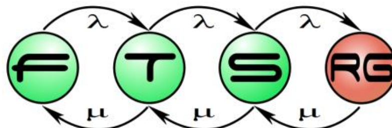
Textual Modeling Languages

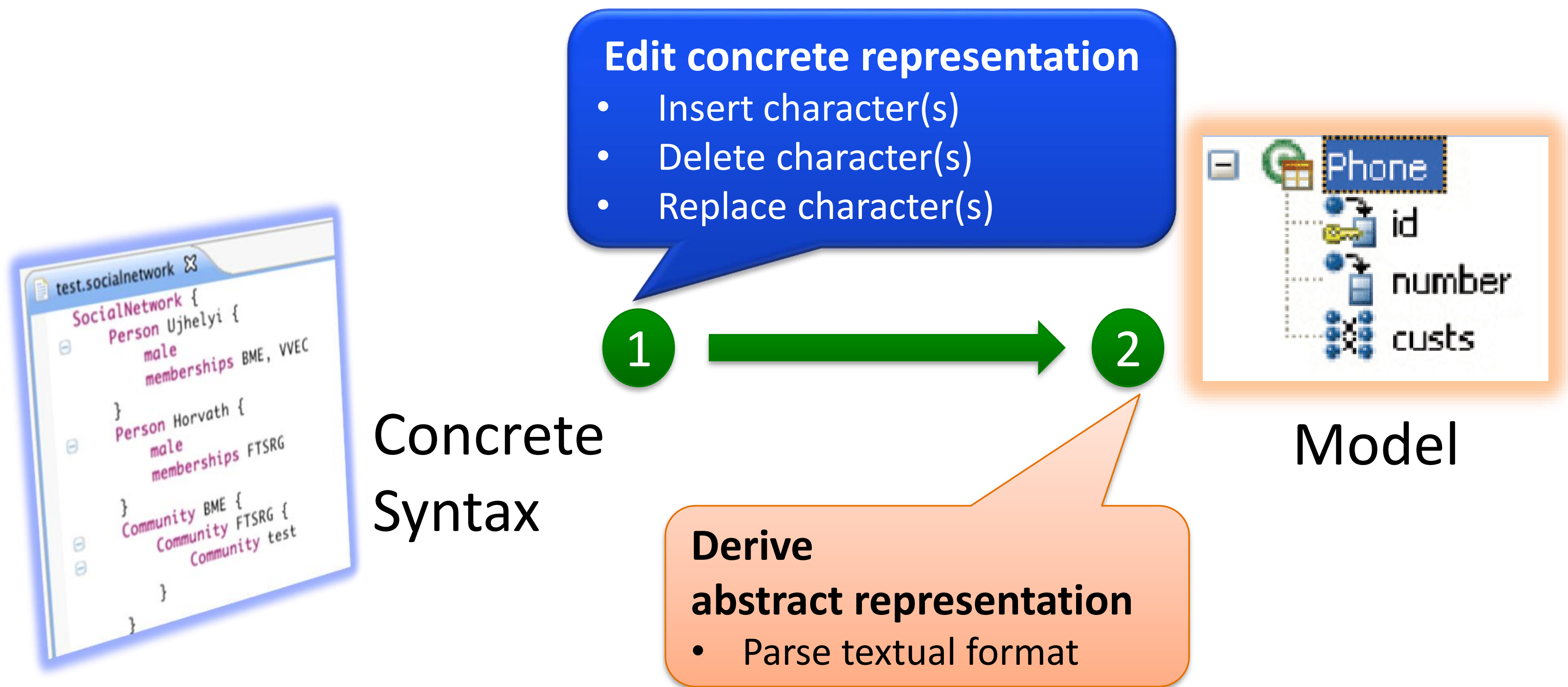
Model Driven Software Development

Lecture 6



Recall: raw editing

- Workflow 2: **raw editing** (w. textual syntax)
  - AKA source editing

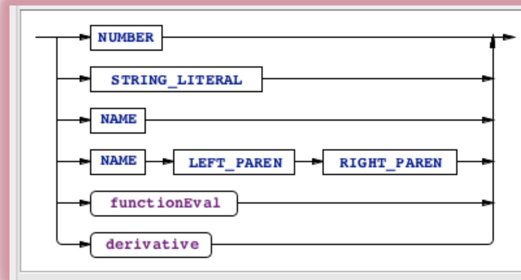


Looking inside advanced IDEs

From parsers to development tools
Roundtrip property
Modern services

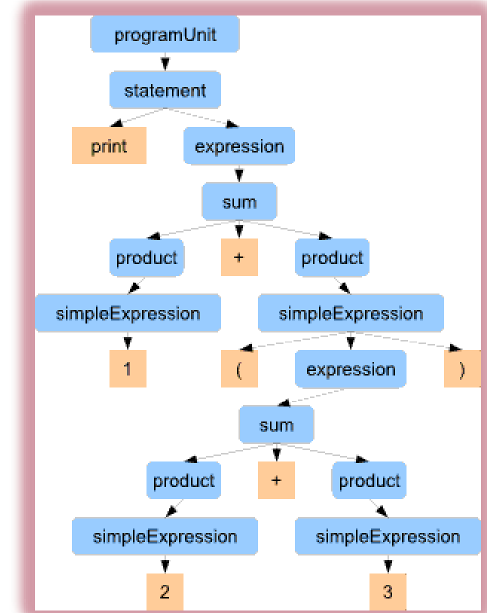
Parsers: The Traditional Setup

Grammar



Parsing
(lexer + parser)

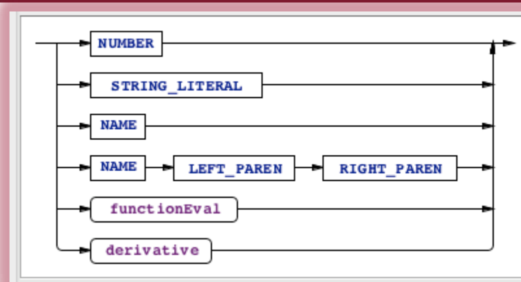
Source code of program



Abstract
syntax tree (AST)

Parsers in Software Engineering Practice

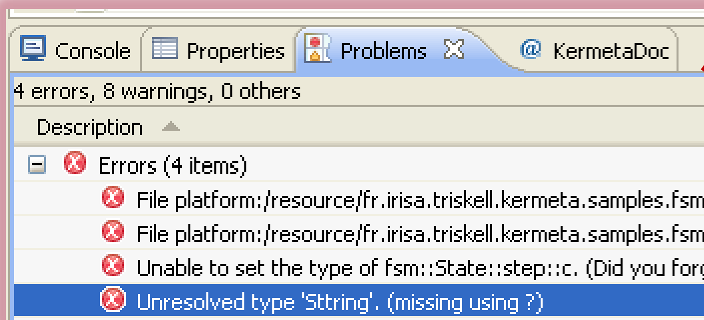
Grammar

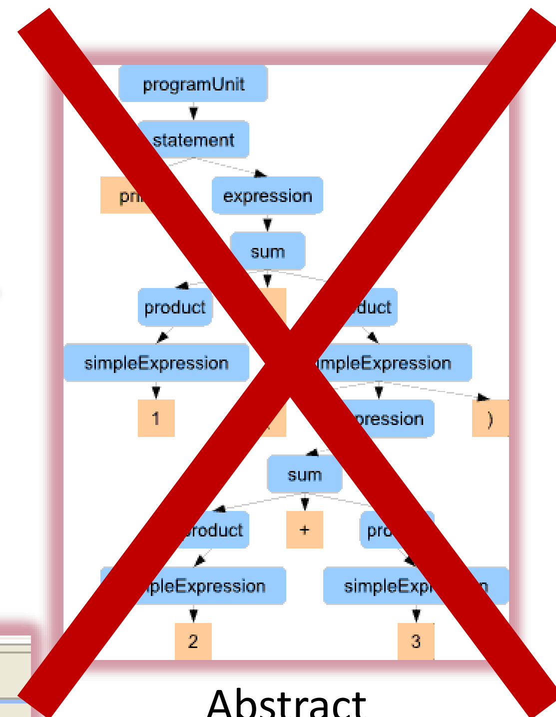


Source code of program

Parsing (lexer + parser)

Error report





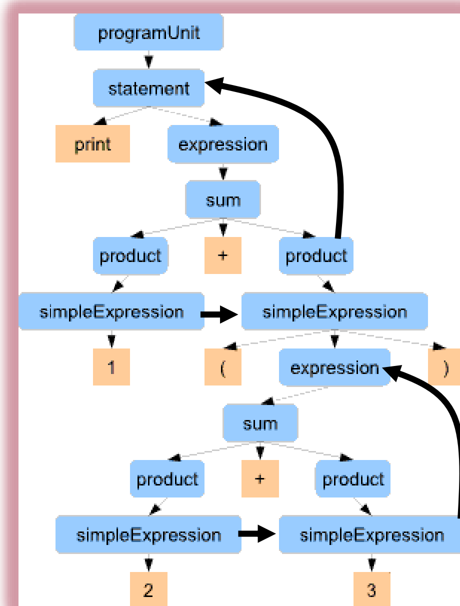
Abstract syntax tree (AST)

Error recovery parsing

View Generation + Program Analysis

Source code of program

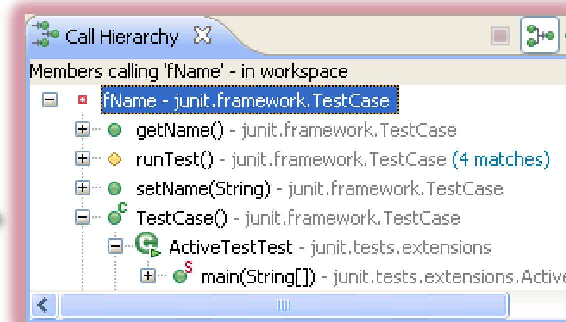
Parsing



AST: Abstract syntax tree

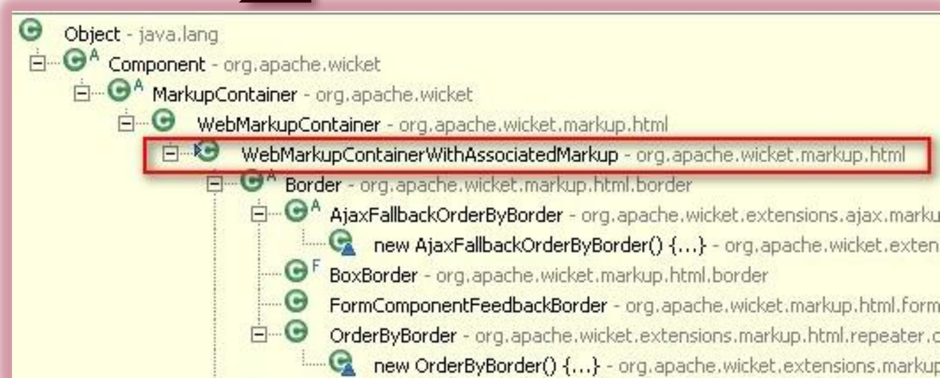
„Visitor"

