">,
                         <"b", "d">, <"d", "c">,
                         <"d", "e">, <"f", "e">,
                         <"f", "g">, <"g", "e">}

str nCalls = # Calls

set[proc] procs = carrier(Calls)

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set[str] dCalls = domain(Calls)
set[str] rCalls = range(Calls)

set[proc] entryPoints = top(Calls)

set[proc] bottomCalls = bottom(Calls)

rel[proc,proc] closureCalls = Calls+
```
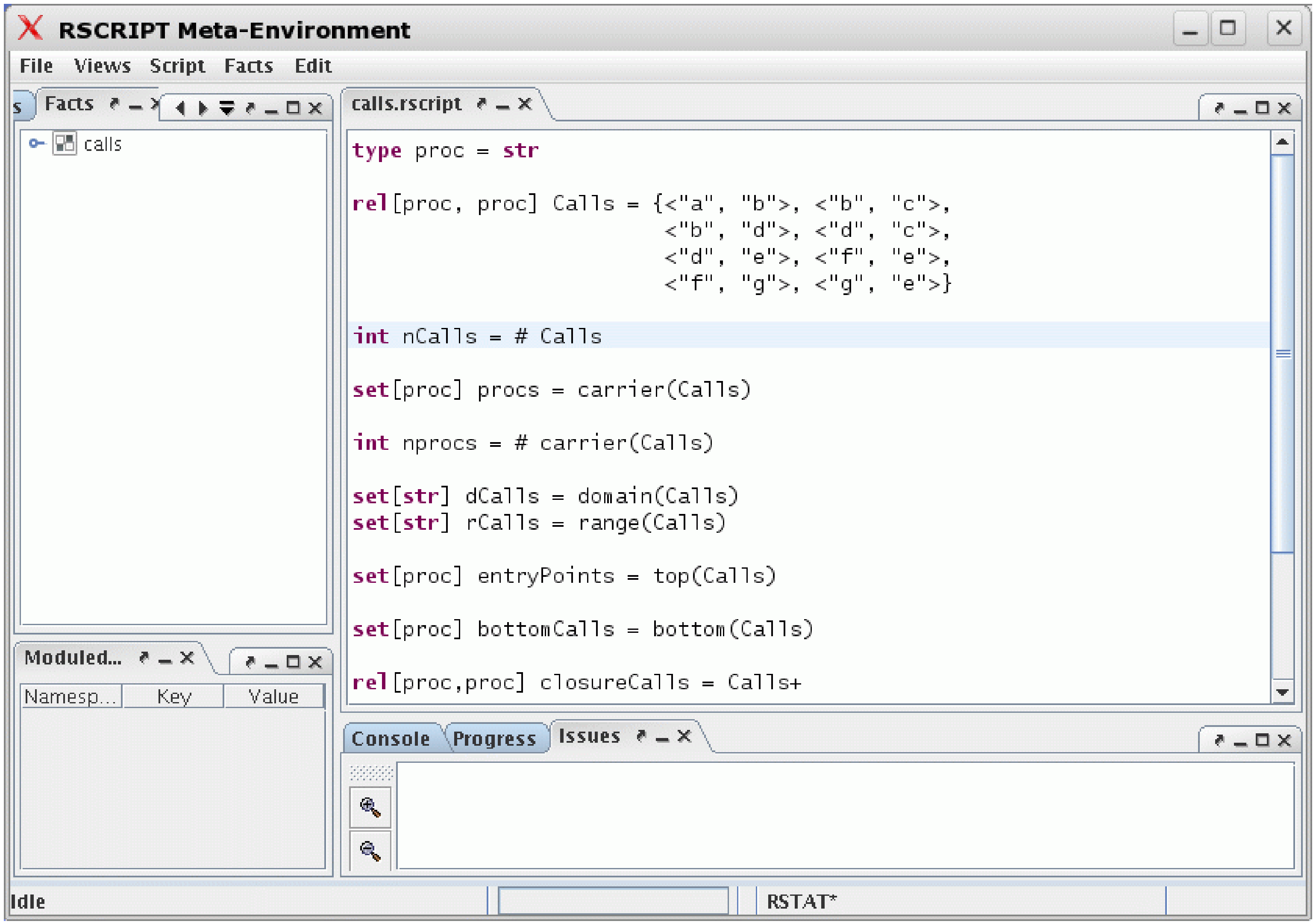

```
Expression should have different type
    str
    expression
```

Script -> Run



```
type proc = str

rel[proc, proc] Calls = {<"a", "b">, <"b", "c">,
                         <"b", "d">, <"d", "c">,
                         <"d", "e">, <"f", "e">,
                         <"f", "g">, <"g", "e">}

int nCalls = # Calls

set[proc] procs = carrier(Calls)

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set[proc] bottomCalls = bottom(Calls)

rel[proc,proc] closureCalls = Calls+
```
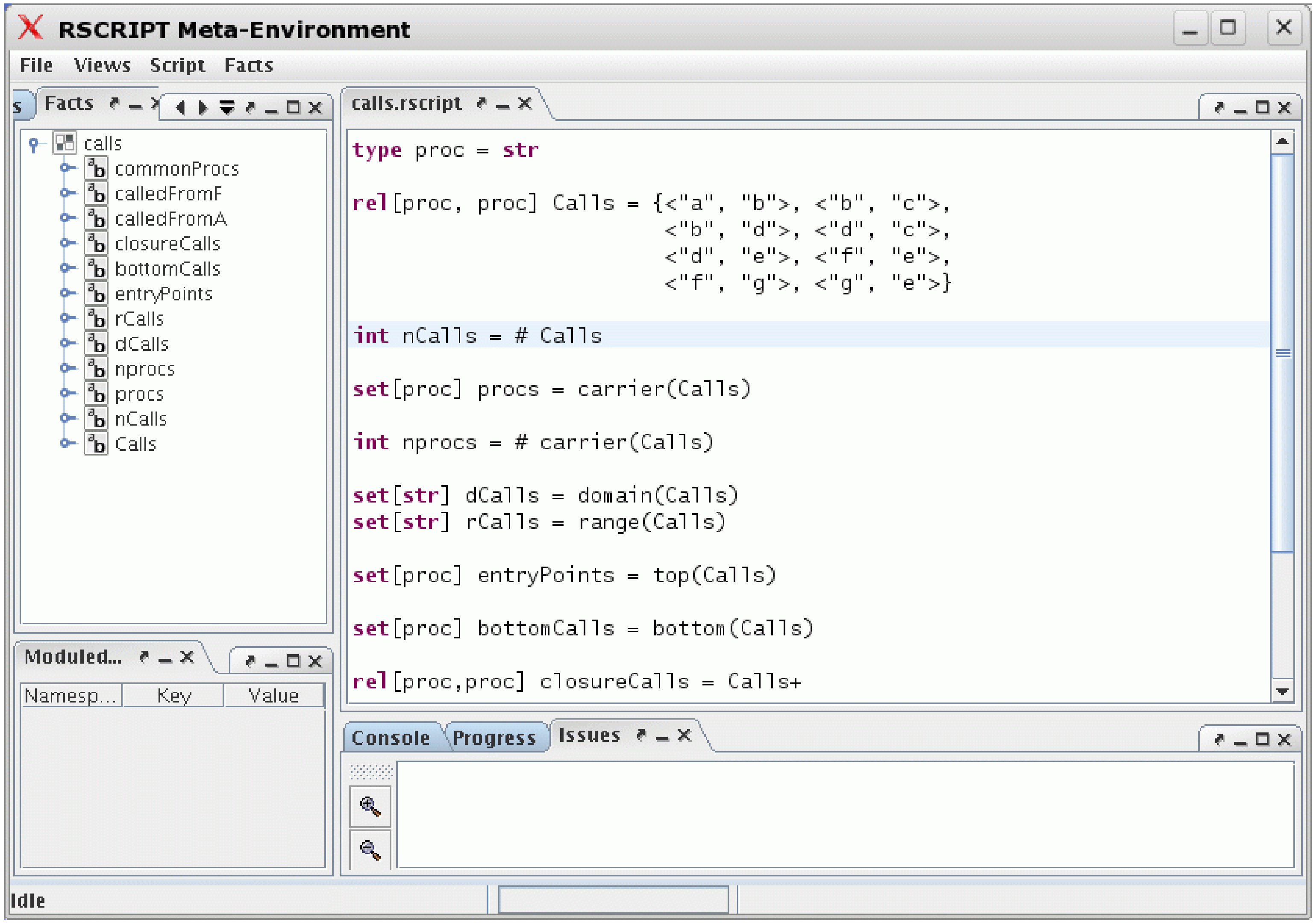
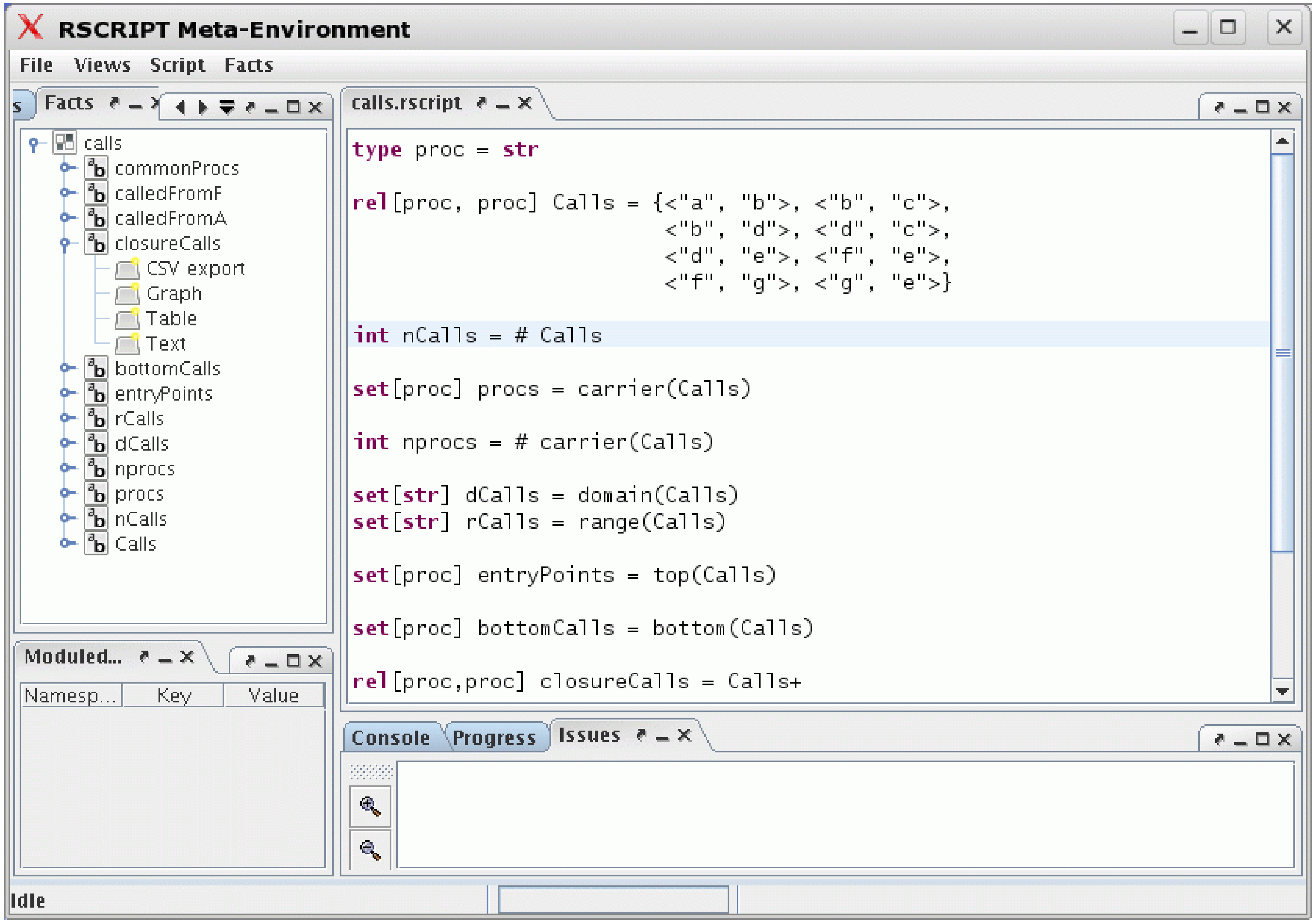

Unfolding the rstore ...



