Introduction to Generic Language Technology

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How can we ...

- ... build *tools* for software analysis and manipulation?
- ... make the tools *programming language independent* (language-parametric)?
- ... integrate the tools in Interactive Development Environment (IDE)?
- ... a quick general overview, and then an introduction to specific technologies?

What ...

- ... is a language?
- ... is a Programming Environment (PE)?
- ... is Generic Language Technology (GLT)?
- ... is a Program Generator?
- ... is a Programming Environment Generator?
- ... are the applications areas of GLT?
- ... technology is used for GLT?

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What is a Language?

- A programming language
  - Assembler, Cobol, PL/I, C, C++, Java, C#, ...
- A Domain-Specific Language (DSL)
  - SQL for queries
  - BibTex for entries in a bibliography
  - Euris for railroad emplacement safety
  - Risla for financial products

Aspects of a Language

- Syntax
  - Textual form of declarations, statements, etc.
- Static Semantics
  - Scope and type of variables, conversions, formal/actual parameters, etc.
  - Queries: who calls who, who uses variable X, ...
- Dynamic Semantics
  - Program execution

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What is a Programming Environment?

A system that supports the development of programs in order to:

- Increase productivity:
  - Uniform user-interface (UI); integrated tools
  - Increased interaction; early error detection
- Increase quality:
  - Integrated version management
  - Integrated testing

Classical PE

- Text editor only
- Programs stored in files
- Complete recompilation after each change
- Late error detection
- Debugging requires recompilation
- Example:
  - xemacs or vim
  - gcc or javac

Integrated PE (IPE)

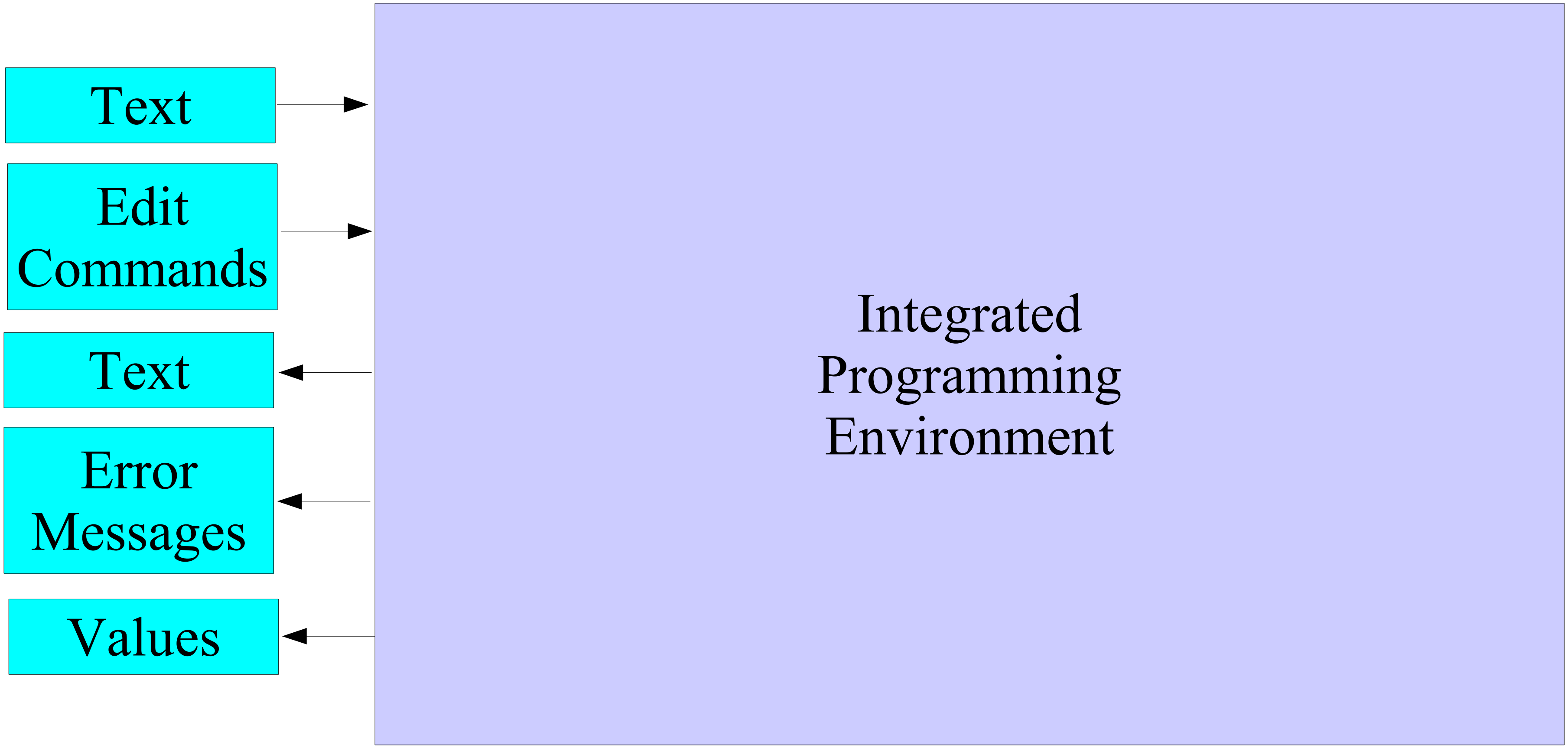
also: Integrated Development Environment (IDE)

- Specialized, syntax-directed, editor for each language
- Common intermediate representation for all tools
- Incremental processing
- Early error detection
  - Syntax errors
  - Undeclared variables
  - Type errors in expressions

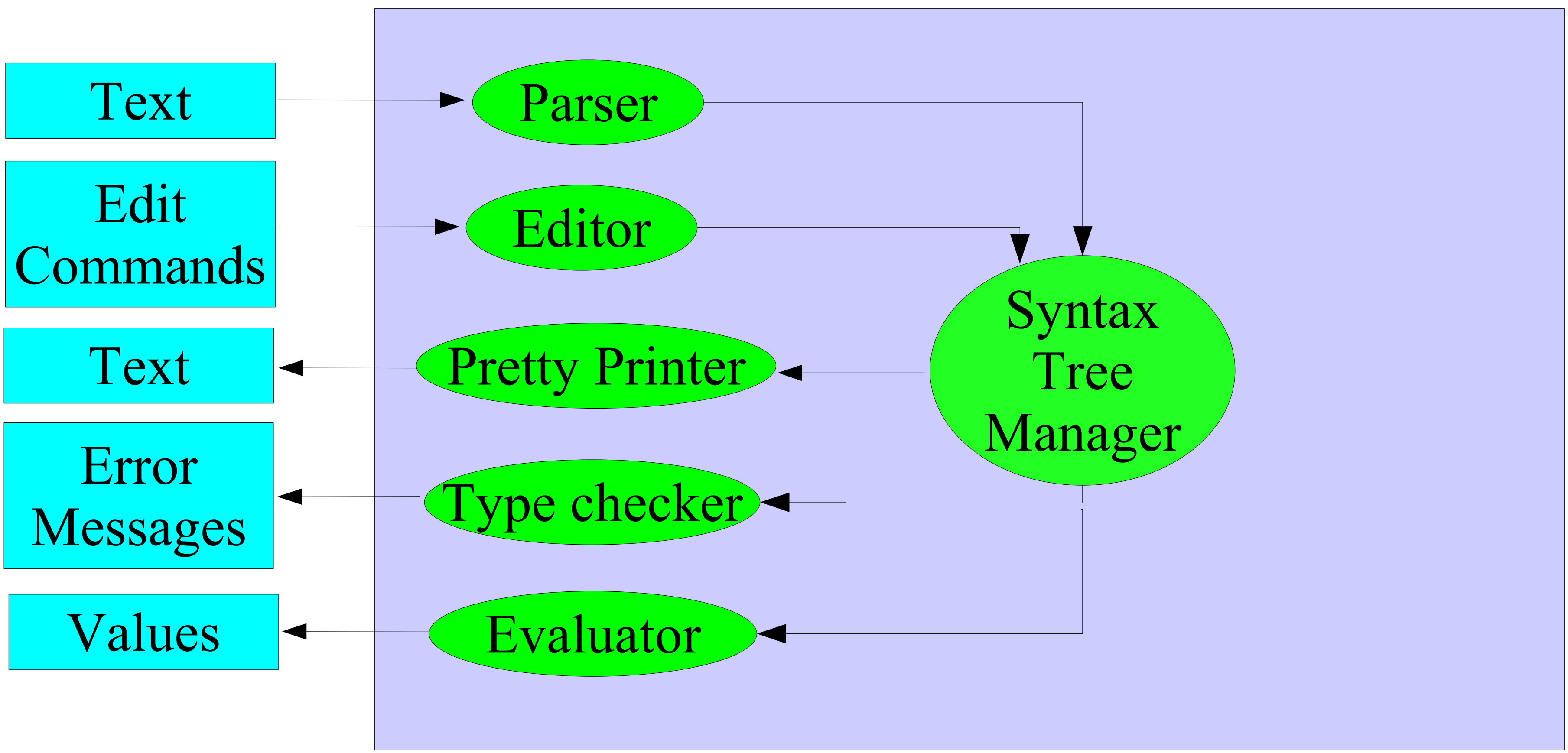
Functionality of a IPE

- Syntax-directed editing/highlighting, pretty printing
- Typechecking
- Restructuring
- Versioning
- Executing, debugging, profiling
- Testing
- Documenting

Simple, External, View of IPE



Simple, Internal, View of IPE



Examples of IPEs

- Eclipse: www.eclipse.org
  - Integrated Development Environment (IDE) for Java
  - Plug-in mechanism for extensions
- MS Visual Studio: msdn.microsoft.com/vstudio
  - IDE for various languages VB, C, C++, C#

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What is Generic Language Technology?