Call graph



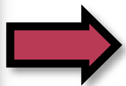
„Visitor"

Type hierarchy

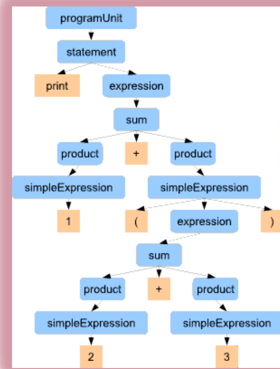


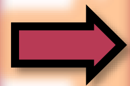
ASTs vs DOMs

Source code of program

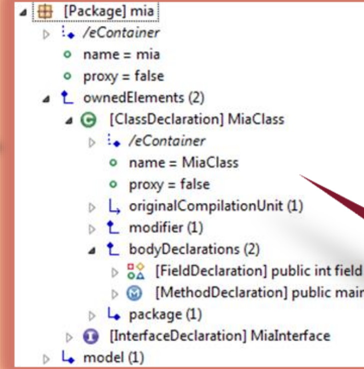


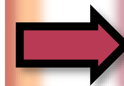
AST: Abstract syntax tree





DOM: Document Object Model

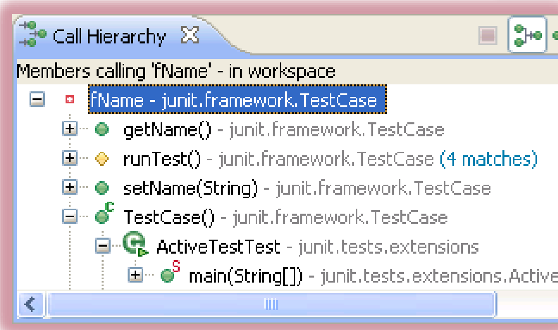




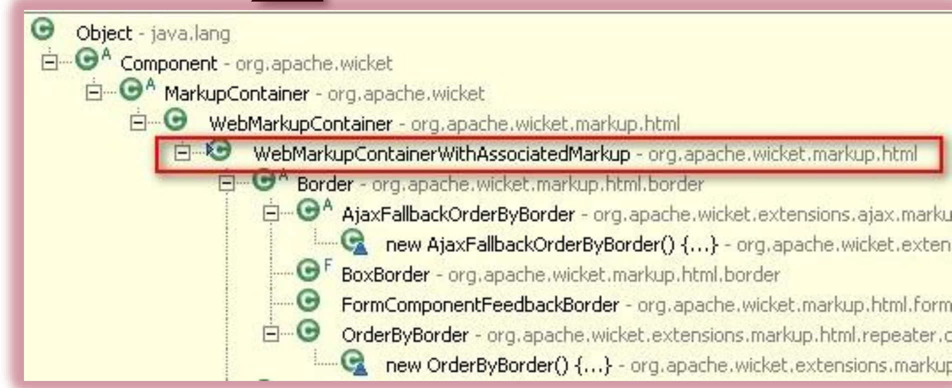
Well-formedness constraints

Errors (4 items)
File platform:/resource/fr.irisa.triskell.kerme
File platform:/resource/fr.irisa.triskell.kerme
Unable to set the type of fsm::State::step:
Unresolved type 'Sttring'. (missing using ?)

Defined by a metamodel

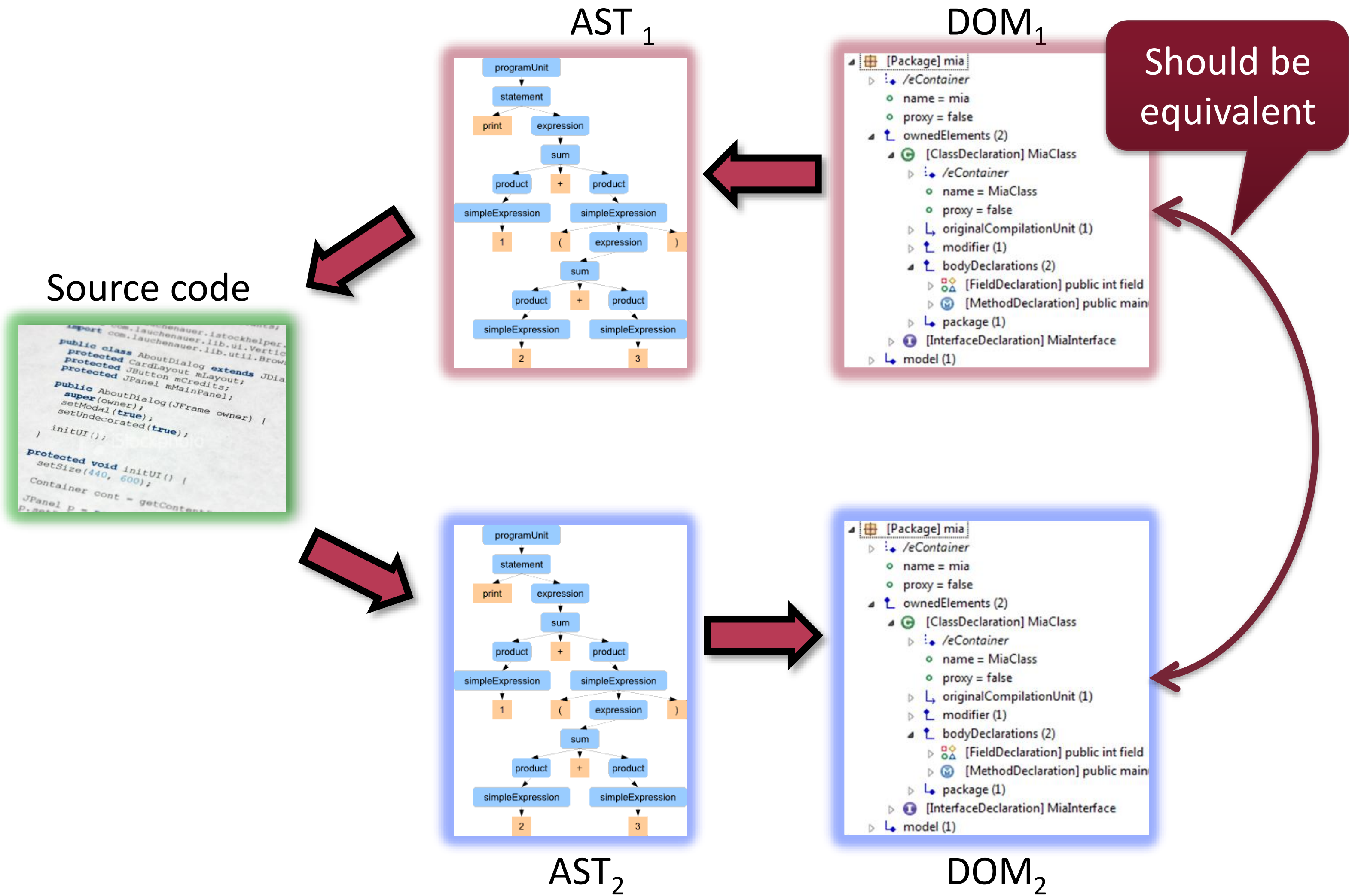


Call graph (View)



Type hierarchy (View)

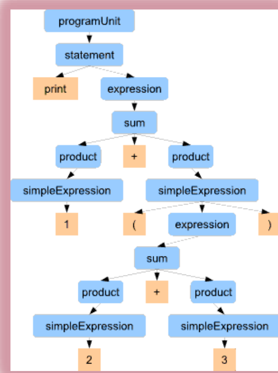
Persitence Roundtrip



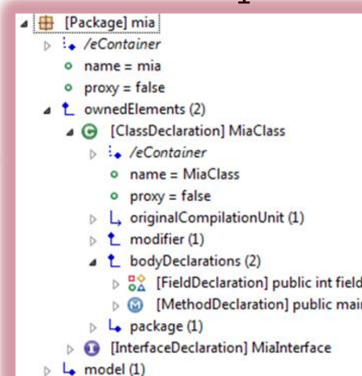
Model Editing Roundtrip (e.g refactoring)

Source code $_1$

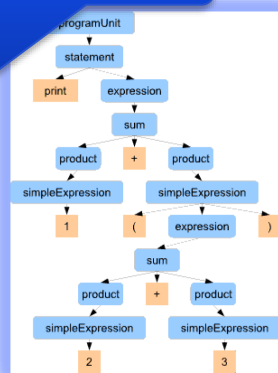
AST $_1$

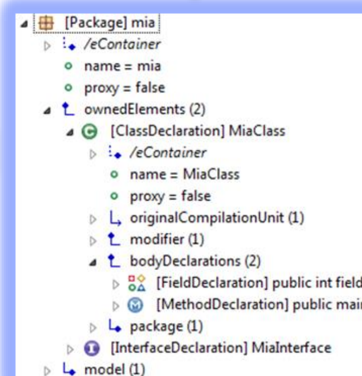


DOM$_1$



„Serialization": this is projection!





May or may not correctly reproduce formatting etc.

