Enum types

Special classes that define ordered groups of logically related constants

Simple example

```java
public enum Season {
    WINTER, SPRING, SUMMER, FALL
}
public class SeasonTest {
    public static String feeling(Season s) {
        return switch (s) { // new Java 12 switch expressions
        case WINTER -> "Cold!";
        case SPRING -> "Flowers!";
        case SUMMER -> "Vacations!";
        case FALL -> "Rain!";
        };
    }
    public static void main(String[] args) {
        assert feeling(Season.SUMMER).equals("Vacations!");
        assert feeling(Season.SPRING).equals("Flowers!");
    }
}
```

More details on enum types

Basic rules

- each constant of the enum type corresponds to a **`public static final`** field (=public constant class field)
- an enum type has no objects other than those defined by its enum constants; it is not allowed to create new objects of an enum type
- it is safe to use == with enum constants

Example

```
public enum Season {
    WINTER, SPRING, SUMMER, FALL;

    public static boolean niceSeason(Season s) {
        return s == SPRING || s == SUMMER;
    }
}
```

Other rules and features of enum types

Rules on inheritance/implementation

- Enum types cannot be extended
- Enum types can implement interfaces
- Each enum type `T` implicitly extends the predefined class `Enum<T>`

Example

```
enum Season {
  WINTER, SPRING, SUMMER, FALL
}

public class SeasonTest {
  public static void main(String[] args) {
    Season[] seasons = Season.values(); // an array in definition order
    for (Season s : seasons) { // iterates over seasons
      // s.ordinal() returns the position of the element starting from 0
      assert seasons[s.ordinal()] == s;
      assert s.toString().equals(s.name()); // toString() redifinable, not name()
      assert Season.valueOf(s.name()) == s;
    }
  }
}
```

Enum types and token types

A practical use of enum types in tokenizers

```
public enum TokenType {
  // symbols
  ASSIGN, MINUS, PLUS, TIMES, NOT, AND, EQ, STMT_SEP, PAIR_OP, OPEN_PAR,
       CLOSE_PAR, OPEN_BLOCK, CLOSE_BLOCK,
  // keywords
  PRINT, VAR, BOOL, IF, ELSE, FST, SND,
  // non singleton categories
  SKIP, IDENT, NUM,
  // end-of-file
  EOF,
}
public class MyLangTokenizer implements Tokenizer {
  ...
  public TokenType next() throws TokenizerException {...}
  public TokenType tokenType() {...}
  ...
}
```

Recap on parsers

Syntax analysis defined on top of lexical analysis

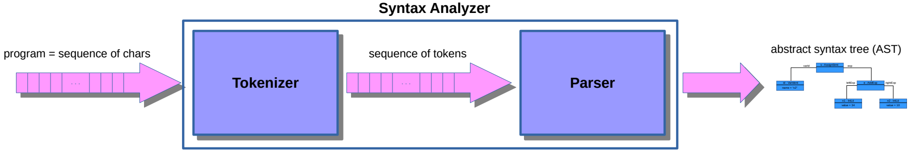
Syntax analysis is the problem of

- recognizing as valid the sequence of tokens of a program by following the syntactic rules of the language
- building, in case of success, an Abstract Syntax Tree (AST)
- AST = an abstract representation of the syntax of the recognized program
- an AST makes explicit the structure of the syntax: it shows how statements and expressions are built on top of simpler sub-statements and sub-expressions
- AST = input to the other steps of a programming language implementation:
  - typechecking specified by the static semantics
  - interpretation/compilation specified by the dynamic semantics

Parser

A program which performs syntax analysis

Recap on parsers



Parser for a programming language

- input: sequence of tokens of a program, recognized by a tokenizer
- it checks that the sequence of tokens verifies the syntax rules
- the syntax rules are formally defined by a grammar
- output:
  - a parse (or derivation) tree: a concrete representation of the syntax
    or
  - an Abstract Syntax Tree (AST): a more abstract representation of the syntax
- it can be hand-written or automatically generated by an application (ANTLR, Bison, ...)