- Goal: Enable the easy creation of language-specific tools and programming environments
- Separate language-specific aspects from generic aspects
- Approach:
  - Find good, reusable, solutions for generic aspects
  - Find ways to define language-specific aspects
  - Find ways to generate tools from language-specific definitions

Generic aspects

- User-interface
- Text editor
- Program storage
- Documentation

Defining Language Aspects

- Syntax
  - Context-free grammar
- Static semantics
  - Algebraic specification/rewrite rules
- Dynamic semantics
  - Algebraic specification/rewrite rules

From Definition to Tool

- Syntax
  - Parser generation
- Static semantics
  - Term rewriting
- Dynamic semantics
  - Term rewriting

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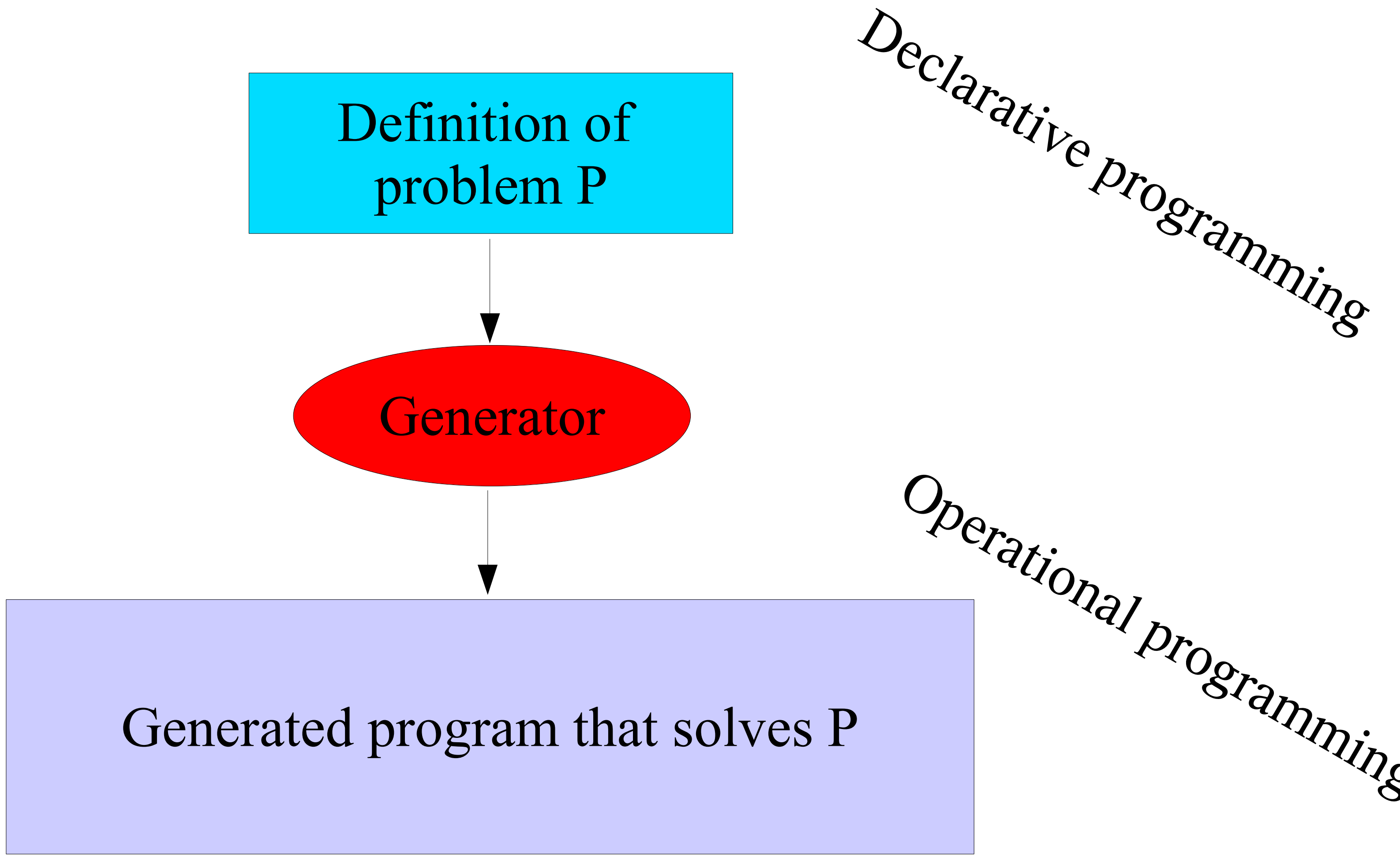
What is a Program Generator?



Examples of Program Generators (1)

- Regular expression matching:
  - Problem: recognize regular expressions R_1, ..., R_n in a text
  - Generates: finite automaton
- Web sites
  - Problem: create uniform web site for set of HTML pages
  - Generate: HTML code with standard layout and site map

Examples of Program Generators (2)

- Generate bibliographic entries; input

```
@article{BJKO00,   author  = {Brand, {M.G.J. van den} and Jong,  {H.A. de}
                              and P. Klint and P. Olivier},
                   title   = {{E}fficient {A}nnotated {T}erms},
                   journal = {Software, Practice \& Experience},
                   year    = {2000},
                   pages   = {259—291},
                   number  = {3},
                   volume  = {30}}
```

generates:

M.G.J. van den Brand, H.A. de Jong, P. Klint and P.A. Olivier, Efficient Annotated Terms, *Software, Practice & Experience*, **30**(3):259—291, 2000

Examples of Program Generators (3)

- Compiler:
  - Input: Java program
  - Generates: JVM code
- C preprocessor:
  - Input C program with `#include`, `#define` directives
  - Generates C program with directives replaced.

Program Generators (summary)

- Problem description is specific and is usually written in a Domain-Specific Language (DSL)
- Generator contains generic algorithms and information about application domain.
- A PG isolates a problem description from its implementation $\Rightarrow$ easier to switch to other implementation methods.
- Improvements/optimizations in the generator are good for all generated programs.