Source code$_2$

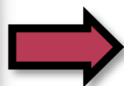
AST$_2$

DOM$_2$

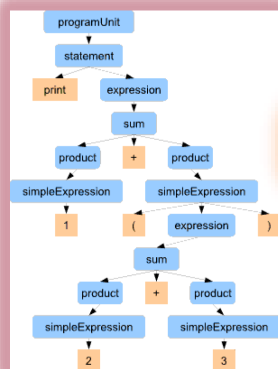
Aside: yes, this requires a notation model - CST (concrete syntax tree)

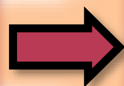
Textual DSM Languages: An Overview

Source code

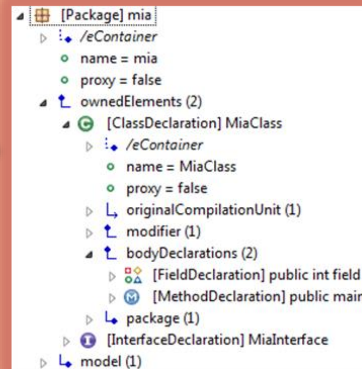


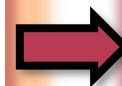
AST





DOM /
Abstract syntax





Well-formedness
constraints

Errors (4 items)
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File platform:/resource/fr.irisa.triskell.kerme
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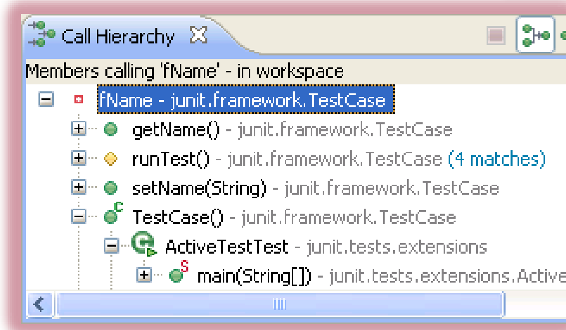
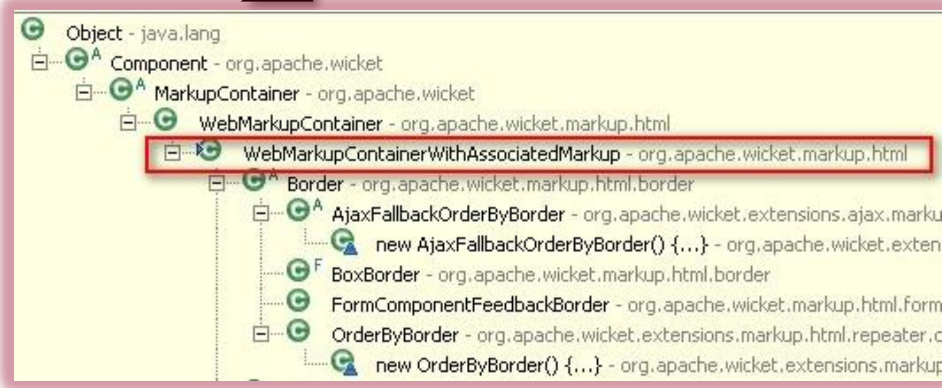
Refactoring,
Simulation step



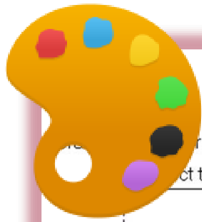
Call graph
(Analysis model / View)

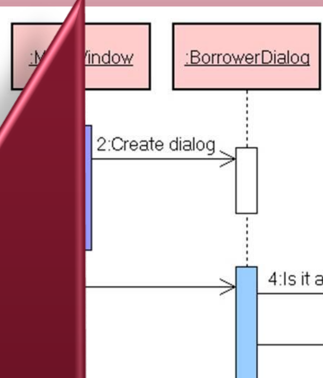


Type hierarchy
(Analysis model / View)

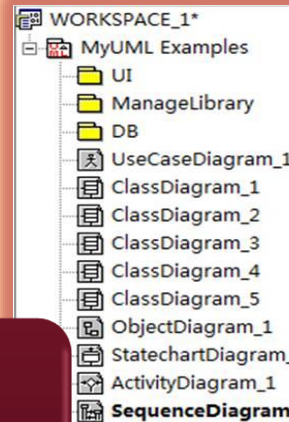
Graphical DSM Languages

Diagram model





Abstract syntax



Well-formedness constraints

Errors (4 items)
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File platform:/resource/fr.irisa.triskell.kerme
Unable to set the type of fsm::State::step:
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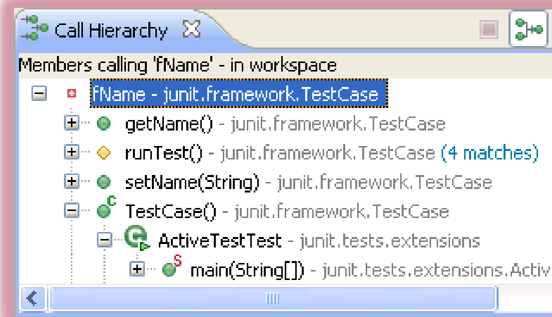
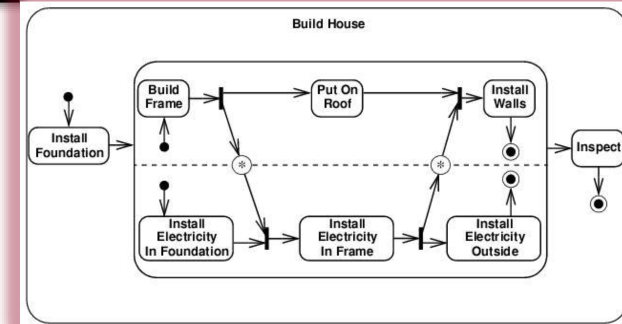
Refactoring, Simulation

This is the notation model
The diagram image itself is not parsed!



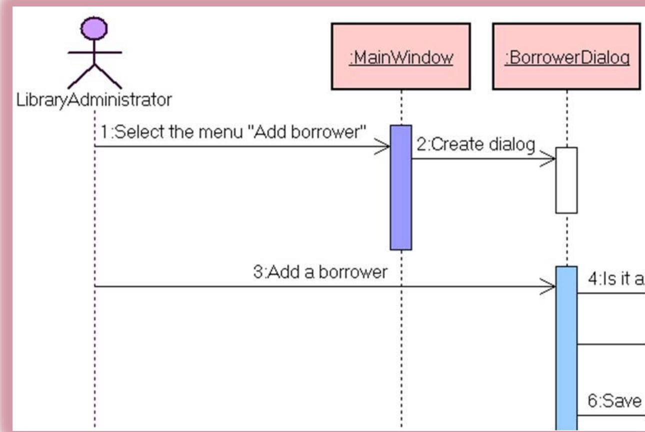
Call graph (View)



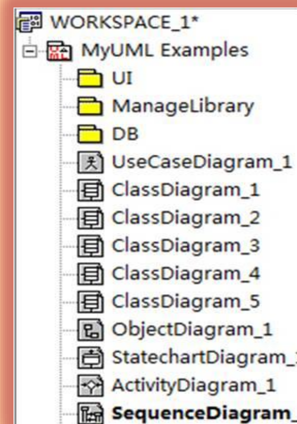
Statechart (other DSM)

Graphical DSM Languages

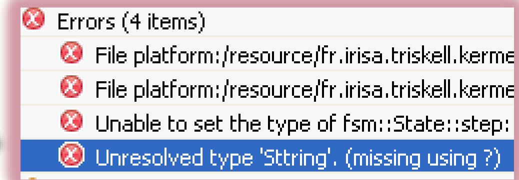
Diagram image



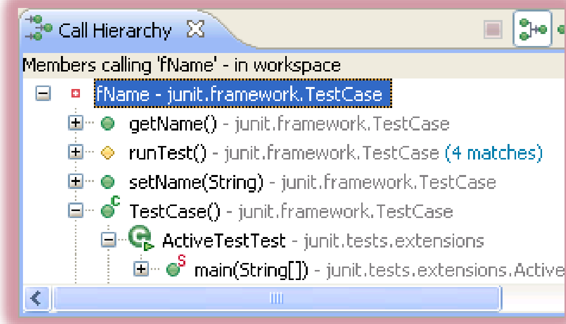
Abstract syntax incl. notation



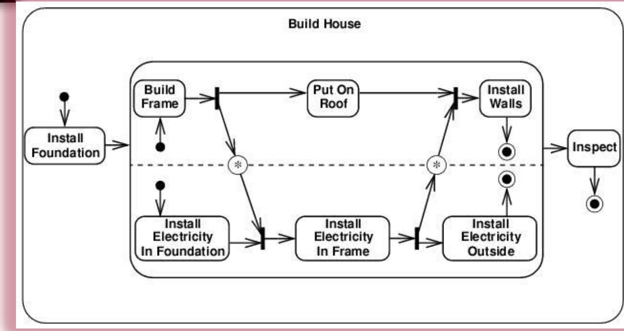
Well-formedness constraints



Refactoring, Simulation

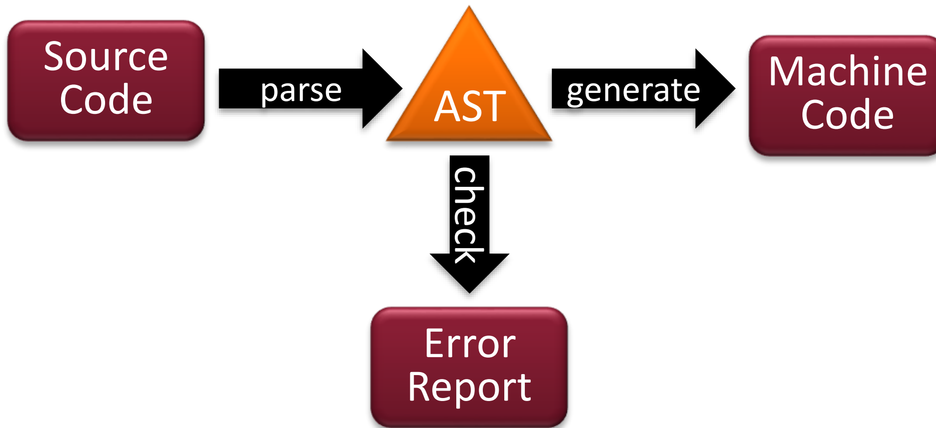


Call graph (View)



Statechart (other DSM)

Traditional Architecture of Compilers



- On demand parsing
  - Explicit user’s request
  - E.g. javac myClass.java
- Parsing:
  - Successful: AST generated
  - Failed: Errors reported (no AST)
- Semantic checks
  - Successful: Machine code generated
  - Failed: Errors reported

Source: c

Modern Compilers in IDEs

Syntactic editor services:
- syntax checking
- syntax highlighting
- outline view
- code folding
- bracket matching…

Semantic editor services:
- error checking
- reference resolving
- hover help
- „code mining”
- code completion
- refactoring…

- Auto-parse-and-check
  - During typing: Parse
  - Upon save: Analyze
- Parsing:
  - AST always generated
  - Error markers on failure
- Semantic analysis
  - Successful:
    Machine code generated
  - Failed: Errors reported

Source: Guido Wachsmuth (Compiler Construction at TU Delft)

Textual syntax specification

Regular grammars

Context-free grammars

Textual Domain-specific Languages

- Idea
  - Describing models as text files
- Textual development
  - Long history (30+ years)
  - Well-researched theory
  - Mature tools

Regular expressions

- Pattern matching for strings
  - Good support
    - Most programming languages
    - More or less the same syntax
  - Calculates and returns matches
- Usable as DSL parser?
  - Weak expressive power
    - Example: balanced parentheses (see pumping lemma)
  - Output is a single boolean variable (does it match?)
    - Missing: interpretability of contents, error localization
  - In some cases, not very concise…

