Software Language Engineering

Tijs van der Storm
storm@cwi.nl

About me

- Senior researcher at CWI in the Software Analysis & Transformation team (SWAT)

- Professor software engineering at University of Groningen

- Expertise: language design, language engineering, language workbenches, … META stuff ;)

CWI

Centrum Wiskunde & Informatica

university of groningen

www.rascal-mpl.org

Outlook

- Lecture (Fridays, 11.00 - 13.00)
  - First part: <topic>
  - Coffee break
  - Second part: live coding by me
- Lab hours (Friday, 13.00 - 15.00)

Software Languages?

- Programming languages
- Domain-specific languages
- Data formats
- Specification languages
- Modeling languages

Software Languages?

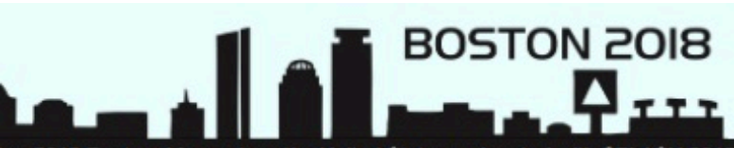
- Programming languages
- Domain-specific languages
- Data formats
- Specification languages
- Modeling languages

- Java, C#, C, Ruby, Pascal, etc.
- SQL, HTML, make, LaTeX
- XML, CSV, JSON, YAML
- Event-B, Alloy, Promela
- Modelica, UML, BPMN

Software Languages: languages used for/in/during software engineering

Software Language *Engineering*

- Engineering ~ maturity of a field of creating stuff
  - Repeatable, reliable, maintainable, performant language implementation
- Principled techniques
- Best practices
- Tools



SLE 2018

Software language engineering (SLE) is the discipline of engineering languages and their tools required for the creation of software. It abstracts from the differences between programming languages, modeling languages, and other software languages, and emphasizes the engineering facet of the creation of such languages, that is, the establishment of the scientific methods and practices that enable the best results.

SIGPLAN

The **Most Influential Paper Award** of the
2023 ACM SIGPLAN International Conference on
Software Language Engineering (SLE)
is awarded to

S Erdweg, T van der Storm, M Völter, M Boersma, R Bosman, WR Cook†, A Gerritsen, A Hulshout, S Kelly, A Loh, GDP Konat, PJ Molina, M Palatnik, R Pohjonen, E Schindler, K Schindler, R Solmi, VA Vergu, E Visser†, K van der Vlist, GH Wachsmuth and J van der Woning

for their paper at SLE 2013 titled

The State of the Art in Language Workbenches

Friedrich Steimann
(Steering Committee Chair)