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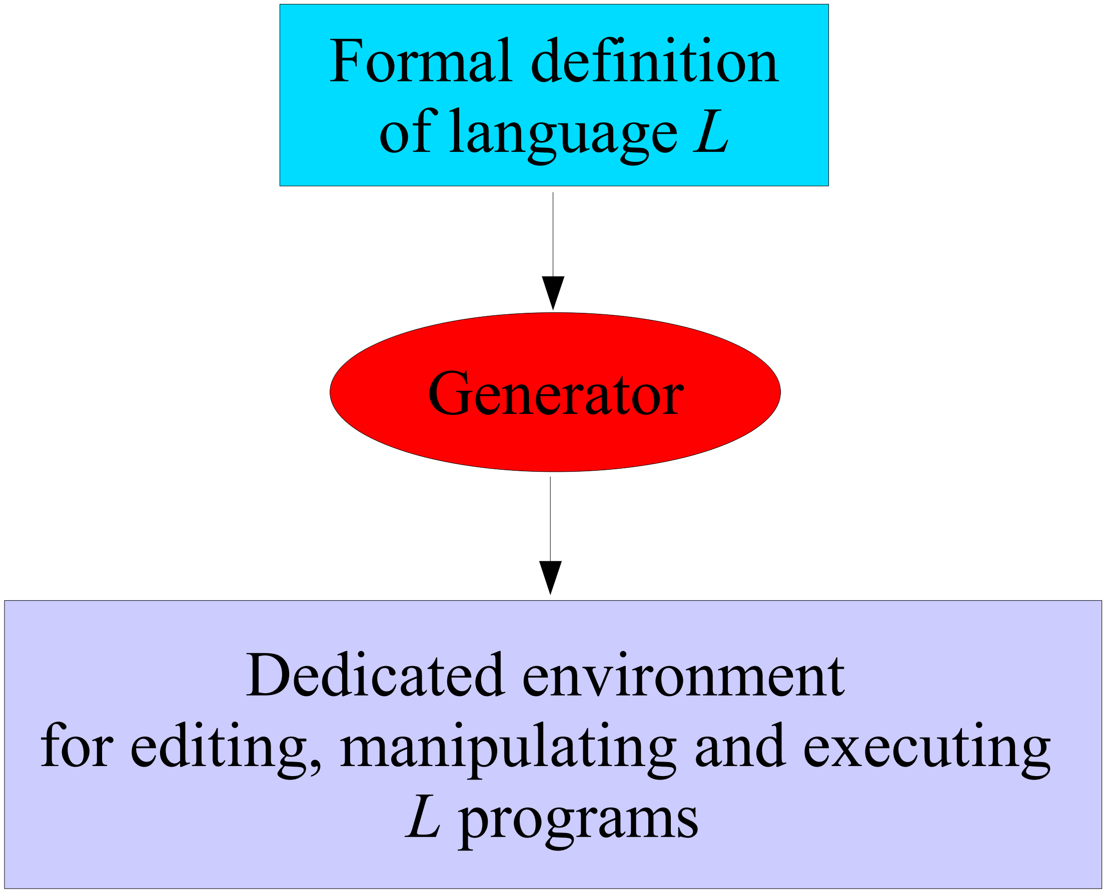
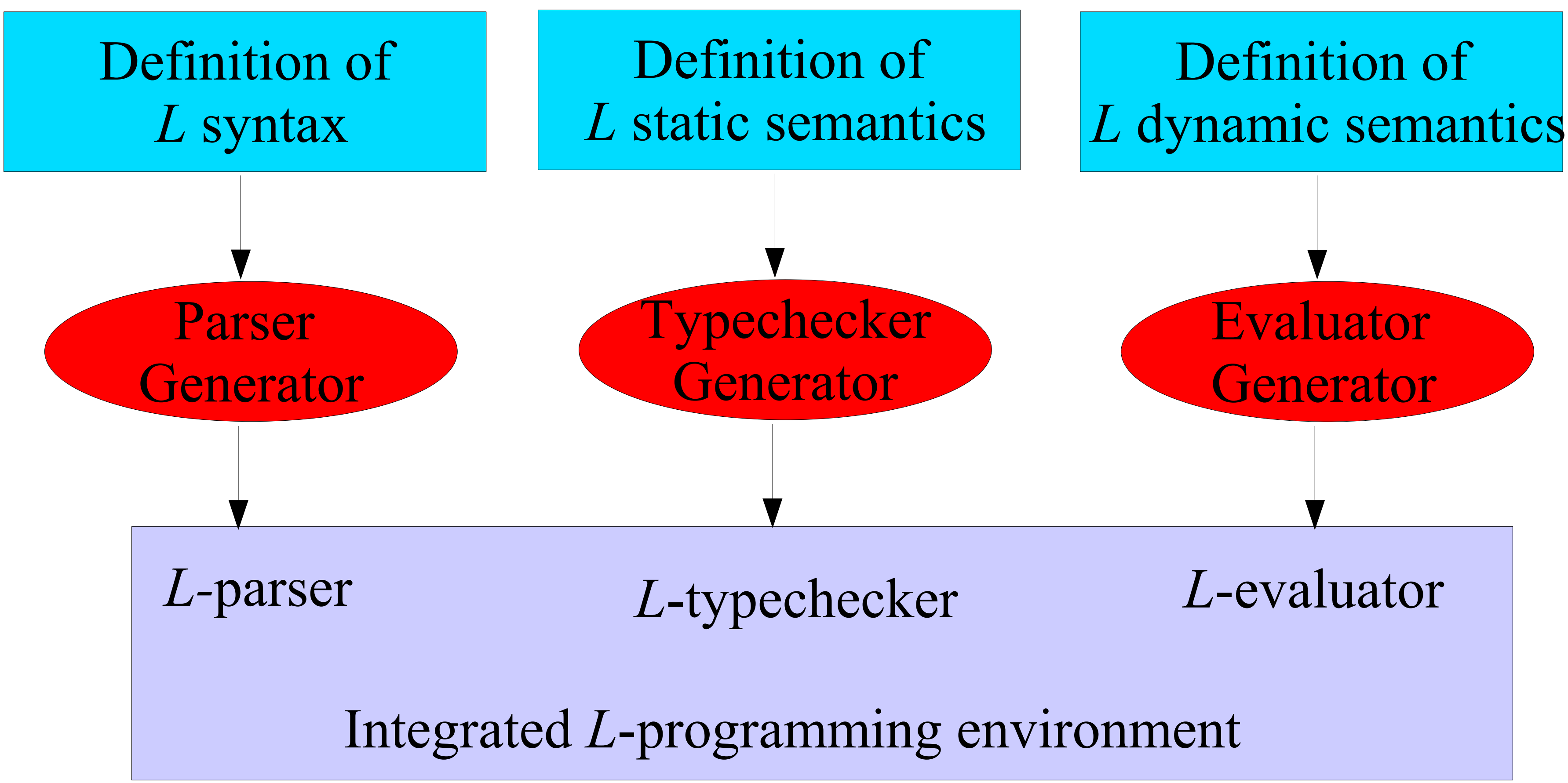
What is a Programming Environment Generator (PEG)?

- A PEG is a program generator applied in the domain of programming environments
- Input: description of a desired language *L*
- Output: (parts of) a dedicated *L* environment
- Advantages:
  - Uniform interface across different languages
  - Generator contains generic, re-usable, implementation knowledge
- Disadvantage: some UI optimizations are hard