RegExp: Validation of email addresses

```
(?:(?:\r\n)?[ \t])*(?:(?:(?:[^()<>@,;:\\".\[\] \000-\031]+(?:(?:(?:\r\n)?[ \t] )+|\Z|(?=[\["()<>@,;:\\".\[\]]))|"(?:[^\"\r\\]|\\.|(?:(?:\r\n)?[ \t]))*"(?:(?: \r\n)?[
\t])*)(?:\.(?:(?:\r\n)?[ \t])*(?:[^()<>@,;:\\".\[\] \000-\031]+(?:(?:( ?:\r\n)?[ \t])+|\Z|(?=[\["()<>@,;:\\".\[\]]))|"(?:[^\"\r\\]|\\.|(?:(?:\r\n)?[ \t]))*"(?:(?:\r\n)?[
\t])*))*@(?:(?:\r\n)?[ \t])*(?:[^()<>@,;:\\".\[\] \000-\0 31]+(?:(?:(?:\r\n)?[ \t])+|\Z|(?=[\["()<>@,;:\\".\[\]]))|\[([^\[\]\r\\]|\\.)*\ ](?:(?:\r\n)?[ \t])*)(?:\.(?:(?:\r\n)?[
\t])*(?:[^()<>@,;:\\".\[\] \000-\031]+ (?:(?:(?:\r\n)?[ \t])+|\Z|(?=[\["()<>@,;:\\".\[\]]))|\[([^\[\]\r\\]|\\.)*\](?: (?:\r\n)?[ \t])*))*|(?:[^()<>@,;:\\".\[\] \000-
\031]+(?:(?:(?:\r\n)?[ \t])+|\Z |(?=[\["()<>@,;:\\".\[\]]))|"(?:[^\"\r\\]|\\.|(?:(?:\r\n)?[ \t]))*"(?:(?:\r\n) ?[ \t])*)*\<(?:(?:\r\n)?[ \t])*(?:@(?:[^()<>@,;:\\".\[\] \000-
\031]+(?:(?:(?:\ r\n)?[ \t])+|\Z|(?=[\["()<>@,;:\\".\[\]]))|\[([^\[\]\r\\]|\\.)*\](?:(?:\r\n)?[ \t])*)(?:\.(?:(?:\r\n)?[ \t])*(?:[^()<>@,;:\\".\[\] \000-\031]+(?:(?:(?:\r\n) ?[
\t])+|\Z|(?=[\["()<>@,;:\\".\[\]]))|\[([^\[\]\r\\]|\\.)*\](?:(?:\r\n)?[ \t] )*))*(?:,@(?:(?:\r\n)?[ \t])*(?:[^()<>@,;:\\".\[\] \000-\031]+(?:(?:(?:\r\n)?[
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)+|\Z|(?=[\["()<>@,;:\\".\[\]]))|\[([^\[\]\r\\]|\\.)*\](?:(?:\r\n)?[ \t])*))*) *:(?:(?:\r\n)?[ \t])*)?(?:[^()<>@,;:\\".\[\] \000-\031]+(?:(?:(?:\r\n)?[ \t])+
|\Z|(?=[\["()<>@,;:\\".\[\]]))|"(?:[^\"\r\\]|\\.|(?:(?:\r\n)?[ \t]))*"(?:(?:\r \n)?[ \t])*)(?:\.(?:(?:\r\n)?[ \t])*(?:[^()<>@,;:\\".\[\] \000-\031]+(?:(?:(?: \r\n)?[
\t])+|\Z|(?=[\["()<>@,;:\\".\[\]]))|"(?:[^\"\r\\]|\\.|(?:(?:\r\n)?[ \t ]))*"(?:(?:\r\n)?[ \t])*))*@(?:(?:\r\n)?[ \t])*(?:[^()<>@,;:\\".\[\] \000-\031 ]+(?:(?:(?:\r\n)?[
\t])+|\Z|(?=[\["()<>@,;:\\".\[\]]))|\[([^\[\]\r\\]|\\.)*\]( ?:(?:\r\n)?[ \t])*)(?:\.(?:(?:\r\n)?[ \t])*(?:[^()<>@,;:\\".\[\] \000-\031]+(? :(?:(?:\r\n)?[
\t])+|\Z|(?=[\["()<>@,;:\\".\[\]]))|\[([^\[\]\r\\]|\\.)*\](?:(? :\r\n)?[ \t])*))*\>(?:(?:\r\n)?[ \t])*)|(?:[^()<>@,;:\\".\[\] \000-\031]+(?:(? :(?:\r\n)?[
\t])+|\Z|(?=[\["()<>@,;:\\".\[\]]))|"(?:[^\"\r\\]|\\.|(?:(?:\r\n)? [ \t]))*"(?:(?:\r\n)?[ \t])*)*:(?:(?:\r\n)?[ \t])*(?:(?:(?:[^()<>@,;:\\".\[\] \000-\031]+(?:(?:(?:\r\n)?[
\t])+|\Z|(?=[\["()<>@,;:\\".\[\]]))|"(?:[^\"\r\\]| \\.|(?:(?:\r\n)?[ \t]))*"(?:(?:\r\n)?[ \t])*)(?:\.(?:(?:\r\n)?[ \t])*(?:[^()<> @,;:\\".\[\] \000-\031]+(?:(?:(?:\r\n)?[
\t])+|\Z|(?=[\["()<>@,;:\\".\[\]]))|" (?:[^\"\r\\]|\\.|(?:(?:\r\n)?[ \t]))*"(?:(?:\r\n)?[ \t])*))*@(?:(?:\r\n)?[ \t] )*(?:[^()<>@,;:\\".\[\] \000-\031]+(?:(?:(?:\r\n)?[
\t])+|\Z|(?=[\["()<>@,;:\\ ".\[\]]))|\[([^\[\]\r\\]|\\.)*\](?:(?:\r\n)?[ \t])*)(?:\.(?:(?:\r\n)?[ \t])*(? :[^()<>@,;:\\".\[\] \000-\031]+(?:(?:(?:\r\n)?[
\t])+|\Z|(?=[\["()<>@,;:\\".\[ \]]))|\[([^\[\]\r\\]|\\.)*\](?:(?:\r\n)?[ \t])*))*|(?:[^()<>@,;:\\".\[\] \000- \031]+(?:(?:(?:\r\n)?[
\t])+|\Z|(?=[\["()<>@,;:\\".\[\]]))|"(?:[^\"\r\\]|\\.|( ?:(?:\r\n)?[ \t]))*"(?:(?:\r\n)?[ \t])*)*\<(?:(?:\r\n)?[ \t])*(?:@(?:[^()<>@,; :\\".\[\] \000-\031]+(?:(?:(?:\r\n)?[
\t])+|\Z|(?=[\["()<>@,;:\\".\[\]]))|\[([ ^\[\]\r\\]|\\.)*\](?:(?:\r\n)?[ \t])*)(?:\.(?:(?:\r\n)?[ \t])*(?:[^()<>@,;:\\" .\[\] \000-\031]+(?:(?:(?:\r\n)?[
\t])+|\Z|(?=[\["()<>@,;:\\".\[\]]))|\[([^\[\ ]\r\\]|\\.)*\](?:(?:\r\n)?[ \t])*))*(?:,@(?:(?:\r\n)?[ \t])*(?:[^()<>@,;:\\".\ [\] \000-\031]+(?:(?:(?:\r\n)?[
\t])+|\Z|(?=[\["()<>@,;:\\".\[\]]))|\[([^\[\]\ r\\]|\\.)*\](?:(?:\r\n)?[ \t])*)(?:\.(?:(?:\r\n)?[ \t])*(?:[^()<>@,;:\\".\[\] \000-\031]+(?:(?:(?:\r\n)?[
\t])+|\Z|(?=[\["()<>@,;:\\".\[\]]))|\[([^\[\]\r\\] |\\.)*\](?:(?:\r\n)?[ \t])*))*)*:(?:(?:\r\n)?[ \t])*)?(?:[^()<>@,;:\\".\[\] \0 00-\031]+(?:(?:(?:\r\n)?[
\t])+|\Z|(?=[\["()<>@,;:\\".\[\]]))|"(?:[^\"\r\\]|\\ .|(?:(?:\r\n)?[ \t]))*"(?:(?:\r\n)?[ \t])*)(?:\.(?:(?:\r\n)?[ \t])*(?:[^()<>@, ;:\\".\[\] \000-\031]+(?:(?:(?:\r\n)?[
\t])+|\Z|(?=[\["()<>@,;:\\".\[\]]))|"(? :[^\"\r\\]|\\.|(?:(?:\r\n)?[ \t]))*"(?:(?:\r\n)?[ \t])*))*@(?:(?:\r\n)?[ \t])* (?:[^()<>@,;:\\".\[\] \000-\031]+(?:(?:(?:\r\n)?[
\t])+|\Z|(?=[\["()<>@,;:\\". \[\]]))|\[([^\[\]\r\\]|\\.)*\](?:(?:\r\n)?[ \t])*)(?:\.(?:(?:\r\n)?[ \t])*(?:[ ^()<>@,;:\\".\[\] \000-\031]+(?:(?:(?:\r\n)?[
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|(?=[\["()<>@,;:\\".\[\]]))|\[([^\[\]\r\\]|\\.)*\](?:(?:\r\n)?[ \t])*))*\>(?:( ?:\r\n)?[ \t])*))*)?;\s*)
```

This regular expression will only validate addresses that have had any comments stripped and replaced with whitespace

Context-Free (CF) grammars

- Wide-spread adoption
  - Sufficient expressive power for describing models
  - Intuitive semantics and usage
  - Advanced parsing techniques
    - Performance
    - Error localization
    - …
  - Automated tooling for parser generation

Example: CF grammar for describing name lists

- Terminal Symbols
  - *"Dániel", "István", "Zoltán", "and", ","*
- Non-terminal Symbols
  - «Name», «Sentence», «List»