```
calls
  commonProcs
  calledFromF
  calledFromA
  closureCalls
  bottomCalls
  entryPoints
  rCalls
  dCalls
  nprocs
  procs
  nCalls
  Calls
```

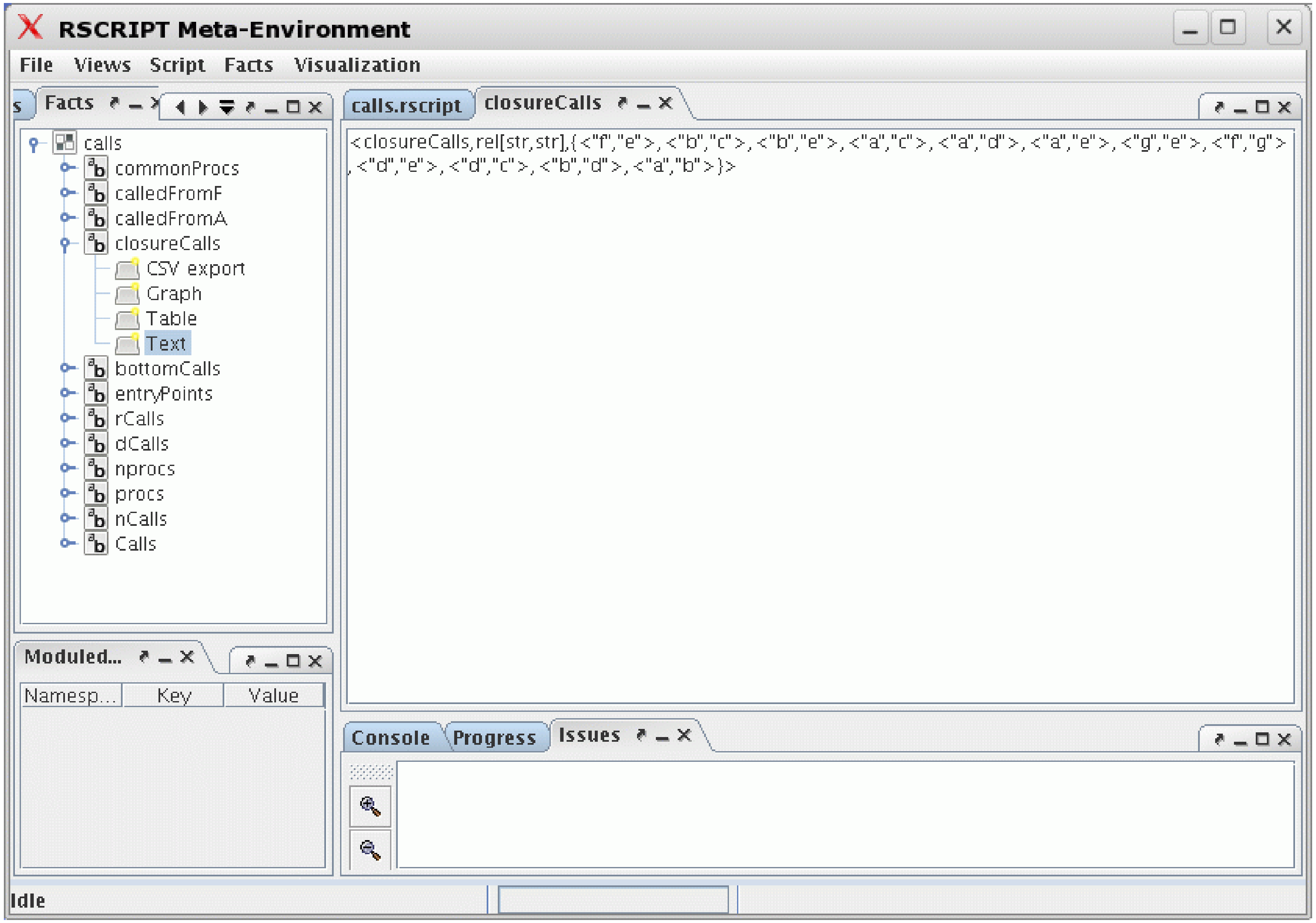
```
type proc = str

rel[proc, proc] Calls = {<"a", "b">, <"b", "c">,
                         <"b", "d">, <"d", "c">,
                         <"d", "e">, <"f", "e">,
                         <"f", "g">, <"g", "e">}

int nCalls = # Calls

set[proc] procs = carrier(Calls)

int nprocs = # carrier(Calls)

set[str] dCalls = domain(Calls)
set[str] rCalls = range(Calls)

set[proc] entryPoints = top(Calls)

set[proc] bottomCalls = bottom(Calls)