Cascais, Portugal, 23 October 2023

Syntax

Semantics

Representation

Software Language

Tooling

Analysis

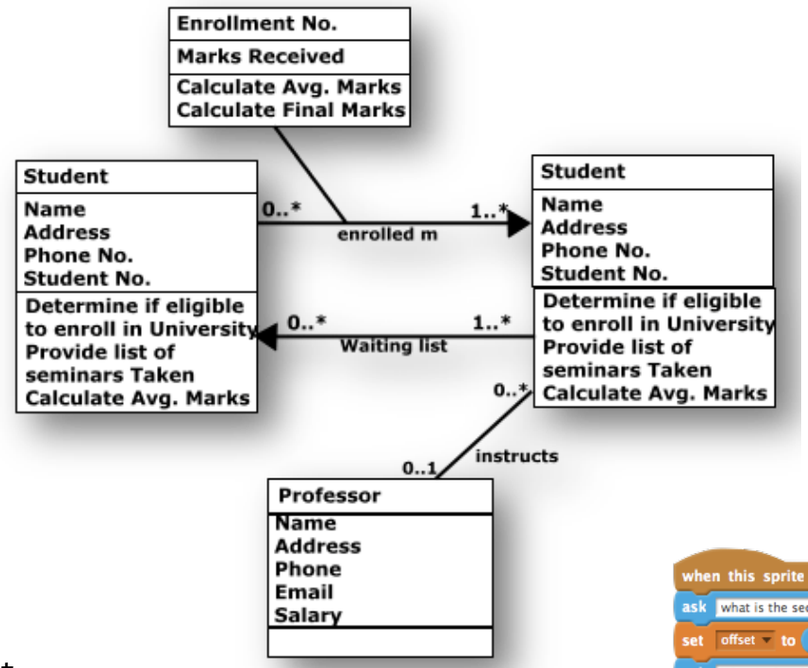
Transformation

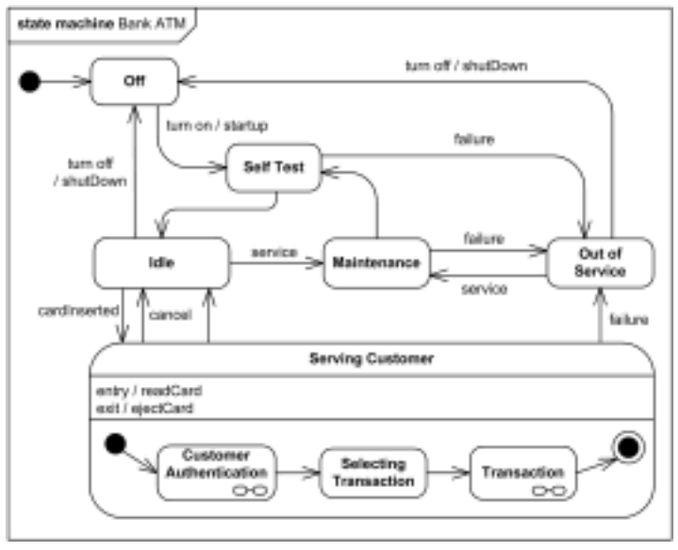
Topics of this course

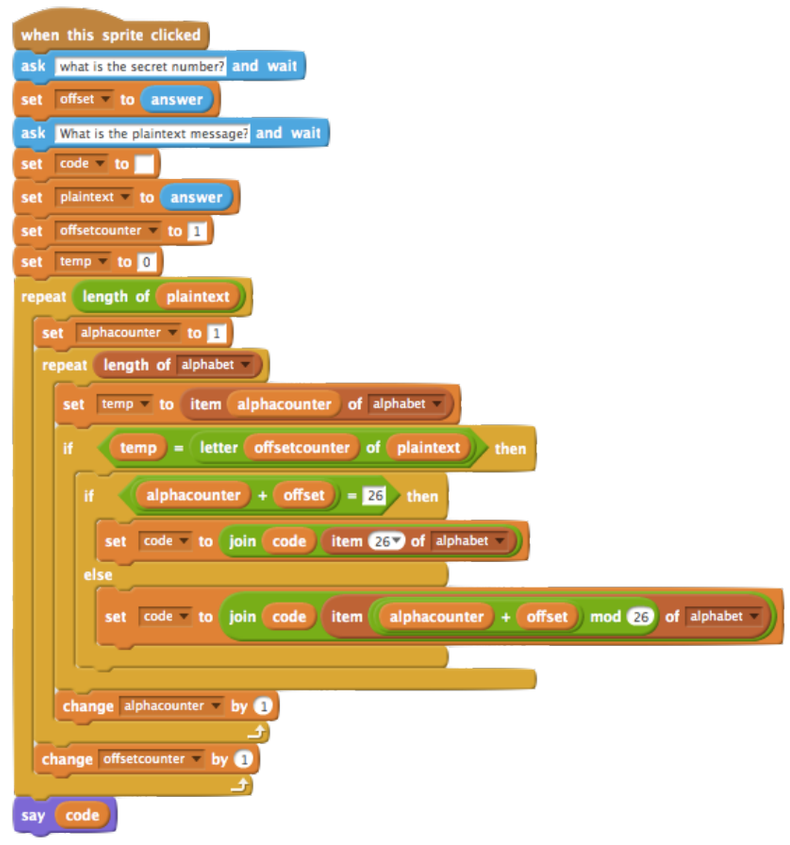
- Concrete syntax: grammars, parsing
- Abstract syntax: data types, meta models
- Wellformedness: type and name checking
- Semantics: interpretation, simulation, evaluation
- Semantics: compilation, code generation
- Transformation: normalization and refactoring

Concrete syntax

```
form taxOfficeExample {
  "Did you buy a house in 2010?"
    hasBoughtHouse: boolean

  "Did you enter a loan?"
    hasMaintLoan: boolean

  "Did you sell a house in 2010?"
    hasSoldHouse: boolean

  if (hasSoldHouse) {
    "What was the selling price?"
      sellingPrice: money
    "Private debts for the sold house:"
      privateDebt: money
    "Value residue:"
      valueResidue: money = sellingPrice - privateDebt

  }
}
```







Defining Concrete Syntax

- Context-free grammars, parser generators, parser combinators, etc.

$$S \rightarrow AC \mid CB$$
$$C \rightarrow aCb \mid a \mid b$$
$$A \rightarrow aA \mid \epsilon$$
$$B \rightarrow Bb \mid \epsilon$$