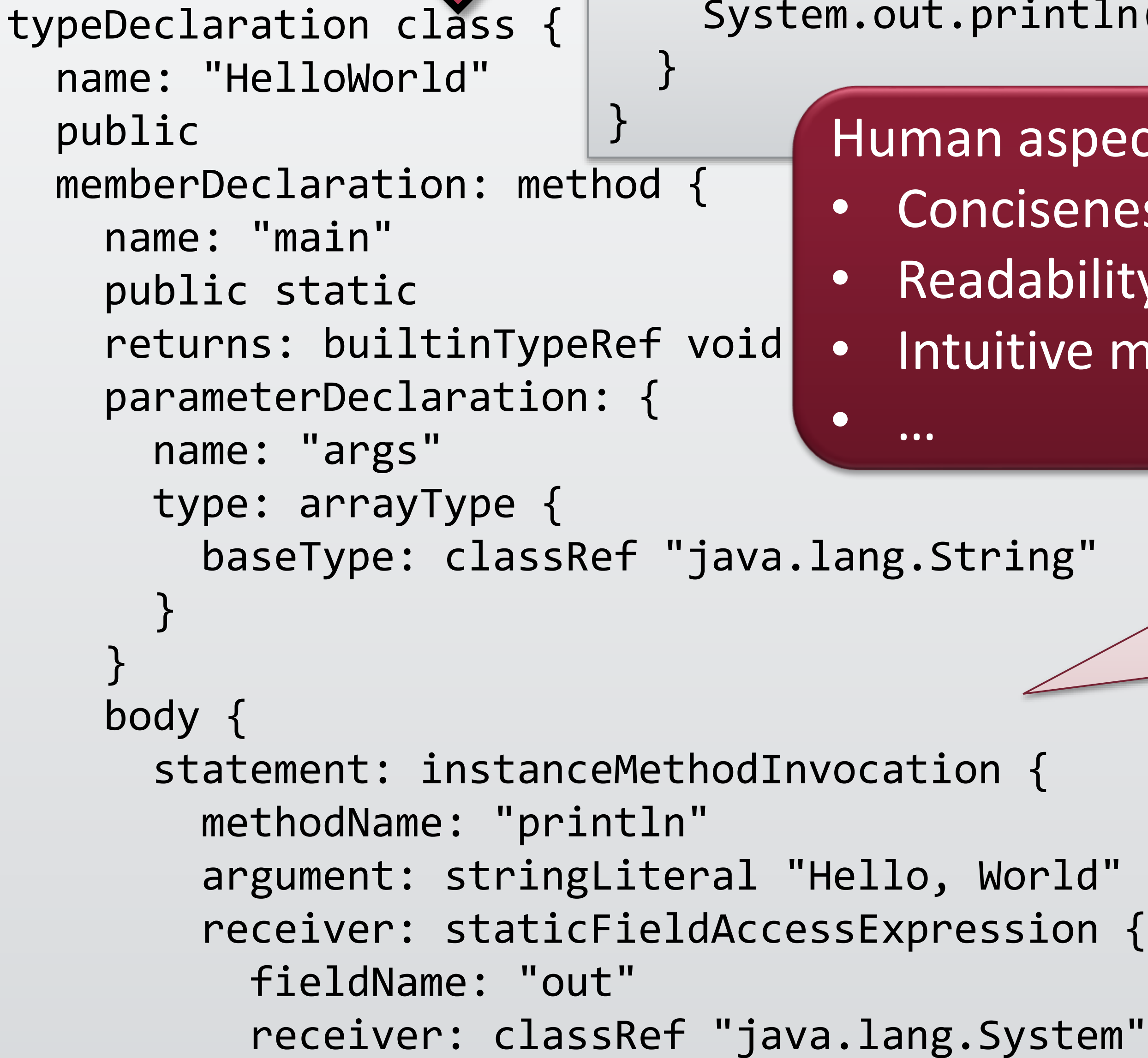
«Name»::= *Zoltán* | *István* | *Dániel*

«Sentence»::= «Name» | «List» *and* «Name»

«List»::= «List», «Name»| «Name»

Expressive power is not everything

```
public class HelloWorld {
  public static void main(String[] args) {
    System.out.println("Hello, World");
  }
}
```



Human aspects in grammar design:

- Conciseness
- Readability
- Intuitive meaning
- …

~ Default syntax generated from metamodel

The Parsing Process

Derivation trees

Lexer vs parser

Linking & scoping

Example: CF grammar for describing name lists

- Terminal Symbols
  - *"Dániel", "István", "Zoltán", "and", ","*
- Non-terminal Symbols
  - «Name», «Sentence», «List»

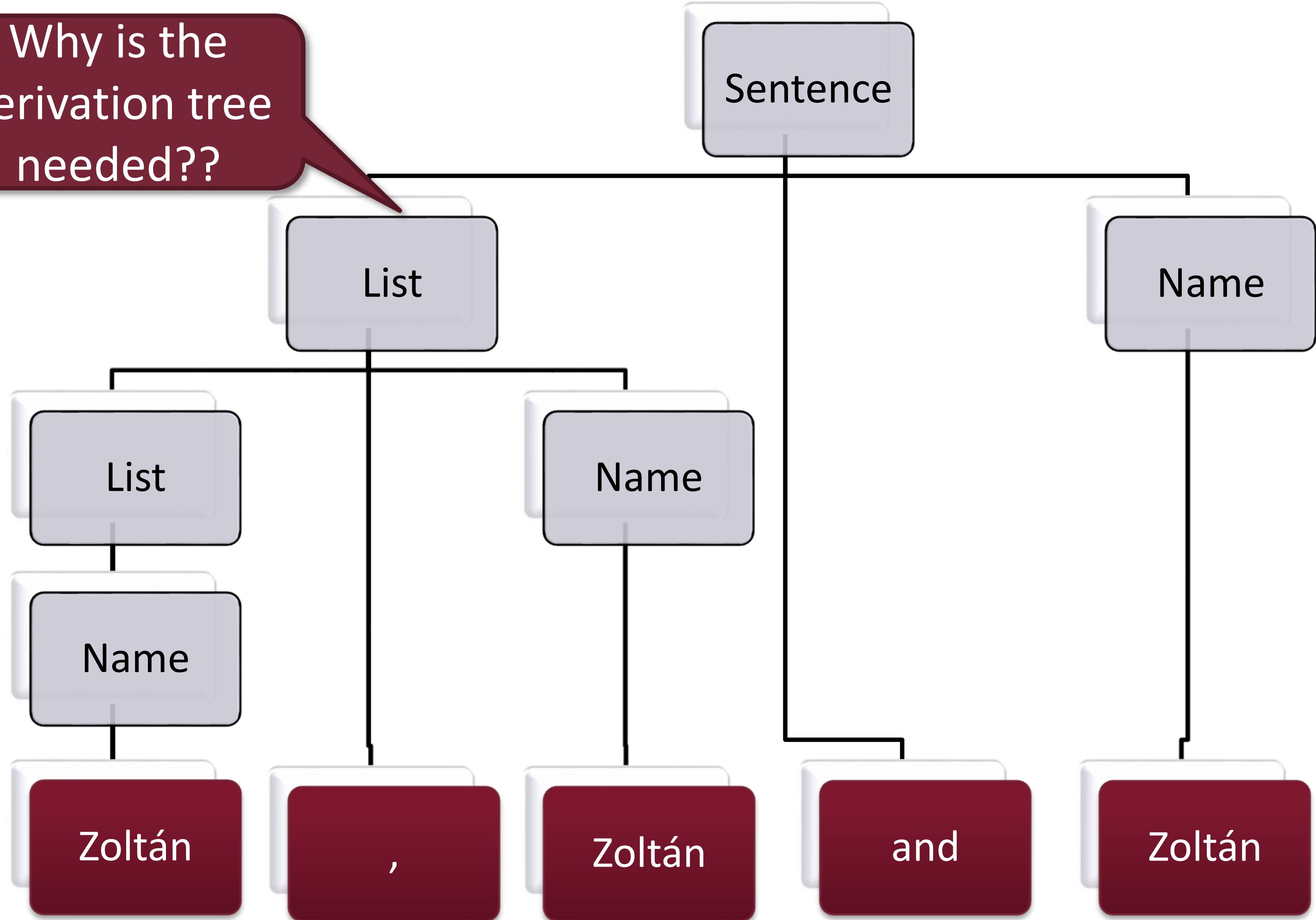
«Name»::= *Zoltán* | *István* | *Dániel*

«Sentence»::= «Name» | «List» *and* «Name»

«List»::= «List», «Name»| «Name»

Example from: Dick Grune, Ceriel J.H. Jacobs: Parsing Techniques

Derivation / Parse Tree



Additional practical tasks

- Handling input strings
- Variable handling
- High level analysis

Input

Input string:

'Z' 'o' 'l' 't' 'á' 'n' ' ' ',' 'Z'
'o' 'l' 't' 'á' 'n' ' ' 'a' 'n' ’d’
' ' 'Z' 'o' 'l' 't' 'á' 'n’

Zoltán | , | Zoltán | and | Zoltán

Input handling

Input:	Parser input:	Input gap
Character stream	Higher level tokens • «Name» • ‘,’ • “and”	Filled by ‘lexer’

- Why is this indirection useful?
  - Error handling
  - Performance
  - Problem decomposition

Lexer (tokenizer)

- Goal:
  - Tokenizing the input character stream
  - Similar to the parsing problem
    - But usually simpler – Typically regular expressions
    - Only word/token identification
    - Optional task: leaving out comments
  - Simplifies parsing significantly

Variable / Identifier Handling

- Variables
  - At runtime:
    Value calculation/substitution
  - Editing/analysis time:
    Refers to other parts of the AST
- *Variable definition*
  - A declaration of a variable
  - Unique naming
    - Variable definitions must be resolvable
    - Extra phase required after parsing
- *Variable reference*
  - Use of an already defined variable

```
int a=3;
System.out.println(a);
```

- Parser checks
  - “Can a variable be named ‘a’?”
- Reference resolution
  - “Is a variable defined?”
    - Scoping problem
  - “Is a variable uniquely defined?”

Scoping (Linking) Problem

```
private int value;

public void setValue(int value)
{
        this.value = value;
}
```

Which variable declaration is referred by ‘value’?