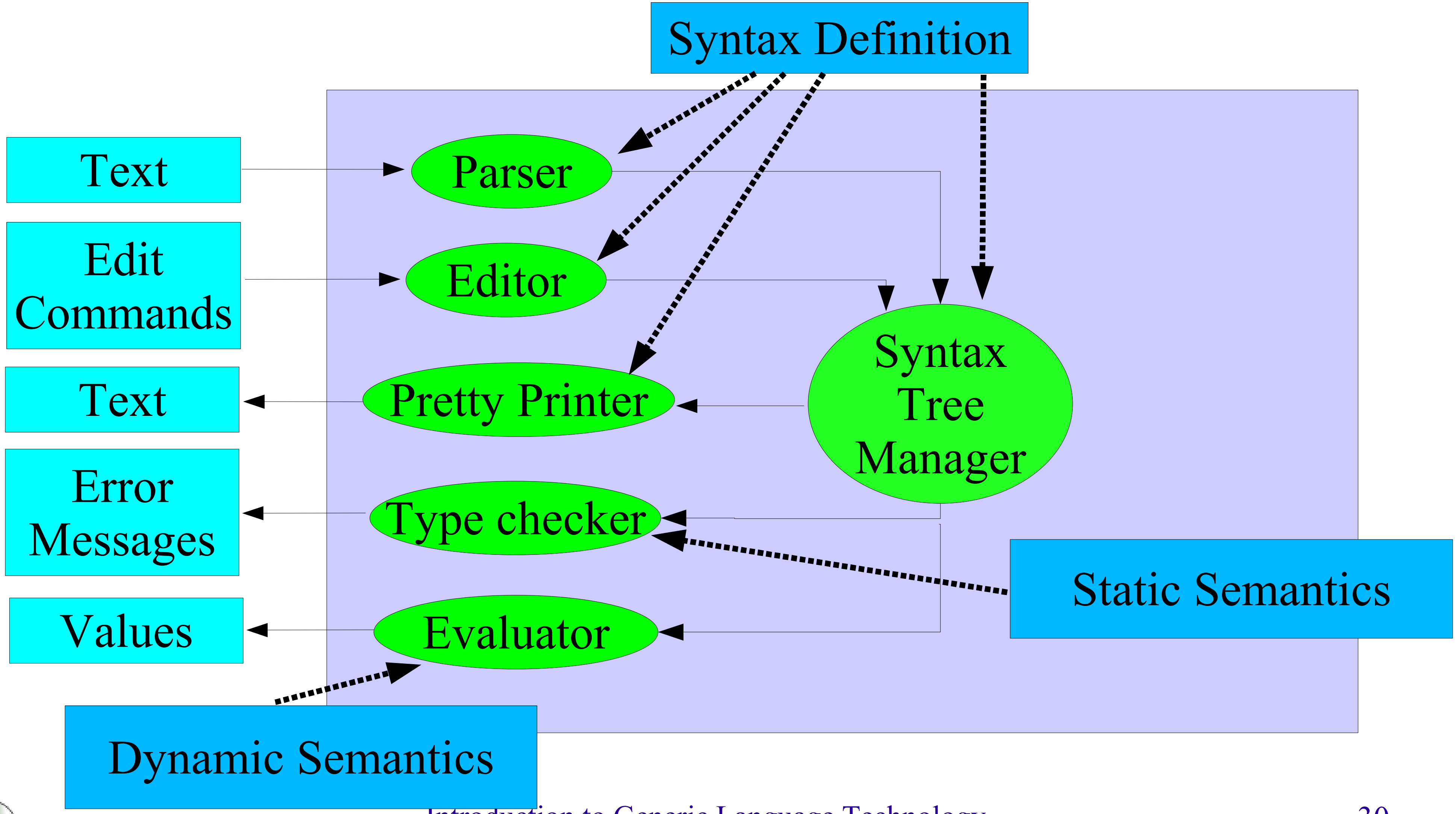
Programming Environment Generator



PEG = collection of program generators



From Definitions to Components



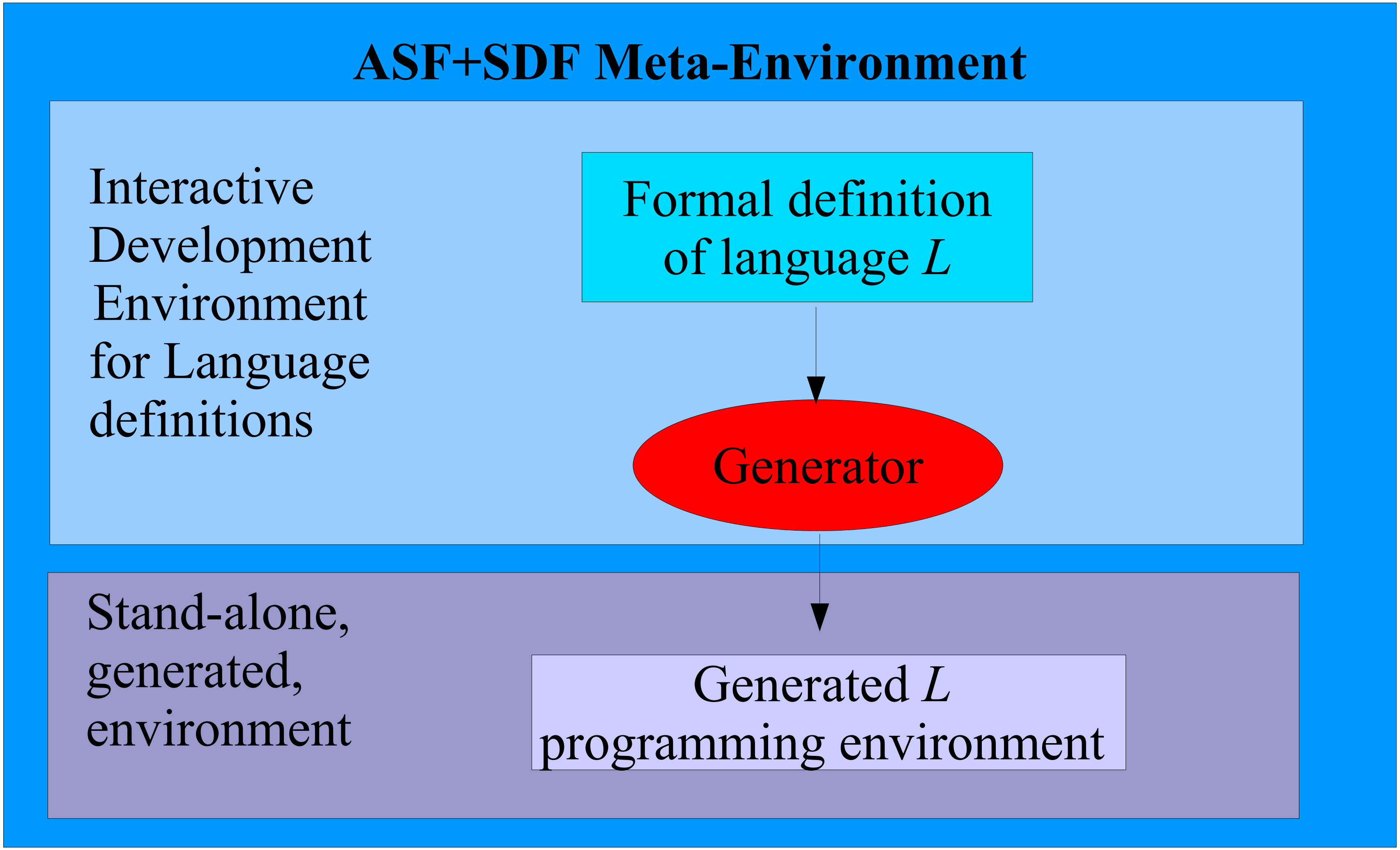
PEG: further definitions

- Lexical syntax
- Concrete syntax
- Abstract syntax
- Pretty printing
- Editor behaviour
- Dataflow
- Control flow
- Program Analysis
- Program Queries
- Evaluation rules
- Compilation rules
- User Interface
- Help rules
- ...

ASF+SDF Meta-Environment (1)

- An interactive development environment for generating tools from formal language definitions
- Based on:
  - Full context-free grammars
  - Conditional term rewriting
- Language definitions written in ASF+SDF
  - SDF: Syntax definition Formalism
  - ASF: Algebraic Specification Formalism

ASF+SDF Meta-Environment (2)



ASF+SDF Specifications

- Series of modules
- A module can import other modules
- A module can be parameterized
- Each module consists of two parts:
  - SDF-part defines lexical and context-free syntax, priorities and variables
  - ASF-part defines arbitrary functions, e.g. for typechecking, analysis, evaluation, transformation, ...

Booleans: syntax

```
module Booleans
 exports
  sorts BOOL
  context-free syntax
     "true"            -> BOOL
     "false"           -> BOOL
     and(BOOL,BOOL) -> BOOL
 variables
    "B" -> BOOL
```

Simplified version of a library module

Booleans: terms

Defines the syntax of the language of Booleans, e.g.

- true
- and(true,false)
- and(and(true,false), and(false, false))

- or, terms with variables (as used in equations):
  - and(true,B)
  - and(and(true,false), and(B, false))

Booleans: semantics

Add semantics for and function:

```
equations
[1] and(true, true) = true
[2] and(true,false) false
[3] and(false,true) = false
[4] and(false, false) = false
```

Alternative:

```
equations
[1] and(true, B) = B
[2] and(false, B) = false
```

Booleans: complete module

```
module Booleans
 exports
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     true                -> BOOL
     false               -> BOOL
     and(BOOL,BOOL) -> BOOL
   variables
     B -> BOOL
 equations
  [1] and(true, B) = B
  [2] and(false, B) = false
```

Arithmetic (1)

- The successor notation is a well-known device to define numbers and arithmetic:
  - 0 is represented by 0
  - 1 is represented by s(0)
  - 2 is represented by s(s(0))
  - *n* is represented by $s^n(0)$

Arithmetic (2)

```
module Arithmetic
exports
  sorts  INT
  context-free syntax
    "0"              -> INT
    s(INT)           -> INT
    plus(INT, INT)   -> INT
  variables
    "X"              -> INT
    "Y"              -> INT
```

Arithmetic (3)

Add semantics for function `plus`:

```
equations
[p1] plus(0, X) = X
[p2] plus(s(X), Y) = s(plus(X, Y))
```

Or using infix notation:

```
equations
[p1'] 0 + X = X
[p2'] (X+1) + Y = (X + Y) + 1
```

Arithmetic (4)

```
module Arithmetic
 exports
   sorts  INT
   context-free syntax
     "0"                    -> INT
     s(INT)                 -> INT
     plus(INT, INT)         -> INT
   variables
     X                      -> INT
     Y                      -> INT
equations
[p1] plus(0, X) = X
[p2] plus(s(X), Y) = s(plus(X, Y))
```

Arithmetic (5)

Using these rules

we can start computing:

[p1] plus(0, X) = X

[p2] plus(s(X), Y) = s(plus(X, Y))

plus(s(s(0)), s(s(s(0)))) $=^{p2}$

s(plus(s(0), s(s(s(0))))) $=^{p2}$

s(s(plus(0, s(s(s(0)))))) $=^{p1}$

s(s(s(s(s(0)))))

In other words: **2 + 3 = 5**

Term Rewriting (1)

Rewrite rules $\{L_i \rightarrow R_i\}^{r}_{i=1}$ and initial term T_0

Example:

- [p1] plus(0, X) = X
- [p2] plus(s(X), Y) = s(plus(X, Y))

Initial term:

- plus(s(s(0)), s(s(s(0))))

Term Rewriting (2)

Match subterm (redex) of T_j with some L_i and replace by R_i (after variable substitution); this gives T_{j+1}

- Try to apply [p2] plus(s(X), Y) = s(plus(X, Y)) to plus(s(s(0)), s(s(s(0))))
- Match plus(s(s(0)), s(s(s(0)))) with plus(s(X), Y)
- Yields X=s(0) and Y= s(s(s(0)))
- Substitute in r.h.s.: s(plus(s(0), s(s(s(0)))))

Term Rewriting (3)

- We have reached a normal form T_n when no more matches in T_i are possible
- The reduction sequence is: $T_0 \rightarrow T_1 \rightarrow \ldots \rightarrow T_n$

```
plus(s(s(0)), s(s(s(0)))) ->
s(plus(s(0), s(s(s(0)))) ->
s(s(plus(0, s(s(s(0)))) ->
s(s(s(s(s(0)))))
```

Term Rewriting (4)

- The order in which a redex is selected may differ
- We use innermost selection
- There is more to term rewriting:
  - Lists and list matching
  - Conditional rules
  - Default rules
  - Traversal functions
  - ...

ASF+SDF (summary)

Surprisingly, these trivial examples scale to large applications. The pattern is always:

- define a syntax (Booleans, numbers, COBOL programs)
- define functions on terms in this syntax (and, plus, eliminate-goto's)
- apply to examples of interest

We will hear later about other interesting features of ASF+SDF

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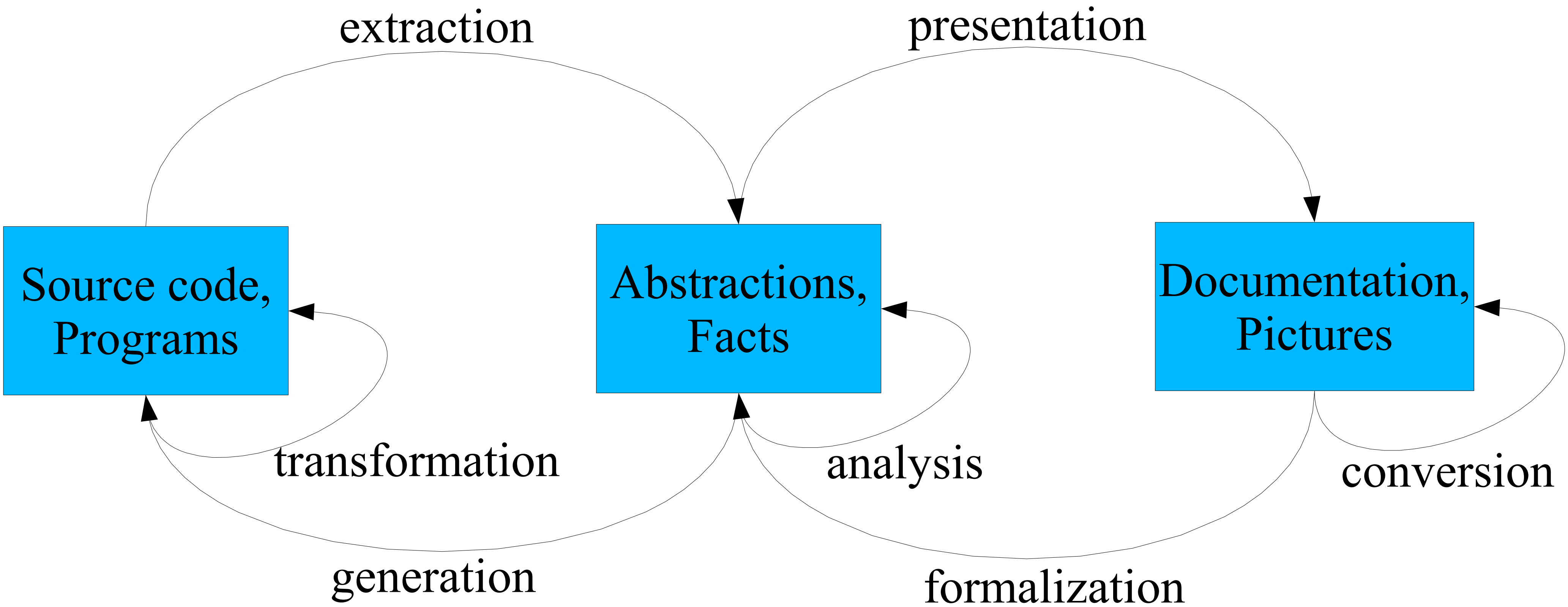
What are applications of GLT? (1)