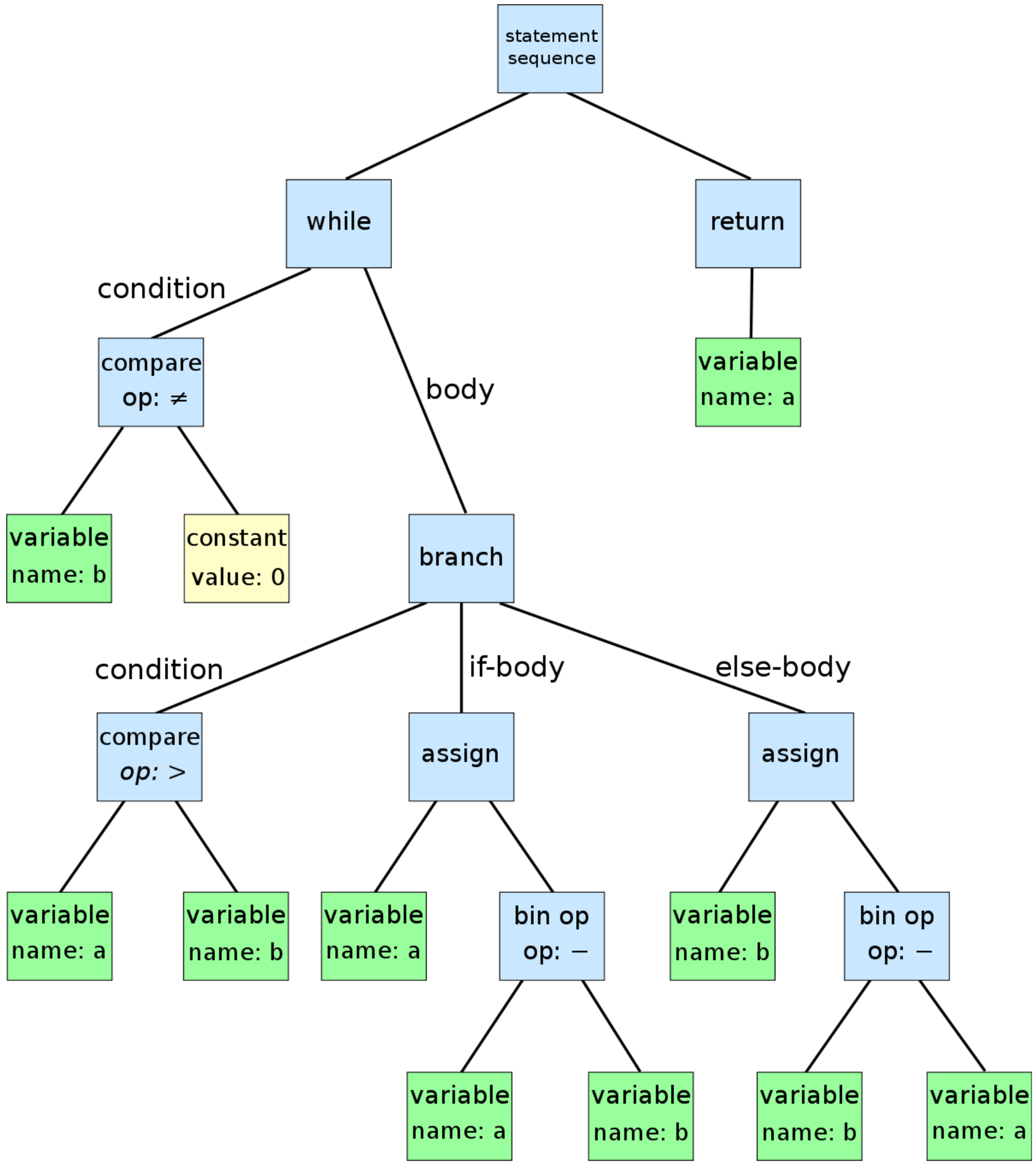
- Diagram editor frameworks (e.g., Eclipse Sirius)

- Structure editor frameworks (e.g., Jetbrains MPS)

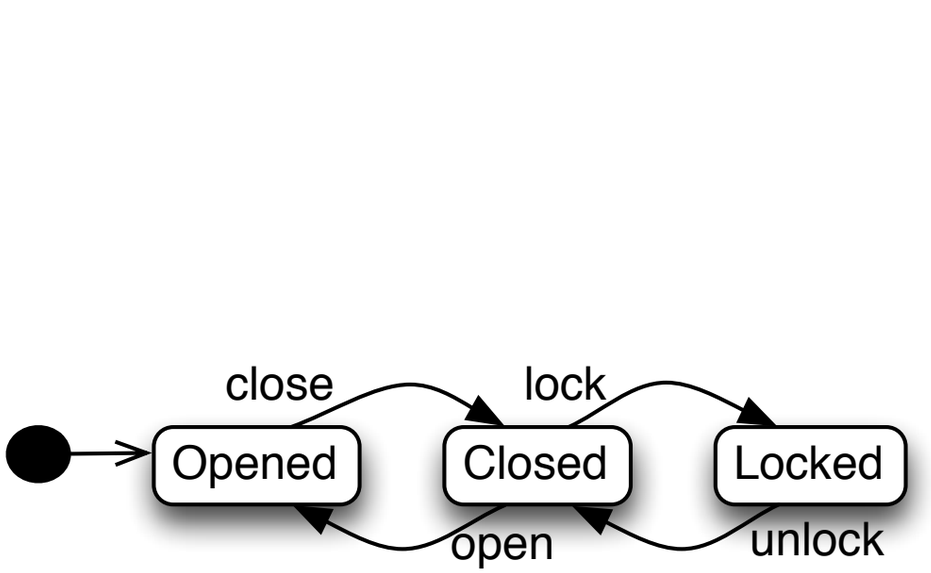
$$S \rightarrow AC \mid CB$$
$$C \rightarrow aCb \mid \epsilon$$
$$A \rightarrow aA \mid \epsilon$$
$$B \rightarrow Bb \mid \epsilon$$

