Syntax Analysis
(a.k.a. Parsing)

Grammar analysis and recursive descent parsing.

1

Parser

- Verifies that the grammatical rules of the language are satisfied
- Overall parser structure is based on context-free grammars (a.k.a. BNF/EBNF grammars)
- Input: stream of tokens from the scanner
  From the perspective of the parser, each token is treated as a terminal symbol.
- Output: intermediate representation of the source code (e.g., abstract syntax trees)

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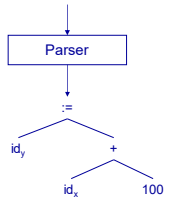
Parser
(continued)

Sequence of tokens returned by the scanner

identifier ["y", (1, 1)] := [(1, 3)] identifier ["x", (1, 6)] + [(1, 8)] intLiteral [("100", (1, 10)]



3

Functions of the Parser

- Language recognition based on syntax, as defined by a context-free grammar
- Error Handling/Recovery
- Generation of intermediate representation
  (We will generate abstract syntax trees.)

The primary focus of this section is language recognition. Subsequent sections will cover error recovery and generation of abstract syntax trees.

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Recursive Descent Parsing

- Parsing technique used in this course: recursive descent with single symbol lookahead.
  (Briefly discuss other options.)
- Uses recursive methods to "descend" through the parse tree (top-down parsing) as it parses a program.
- The parser is constructed systematically from the grammar using a set of programming refinements.

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Initial Grammar Transformations

- Start with an unambiguous grammar.
- Separate lexical grammar rules from structural rules.
  - Let the scanner handle simple rules (operators, identifiers, etc.).
  - Symbols from the scanner become terminal symbols in the grammar for the parser.
- Use a single rule for each nonterminal; i.e., each nonterminal appears on the left side of only one rule.
- Eliminate left recursion.
- Left factor wherever possible.
- Certain grammar restrictions will be discussed in subsequent slides.

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Recursive Descent Parsing Refinement 1

- For every rule in the grammar
  `N = … .`
  we define a parsing method with the name
  `parseN()`
- Example: For the rule
  `assignmentStmt = variable ":=" expression ";" .`
  we define a parsing method named
  `parseAssignmentStmt()`
- Grammar transformations can be used to simplify the grammar before applying this refinement; e.g., substitution of nonterminals.

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Recursive Descent Parsing Methods

The `parseN()` methods of the parser function as follows:

- The scanner method `getSymbol()` provides one symbol "lookahead" for the parsing methods.
- On entry into the method `parseN()`, the symbol returned from the scanner should contain a symbol that could start on the right side of the rule `N = … .`
- On exit from the method `parseN()`, the symbol returned from the scanner should contain the first symbol that could follow a syntactic phrase corresponding to N.
- If the production rules contain recursive references, the parsing methods will also contain recursive calls.

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Parsing the "Right" Side of a Rule

- We now turn our attention to refinement of the method `parseN()` associated with a production rule "`N = … .`" by examining the form of the grammatical expression on the right side of the rule.
- As an example, for the rule
  `assignmentStmt = variable ":=" expression ";" .`
  we have defined a parsing method named
  `parseAssignmentStmt()`
  We focus on systematic implementation of this method by examining the right side of the rule.

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Recursive Descent Parsing Refinement 2

- A sequence of syntax factors F_1 F_2 F_3 … is recognized by parsing the individual factors one at a time in order.
- In other words, the algorithm for parsing F_1 F_2 F_3 … is simply
  - the algorithm for parsing F_1 followed by
  - the algorithm for parsing F_2 followed by
  - the algorithm for parsing F_3 followed by
  - …

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Example: Recursive Descent Parsing Refinement 2

The algorithm used to parse
`variable ":=" expression ";"`
is simply
- the algorithm used to parse `variable` followed by
- the algorithm used to parse `":="` followed by
- the algorithm used to parse `expression` followed by
- the algorithm used to parse `";"`

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Recursive Descent Parsing Refinement 3