- Domain-specific languages
  - RISLA (financial software, Fortis, ING)
  - EURIS (railroad safety, Dutch Rail)
- Software renovation
  - Analysis of telephone software (Ericsson)
  - Analysis and transformation of COBOL systems
  - Analysis of Java systems (code smells)

What are applications of GLT? (2)

- Code generation from UML
- Java verification
- Tools for various specification languages: CHI, Elan, Action Semantics, LOTOS, muCRL, ...
- Various tools of the Meta-Environment: parser generator, compiler, checkers, ...

What are applications of GLT (3)



Generic Language Technology helps implementing translations between source code representations

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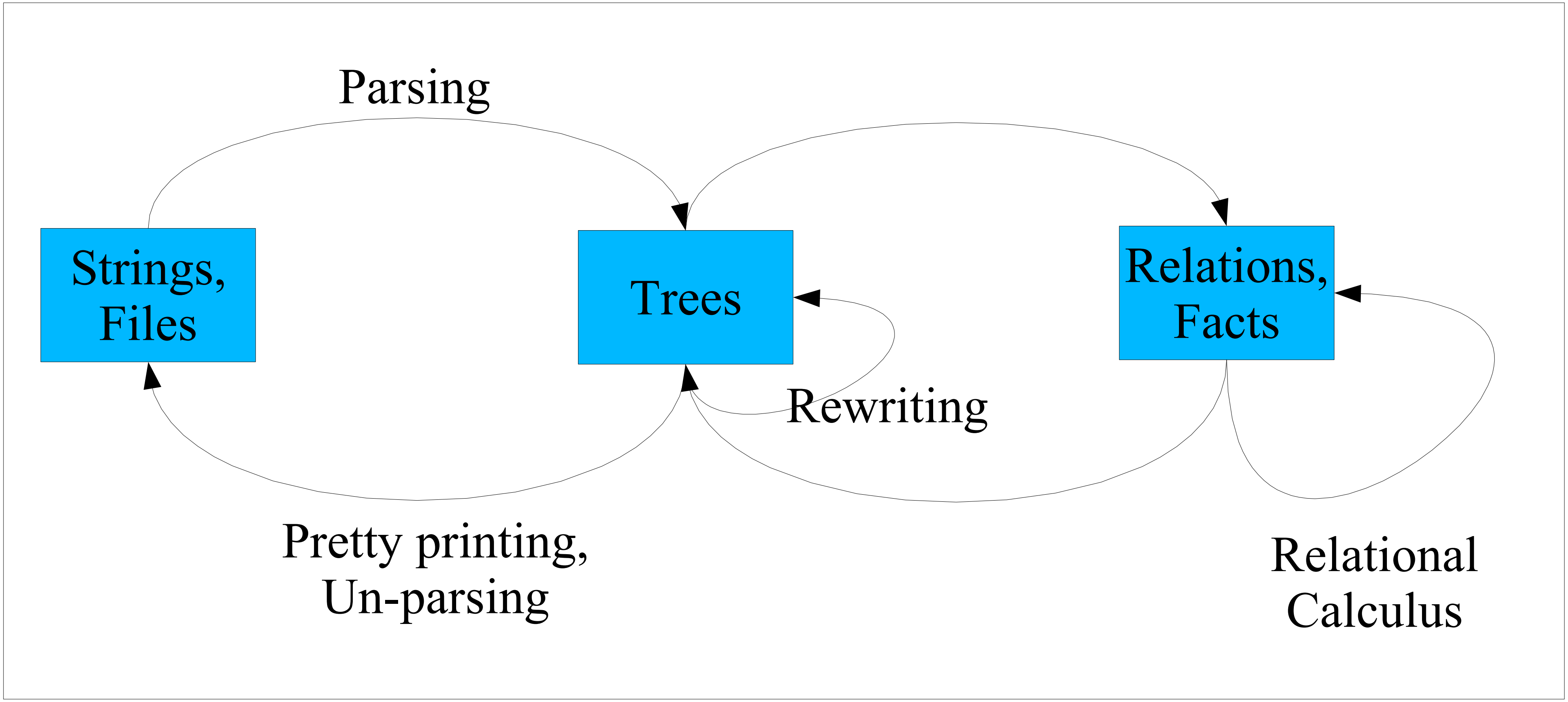
What technology is used for GLT?

ToolBus/ATerm middleware



What Technology is used for GLT?

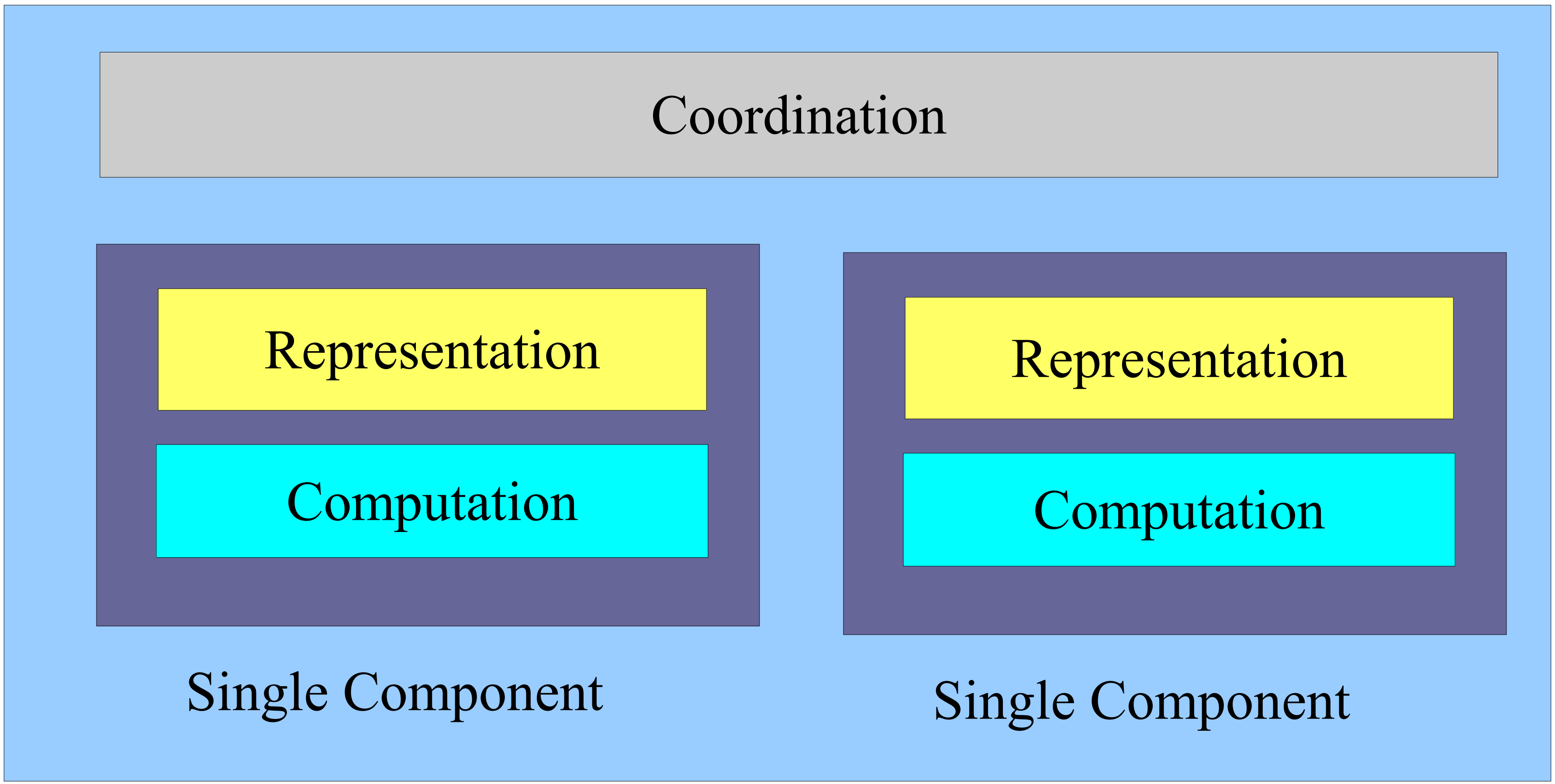
- ToolBus: a software coordination architecture used for connecting tools
- ATerms: Annotated Terms used to exchange data between tools
- SGLR: Scannerless Generalized LR parsing
- Conditional term rewriting and efficient compilation techniques