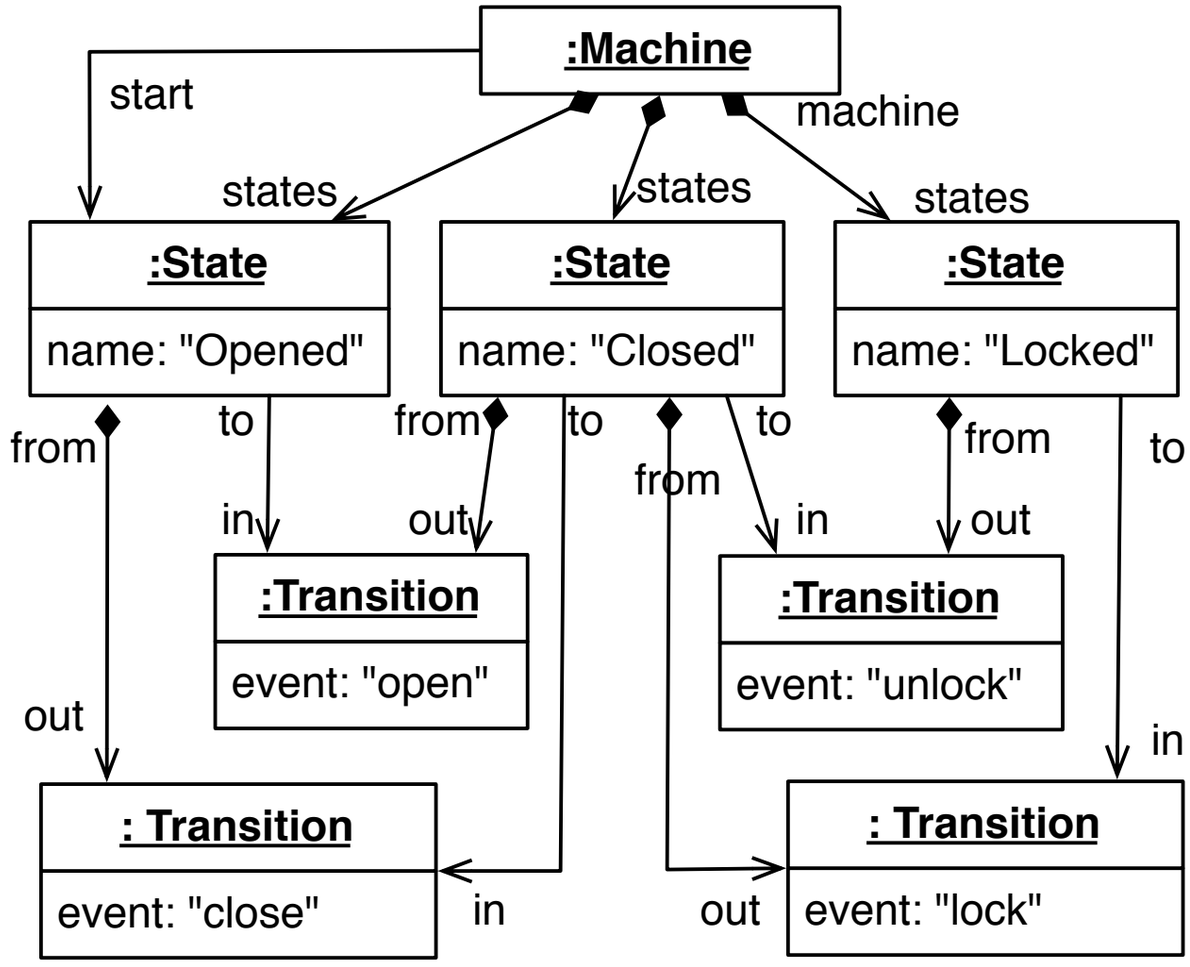
- …

Abstract Syntax



Abstract Syntax



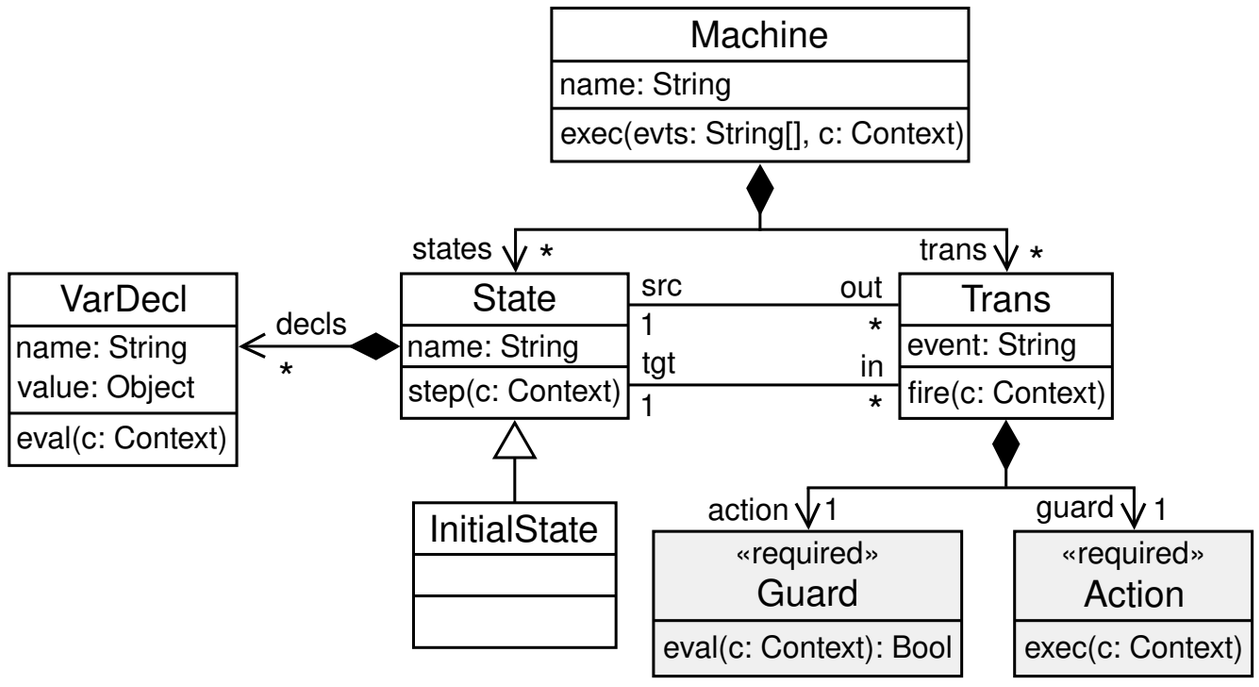


Defining Abstract Syntax

- Algebraic Data Types

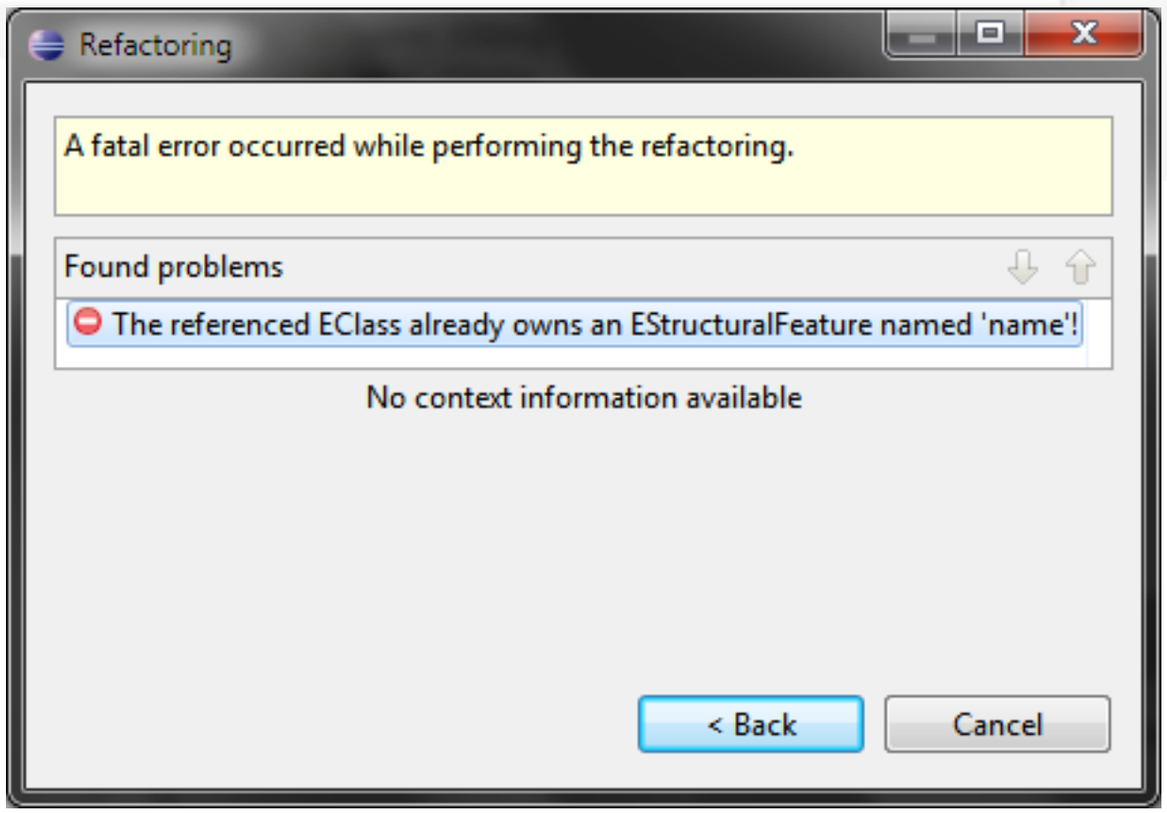
```
data Expr
  = var(Id id)
  | integer(int intValue)
  | string(str strValue)
  | money(real realValue)
  | \true()
  | \false()
  | not(Expr arg)
  | mul(Expr lhs, Expr rhs)
  | div(Expr lhs, Expr rhs)
  | add(Expr lhs, Expr rhs)
  | sub(Expr lhs, Expr rhs)
```

- Meta models
(OO Class hierarchy)



Wellformedness

```
9   import UIKit
10
11  class ViewController: UIViewController {
12
13      override func viewDidLoads() {   Method does not override any method from its superclass
14          super.viewDidLoad()
15      }
16
17      override func didReceiveMemoryWarning() {
18          super.didReceiveMemoryWarning()
19      }
20
21  }
```



Wellformedness

- All checks outside the realm of syntax.
    - Reference checking: no dangling references, duplicate declarations etc.
    - Type checking: are operations applied to operands of the right type?
    - => static analysis, constraint checking, validation etc.