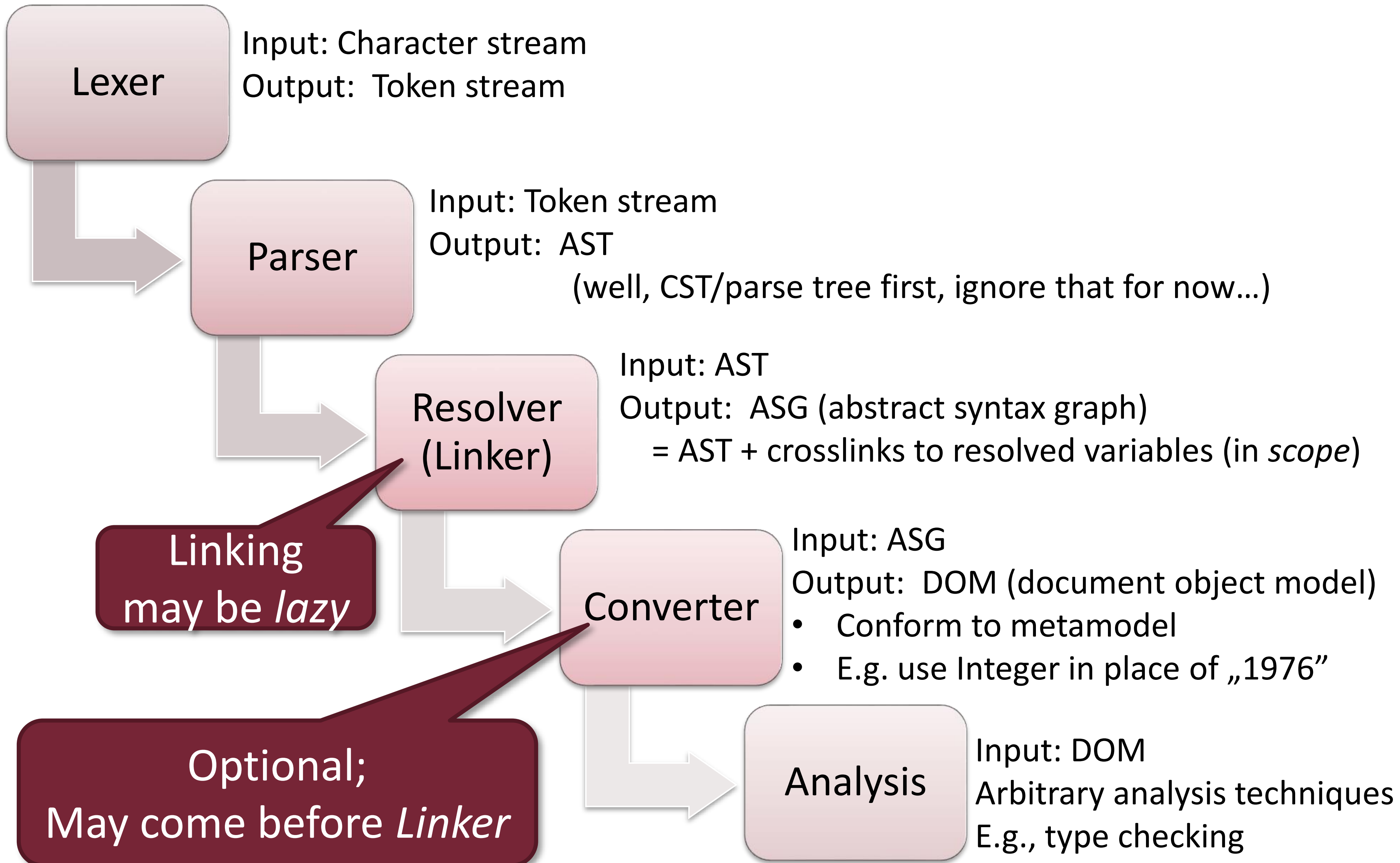
- Possible approaches
  - Most specific declaration
    - **Hierarchical scopes**
  - Conflict is error
  - Qualified references
  - …

Scope: the set of elements (variable names, identifiers) that can be referenced at a given point

Used:

- During parsing (resolving/linking)
- During editing (content assist)

The Parsing Process



Technologies

for textual syntax editors in Eclipse

Technologies 1. – IMP

- IDE Meta-tooling platform
  - Goal:
    - Language editor creation
  - Every parser-generator should be re-usable
  - Manual coding required
  - Project is close to dead

Technologies 2. - EMFText

- Editor generation
  - Based on existing EMF model
  - Different generated grammar styles
    - Manually modifiable
    - Limited grammar support
- Syntax Zoo
  - ~100 different syntax examples available
  - Including a Java implementation (called JaMoPP)

Technologies 3. – Xtext

- Editor and EMF model generation
  - Based on high-level grammar
  - Optionally can be initiated from an existing EMF model
- Easy to work with but highly customizable
  - Both the grammar and the generated code
- New developments:
  - Xbase expression language – DSLs over JVM
    - JVM Model Inference instead of direct code generation
    - Interpreter also available
  - Can generate **LSP** language server (fewer features)

LSP4E Client (Generic Editor)

- Eclipse **Generic Text Editor** extensibility
  - Syntax highlight from *TextMate Grammar* (TM4E)
  - Editing services from an LSP *Language Server* (LSP4E)
    - Diagnostics
    - Completion
    - Doc hover
    - Navigation
    - Find references
    - Rename
    - Outline
    - …

Grammars, CF Parsing

Theoretical Background

Formal Grammar

Formal grammar

$G = (N, T, P, S)$

- N: nonterminal symbols
- T: terminal symbols (alphabet)
- P: production rules
- S: start symbol (S ∈ N)

Example: G = (N, T, P, S)

- Num → Digit Num
- Num → Digit
- Digit → 0 | 1 | 2 … | 9

- Notation:
  - A, B, C: nonterminals in N,
  - a, b, c: terminals in T
  - $\alpha,\beta,\gamma \in (T \cup N)^*$
- Regular rules:
  - B → a
  - B → aC
- Context-free (CF) rules:
  - B → α
  - B → ε

Empty symbol

Derivation and Language

- **Derivation step**: using grammar G = (T,N,P,S)
  - $\alpha A\gamma \rightarrow \alpha\beta\gamma$
  - applying production rule: $A \rightarrow \beta$
  - $\alpha A\gamma$, $\alpha\beta\gamma$: sentential forms
- **Derivation over G**: $S \rightarrow^{*} w$ where
  - S: start symbol
  - $\rightarrow^{*}$ transitive closure (apply as long as possible)
  - $w \in T^{*}$: sentence, i.e. string of terminals only
- **Language generated by G**
  - $L(G) = \{w \in T^{*} \mid$ there exists a derivation $S \rightarrow^{*} w$ of $G\}$
  - Set of sentences derivable from S

Example derivation

Num	Num → Digit Num
Digit Num	Digit → 1
1 Num	Num → Digit Num
1 Digit Num	Digit → 9
1 9 Num	Num → Digit Num
1 9 Digit Num	Num → Digit
1 9 Digit Digit	Digit → 6
1 9 Digit 6	Digit → 7
1 9 7 6	

- Remarks:
  - In general, nonterminals can be resolved in arbitrary order (non-deterministic)
  - Leftmost vs. Rightmost derivation: always resolve the left/rightmost nonterminal as next step
- Parsing is polynomical algorithm for regular and context-free grammars

Binary Operations over Numbers

Example: G = (N, T, P, S)

Exp → Num

Exp → Exp ”+” Exp

Exp → Exp ”-” Exp

Exp → Exp ”*” Exp

Exp → Exp ”/” Exp

Exp → ”(” Exp ”)”

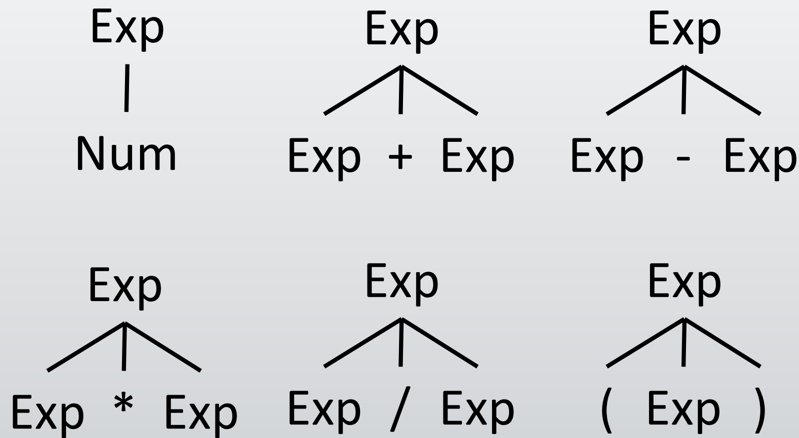
Problem:
Exp * 3
1 + 2 * 3

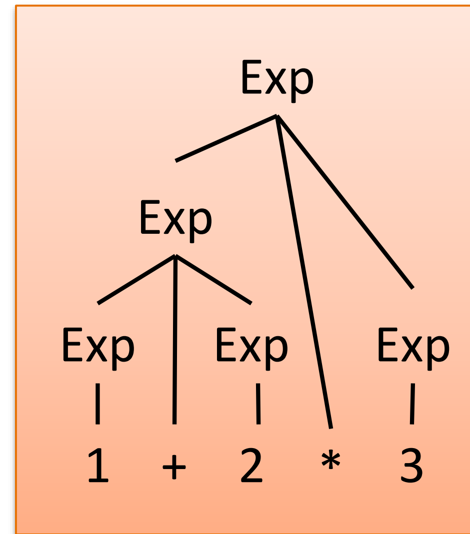
Two Derivations:

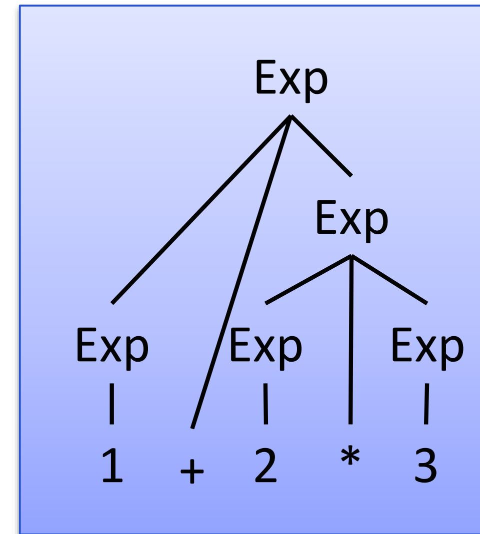
Exp	Exp → Exp ”+” Exp
Exp + Exp	Exp → Num
1 + Exp	Exp → Exp ”*” Exp
1 + Exp * Exp	Exp → Num
1 + 2 * Exp	Exp → Num
1 + 2 * 3	

Exp	Exp → Exp ”*” Exp
Exp * Exp	Exp → Num
Exp * 3	Exp → Exp ”+” Exp
Exp + Exp * 3	Exp → Num
Exp + 2 * 3	Exp → Num
1 + 2 * 3	

Parse Tree Construction







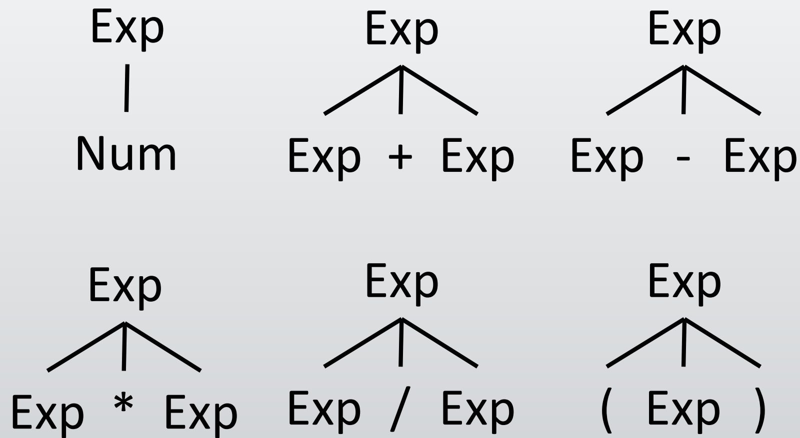
- **Parse Tree:**
  - Parent node: nonterminals
  - Child node: nonterminals/terminals
  - Built up according to productions of the grammar

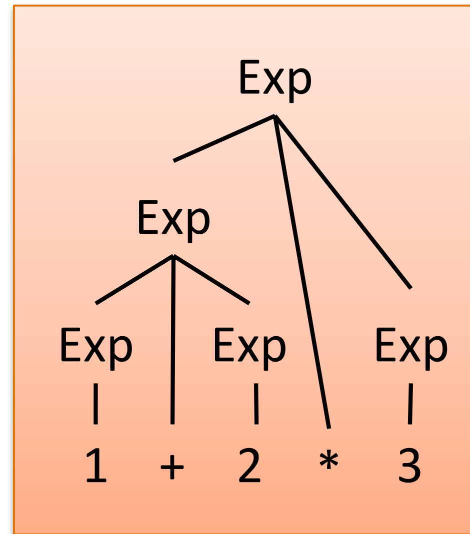
Ambiguous derivation!
How to disambiguate?