rel[proc,proc] closureCalls = Calls+
```

Unfolding closureCalls



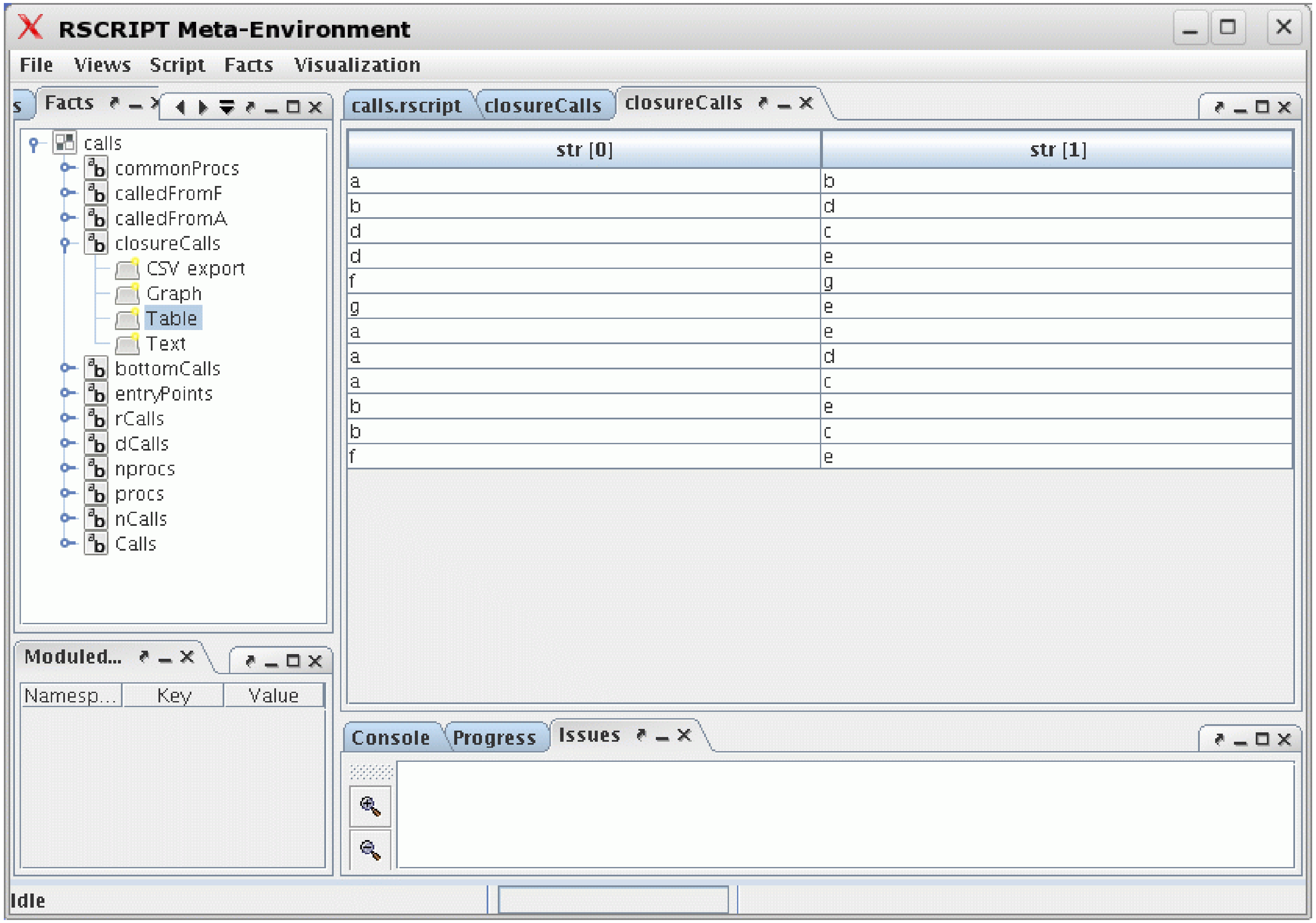
```
type proc = str

rel[proc, proc] Calls = {<"a", "b">, <"b", "c">,
                         <"b", "d">, <"d", "c">,
                         <"d", "e">, <"f", "e">,
                         <"f", "g">, <"g", "e">}

int nCalls = # Calls

set[proc] procs = carrier(Calls)

int nprocs = # carrier(Calls)

set[str] dCalls = domain(Calls)
set[str] rCalls = range(Calls)

set[proc] entryPoints = top(Calls)

set[proc] bottomCalls = bottom(Calls)

rel[proc,proc] closureCalls = Calls+
```

closureCalls as Text



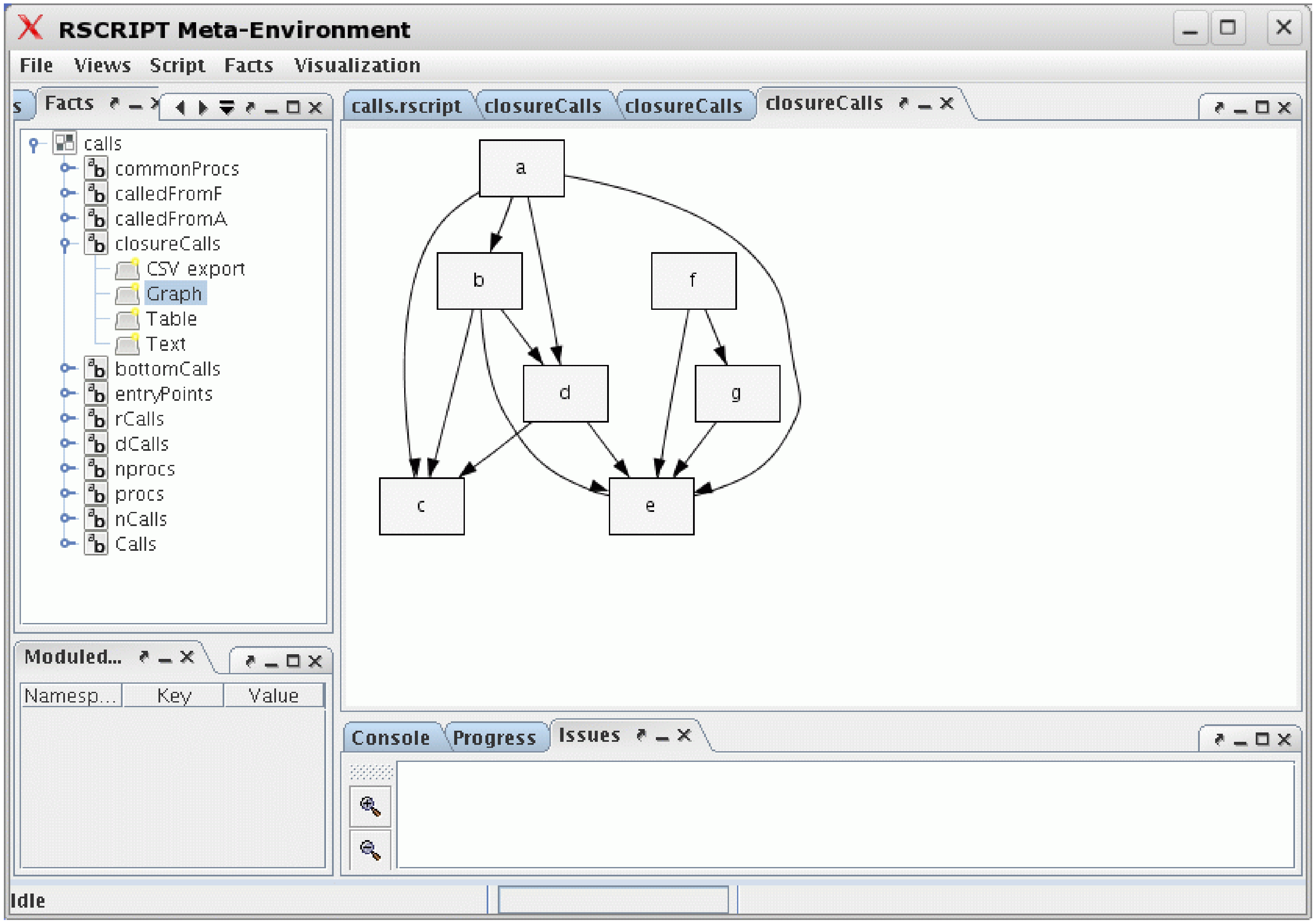
```
<closureCalls,rel[str,str],{<"f","e">,<"b","c">,<"b","e">,<"a","c">,<"a","d">,<"a","e">,<"g","e">,<"f","g">
,<"d","e">,<"d","c">,<"b","d">,<"a","b">}>
```

closureCalls as Table



str [0]	str [1]
a	b
b	d
d	c
d	e
f	g
g	e
a	e
a	d
a	c
b	e
b	c
f	e

closureCalls as Graph



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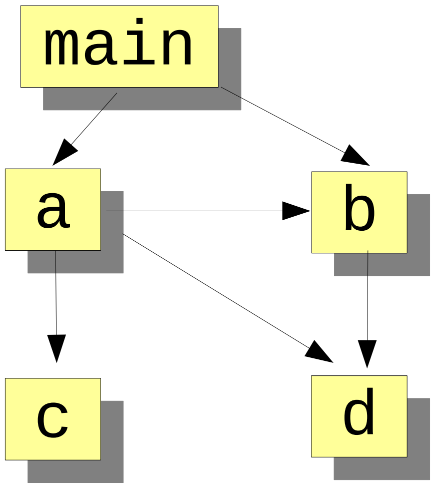
Component Structure of Application

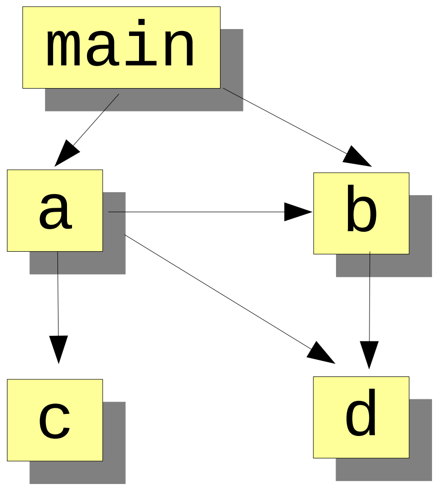
- Suppose, we know:
  - the call relation between procedures (`Calls`)
  - the component of each procedure (`PartOf`)
- Question:
  - Can we lift the relation between procedures to a relation between components (`ComponentCalls`)?
- This is usefull for checking that real code conforms to architectural constraints

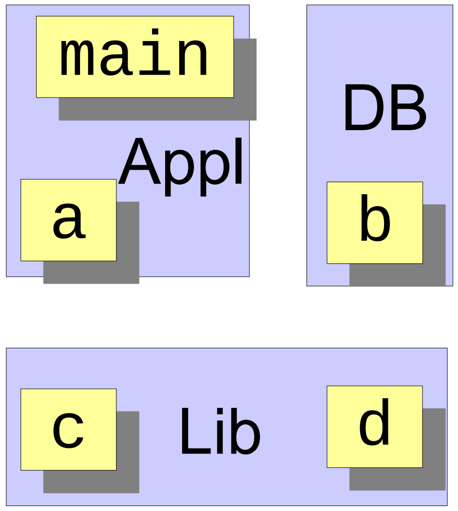
Calls



