Infrastructure for Transformation Systems

Concrete and Abstract Syntax

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Planet Stratego/XT

Stratego

- Language for program transformation
- Suitable for implementing complete programs

XT

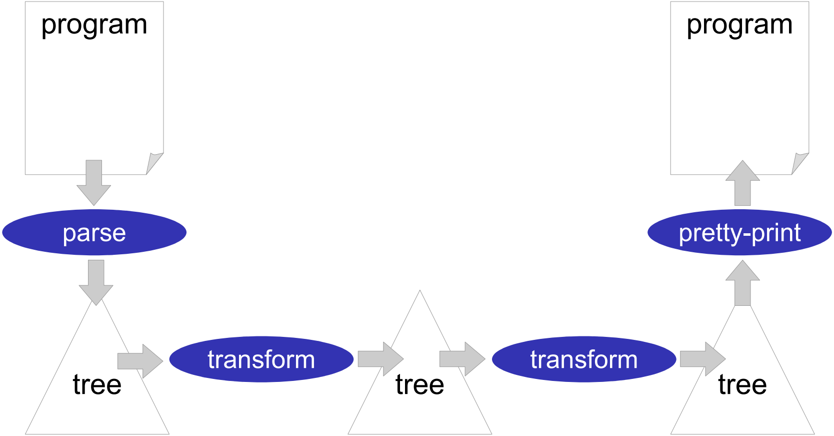
- Collection of Transformation (X) Tools
- Infrastructure for implementing transformation systems
- Parsing, pretty-printing, interoperability

XT Orbit

- Language specific tools
- Java, C, C++, Octave, ...

This lecture: the XT of Stratego/XT

Program Transformation Pipeline



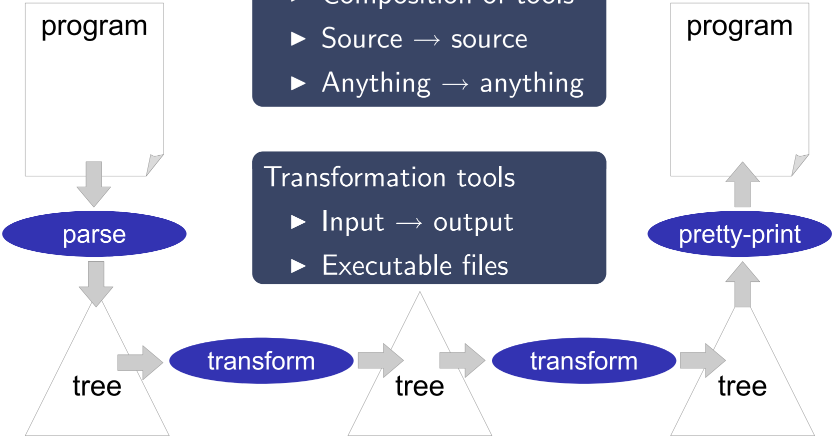
Program Transformation Pipeline

Transformation systems

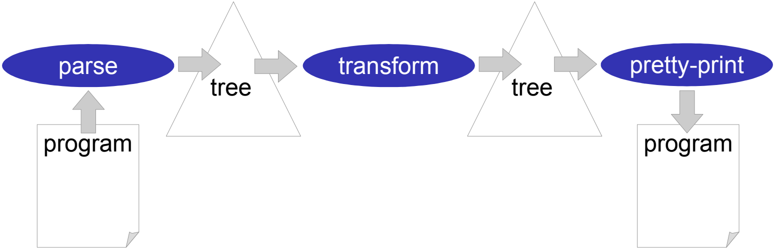
- Composition of tools
- Source $\longrightarrow$ source
- Anything $\longrightarrow$ anything