Semantics

$$\frac{}{\mathbf{R} \vdash e_{empty} \Rightarrow \mathbf{R}} \text{ (EMPTY)} \qquad \frac{e_2 \in \mathbf{R}}{\mathbf{R} \vdash e_1 = e_2 \Rightarrow \mathbf{R} \cup \{e_1\}} \text{ (ASSIGN)}$$

$$\frac{e_2 \in \mathbf{R}}{\mathbf{R} \vdash e_1.field* = e_2 \Rightarrow \mathbf{R} \cup \{e_1\}} \text{ (ASSIGN-FIELD)} \qquad \frac{e_2 \in \mathbf{R}}{\mathbf{R} \vdash e_1[*]* = e_2 \Rightarrow \mathbf{R} \cup \{e_1\}} \text{ (ASSIGN-ARRAY)}$$

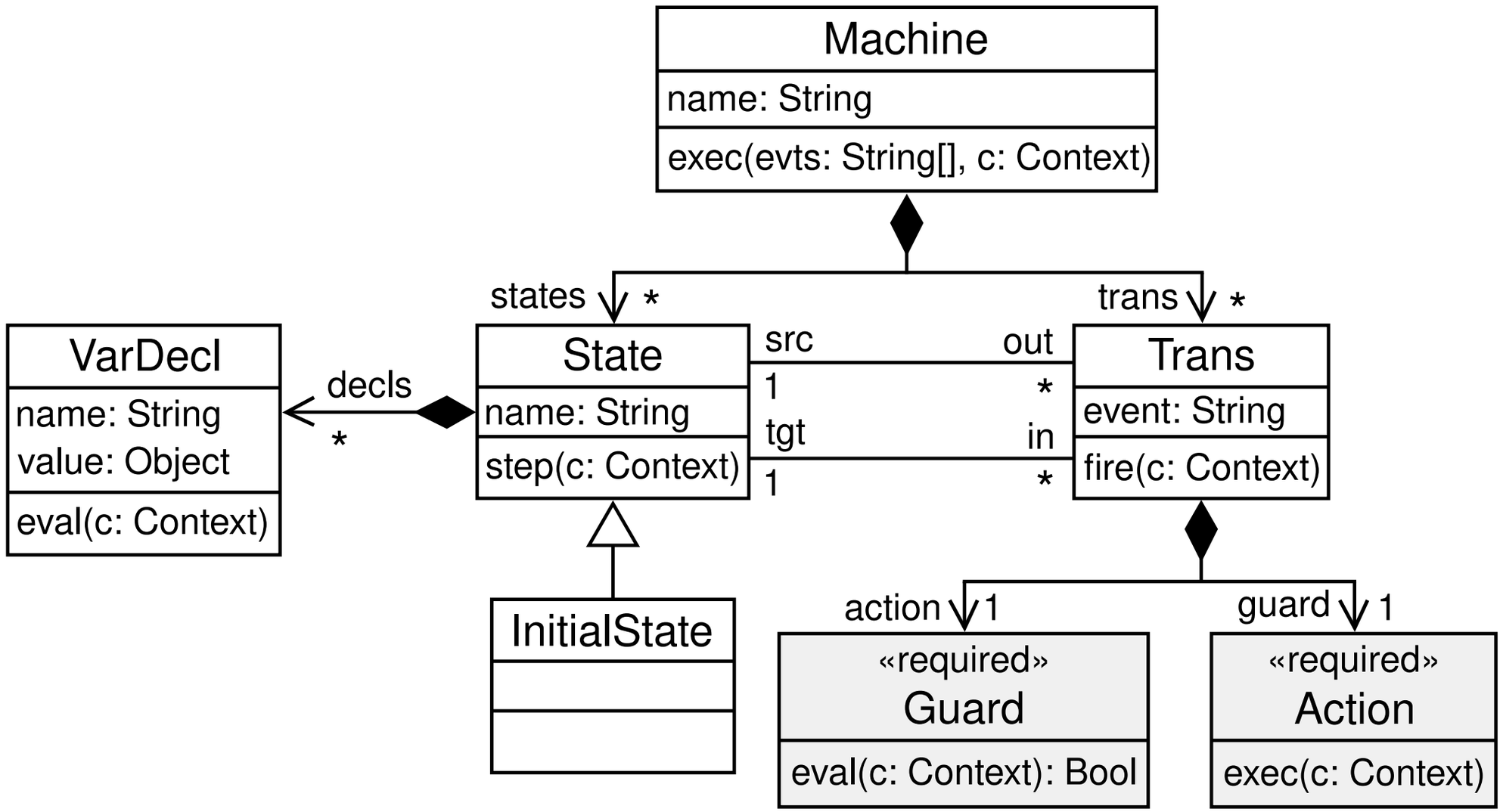
$$\frac{v \in \mathbf{R}\,;\ \texttt{pointer\_type\_p}(v)\,;\ \mathbf{R} \vdash e \Rightarrow \mathbf{R}'}{\mathbf{R} \vdash v \oplus e \Rightarrow \mathbf{R}' \cup \{v \oplus e\}} \text{ (BINOP1)}$$