Coordination, Representation & Computation

- Coordination: the way in which program and system parts interact (procedure calls, RMI, ...)
- Representation: language and machine neutral data exchanged between components
- Computation: program code that carries out a specialized task

A rigorous separation of coordination from computation is the key to flexible and reusable systems

Architectural Layers

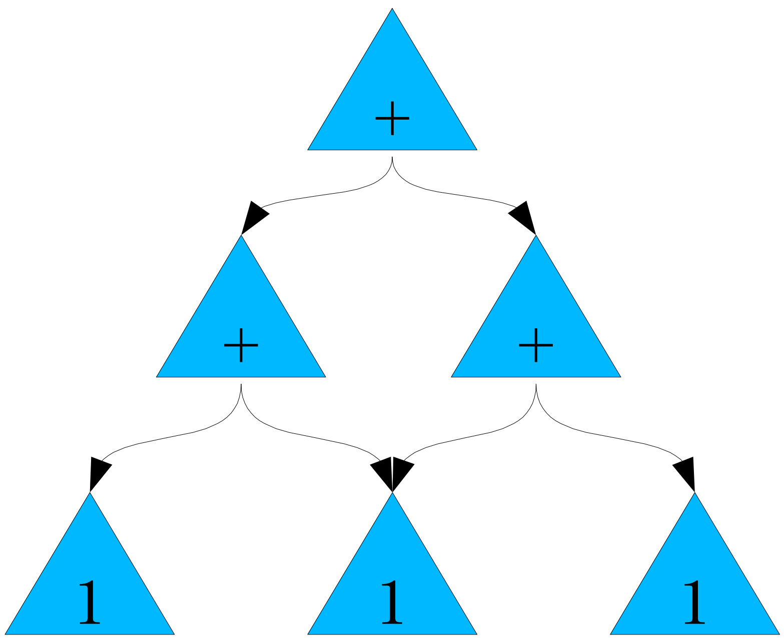


Cooperating Components

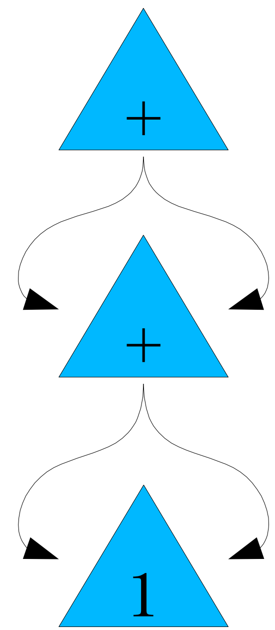
Generic Representation
Annotated Terms (ATerms)

- Applicative, prefix terms
- Maximal subterm sharing ($\Rightarrow$ DAG)
  - cheap equality test, efficient rewriting
  - automatic generational garbage collection
- Annotations (text coordinates, dataflow info, ...)
- Very concise, binary, sharing preserving encoding
- Language & machine independent exchange format