```
type proc = str
type comp = str
rel[proc,proc] Calls = {<"main", "a">, <"main", "b">, <"a", "b">,
                         <"a", "c">, <"a", "d">, <"b", "d">}
```

PartOf

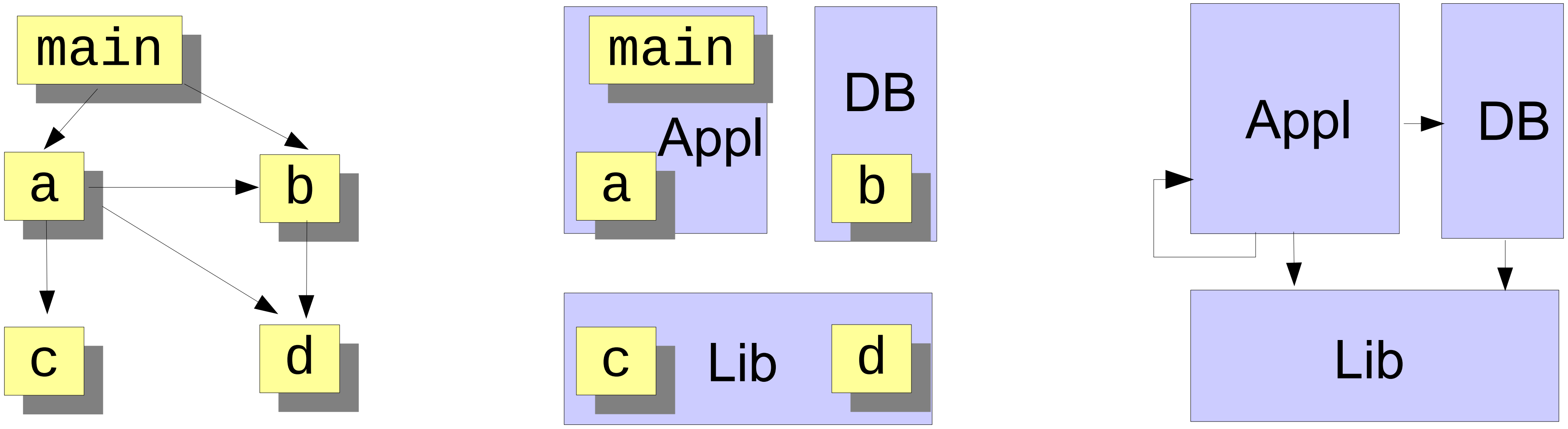




```
set[comp] Components = {"Appl", "DB", "Lib"}

rel[proc, comp] PartOf =
    {<"main", "Appl">, <"a", "Appl">, <"b", "DB">,
                                        <"c", "Lib">, <"d", "Lib">}
```

lift



```
rel[comp,comp] lift(rel[proc,proc] aCalls,  rel[proc,comp] aPartOf) =
   { <C1, C2> | <proc P1, proc P2> : aCalls,
             <comp C1, comp C2> : aPartOf[P1] x aPartOf[P2] }

rel[comp,comp] ComponentCalls = lift(Calls2, PartOf)
```

Result: {<"DB", "Lib">, <"Appl", "Lib">, <"Appl", "DB">, <"Appl", "Appl">}

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Cyclic Dependencies

- A class uses (directly or indirectly) itself
- Use = methods calls, inheritance, containment

```
class ContainedClass { }
class SuperClass {}
class SubClass extends SuperClass {
   ContainedClass C;
 }
```

Example of
a contained class

Motivation: cyclic class dependencies are difficult to understand/maintain

Cyclic Dependencies: Examples

```
class A {  B B1; ... }
class B extends A { ... }
```

```
class A {  C C1; ... }
class B extends A{ ... }
class C { B B1;  ...}
```

Java analysis: classes in cycles

- Assume the following extracted information:
  - rel[str,str] CALL
    - method call from first class to the second
  - rel[str,str] INHERITANCE
    - extends and implements
  - rel[str,str] CONTAINMENT
    - attribute of first class is of the type of the second class
- Question: which classes occur in a cyclic dependency?

Java analysis: cycles in classes

- Define the USE relation between two classes:

  -
    ```
    rel[str,str] USE = CALL union CONTAINMENT
                                union INHERITANCE
    ```

  -
    ```
    set[str] ClassesInCycle =
    {C1 | <str C1, str C2> : USE+, C1 == C2}
    ```
- In this way we get a set of classes that occur in a cyclic dependency, but ...
- ... which classes are in the cycle?

Java analysis: cyclic classes

```
rel[str,str] USE = CALL union CONTAINMENT
                   union INHERITANCE

set[str] CLASSES = carrier(USE)

rel[str,str] USETRANS = USE+

rel[str,set[str]] =  {<C, USETRANS[C]> |
                           str C : CLASSES,
                         <C, C> in USETRANS}
```

Each cyclic class is associated with a set of classes that form a cycle

Applications of this approach

- Search for “similar” classes
- Search for design patterns (as characterized by specific relations between the classes in the pattern)
- …

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Toy program

```
begin declare x : natural, y : natural,
                z : natural;
    x :=  3;
    if      3 then
            z := y + x
    else
            x := 4
    fi
     y := z
end
```

y is undefined

z may be undefined

Toy program

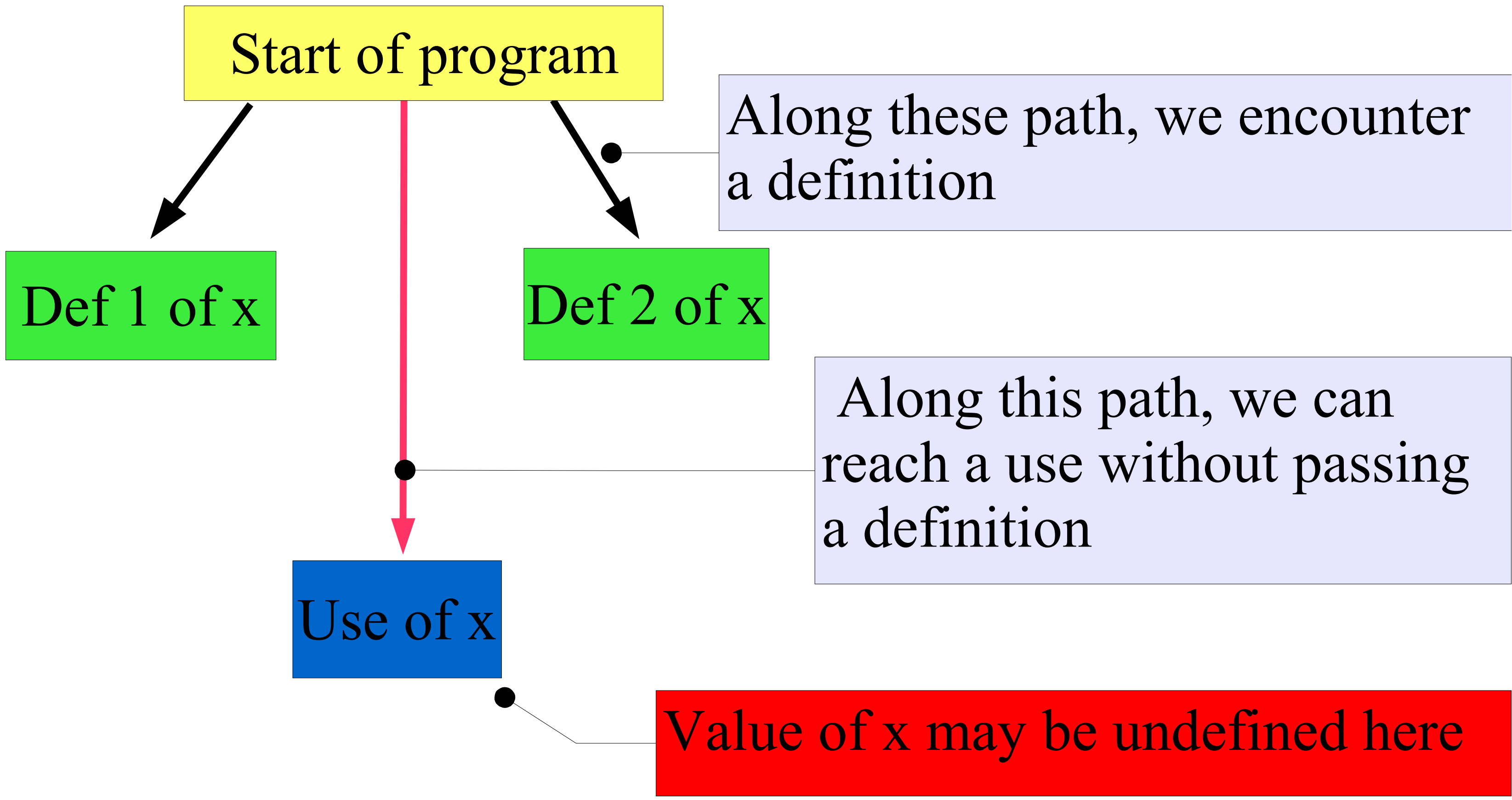
```
rel[int,str] DEFS = {<1,"x">, <3,"z">, <4,"x">, <5,"y">}
```