Transformation tools

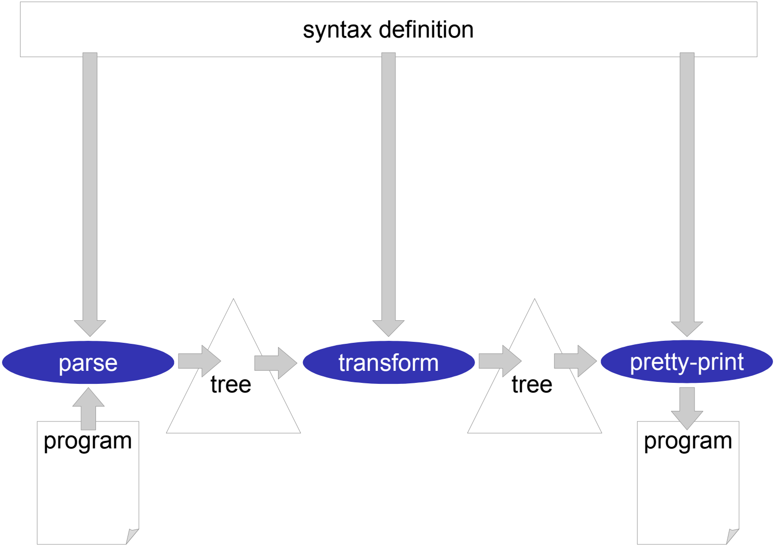
- Input $\longrightarrow$ output
- Executable files