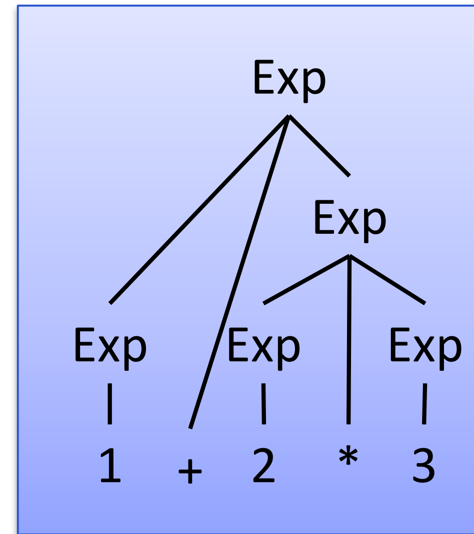
- **Ambiguous grammar**:
  - Generates two distinct parse trees
  - Serious problem for a parser!
  - Difficult to disambiguate!

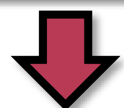
Idea: Change the grammar to force the correct parse tree!

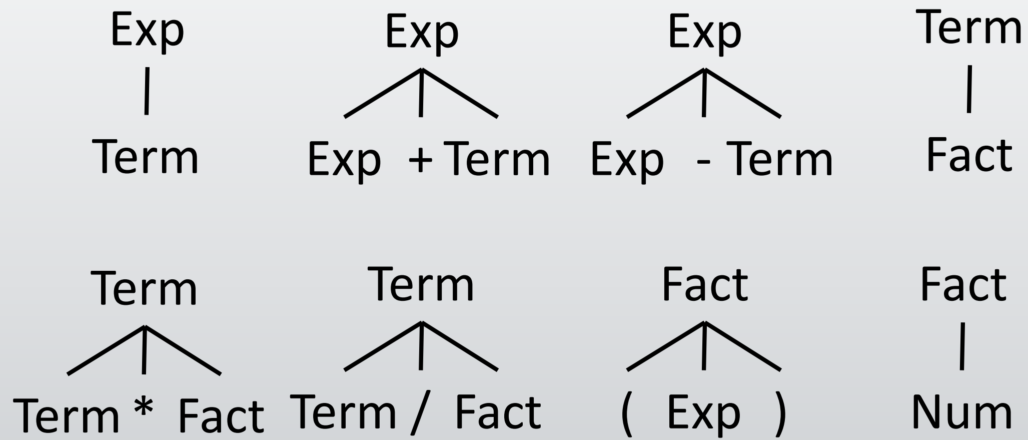
Disambiguation: Binary Expression

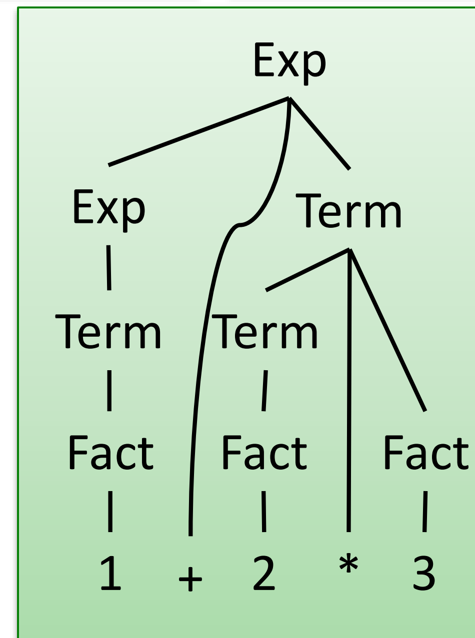










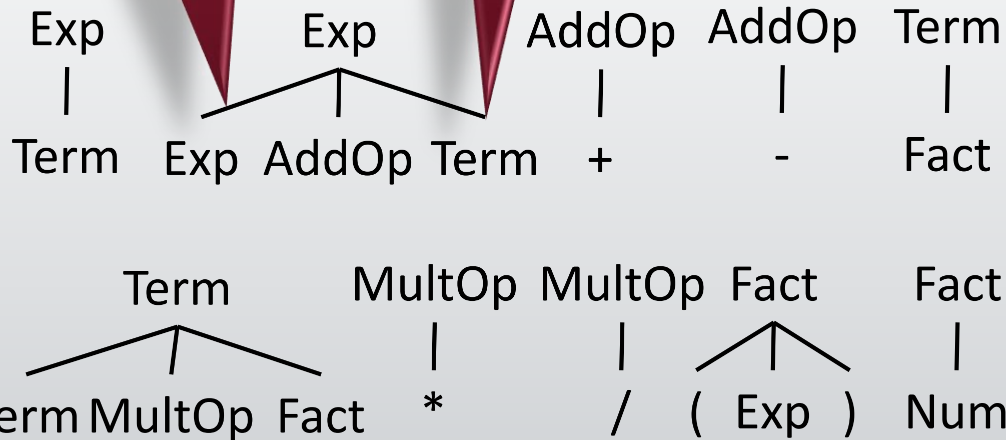


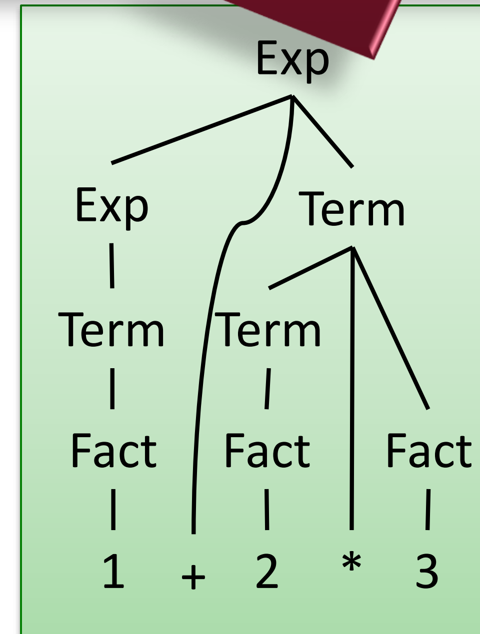
Simplifying Grammar: Binary Expression

Precedence: multiplicatives bind stronger than additives

Left associative

Parse tree respects **associativity** and **operator precedence**





Disambiguation: If-then-else

Grammar: (bold=terminals)

Stmt → IfStmt | **other**

IfStmt →

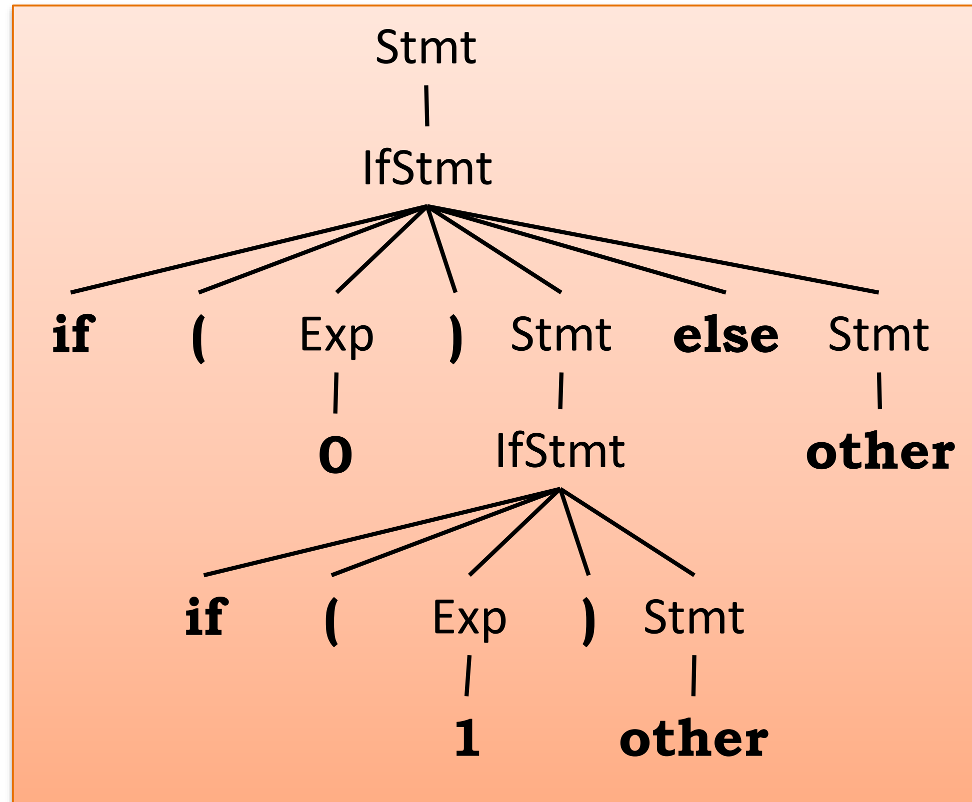
  if (Exp **)** Stmt |

  if (Exp **)** Stmt **else** Stmt

Exp → **0** | **1**

Ambiguous sample program:

if (0) if (1) other else other



Disambiguation: If-then-else

Grammar: (bold=terminals)