```
 begin declare x : natural, y : natural,
                   z : natural;
[1]  x :=  3;
     if[2]  3 then
       [3]  z := y + x
     else
       [4]  x := 4
     fi
[5]  y := z
 end
```

```
rel[int,str] USES = {<3,"y">, <3,"x">, <5,"z">}
```

```
rel[int,int] PRED = {<0,1>, <1,2>, <2,3>,<2,4>,
                 <3,5>,<4,5>}
```

Finding uninitialized variables


Start of program
Def 1 of x
Def 2 of x
Use of x
Along these path, we encounter a definition
Along this path, we can reach a use without passing a definition
Value of x may be undefined here

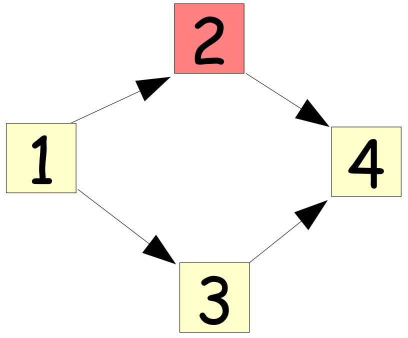
Intermezzo: reachX

- Reachability with exclusion of certain elements
- set[&T] reachX(

  set[&T] Start,

  set[&T] Excl,

  rel[&T,&T] Rel)



- reachX({1}, {2}, {<1,2>,<1,3>,<2,4>,<3,4>})

  yields {<3,4>}

The undefined query

```
rel[int,str] DEFS = ...
rel[int,str] USES = ...
rel[int,int] PRED = ...

rel[int,str] UNINIT =
{ <N,V> | <int N, str V>:USES, N in reachX({0}, DEFS[-,V],PRED)}
```

Start from the root

Exclude all definitions of V

There is a path from the root to N: V is not initialized

Use the PRED relation

Reach exclude

Applying the undefined query

```
 begin declare x : natural, y : natural,
               z : natural;
[1]  x :=  3;
     if [2]  3 then
        [3]  z := y • + x
     else
        [4]  x := 4
     fi
[5]  y := z•
 end
```

y is undefined

z may be undefined

Result:

{<5,"z">, <3,"y">}

Some Questions

- There are several additional questions:
  - In the example so far we have worked with statement numbers but how do we make a connection with the source text? (Discussed now)
  - How do we extract relations like PRED and USE from the source text? (Discussed later)

Use locations to connect with the source text

```
rel[int,str] DEFS = ...
rel[int,str] USES = ...
rel[int,int] PRED = ...
```

Use *location* instead of number

```
rel[loc,str] DEFS
rel[loc,str] USES
rel[loc,loc] PRED
rel[str, loc] OCCURS
```

Variable occurrence
in a statement

Example Rstore

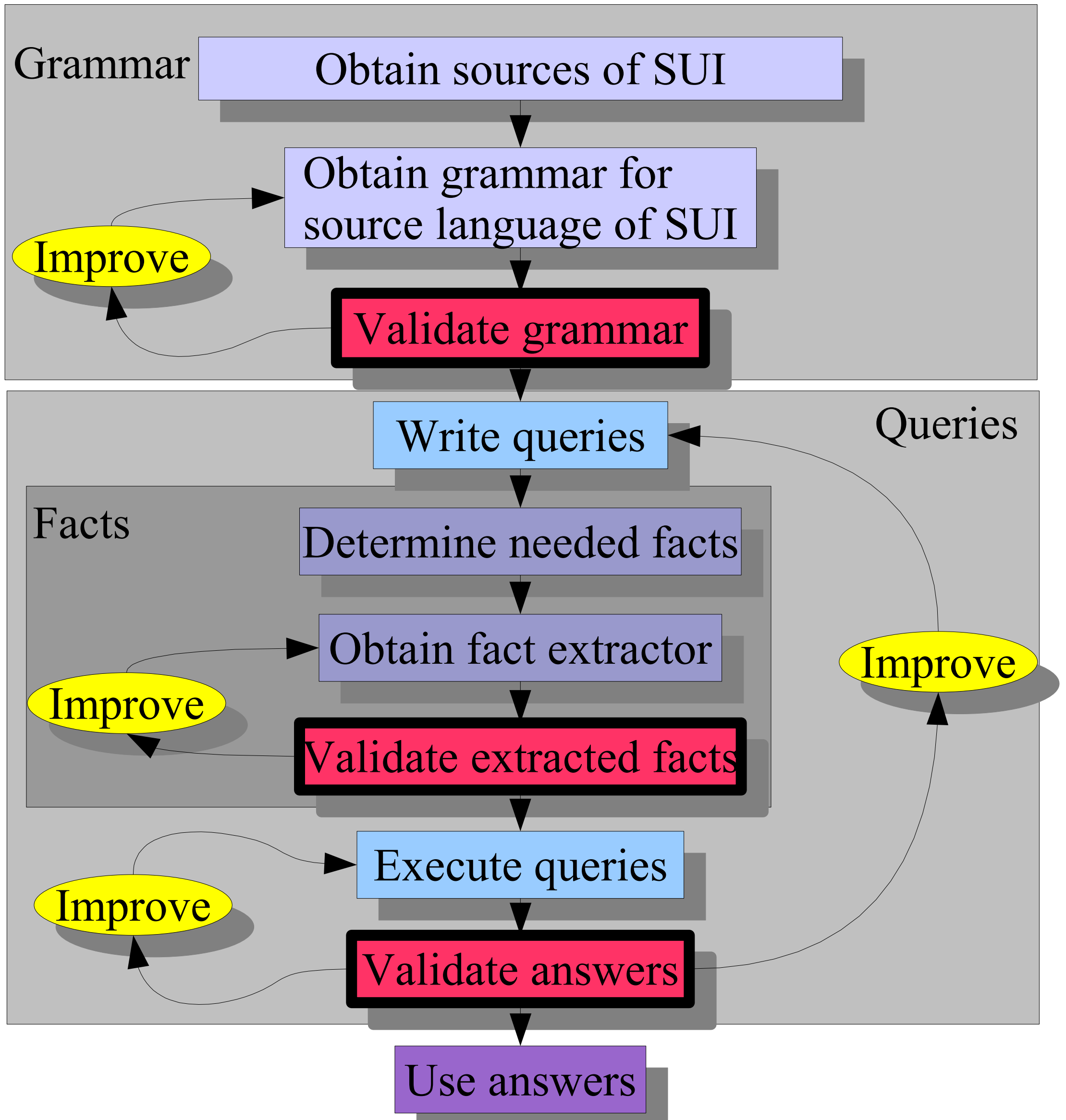
```
rstore(
  <PRED, rel[loc,loc],
           {<area-in-file("/home/paulk/.../example.pico", area(4, 2,4, 8,84, 6)),
              area-in-file("/home/paulk/.../example.pico", area(5, 2,5, 8,94, 6))>,
            <area-in-file("/home/paulk/.../example.pico", area(5, 2,5, 8, 94, 6)),
              area-in-file("/home/paulk/.../example.pico", area(6, 2,10, 4, 104, 56))>,
             ... }>,