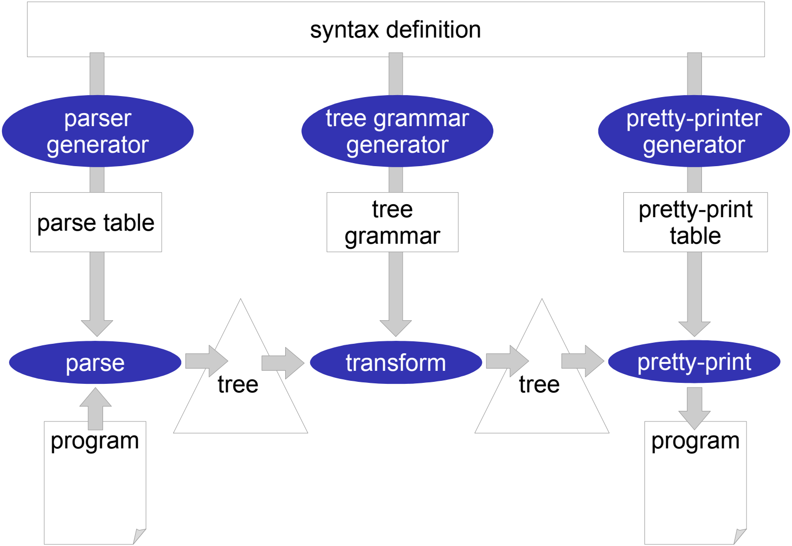
Architecture of Stratego/XT



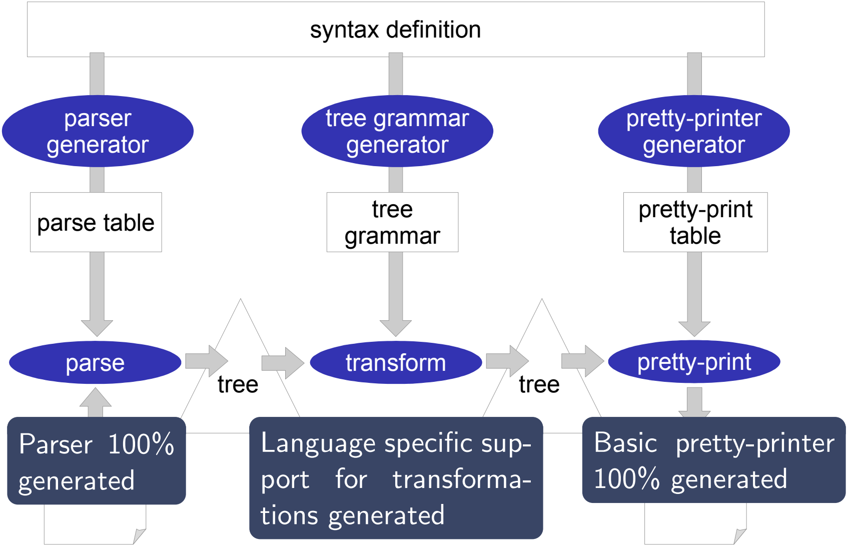
Architecture of Stratego/XT



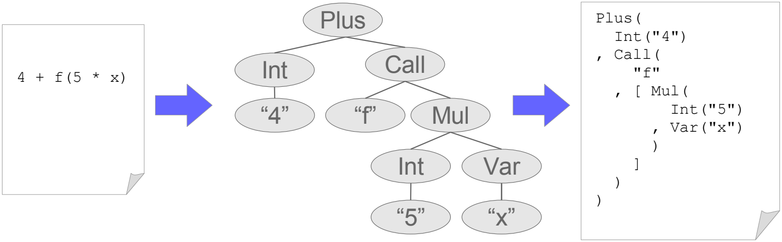
Architecture of Stratego/XT



Architecture of Stratego/XT



Tree Representation



Trees are represented as terms in the ATerm format

```
Plus(Int("4"), Call("f", [Mul(Int("5"), Var("x"))]))
```

ATerm Format

Application	`Void()`, `Call(`t`, `t`)`
List	`[]`, `[`t`, `t`, `t`]`
Tuple	`(`t`, `t`)`, `(`t`, `t`, `t`)`
Integer	`25`
Real	`38.87`
String	`"Hello world"`
Annotated term	t`{`t`, `t`, `t`}`

- Exchange of structured data
- Efficiency through maximal sharing
- Binary encoding

Structured Data: comparable to XML
Stratego: internal is external representation

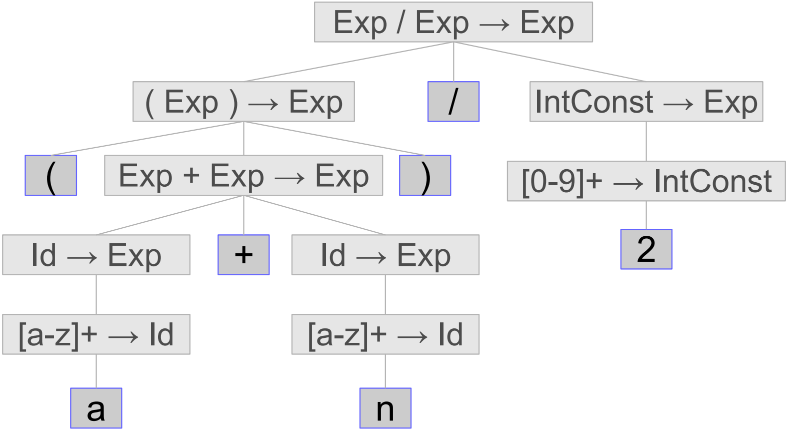
Context-Free Grammars

Simple Expression Language

$$
\begin{array}{lcl}
\mathit{Id} & \rightarrow & \texttt{[a-z]+} \\
\mathit{IntConst} & \rightarrow & \texttt{[0-9]+} \\
\mathit{Exp} & \rightarrow & \mathit{Id} \\
 & & \mathit{IntConst} \\
 & & \mathit{Exp}\ \texttt{+}\ \mathit{Exp} \\
 & & \mathit{Exp}\ \texttt{-}\ \mathit{Exp} \\
 & & \mathit{Exp}\ \texttt{*}\ \mathit{Exp} \\
 & & \mathit{Exp}\ \texttt{/}\ \mathit{Exp} \\
 & & \texttt{(}\ \mathit{Exp}\ \texttt{)}
\end{array}
$$