Recap on parsers

Example 1 with C/Java/C++/C# syntax

Input string: `"x2 042=;"`

Recognized tokens:

- type `IDENT` with syntactic data: the name `"x2"`
- type `NUM` with semantic data: the value thirty-four
- type `ASSIGN` with no further data
- type `STMT_END` with no further data

Result of the parser

failure, the sequence is not recognized and error messages are reported

Recap on parsers

Example 2 with C/Java/C++/C# syntax

Input string: `"x2=042+012;"`

Recognized tokens:

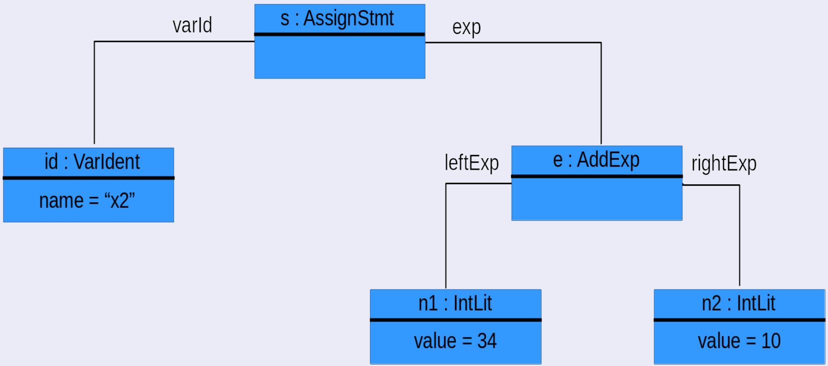
- type `IDENT` with syntactic data: the name `"x2"`
- type `ASSIGN` with no further data
- type `NUM` with semantic data: the value thirty-four
- type `PLUS` with no further data
- type `NUM` with semantic data: the value ten
- type `STMT_END` with no further data

Result of the parser

success, the sequence is recognized and an AST is generated (see next slide)

Recap on parsers

Result of the parser: an AST



Parsers and grammars

Problem

How is it possible to implement a parser from a grammar?

- if the grammar has a certain shape, then the parser can be generated automatically
- two main approaches
  - top-down parser: checks if there is a parse tree starting from its root
  - bottom-up parser: checks if there is a parse tree starting from its leaves
- top-down parsers are simpler
  - they consist of several procedures, one for each non-terminal symbol of the grammar
  - the code of the procedures is driven by the productions
  - most of the procedures are mutually recursive

Parsers and grammars

Some general assumptions

- the parser reads the tokens from left to right by using a tokenizer
- it needs a fixed number of lookahead tokens to decide how to proceed
- parsers that use one lookahead token are the simplest ones

Simplification

For simplicity, we only consider grammars for which it is possible to develop top-down parsers that use one lookahead token

How to build a parser from a grammar

Important assumption: the grammar must be non-ambiguous, otherwise it is not possible to build a unique AST

A non-ambiguous grammar

A grammar where `'*'` has higher precedence than `'+'` and both operators are left associative

```
Prog ::= Exp EOF // the program should end with the EOF token
Exp ::= Mul | Exp '+' Mul
Mul ::= Atom | Mul '*' Atom
Atom ::= Num | '(' Exp ')'
Num ::= '0' | '1'
```

How to build a parser from a grammar

A non-ambiguous grammar

```
Prog ::= Exp EOF
Exp ::= Mul | Exp '+' Mul
Mul ::= Atom | Mul '*' Atom
Atom ::= Num | '(' Exp ')'
Num ::= '0' | '1'
```

Main guidelines

- define a parsing method for each non-terminal symbol
  Example: `parseExp()` parses all strings defined by `Exp`
- the implementation is driven by the definition of the non-terminal symbol
- multiple productions correspond to branches that have to be selected
  Example: `parseExp()` should run the following code:
  - either call `parseMul()`
  - or call `parseExp()`, consume token of type `PLUS` and call `parseMul()`

How to build a parser from a grammar

Problems

```
Prog ::= Exp EOF
Exp ::= Mul | Exp '+' Mul
Mul  ::= Atom | Mul '*' Atom
Atom ::= Num | '(' Exp ')'
Num ::= '0' | '1'
```

`parseExp()` should run the following code:

- either call `parseMul()`
- or call `parseExp()`, consume token of type `PLUS` and call `parseMul()`

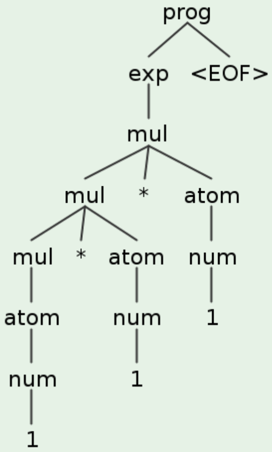
Problems:

- does one lookahead token allows selection of one of the two branches? no, for this grammar it is not possible to develop a parser using a fixed number of lookahead tokens
- the 2nd branch leads to non-terminating recursion

How to build a parser from a grammar

A problematic grammar

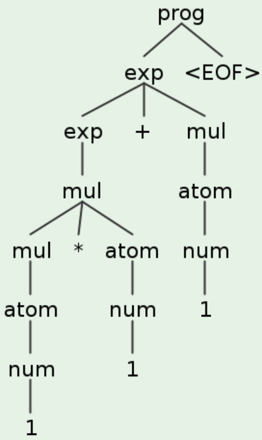
Example 1: parse tree for the string `"1*1*1"` (generated by ANTLR)



How to build a parser from a grammar

A problematic grammar

Example 2: parse tree for the string `"1*1+1"` (generated by ANTLR)



How to build a parser from a grammar

Solution

Merge the two productions into a single one by using the extended BNF notation

`Exp ::= Mul | Exp '+'Mul` is changed into `Exp ::= Mul ('+'Mul)*`

Explanation

- production (Exp, Mul) will eventually be used
- production (Exp, $Exp + Mul$) can be used n times, with $n \geq 0$, before production (Exp, Mul) is used
- n is the number of tokens of type `PLUS` read with the tokenizer

Examples:

- $n = 0$: $Exp \rightarrow Mul$
- $n = 1$: $Exp \rightarrow Exp + Mul \rightarrow Mul + Mul$
- $n = 2$: $Exp \rightarrow Exp + Mul \rightarrow Exp + Mul + Mul \rightarrow Mul + Mul + Mul$
- ...

How to build a parser from a grammar

Full solution

```
Prog ::= Exp EOF
Exp  ::= Mul ('+' Mul)*        // only one production
Mul  ::= Atom ('*' Atom)*      // only one production
Atom ::= Num | '(' Exp ')'     // one lookahead token needed here
Num ::= '0' | '1'
```

Recap on the EBNF notation

- the BNF notation is extended with the usual post-fix operators of regular expressions: `*`, `+`, `?`
- parentheses can be used to force the precedence rules between the grammar operators
- Remark: `'('`, `')'`, `'+'` and `'*'` are terminal symbols, while `(` and `)` are EBNF parentheses and `+` and `*` are EBNF operators

How to build a parser from a grammar

Some auxiliary methods used by the parser

Methods of the tokenizer:

- `next()`: the next lookahead token is read and its type returned
- `tokenType()`: the type of the current lookahead token is returned

Methods of the parser:

- `nextToken()`: calls `next()` on the tokenizer, throws an exception of type `ParserException` in case of error
- `match(type)`: checks that the next lookahead token has type `type`, throws an exception of type `ParserException` if not
- `consume(type)`: defined by

  ```
  parser.match(type); tokenizer.nextToken();
  ```

How to build a parser from a grammar

Java code

Parsing methods for `Prog` and `Exp`

```
public Prog parseProg() throws ParserException {
  nextToken(); // one lookahead token
  var prog = new MyLangProg(parseExp());
  match(EOF); // last token must have type EOF
  return prog;
}
private Exp parseExp() throws ParserException {
  var exp = parseMul();
  while (tokenizer.tokenType() == PLUS) {
    nextToken();
    exp = new Add(exp, parseMul());
  }
  return exp;
}
```

How to build a parser from a grammar

Remarks

- except for the main method `parseProg()`, all other parsing methods need to be synchronized with the tokenizer
  - before calling `parseExp()`, `parseMul()`, `parseAtom()`, the current lookahead token must be the first token of the sequence to be parsed
  - before exiting from `parseExp()`, `parseMul()`, `parseAtom()`, the current lookahead token must be the token that follows the parsed sequence
- the EBNF star operator is implemented through a while statement

How to build a parser from a grammar

Right-associative operators

With right-associative operators productions can be merged with `?`

Non-ambigous grammar

```
Exp ::= Mul | Mul '+' Exp
Mul ::= Atom | Atom '*' Mul
Atom ::= Num | '(' Exp ')'
Num ::= '0' | '1'
```

Equivalent EBNF grammar

```
Exp ::= Mul ('+' Exp)?
Mul ::= Atom ('*' Mul)?
Atom ::= Num | '(' Exp ')'
Num ::= '0' | '1'
```

Exercise: write the corresponing Java parser