$$\frac{v \in \mathbf{R}'\,;\ \texttt{pointer\_type\_p}(v)\,;\ \mathbf{R} \vdash e \Rightarrow \mathbf{R}'}{\mathbf{R} \vdash e \oplus v \Rightarrow \mathbf{R}' \cup \{e \oplus v\}} \text{ (BINOP2)} \qquad \frac{\mathbf{R} \vdash e_1 \Rightarrow \mathbf{R}'\,;\ \mathbf{R}' \vdash e_2 \Rightarrow \mathbf{R}''}{\mathbf{R} \vdash e_1; e_2 \Rightarrow \mathbf{R}''} \text{ (SEQ)}$$

$$\frac{\mathbf{R} \vdash e_1 \Rightarrow \mathbf{R}_1\,;\ \mathbf{R}_1 \vdash e_2 \Rightarrow \mathbf{R}_2\,;\ \mathbf{R}_1 \vdash e_3 \Rightarrow \mathbf{R}_3\,;\ \mathbf{R}_2 \cup \mathbf{R}_3 \vdash e_4 \Rightarrow \mathbf{R}'}{\mathbf{R} \vdash if\ (e_1)\ then\ \{e_2\}\ else\ \{e_3\}\ e_4 \Rightarrow \mathbf{R}'} \text{ (IF)}$$

$$\frac{\begin{array}{c}\texttt{function\_type\_p}(e) \\ \{e.args[i] \mid 0 < i < e.numargs \wedge \texttt{pointer\_type\_p}(e.args[i])\} \\ \cup\ \{v \mid \texttt{global\_p}(v)\} \vdash e.body \Rightarrow \mathbf{R}\end{array}}{\{\} \vdash e \Rightarrow \mathbf{R}} \text{ (FUNCTION)}$$

Interpretation



Interpretation

```
int eval0(nat(int nat), PEnv penv)  = nat;

int eval0(mul(Exp lhs, Exp rhs), PEnv penv) = eval0(lhs, penv) * eval0(rhs, penv);

int eval0(div(Exp lhs, Exp rhs), PEnv penv) = eval0(lhs, penv) / eval0(rhs, penv);

int eval0(add(Exp lhs, Exp rhs), PEnv penv) = eval0(lhs, penv) + eval0(rhs, penv);

int eval0(sub(Exp lhs, Exp rhs), PEnv penv) = eval0(lhs, penv) - eval0(rhs, penv);

int eval0(gt(Exp lhs, Exp rhs), PEnv penv) = eval0(lhs, penv) > eval0(rhs, penv) ? 1 : 0;

int eval0(lt(Exp lhs, Exp rhs), PEnv penv) = eval0(lhs, penv) < eval0(rhs, penv) ? 1 : 0;

int eval0(geq(Exp lhs, Exp rhs), PEnv penv) = eval0(lhs, penv) ⩾ eval0(rhs, penv) ? 1 : 0;

int eval0(leq(Exp lhs, Exp rhs), PEnv penv) = eval0(lhs, penv) ⩽ eval0(rhs, penv) ? 1 : 0;
```

Compilation

```
Instrs compileStat(whileStat(EXP exp, list[STM] stats1)) {
  entryLab = nextLabel();
  endLab = nextLabel();
  return [label(entryLab),
          *compileExp(exp),
          gofalse(endLab),
          *compileStats(stats1),
          go(entryLab),
          label(endLab)];
}
```

Code generation

```
str question2widget(Label l, Id v, QType t, str parent, str e)
  = "var <v.name> = new QLrt.SimpleFormElementWidget({
    '  name: \"<v.name>\",
    '  label: <l.label>,
    '  valueWidget: new QLrt.<type2widget(t)>(<e>)
    '}).appendTo(<parent>);";

str exp2lazyValue(Expr e)
  = "new QLrt.LazyValue(
    '  function () { return [<ps>]; },
    '  function (<ps>) { return <expr2js(e)>; }
    ')"
  when str ps := expParams(e);
```

Transformations everywhere

- Parsing, deserialization/unparsing serialization
- Compilation, generation, translation
- Optimization, normalization, simplification
- Refactoring, reengineering, visualization