 <DEFS, {
   <OCCURS, rel[str,loc],
            {<"y", area-in-file("/home/paulk/.../example.pico",area(11, 2,11, 3,164, 1))>,
             <"z", area-in-file("/home/paulk/.../example.pico", area(11, 7,11, 8,169, 1))>,
             ... }
 }
)
```

Extracting Facts

- Goal: extract facts from source code and use as input for queries
- How should fact extraction be organized?
- How to write a fact extractor?

Workflow Fact Extraction



SUI
=
System
Under
Investigation

Roadmap

- Rscript in a nutshell
- Example 1: call graph analysis
- Example 2: component structure
- Example 3: Java analysis
- Example 4: a toy language
- A vizualization experiment

Roadmap

- Rscript in a nutshell
- Example 1: call graph analysis
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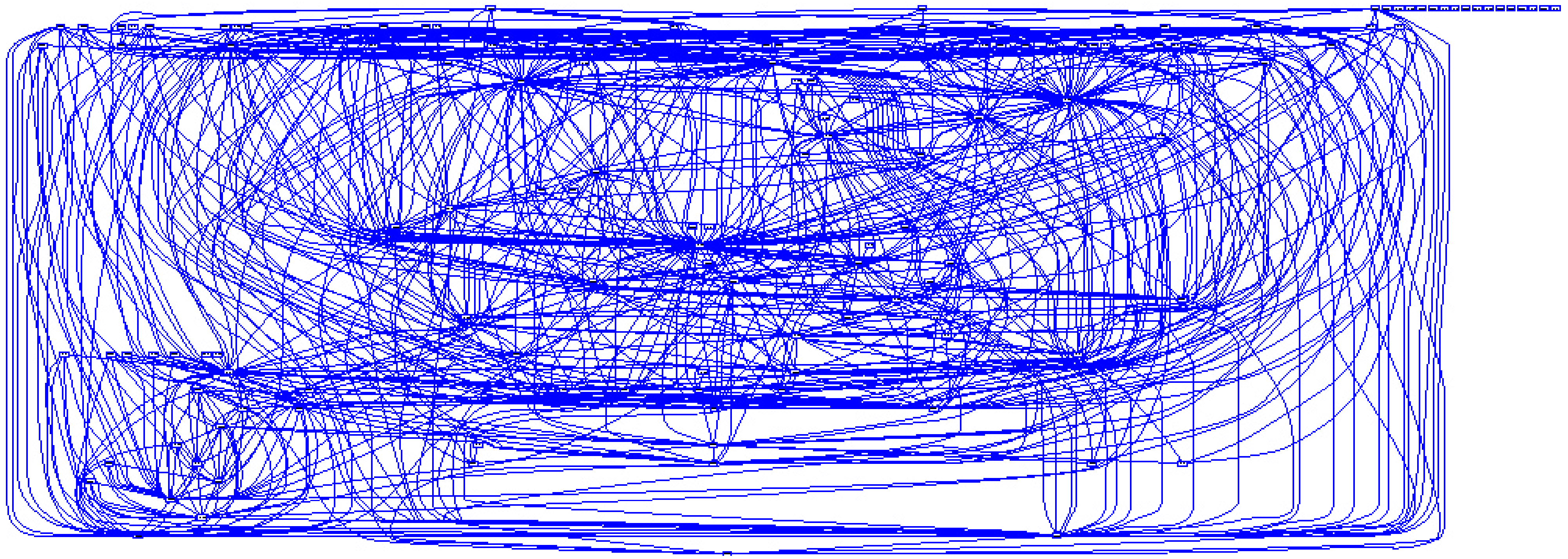
- Example 3: Java analysis
- Example 4: a toy language
- A vizualization experiment

Issues in Program Visualization

- Small graphs are nice, large graph are a disaster



(Courtesy: Arie van Deursen)

Issues in Program Visualization

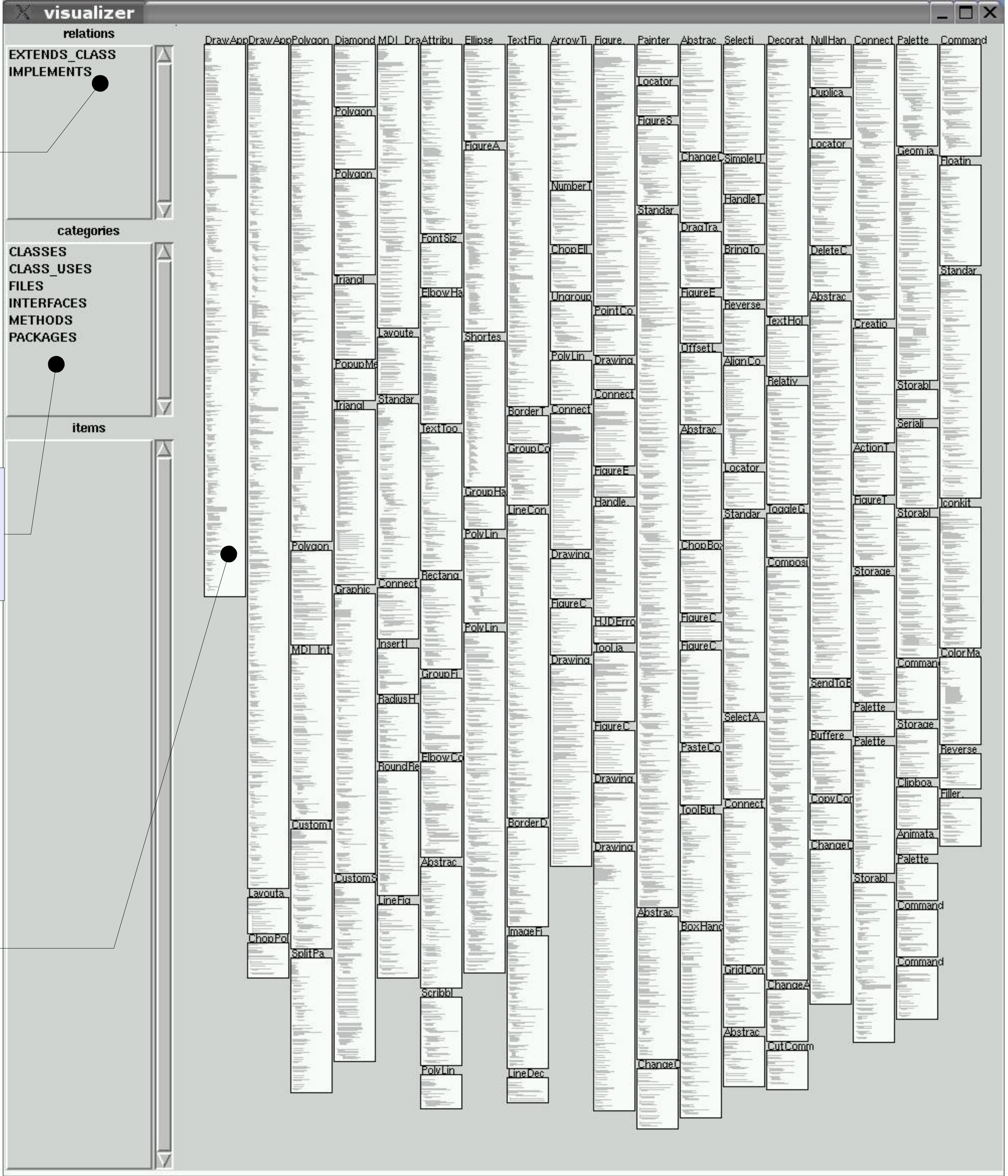
- Howto display information related to source text?
- Approach (Steven Eick): use a pixel-based image of the source text
- Over 100.000 LOC on one screen!
- Experiment: visualize an Rstore for JHotDRaw (15.000 LOC)

Extraction by Hayco de Jong and Taeke Kooiker (using ASF+SDF)

Relations

Categories of names

Rectangle per file

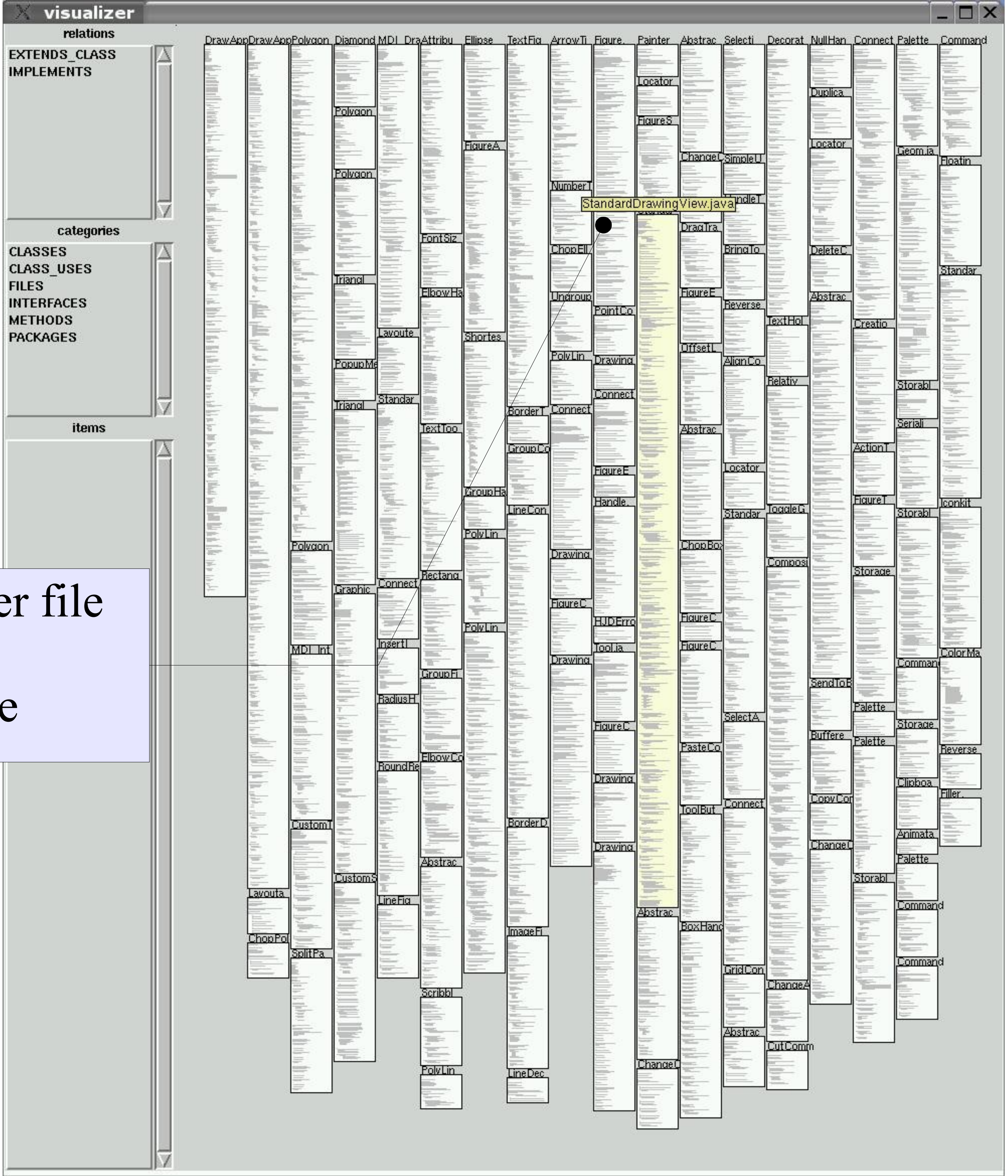


relations

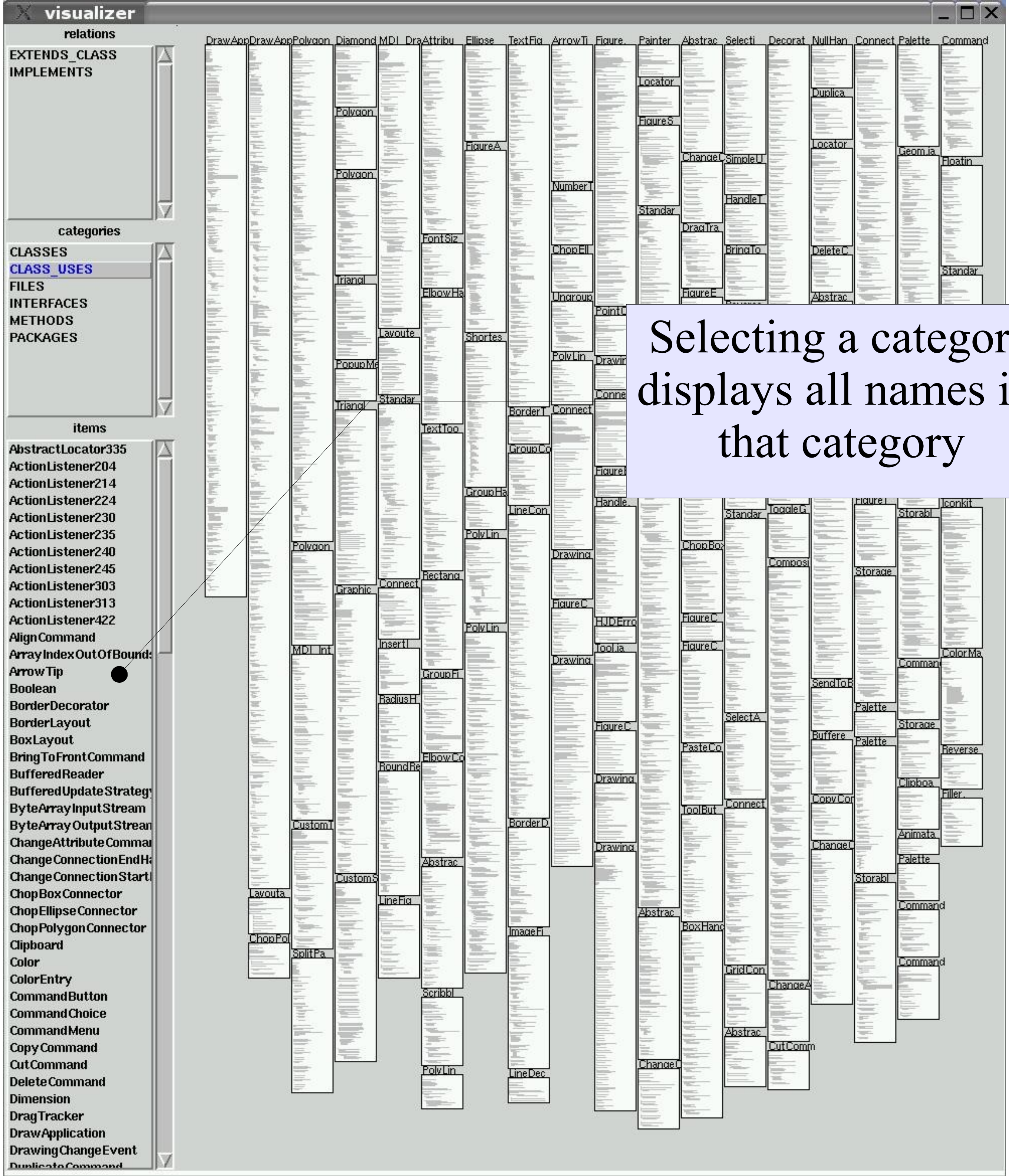
EXTENDS_CLASS
IMPLEMENTS

categories

CLASSES
CLASS_USES
FILES
INTERFACES
METHODS
PACKAGES



Hovering over file shows full name



relations

EXTENDS_CLASS
IMPLEMENTS

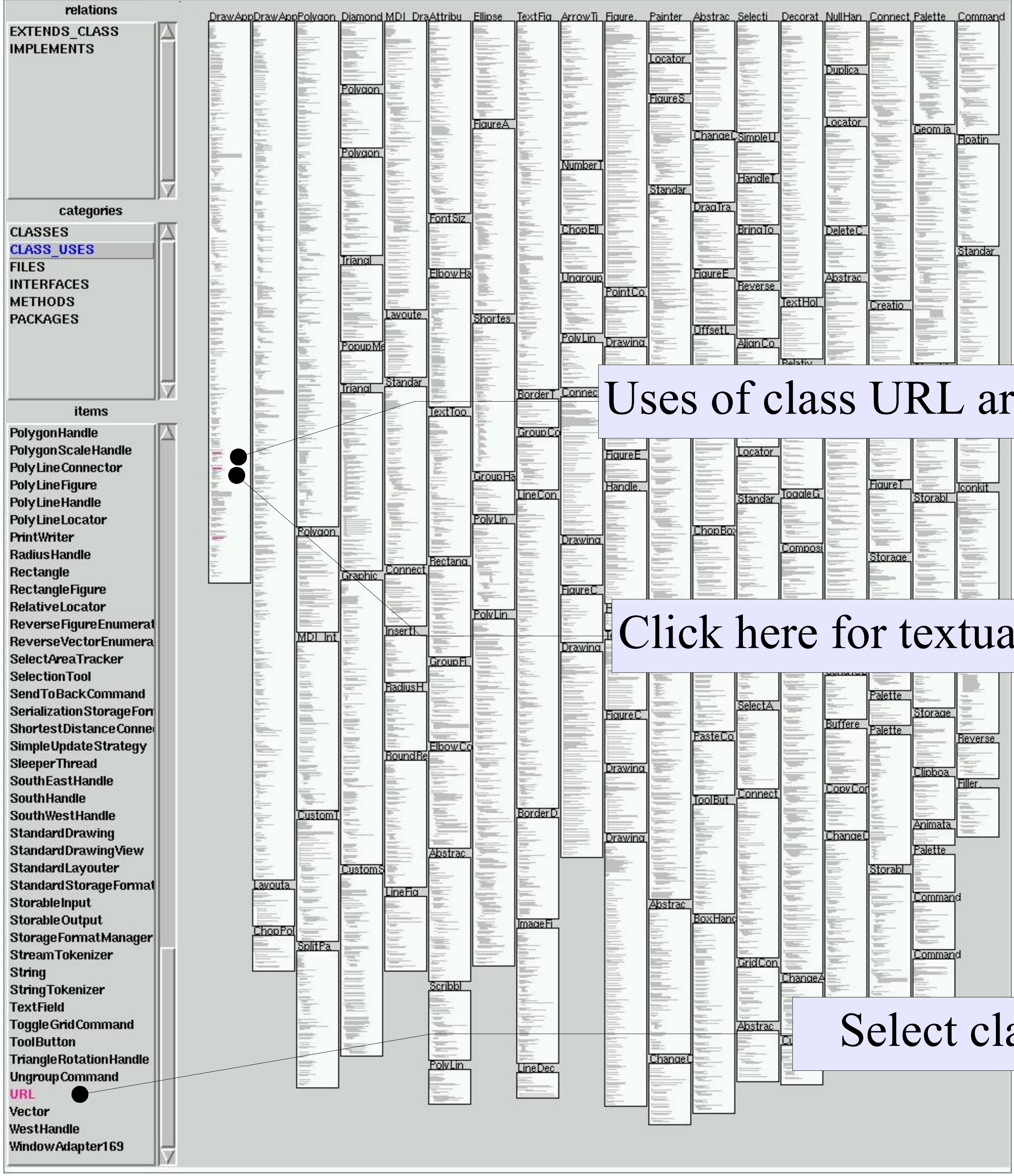
categories

CLASSES
CLASS_USES
FILES
INTERFACES
METHODS
PACKAGES

items