- A single terminal symbol `t` on the right side of a rule is recognized by calling the "helper" parsing method `match(t)` defined as

```
private fun match(expectedSymbol : Symbol)
  {
    if (scanner.symbol == expectedSymbol)
        scanner.advance()
    else
       ...   // throw ParserException
   }
```

- Example: The algorithm for recognizing the assignment operator `":="` is simply the method call
  `match(Symbol.assign)`

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Recursive Descent Parsing Refinement 4

- A nonterminal symbol N on the right side of a rule is recognized by calling the method corresponding to the rule for N; i.e., the algorithm for recognizing nonterminal N is simply a call to the method `parseN()`.
- Example: The algorithm for recognizing the nonterminal symbol `expression` on the right side of a rule is simply a call to the method `parseExpression()`.

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Example: Application of the Recursive Descent Parsing Refinements

- Consider the rule for an assignment statement:

```
assignmentStmt = variable ":=" expression ";" .
```

- The complete parsing method for recognizing an assignment statement is as follows:

```
fun parseAssignmentStmt()
  {
    parseVariable()
    match(Symbol.assign)
    parseExpression()
    match(Symbol.semicolon)
  }
```


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First Sets

- The set of all **terminal** symbols that can appear at the start of a syntax expression E is denoted First(E).
- First sets provide important information that can be used to guide decisions during parser development.

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First Set Examples from CPRL

- `constDecl = "const" constId ":=" literal ";" .`
  First(constDecl) = { "const" }
- `varDecl = "var" identifiers ":" typeName ";" .`
  First(varDecl) = { "var" }
- `arrayTypeDecl = "type" typeId "=" "array" ... ";" .`
  First(arrayTypeDecl) = { "type" }
- `initialDecl = constDecl | arrayTypeDecl | varDecl .`
  First(initialDecl) = { "const", "var", "type" }
- `statementPart = "begin" statements "end" .`
  First(statementPart) = { "begin" }
- `loopStmt = ( "while" booleanExpr )? "loop" ... ";" .`
  First(loopStmt) = { "while", "loop" }

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Rules for Computing First Sets

- If t is a terminal symbol, First(t) = { t }
- If all strings derived from E are nonempty, then First(E F) = First(E)
- If some strings derived from E can be empty, then First(E F) = First(E) ⋃ First(F)
- First(E | F) = First(E) ⋃ First(F)

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Computing First Sets: Special Cases

The following rules can be derived as special cases of the previous rules

- First((E)*) = First(E)
- First((E)+) = First(E)
- First((E)?) = First(E)
- First((E)* F) = First(E) ⋃ First(F)
- First((E)+ F) = First(E) if all strings derived from E are nonempty
- First((E)+ F) = First(E) ⋃ First(F) if some strings derived from E are empty
- First((E)? F) = First(E) ⋃ First(F)

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Strategy for Computing First Sets

- Use a bottom-up approach
- Start with simplest rules and work toward more complicated (composite) rules.

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Follow Sets

- The set of all **terminal** symbols that can follow immediately after a syntax expression E is denoted Follow(E).
- Understanding Follow sets is important not only for parser development but also for error recovery.
- If N is a nonterminal, we will use Follow(N) during error recovery when trying to parse N. To compute Follow(N) for a nonterminal N, you must analyze all rules that reference N.
- Computation of follow sets can be a bit more involved than computation of first sets.

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Follow Set Examples from CPRL

- What can follow an initialDecl?
  - From the rule
    ```
    initialDecls = ( initialDecl )* .
    ```
    we know that any initialDecl can follow an initialDecl, so the follow set for initialDecl includes the first set of initialDecl; i.e., “const”, “var”, and “type”.
  - From the rules
    ```
    declarativePart = initialDecls subprogramDecls .
    subprogramDecls = ( subprogramDecl )* .
    subprogramDecl = procedureDecl | functionDecl .
    ```
    we know that a procedureDecl or functionDecl can follow an initialDecl, so the follow set for initialDecl includes “procedure” and “function”.