Parse Trees

(a + n) / 2



Parse Trees and Abstract Syntax Trees

Text → Parse Tree → Abstract Syntax Tree

AsFix: ATerm language for parse trees

- Describes Applications of productions
- All characters of the input
  - Even whitespace and comments!
- Yield parse tree to text

```
$ asfix-yield -i exp.asfix
(a + n) / 2
```

Abstract Syntax Trees

- Remove literals, whitespace, comments

```
$ implode-asfix -i exp.asfix
Div(Plus(Var("a"), Var("n")), Int("2"))
```

Generic Tools for ATerms

Pretty-print an ATerm in a nice layout

```
$ pp-aterm -i foo.aterm
```

Usually applied at the end of a pipeline:

```
$ echo "foo([0], bar(1, 2), fred(3,4))" | ... | pp-aterm
foo(
  [0]
, bar(1, 2)
, fred(3, 4)
)
```

Exercise 2.1: Inspecting ATerms

Create a small Java class in a file and parse it using the `parse-java` command:

```
$ parse-java -i hello.java
```

Use pp-aterm to pretty-print the result.

```
$ parse-java -i hello.java | pp-aterm | less
```

Try some Java constructs and inspect the abstract syntax trees.

Syntax Definition in Stratego/XT

SDF – Syntax Definition Formalism

1. **Declarative**
   - Important for code generation
   - Completely define the syntax of a language
2. **Modular**
   - Syntax definitions can be composed!
3. **Context-free and lexical syntax**
   - No separate specification of tokens for scanner
4. **Declarative disambiguation**
   - Priorities, associativity, follow restrictions
5. **All context-free grammars**
   - Beyond LALR, LR, LL

SDF: Modular

```
module Lexical
exports
  lexical syntax
    ...
```

```
module Expressions
imports Lexical
exports
  context-free syntax
    ...
```

```
module Main
imports Expressions
exports
  context-free start-symbols Exp
```

SDF: Lexical Syntax

Lexical syntax is defined with ordinary productions.

```
module Lexical
exports
  sorts Id IntConst BoolConst
  lexical syntax
    [A-Za-z][A-Za-z0-9]* -> Id

    [0-9]+  -> IntConst
    "true"  -> BoolConst
    "false" -> BoolConst

    [\r\n\t\ ] -> LAYOUT
    "//" ~[\n]* [\n] -> LAYOUT
```

- Even *context-free* lexical syntax is possible
- Avoid complex regular expressions

SDF: Context-free Syntax

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

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

  Exp "+" Exp -> Exp {cons("Plus")}
  Exp "-" Exp -> Exp {cons("Min")}
  Exp "*" Exp -> Exp {cons("Mul")}
  Exp "/" Exp -> Exp {cons("Div")}

  Exp "&" Exp -> Exp {cons("And")}
  Exp "|" Exp -> Exp {cons("Or")}
  "!" Exp     -> Exp {cons("Not")}

  Id "(" {Exp ","}* ")" -> Exp {cons("Call")}
```

Ambiguity in Context-Free Grammars

- **e1 + e2 * e3**
  - `(e1 + e2) * e3`
  - `e1 + (e2 * e3)`

- **e1 + e2 + e3**
  - `(e1 + e2) + e3`
  - `e1 + (e2 + e3)`

- **++a**
  - `+(+a)`
  - `++ a?`

- **null**
  - Keyword or identifier?

- **if e1 then if e2 then e3 else e4**
  - `if e1 then (if e2 then e3) else e4`
  - `if e1 then (if e2 then e3 else e4)`

SDF: Lexical Syntax

Lexical syntax is defined with ordinary productions.