AbstractLocator335
ActionListener204
ActionListener214
ActionListener224
ActionListener230
ActionListener235
ActionListener240
ActionListener245
ActionListener303
ActionListener313
ActionListener422
AlignCommand
ArrayIndexOutOfBounds
ArrowTip
Boolean
BorderDecorator
BorderLayout
BoxLayout
BringToFrontCommand
BufferedReader
BufferedUpdateStrategy
ByteArrayInputStream
ByteArrayOutputStream
ChangeAttributeComman
ChangeConnectionEndHa
ChangeConnectionStartI
ChopBoxConnector
ChopEllipseConnector
ChopPolygonConnector
Clipboard
Color
ColorEntry
CommandButton
CommandChoice
CommandMenu
CopyCommand
CutCommand
DeleteCommand
Dimension
DragTracker
DrawApplication
DrawingChangeEvent
DuplicateCommand

Selecting a category displays all names in that category



relations

- EXTENDS_CLASS
- IMPLEMENTS

categories

- CLASSES
- CLASS_USES
- FILES
- INTERFACES
- METHODS
- PACKAGES

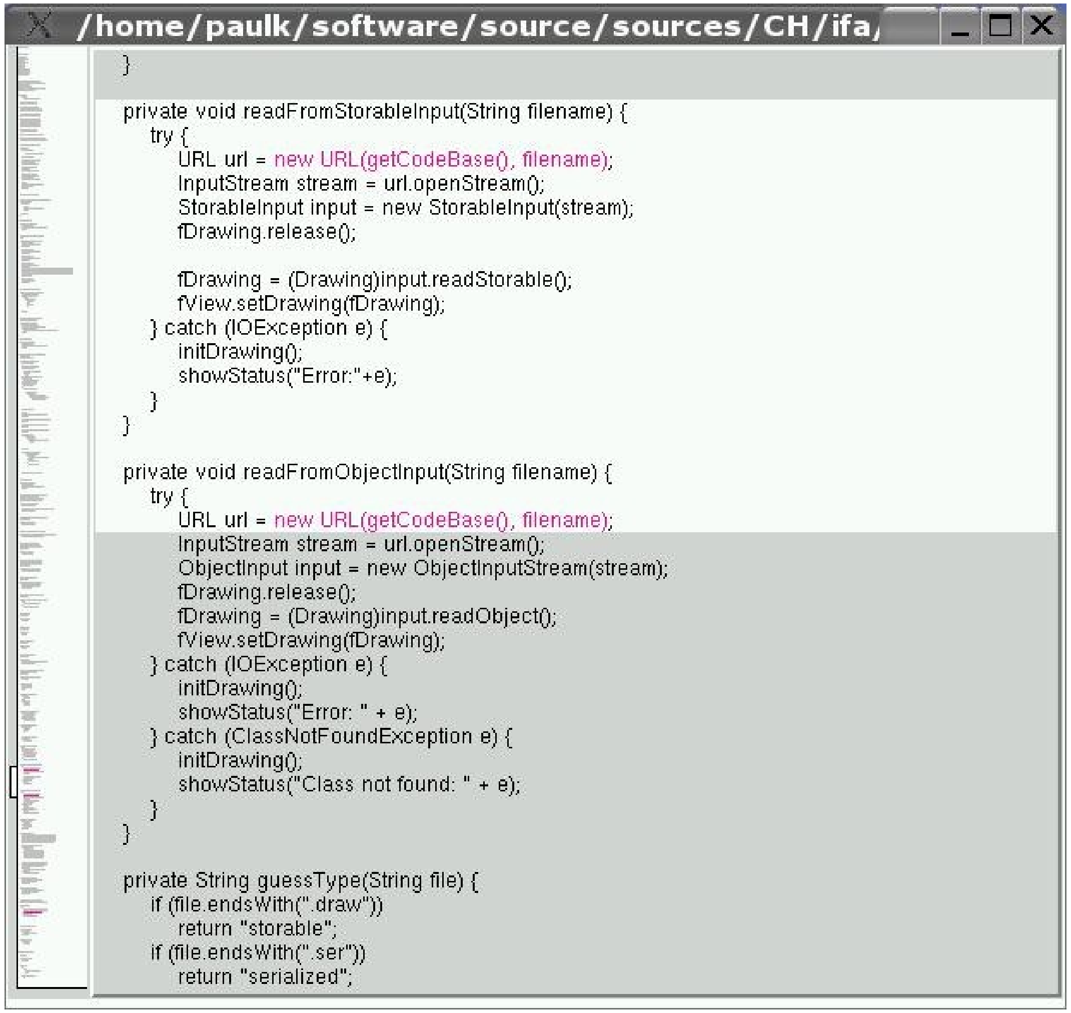
items

- PolygonHandle
- PolygonScaleHandle
- PolyLineConnector
- PolyLineFigure
- PolyLineHandle
- PolyLineLocator
- PrintWriter
- RadiusHandle
- Rectangle
- RectangleFigure
- RelativeLocator
- ReverseFigureEnumerat
- ReverseVectorEnumera
- SelectAreaTracker
- SelectionTool
- SendToBackCommand
- SerializationStorageForr
- ShortestDistanceConne
- SimpleUpdateStrategy
- SleeperThread
- SouthEastHandle
- SouthHandle
- SouthWestHandle
- StandardDrawing
- StandardDrawingView
- StandardLayouter
- StandardStorageFormat
- StorableInput
- StorableOutput
- StorageFormatManager
- StreamTokenizer
- String
- StringTokenizer
- TextField
- ToggleGridCommand
- ToolButton
- TriangleRotationHandle
- UngroupCommand
- URL
- Vector
- WestHandle
- WindowAdapter169

Uses of class URL are here

Click here for textual view ...

Select class URL



/home/paulk/software/source/sources/CH/ifa/