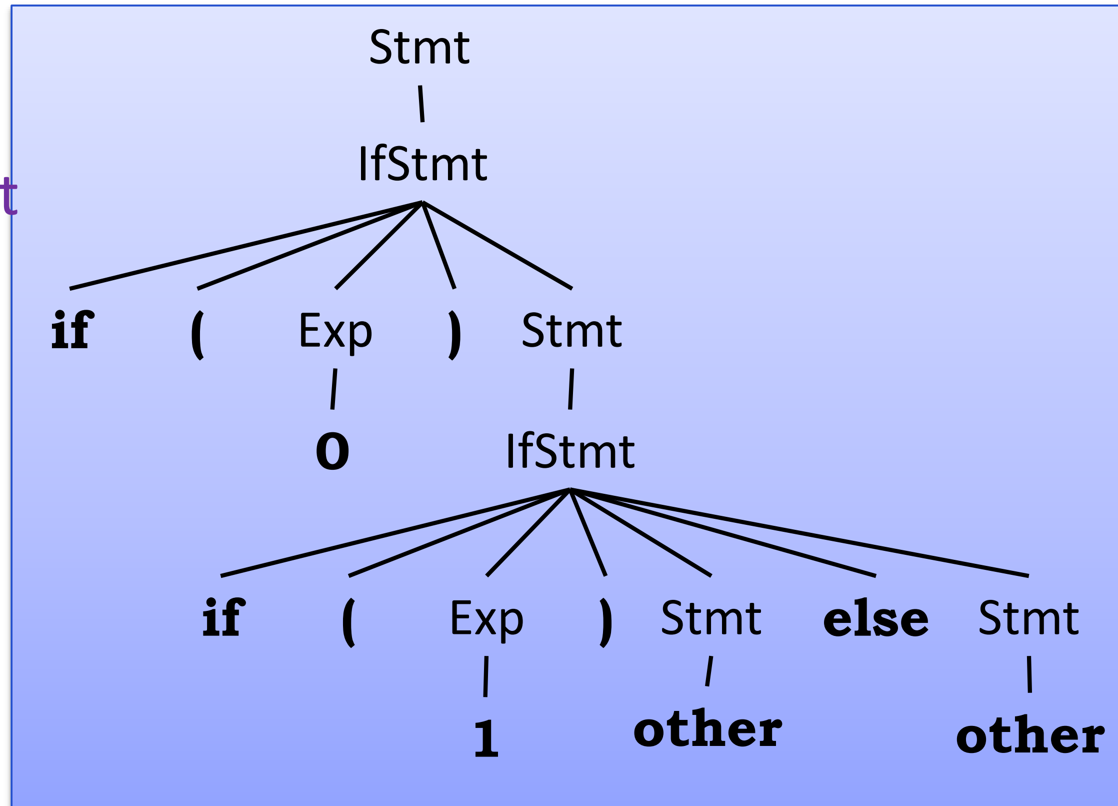
Stmt → IfStmt | **other**

IfStmt →
    if (Exp **)** Stmt |
    if (Exp **)** Stmt **else** Stmt

Exp → **0** | **1**

Ambiguous sample program:

if (0) if (1) other else other



Disambiguation rule:
Most closely nested else

Disambiguation: If-then-else

Grammar: (bold=terminals)

Stmt →
  UnMatched | Matched

Matched →
  if (Exp **)** Matched **else** Matched
  | **other**

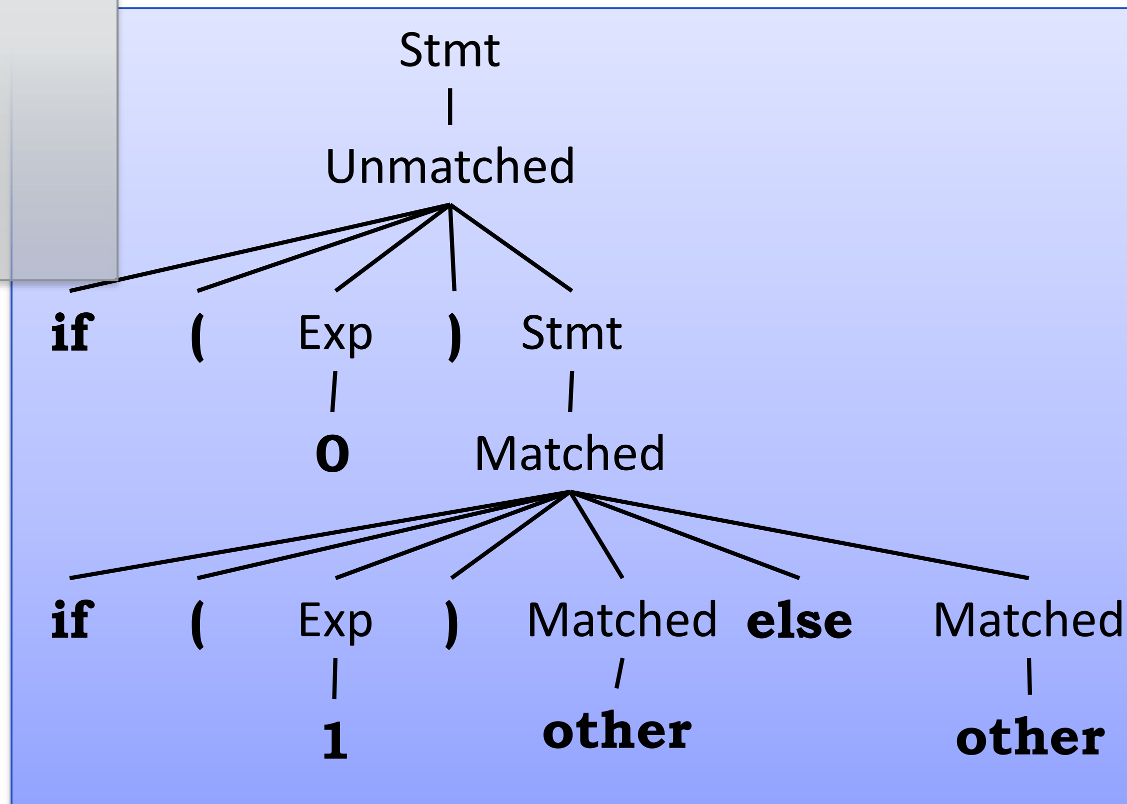
UnMatched →
  if (Exp **)** Stmt |
  if (Exp **)** Matched **else**
  UnMatched

Exp → **0** | **1**

Unambiguous program:

(else matched to 2nd if construct)

if (0) if (1) other else other



More on Associativity and Left Recursion

- Grammar variants for ternary **?:**
  - Naive solution
    - Ambiguity: `a?b:c?d:e?f:g`
  - Bind to right (right associative)
    - `a?b:(c?d:(e?f:g))`
    - Use same trick as if-then-else
  - Bind to left (left associative)
    - `((a?b:c)?d:e)?f:g)`
    - Problem: **left recursive grammar**

Grammar: (bold=terminals)

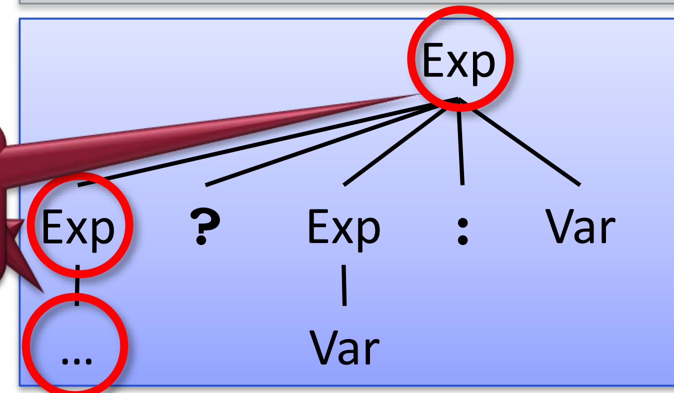
Exp → Var | Exp **?** Exp **:** Exp

Grammar: (bold=terminals)

Exp → Var | Var **?** Exp **:** Exp

Grammar: (bold=terminals)

Exp → Var | Exp **?** Exp **:** Var



Difficult to parse (LR or backtracking LL needed) as first few characters don't determine depth

If-then-else is earier: # of **if**s tells depth

Factoring

Grammar: (bold=terminals)

Stmt → UnMatched | Matched

Matched → **if (** Exp **)** Matched **else** Matched | **other**

UnMatched → **if (** Exp **)** Stmt | **if (** Exp **)** Matched **else** UnMatched

Exp → **0** | **1**

- When parser reads „`if `"
  - Can be the prefix of...
    - Matched_1
    - UnMatched_1
    - UnMatched_2
  - Can the parser avoid speculating?

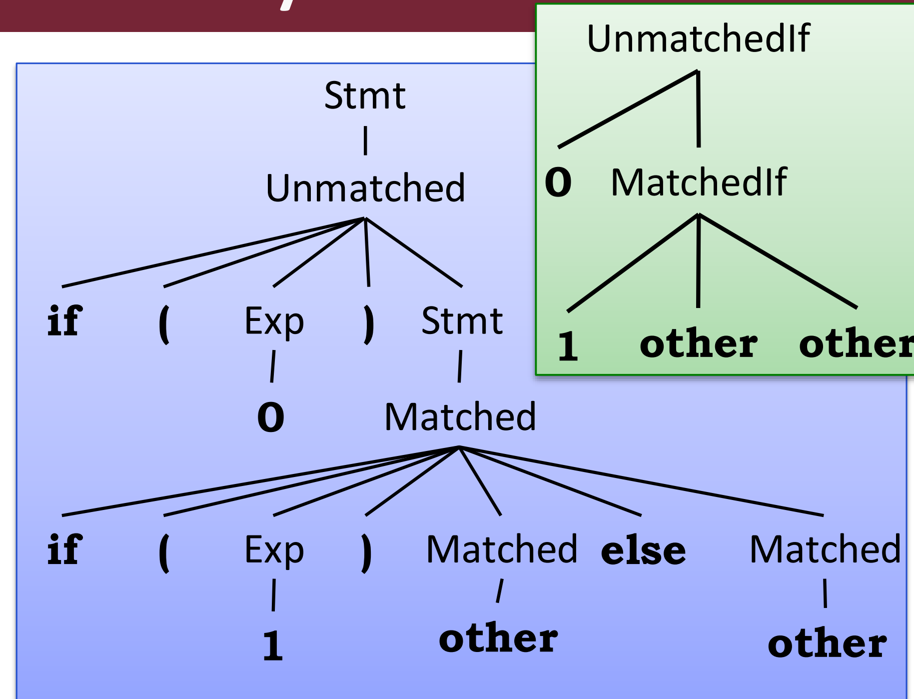
Factoring transformation automated (see later)
Don't worry about it

Factored grammar: (bold=terminals)

Stmt → **other** | **if (** Exp **)** IfSuffix

...

Parse Tree vs. Abstract Syntax Tree



- **Parse tree (Concrete syntax)**
  - Contains more information than necessary for a compiler
  - ~ Notation model
- **Abstract Syntax Tree**:
  - Simplifications
    - Whitespace, syntactic sugar, etc.
      - Individual tokens cannot be recovered
    - Factoring, „Subclasses" e.g. Stmt→Unmatched
    - „Optional"/"Repeating" rules collapsed
  - Defined by **high-level grammar** (EBNF)
    - Block → Stmt+ | Block→Stmt|Stmt Block
    - Low-level generated from high-level

Used in practical technologies (e.g. Xtext)

no need to understand low-level

Grammar Design Conclusions

- Design grammar according to…
  - Precedence of constructs
    - Rules delegate to each other in order of precedence
  - Left/right binding (associativity)
    - Force associativity by controlling which branch is recursive
- Keep your parser happy
  - Avoid ambiguity → single derivation for single string
  - Try to avoid left recursion by…
    - Recursion through discriminator e.g. ”(”…”)”, or
    - Force right associativity
- Keep your human happy (be concise yet readable)