```
module Lexical
exports
  sorts Id IntConst BoolConst
  lexical syntax
    [A-Za-z][A-Za-z0-9]* -> Id

    [0-9]+  -> IntConst
    "true"  -> BoolConst
    "false" -> BoolConst

    [\r\n\t\ ] -> LAYOUT
    "//" ~[\n]* [\n] -> LAYOUT
```

- Even *context-free* lexical syntax is possible
- Avoid complex regular expressions

SDF: Disambiguation of Lexical Syntax

Declaring reserved keywords: reject certain productions

```
lexical syntax
  "true"  -> Id {reject}
  "false" -> Id {reject}
```

Longest match: follow restriction

```
lexical restrictions
  Id       -/- [A-Za-z0-9]
  IntConst -/- [0-9]
```

Require layout after a keyword

```
lexical restrictions
  "if" -/- [A-Za-z0-9]
```

SDF: Disambiguation of Lexical Syntax

Declaring reserved keywords: reject certain productions

```
lexical syntax
  "true"  -> Id {reject}
  "false" -> Id {reject}
```

Solves ambiguity between variable and boolean constant.

```
$ echo "true" | sglri -p Example.tbl
amb([Bool("true"),Var("true")])
```

Longest match: follow restriction

```
lexical restrictions
  Id       -/- [A-Za-z0-9]
  IntConst -/- [0-9]
```

Require layout after a keyword

```
lexical restrictions
  "if" -/- [A-Za-z0-9]
```

SDF: Disambiguation of Lexical Syntax

Declaring reserved keywords: reject certain productions

```
lexical syntax
  "true"  -> Id {reject}
  "false" -> Id {reject}
```

Longest match: follow restriction

```
lexical restrictions
  Id       -/- [A-Za-z0-9]
  IntConst -/- [0-9]
```

Rejects unintended split of identifier

```
$ echo "xinstanceof Foo" | sglri
InstanceOf(Var("x"),"Foo")
```

Require layout after a keyword

```
lexical restrictions
  "if" -/- [A-Za-z0-9]
```

SDF: Disambiguation of Lexical Syntax

Declaring reserved keywords: reject certain productions

```
lexical syntax
  "true"  -> Id {reject}
  "false" -> Id {reject}
```

Longest match: follow restriction

```
lexical restrictions
  Id       -/- [A-Za-z0-9]
  IntConst -/- [0-9]
```

Require layout after a keyword

```
lexical restrictions
  "if" -/- [A-Za-z0-9]
```

Rejects unintended split of keyword

```
$ echo "ifx then y" | sglri
IfThen(Var("x"),Var("y"))
```

SDF: Context-free Syntax

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

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

  Exp "+" Exp -> Exp {cons("Plus")}
  Exp "-" Exp -> Exp {cons("Min")}
  Exp "*" Exp -> Exp {cons("Mul")}
  Exp "/" Exp -> Exp {cons("Div")}

  Exp "&" Exp -> Exp {cons("And")}
  Exp "|" Exp -> Exp {cons("Or")}
  "!" Exp     -> Exp {cons("Not")}

  Id "(" {Exp ","}* ")" -> Exp {cons("Call")}
```

SDF: Associativity of Operators

```
$ echo "1 + 2 + 3" | sglri -p Example.tbl
amb([
  Plus(Plus(Int("1"), Int("2")), Int("3"))
, Plus(Int("1"), Plus(Int("2"), Int("3")))
])
```

Declare associativity in attribute:

```
    Exp "+" Exp -> Exp {left, cons("Plus")}
    Exp ">" Exp -> Exp {non-assoc, cons("Gt")}
```

- `left`
- `right`
- `assoc`
- `non-assoc`

SDF: Priority of Operators

```
$ echo "1 + 2 * 3" | sglri -p Example.tbl
amb([
  Mul(Plus(Int("1"), Int("2")), Int("3"))
, Plus(Int("1"), Mul(Int("2"), Int("3")))
])
```

```
context-free priorities
      "!"  Exp -> Exp
  > {
      Exp "*" Exp -> Exp
      Exp "/" Exp -> Exp
    }
  > {
      Exp "+" Exp -> Exp
      Exp "-" Exp -> Exp
    }
  >   Exp "&" Exp -> Exp
  >   Exp "|" Exp -> Exp
```