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Follow Set Examples from CPRL (continued)

- From the rules
  ```
  program = declarativePart statementPart "." .
  statementPart = "begin" statements "end" .
  ```
  we know that statementPart can follow an initialDecl, so the follow set for initialDecl includes “begin”.
- Conclusion:
  Follow(initialDecl) =
  { “const”, “var”, “type”, “procedure”, “function”, “begin” }
- What can follow a loopStmt?
  - ... (left as an exercise)
  - Conclusion:
    Follow(loopStmt) =
    { identifier, “return”, “end”, “if”, “elsif”, “else”, “while”, “loop”, “exit”, “read”, “write”, “writeln” }

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Rules for Computing Follow Sets

Computing Follow(T)

- Consider all production rules similar to the following:
  N = S T U . N = S (T)* U . N = S (T)? U .
  - Follow(T) includes First(U).
  - If U can be empty, then Follow(T) also includes Follow(N).
- Consider all production rules similar to the following:
  N = S T . N = S (T)* . N = S (T)? .
  In all these cases, Follow(T) includes Follow(N).
- If T occurs in the form (T)* or (T)+, then Follow(T) includes First(T).

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Strategy for Computing Follow Sets

- Use a top-down approach.
- Start with first rule (the one containing the start symbol) and work toward the simpler rules.

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Recursive Descent Parsing Refinement 5

- A syntax factor of the form (E)* is recognized by the following algorithm:

  while current symbol is in First(E) loop
  * apply the algorithm for recognizing E*
  end loop

- **Grammar Restriction 1**: First(E) and Follow((E)*) must be disjoint in this context; i.e.,
  First(E) ⋂ Follow((E)*) = ∅
  (Why?)

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Example: Recursive Descent Parsing Refinement 5

- Consider the rule for `initialDecls`:

```
initialDecls = ( initialDecl )* .
```

- The CPRL method for parsing `initialDecls` is

```
fun parseInitialDecls()
  {
    while (scanner.symbol == Symbol.constRW ||
           scanner.symbol == Symbol.varRW   ||
           scanner.symbol == Symbol.typeRW)
      {
        parseInitialDecl()
      }
  }
```

- In CPRL, the symbols “const”, “var”, and “type” cannot follow initialDecls. (Which symbols can follow?)

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Helper Methods in Class `Symbol`

Class `Symbol` provides several helper methods for testing properties of symbols.

```
fun isReservedWord() : Boolean
fun isInitialDeclStarter() : Boolean
fun isSubprogramDeclStarter() : Boolean
fun isStmtStarter() : Boolean
fun isLogicalOperator() : Boolean
fun isRelationalOperator() : Boolean
fun isAddingOperator() : Boolean
fun isMultiplyingOperator() : Boolean
fun isLiteral() : Boolean
fun isExprStarter() : Boolean
```


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Method `isStmtStarter()`

```
/**
 * Returns true if this symbol can start a statement.
 */
fun isStmtStarter() = this == Symbol.exitRW
                   || this == Symbol.identifier
                   || this == Symbol.ifRW
                   || this == Symbol.loopRW
                   || this == Symbol.whileRW
                   || this == Symbol.readRW
                   || this == Symbol.writeRW
                   || this == Symbol.writelnRW
                   || this == Symbol.returnRW
```


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Method `isInitialDeclStarter()`

```
/**
 * Returns true if this symbol can start an initial declaration.
 */
fun isInitialDeclStarter() = this == Symbol.constRW
                          || this == Symbol.varRW
                          || this == Symbol.typeRW
```


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Using Helper Methods in Class `Symbol`

Using the helper methods in class `Symbol`, we can rewrite the code for `parseInitialDecls()` as follows:

```
fun parseInitialDecls()
  {
    while (scanner.symbol.isInitialDeclStarter())
        parseInitialDecl()
  }
```


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Recursive Descent Parsing Refinement 6

- Since a syntax factor of the form (E)+ is equivalent to E (E)*, a syntax factor of the form (E)+ is recognized by the following algorithm:

apply the algorithm for recognizing E
while current symbol is in First(E) loop
*   apply the algorithm for recognizing E*
end loop