ATerms
Sharing

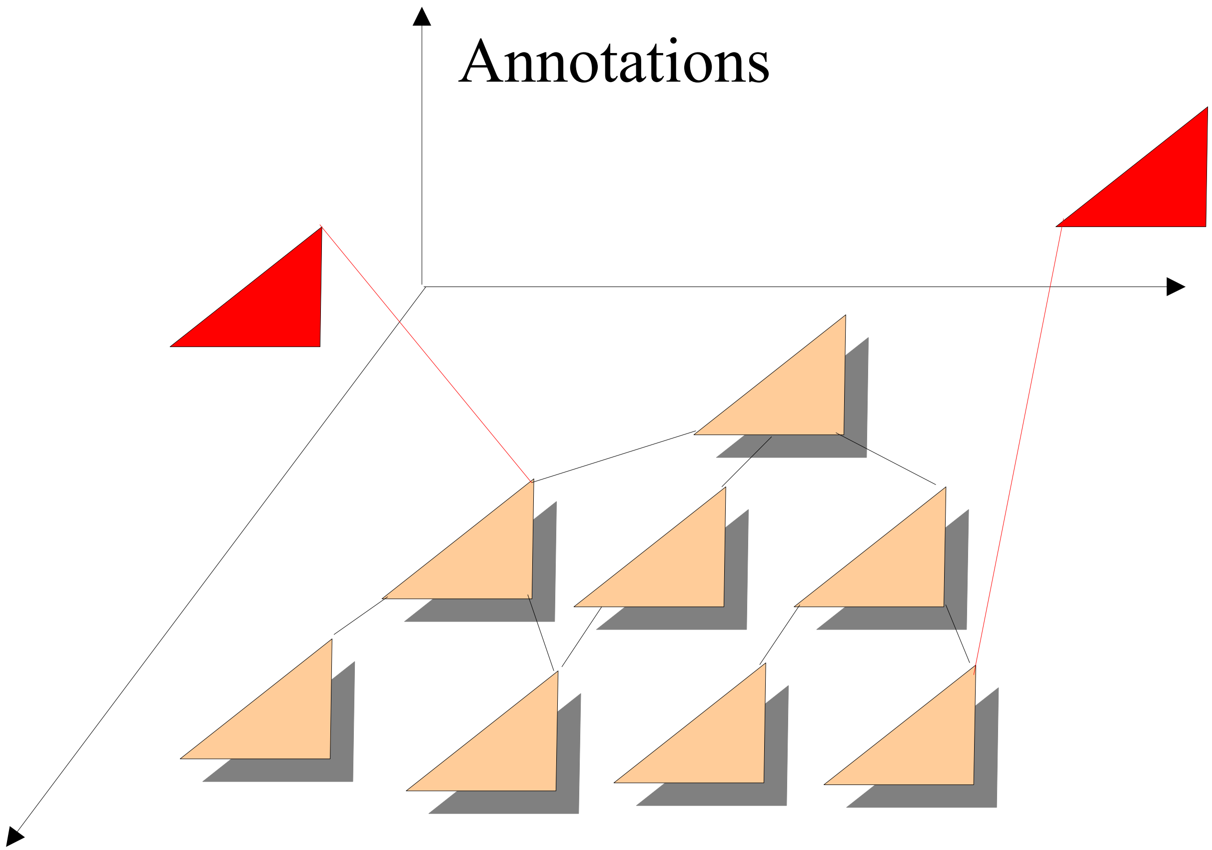


6 nodes



3 nodes

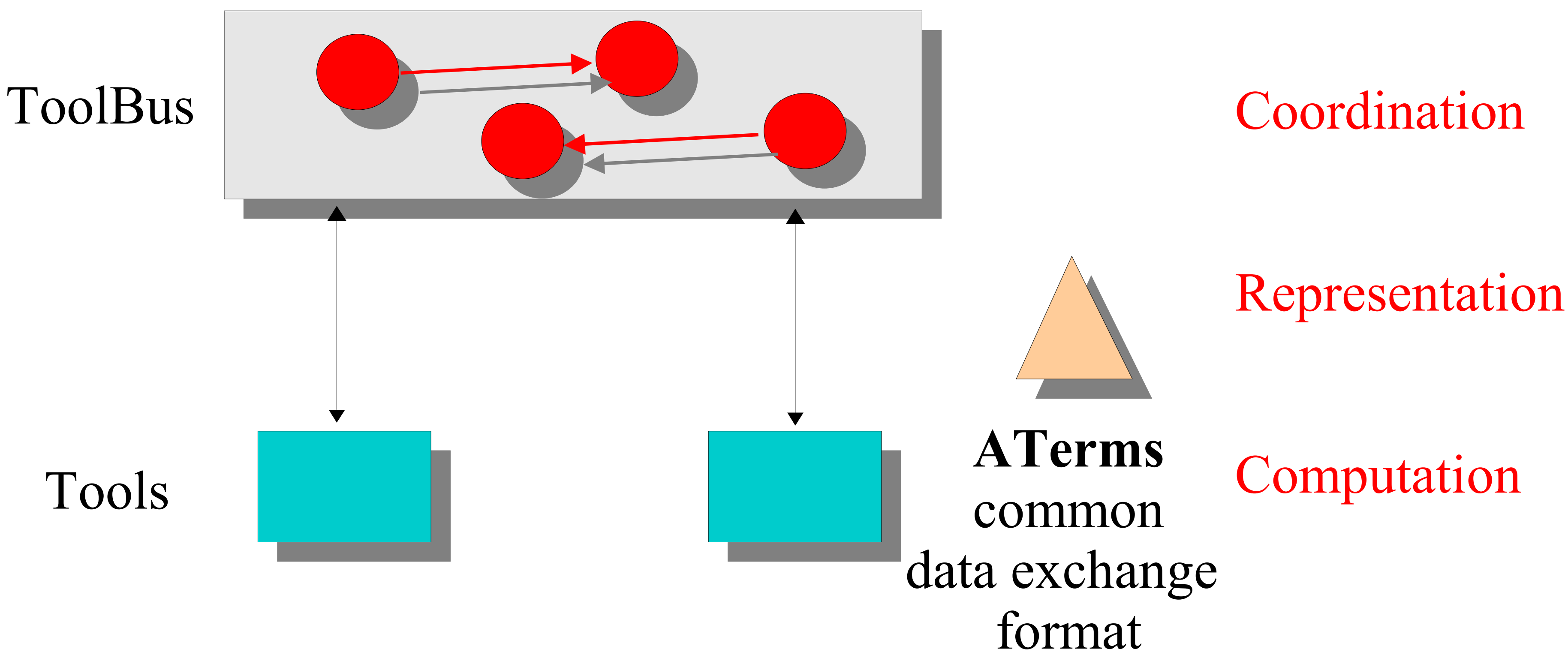
ATerms
Term and Annotations



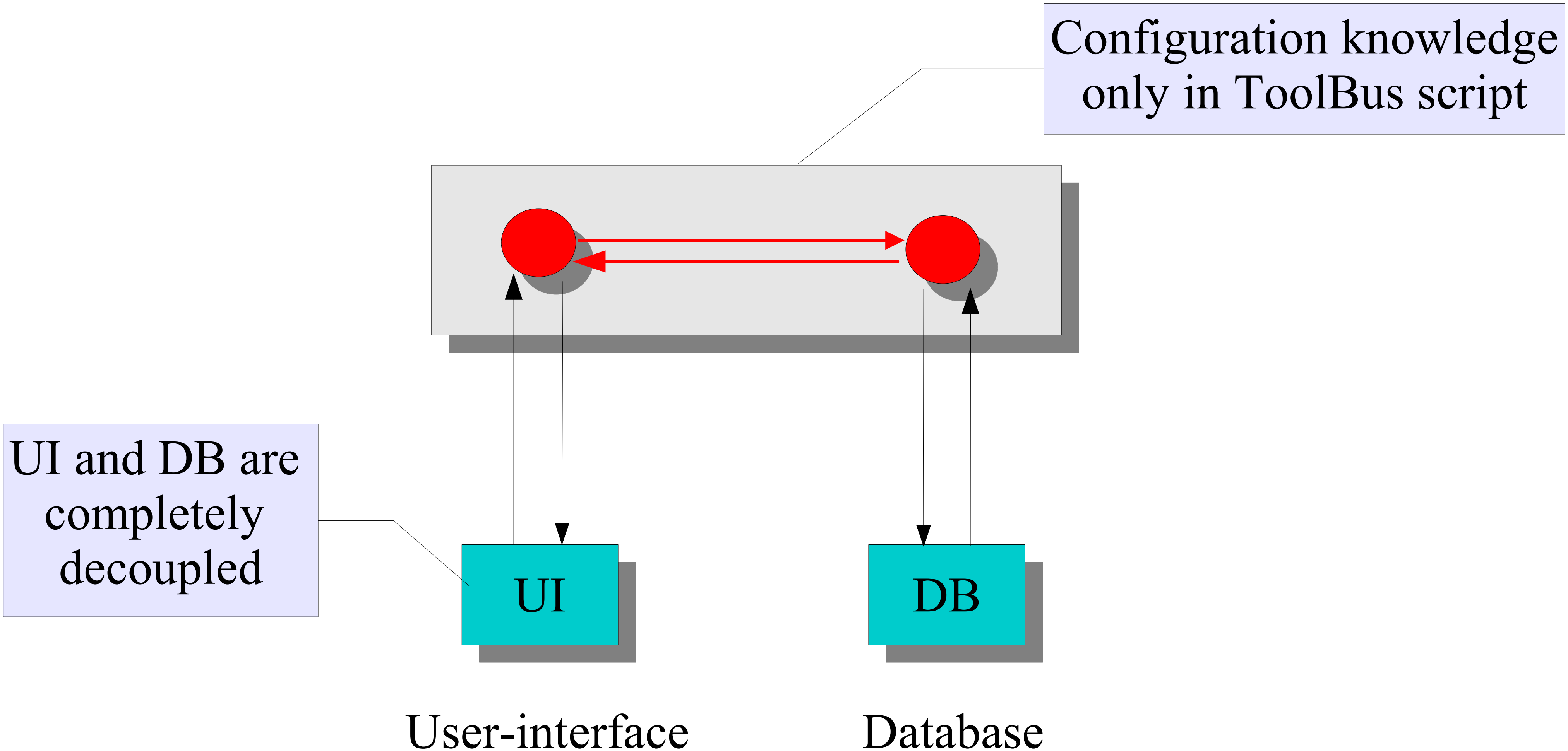
The ToolBus Architecture (1)

- Goals: integrate tools written in different languages running on different machines
- A programmable software bus
- Scripts describe the cooperation of tools
- Scripts are based on Process Algebra

The ToolBus Architecture (2)



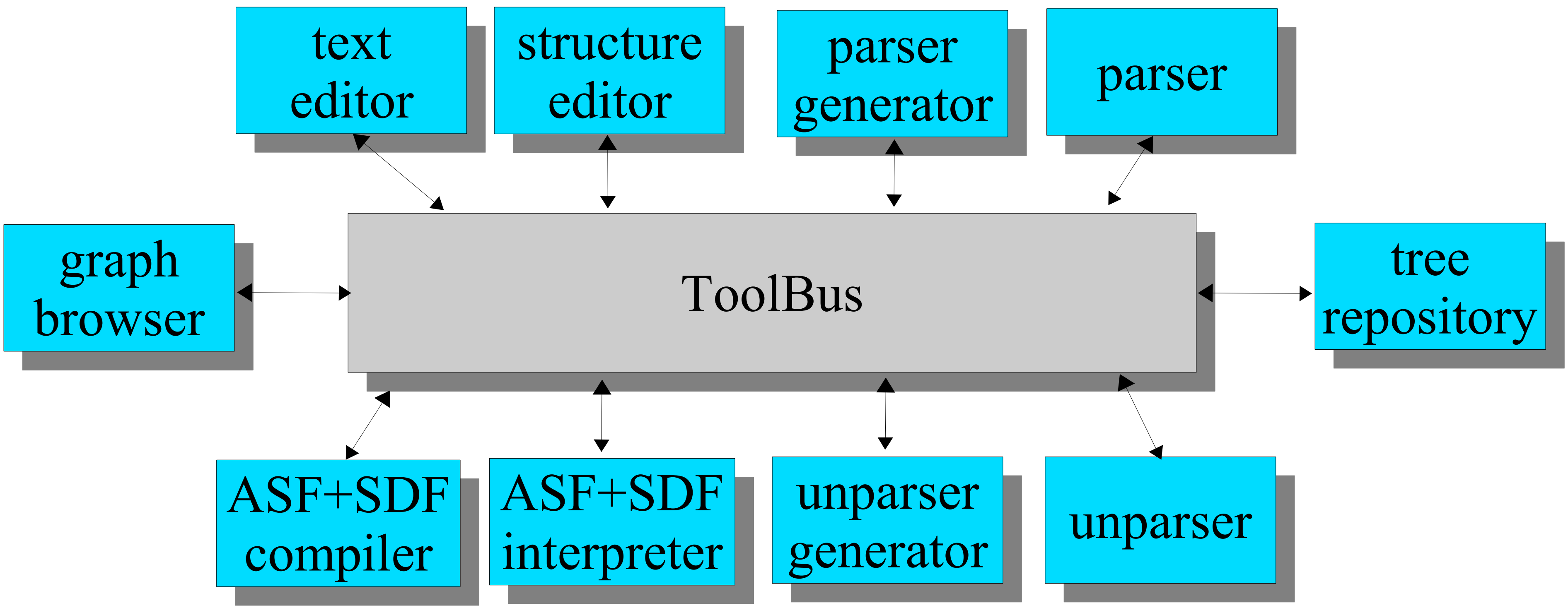
A typical scenario



ToolBus scripts

- Send, receive message (handshaking)
- Send/receive notes (broadcasting)
- $P_1 + P_2$ $P_1 . P_2$ $P_1 || P_2$ $P_1 * P_2$
- :=, if then else
- Absolute/relative delay, timeout
- Dynamic process creation
- Execution, connection & termination of tools

Architecture of the ASF+SDF MetaEnvironment



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Scannerless Generalized LR Parsing (1)

- Scannerless: in a traditional compiler lexical syntax is implemented by a scanner and context-free syntax by a parser. SGLR: scanner and parser are integrated
  - makes resulting parser more expressive
  - simplifies the implementation