SDF: Associativity of Operators in Group

```
$ echo "1 + 2 - 3" | sglri -p Example.tbl
amb([
  Min(Plus(Int("1"),Int("2")),Int("3"))
, Plus(Int("1"),Min(Int("2"),Int("3")))
])
```

```
context-free priorities
      "!"  Exp -> Exp
  > {left:
      Exp "*" Exp -> Exp
      Exp "/" Exp -> Exp
    }
  > {left:
      Exp "+" Exp -> Exp
      Exp "-" Exp -> Exp
    }
  >   Exp "&" Exp -> Exp
  >   Exp "|" Exp -> Exp
```

Parse-unit: Testing SDF Syntax Definitions

```
testsuite Expressions
topsort Exp

test simple addition
  "2 + 3" -> Plus(Int("2"), Int("3"))

test addition is left associative
  "1 + 2 + 3" -> Plus(Plus(_, _), _)

test > is not associative
  "1 > 2 > 3" fails

test
  file foo.exp succeeds
```

```
$ parse-unit -i exp.testsuite -p Example.tbl
...
```

SDF: Parsing Technology

- SDF requires an extraordinary general parsing algorithm.
- SDF relies on **SGLR** parsing
- **Scannerless**: no separate lexical analysis
  - Every character is a token
  - Context-dependent lexical syntax
- **Generalized LR**: allows ambiguities
  - All derivations
  - Produces a parse forest
  - Technique: fork LR parsers
- Advantage: **declarative** syntax definition
  - Excellent for code generation

SDF: Parser Generation

Modules and Definitions

- SDF Module (`.sdf`)
- SDF Definition (`.def`)

Generating a parser

- Collect SDF modules into a single syntax definition

  ```
  $ pack-sdf -i Example.sdf -o Example.def
  ```

- Generate a parse-table

  ```
  $ sdf2table -i Example.def -o Example.tbl -m Main
  ```

- Parse an input file

  ```
  $ sglri -i foo.exp -p Example.tbl
  ```

- Parse an input file (alternative)

  ```
  $ sglr -2 -i foo.exp -p Example.tbl | implode-asfix
  ```

Exercise 2.2: Syntax Definition

Parsing

- cd strategoxt-tutorial/syntax
- inspect `*.sdf` files
- build parse table: WebDSL.tbl (see Makefile)
- parse `test*.app` files
- inspect `test*.trm` files

Syntax Definition

- `make check` (should fail)
- inspect unittest.testsuite
- `WebDSL-Action.sdf`: add syntax for multiplication, division, and modulo:
  `x * y / 3 % 10`
- `WebDSL-UI.sdf`: add syntax for case statements
  `case(x) { "a" { foo{} } default { bar{} } }`

Exercise 2.2: Answers

```
context-free syntax
    Exp "*" Exp  -> Exp {cons("Mul"),assoc}
    Exp "/" Exp  -> Exp {cons("Div"),assoc}
    Exp "%" Exp  -> Exp {cons("Mod"),assoc}

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

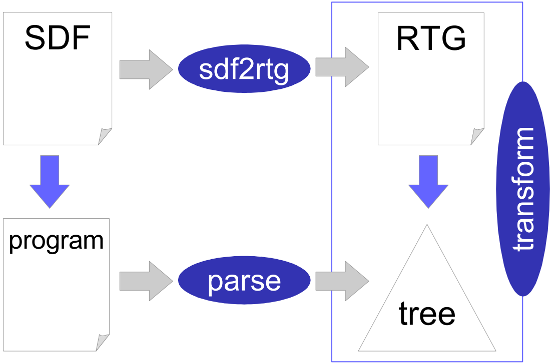
Exercise 2.2: Answers

```
context-free syntax
  "case" "(" Exp ")" "{" TemplateCaseAlt* "}"
       -> TemplateElement {cons("TemplateCase")}