Course Organisation

https://github.com/cwi-swat/sle-master-course

See Brightspace for the link

- Week 1: Intro and DSLs
- Week 2: Syntax and structure
- Week 3: Static checking
- Week 4: Interpretation
- Week 5: Code generation
- Week 6: Transformations
- Week 7: Modularity, extension and evolution
- Week 8: Wrap up

Lab exercises: QL

```
form taxOfficeExample {
  "Did you buy a house in 2010?"
    hasBoughtHouse: boolean

  "Did you enter a loan?"
    hasMaintLoan: boolean

  "Did you sell a house in 2010?"
    hasSoldHouse: boolean

  if (hasSoldHouse) {
    "What was the selling price?"
      sellingPrice: integer
    "Private debts for the sold house:"
      privateDebt: integer
    "Value residue:"
      valueResidue: integer =
        sellingPrice - privateDebt

  }
}
```

Aangifte inkomstenbelasting 2010 – Persoonlijke gegevens

- ✓ Persoonlijke gegevens: Bla
- ✓ Persoonlijke gegevens: Blasa
- ✓ Box 1: werk en woning
- Box 1: andere inkomsten
- Box 1: uitgaven lijfrenten e.d.
- Box 2: aanmerkelijk belang
- Box 3: sparen en beleggen
- Aftrekposten
- Vrijstellingen en verminderingen
- Bijzondere situaties
- Te verrekenen bedragen
- Heffingskortingen: Bla
- Overzicht: Bla
- Voorlopige aanslag 2011
- Naar ondertekenen met DigiD

IB 602E - 2Z01FOL2A

Persoonlijke gegevens

Naam: Bla

Telefoonnummer: 323

Burgerservicenummer/sofinummer: 1430.95.067

? Geboortedatum: 11-02-1979

? Nummer belastingconsulent:

? Hebt u van ons bericht ontvangen om aangifte te doen? ○ Ja ● Nee

Wilt u een rekeningnummer opgeven of wijzigen? ○ Ja ● Nee

? Uw persoonlijke situatie in 2010: Een deel van 2010 getrou...

? Periode dat u getrouwd was in 2010: 01-02 03-05

? Woonde u voor of na deze periode samen met uw echtgenoot? ○ Ja ● Nee

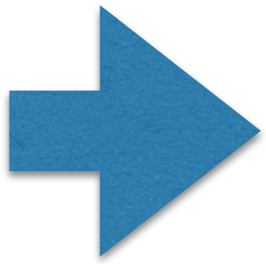
? Willen u en uw echtgenoot heel 2010 als fiscale partners worden beschouwd? ○ Ja ● Nee

? Woonde u buiten de periode dat u getrouwd was nog met iemand anders samen? Bijvoorbeeld met uw kind van 27 jaar of ouder? ○ Ja ● Nee

Akkoord

Stoppen | Instellingen | Rekenmachine | Help | Printen | Open bestand

```
form taxOfficeExample {
  "Did you sell a house in 2010?"
    hasSoldHouse: boolean

  "Did you buy a house in 2010?"
    hasBoughtHouse: boolean

  "Did you enter a loan?"
    hasMaintLoan: boolean

  if (hasSoldHouse) {
    "What was the selling price?"
      sellingPrice: integer
    "Private debts for the sold house:"
      privateDebt: integer
    "Value residue:"
      valueResidue: integer =
        sellingPrice - privateDebt

  }
}
```



Did you sell a house in 2010?

Yes

Did you buy a house in 2010?

Choose an answer

Did you enter a loan?

Choose an answer

What was the selling price?

100

Private debts for the sold house:

200

Value residue:

-100.00

Submit taxOfficeExample

```
form taxOfficeExample {
  "Did you sell a house in 2010?"
    hasSoldHouse: boolean

  "Did you buy a house in 2010?"
    hasBoughtHouse: boolean

  "Did you enter a loan?"
    hasMaintLoan: boolean

  if (hasSoldHouse) {
    "What was the selling price?"
      sellingPrice: integer
    "Private debts for the sold house:"
      privateDebt: integer
    "Value residue:"
      valueResidue: integer =
        sellingPrice - privateDebt

  }
}
```

- Concrete syntax
- Abstract syntax
- Name resolution
- Type checking
- Interpretation
- Code generation
- Normalization
- Rename refactoring

- Week 1: Series1.rsc, Series2.src warm-up exercises
- Week 2: Syntax.rsc, Resolve.rsc
- Week 3: Check.rsc
- Week 4: Eval.rsc, App.rsc
- Week 5: Compile.rsc
- Week 6: Flatten.rsc, Format.rsc, PartialEvaluation.rsc, Visualize.rsc
- Week 7: Modularity, extension and evolution
- Week 8: Wrap up

Practicalities

- **Fork** the repo on the website (github!)
- You can help each other, but no copy-paste!!!
- The lab exercises are part of the material of the individual exam.
- Observe basic code quality guide lines (indentation, functional decomposition, modularity, …)

How to pass the course

- Requirements
  - Complete the lab exercises (pass/fail)
  - Pass the exam
- Advice
  - Attend lectures
  - Use lab hours for Q&A

Next ~45 minutes

- Introduction to Domain-specific Languages

- Then start introductory Rascal tutorial