```
}

private void readFromStorableInput(String filename) {
    try {
        URL url = new URL(getCodeBase(), filename);
        InputStream stream = url.openStream();
        StorableInput input = new StorableInput(stream);
        fDrawing.release();

        fDrawing = (Drawing)input.readStorable();
        fView.setDrawing(fDrawing);
    } catch (IOException e) {
        initDrawing();
        showStatus("Error:"+e);
    }
}

private void readFromObjectInput(String filename) {
    try {
        URL url = new URL(getCodeBase(), filename);
        InputStream stream = url.openStream();
        ObjectInput input = new ObjectInputStream(stream);
        fDrawing.release();
        fDrawing = (Drawing)input.readObject();
        fView.setDrawing(fDrawing);
    } catch (IOException e) {
        initDrawing();
        showStatus("Error: " + e);
    } catch (ClassNotFoundException e) {
        initDrawing();
        showStatus("Class not found: " + e);
    }
}

private String guessType(String file) {
    if (file.endsWith(".draw"))
        return "storable";
    if (file.endsWith(".ser"))
        return "serialized";
```

Wrap up: Rscript

- A simple, language-independent, relational calculus
- Fully typed
- Equation solver (=> dataflow equations)
- Areas allow close link with source text
- Implementation: ASF+SDF
- IDE: `rscript-meta`
  - an instance of The Meta-Environment

Wrap up : Rscript

- Calls analysis
- Lifting of procedure calls to component relations
- Unitialized/unused variables
- McCabe & friends
- Clones in C code
- Dataflow analysis
  - reaching definitions
  - live variables
- Program slicing
- Java &ToolBus analysis
- Feature Descriptions/ package dependencies

Wrap up: visualization

- A lot of work to do but promising start
- Alternative pixel representations?
- Treemaps for directory structure of files?
- Colormaps for displaying metrics?
- Implementation: Tcl/Tk but may change to Swing
- Some simple visualizations are included in `rscript-meta`

Further reading

- P. Klint, How understanding and restructuring differ from compiling: a rewriting approach, IWPC03
- P. Klint, A tutorial introduction to Rscript on www.meta-environment.org
- `www.cwi.nl/~paulk/publications/all.html`