  ConstValue "{" TemplateElement* "}"
       -> TemplateCaseAlt {cons("TemplateCaseAlt")}

  "default"  "{" TemplateElement* "}"
       -> TemplateCaseAlt {cons("TemplateCaseAltDefault")}
```

Tree Grammars as Contracts



- Syntax definitions (grammars) define a set of **strings**
- Transformation tools operate on **trees**
- **Tree grammars** define the format of trees
- Compare to DTD, W3C XML Schema, RELAX NG

Regular Tree Grammars

```
regular tree grammar
  start Exp
  productions
    Exp -> Int(IntConst)
         | Bool(BoolConst)
         | Not(Exp)
         | Mul(Exp, Exp)
         | Plus(Exp, Exp)
         | Call(Id, Exps)

    Exps -> <nil>()
          | <cons>(Exp, Exps)

    BoolConst -> <string>
    IntConst  -> <string>
    Id        -> <string>
```

Tools for Regular Tree Grammars

- Derive from SDF syntax definition

```
$ sdf2rtg -i Example.def -m Example -o Example.rtg
```

- Check the format of a tree

```
$ format-check --rtg Example.rtg
```

```
martin@logistico:~> format-check --rtg Exp.rtg -i exp3.trm --vis
error: cannot type Int(1)
    inferred types of subterms:
    typed 1 as <int>
error: cannot type Div(1,Var("c"))
    inferred types of subterms:
    typed 1 as <int>
    typed Var("c") as Exp
Plus(
  Mul(Int(1), Var("a"))
, Minus(Var("b"), Div(1, Var("c")))
)
martin@logistico:~>
```

- Generate tools and libraries

```
$ rtg2sig -i Example.rtg -o Example.str
```

Exercise 2.3: Tree Grammars

Regular Tree Grammar

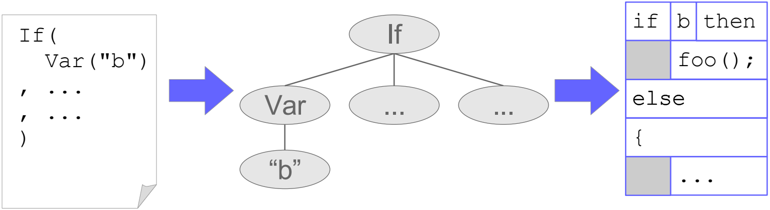
- create and inspect `WebDSL.rtg`
- format check `.trm` files (`make test.trm.chk`)
- what is wrong with `test7.trm`? (can you fix it?)

Signature

- create and inspect `WebDSL.str`

Pretty-printing

Code generators and source to source transformation systems need support for pretty-printing.

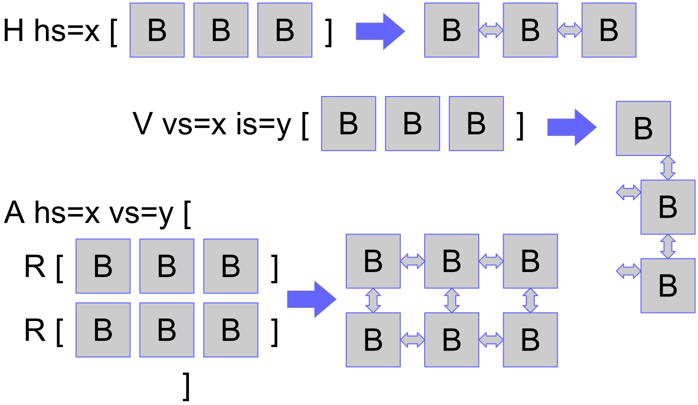


Stratego/XT: GPP (Generic Pretty-Printing)

- Box language
- Pretty-printer generation
- Different back-ends: `abox2text`, `abox2html`, `abox2latex`

Box Language

- Text formatting language
- Options for spacing, indenting
- 'CSS for plain text'



Other boxes: `HV`, `ALT`, `KW`, `VAR`, `NUM`, `C`

Example Box