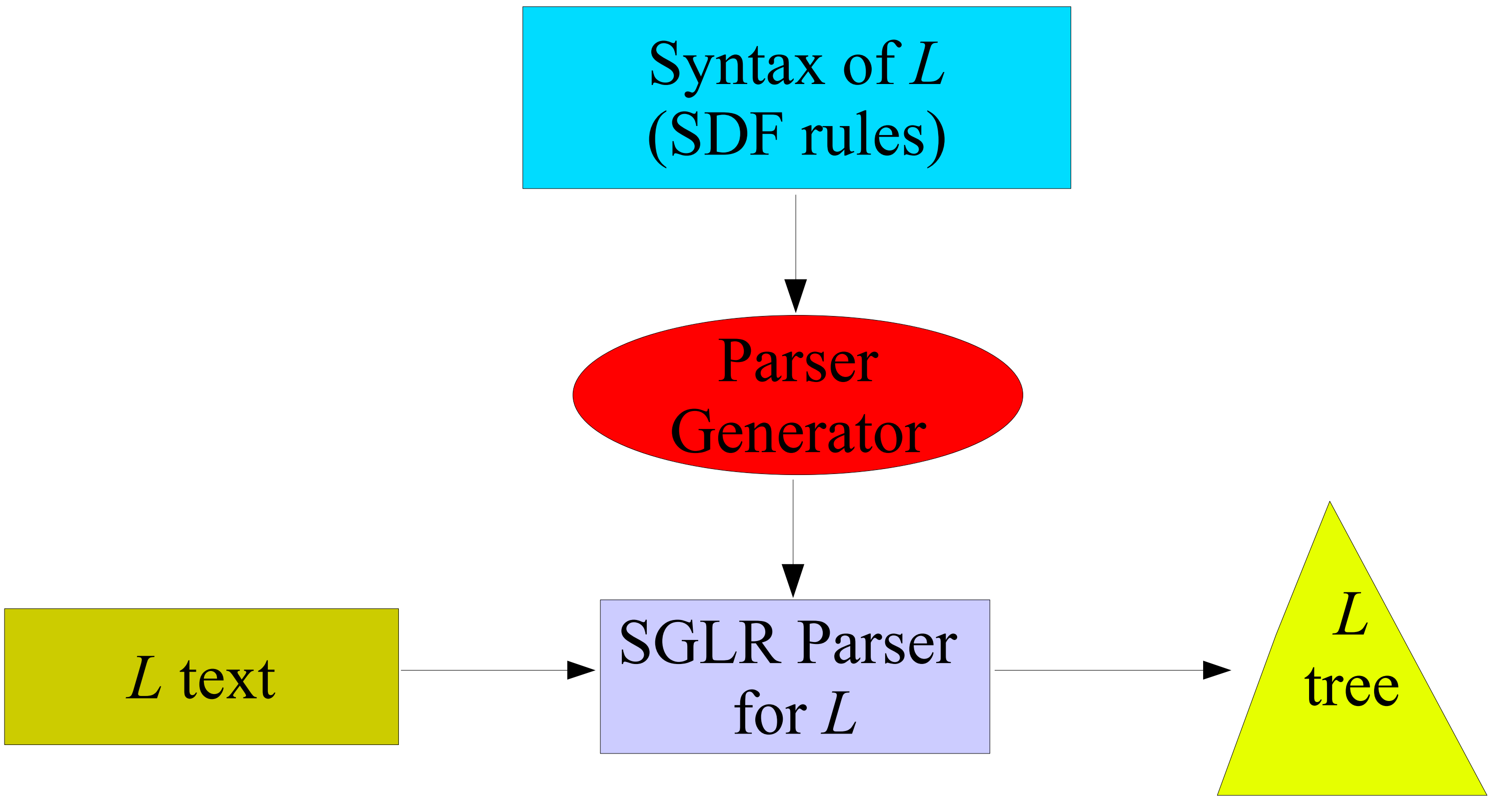
Scannerless Generalized LR Parsing (2)

- LR: left-to-right (bottom-up) parsing as used by Yacc and Bison.
- Generalized: extends the class of accepted grammars to all context-free grammars
  - Context-free grammars are closed under composition (as opposed to, e.g., LR grammars)
  - Enables modular grammars
  - Important for large grammars and language dialects

Scannerless Generalized LR Parsing (3)

- An LR-based parser generator does not allow conflicts: (shift/reduce, reduce/reduce)
- Key ideas in SGLR:
  - split a concurrent parse when a conflict occurs
  - merge concurrent parses as soon as possible
  - an ambiguity node represents alternative parses
- It is undecidable whether a context-free grammar is ambiguous, but heuristics might help.

Parsing Architecture



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Conditional Term Rewriting

- Collect rules with same outermost symbol and generate one C function for them
- Generate a finite automaton for the matching of left-hand sides
- Use ATerms to represent terms:
  - maximal subterm sharing
  - structural equality can be implemented by pointer comparison!

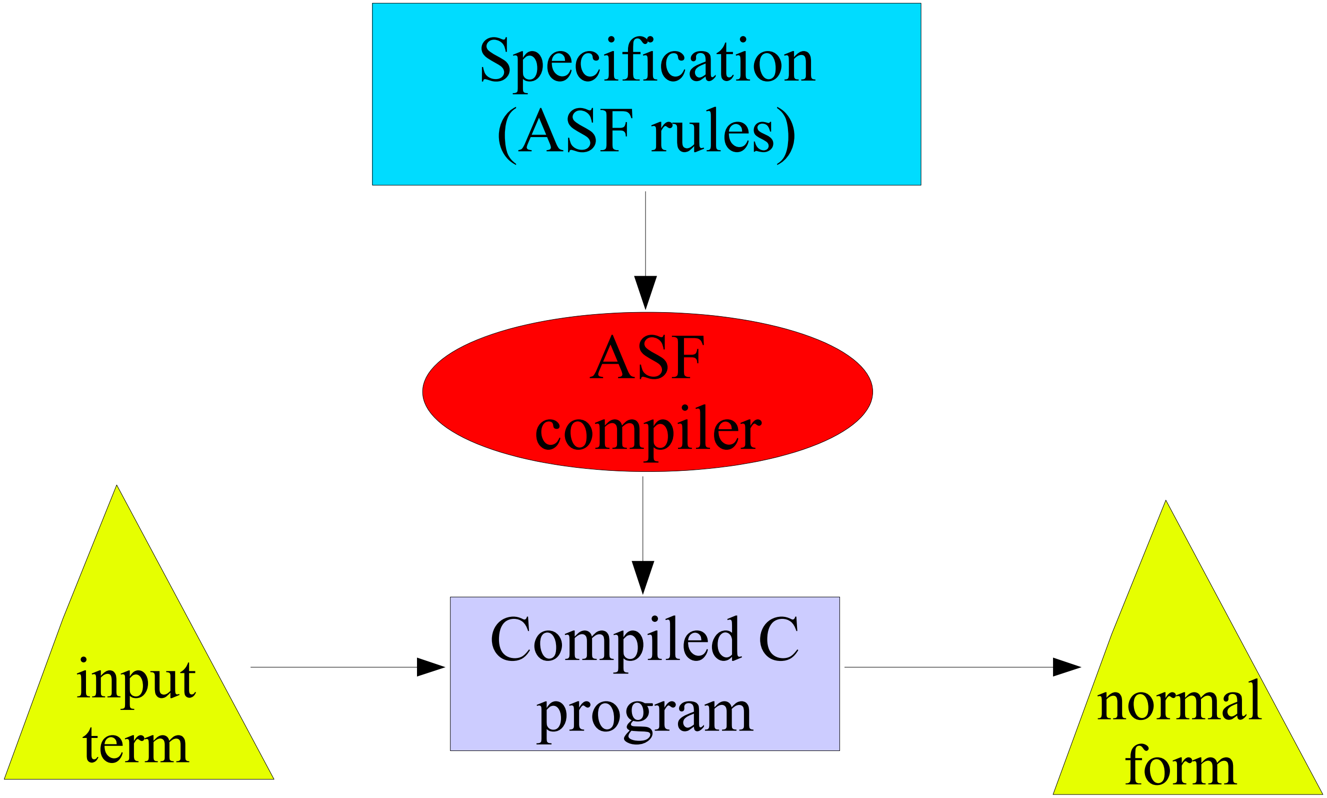
Compilation to C

```
f(a,b,c) = g(a)
f(X,b,d) = g(X)
```

Compiles to

```
ATerm f(ATerm arg0, ATerm arg1, ATerm arg2) {
  if term_equal(arg0,a) {
    if term_equal(arg1,b) {
      if term_equal(arg2,c) {
        return g(a);
      }
    }
  }
  if term_equal(arg1,b) {
    if term_equal(arg2,d) {
      return g(arg0);
    }
  }
  return make_nf3(fsym, arg0, arg1, arg2)
}
```

Rewriting Architecture



Effects of sharing

Application	Time (sec) sharing/no sharing	Memory (Mb) sharing/no sharing
ASF+SDF compiler	45/155	27/134
Java servlet generator	12/50	10/34
Typesetter	10/49	5/5
SDF normalizer	8/28	8/11
Pico interpreter	20/80	4/4

Wrap up

- Summary of GLT
- Current work on applications
- Current work on technology
- Further reading

Summary

- Generic Language Technology helps to build tools for language processing quickly
- Programming Environment Generators are an application of GLT
- The ASF+SDF Meta-Environment is an Interactive Development Environment for language definitions *and* a Programming Environment Generator

Current work on Applications (1)

- Verification of JavaCard
- Detection and visualization of code smells in Java
- Transformation of formulae in Abramowitz and Stegun, Handbook of Mathematical Functions, from LaTeX to MathML and Mathematica
- Using relational calculus for software analysis
- Cobol transformations
- Design of DSL for ASML's chip manufacturing machines

Current work on Applications (2)

- ELAN Environment (Nancy)
- Action Semantics Environment (Aarhus)
- CHI environment (Eindhoven)
- C++ restructuring (Bell Labs)
- Connection with Eclipse

Current work on Technology

- Generic/generated IPE/GUI features
- Redesign/implementation of ToolBus
  - Reimplement in Java
  - Connections with RMI, Corba, .NET, Eclipse
- Grammar engineering
- Smoother coupling between term rewriting and relational calculus

Further reading (1)
technology

- J. Heering and P. Klint, Rewriting-Based Languages and Systems, Chapter 15 in Terese, Term Rewriting Systems, Cambridge University Press, 2003
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Further reading (2)
application areas

- A. van Deursen, P. Klint and J. Visser. Domain-Specific Languages: An Annotated Bibliography ACM SIGPLAN Notices 35(6):26-36, June 2000.
- M.G.J. van den Brand, P. Klint and C. Verhoef, Reverse Engineering and System Renovation: an Annotated Bibliography, ACM Software Engineering Notes, 22(1): 42--57, January 1997
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- See: www.meta-environment.org
- See: Home pages of the authors