```
V is=2 [
  H [KW["while"] "a" KW["do"]]
  V [
    V is=2 [
      H hs=1 [KW["if"] "b" KW["then"]]
      H hs=0 ["foo()" ";"]
    ]
    KW["else"]
    V [V is=2 ["{" "..."] "}"]
  ]
]
```

```
while a do
  if b then
    foo();
  else
  {
    ...
  }
```

Pretty-print Tables

- List of pretty-print rules
- Applied by constructor name (cons attribute)

Example Pretty-Print Table

```
[
   Var  -- _1,
   Bool -- _1,
   Int  -- _1,
   Mul  -- _1 KW["*"] _2,
   Plus -- _1 KW["+"] _2,
   Min  -- _1 KW["-"] _2,
   Call -- _1 KW["("] _2 KW[")"],
   Call.2:iter-star-sep -- _1 KW[","]
]
```

- ast2abox accepts sequence of pretty-print tables
- Tables can be combined and reused

```
$ echo "1 + 2" | sglri -p Ex.tbl | ast2abox -p Ex.pp | abox2text
```

Pretty-printer Generation

- Pretty-print table can be generated from SDF syntax definition (`ppgen`)
  - Complete and correct (usually)
  - Minimal formatting
- Customization by hand for pretty result
  - Tools for consistency checking and patching (`pptable-diff`)
- Parentheses problem: parentheses inserter can be generated from SDF syntax definition (`sdf2parenthesize`).

Exercise 2.4: Pretty-Printing

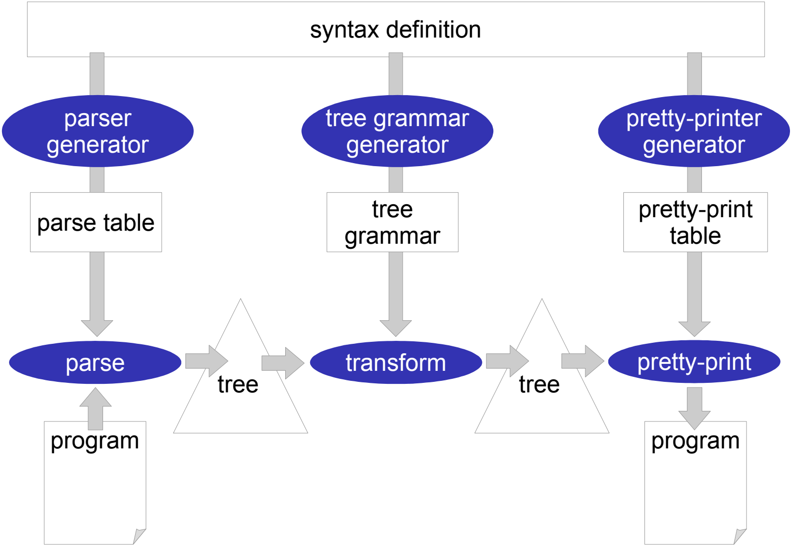
Ugly-Print Table

- generate and inspect `WebDSL.pp`
- use `WebDSL.pp` to format ASTs in `*.trm` files
- (`make *.trm.up`)

Pretty-Print Table

- use `WebDSL-pretty.pp` instead of `WebDSL.pp`
- (`make *.trm.pp`)

Architecture of Stratego/XT



XT Orbit

- **Java**
  - High-quality syntax definition (1.5)
  - Handcrafted pretty-printer (1.5)
  - Disambiguation
  - Type-checker
- **C** (EPITA, France)
  - Syntax definition (C99)
  - Disambiguation
- **Octave**
  - Parser
  - Type-checker
  - Compiler
- **Prolog**
  - Syntax definition
  - Embedding of object languages
- **BibTeX**
  - Syntax definition
  - Web services