- Equivalently, the algorithm for recognizing (E)+ can be written using a loop that tests at the bottom.

loop
*   apply the algorithm for recognizing E*
*   exit when current symbol is **not** in First(E)*
end loop

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Recursive Descent Parsing Refinement 6 (continued)

- In Java, the loop structure that tests at the bottom is called a do-while loop, so the algorithm implemented in Java would more closely resemble the following:

do
*   apply the algorithm for recognizing E*
while current symbol is in First(E)

- **Grammar Restriction 2**: If E can generate the empty string, then First(E) and Follow((E)+) must be disjoint in this context; i.e., First(E) ∩ Follow((E+)) = ∅ (Why?)

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Recursive Descent Parsing Refinement 7

- A syntax factor of the form (E)? is recognized by the following algorithm:

if current symbol is in First(E) then
*   apply the algorithm for recognizing E*
end if

- **Grammar Restriction 3**: First(E) and Follow((E)?) must be disjoint in this context; i.e.,
  First(E) ∩ Follow((E)?) = ∅
  (Same reason as before.)

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Helper Method `matchCurrentSymbol()`

- Method `matchCurrentSymbol()` is similar to method `match()` except that it takes no parameters and doesn't throw an exception. It simply advances the scanner.
- Method `matchCurrentSymbol()` is used when we already know that the next symbol in the input stream is the one we want. We could use `match()` for this purpose, but `matchCurrentSymbol()` is slightly more efficient.
- Method `matchCurrentSymbol()`

```
private fun matchCurrentSymbol()
  {
    scanner.advance();
  }
```


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Example: Recursive Descent Parsing Refinement 7

- Consider the rule for an `exit` statement:

```
exitStmt = "exit" ( "when" booleanExpr )? ";" .
```

- The method for parsing an `exit` statement is

```
fun parseExitStmt()
  {
    match(Symbol.exitRW);

    if (scanner.symbol == Symbol.whenRW)
      {
        matchCurrentSymbol()
        parseExpression()
      }

    match(Symbol.semicolon)
  }
```

first check for optional when clause

slightly more efficient than `match(Symbol.whenRW)`

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Example: Recursive Descent Parsing Refinement 7 (continued)

- The first set for the optional `when` clause is simply { "`when`" }, so we use the reserved word `when` to tell us whether or not to parse a `when` clause.
- Questions: What is the follow set for the optional `when` clause? What problem would we have if it contained the reserved word "`when`"?

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Recursive Descent Parsing Refinement 8

- A syntax factor of the form E | F is recognized by the following algorithm:

```
if current symbol is in First(E) then
    apply the algorithm for recognizing E
elsif current symbol is in First(F) then
    apply the algorithm for recognizing F
else
    parsing error
end if
```

- **Grammar Restriction 4**: First(E) and First(F) must be disjoint in this context; i.e., First(E) ∩ First(F) = ∅

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Example: Recursive Descent Parsing Refinement 8

- Consider the rule in CPRL for `initialDecl`:

```
initialDecl = constDecl | varDecl | arrayTypeDecl .
```

- The CPRL method for parsing `initialDecl` is

```
fun parseInitialDecl()
  {
    if (scanner.symbol == Symbol.constRW)
        parseConstDecl()
    else if (scanner.symbol == Symbol.varRW)
        parseVarDecl()
    else if (scanner.symbol == Symbol.typeRW)
        parseArrayTypeDecl()
    else
        ...   // throw an InternalErrorException
  }
```

(This logic could also be implemented using a when statement.)

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LL(1) Grammars

- If a grammar satisfies the restrictions imposed by the previous parsing rules, then the grammar is called an ***LL(1) grammar***.
- Recursive descent parsing using one symbol lookahead can be used only if the grammar is LL(1).
  - First 'L': read the source file from left to right
  - Second 'L': descend into the parse tree from left to right
  - Number '1': one token lookahead
- Not all grammars are LL(1).
  - e.g., any grammar has left recursion is not LL(1)

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LL(1) Grammars (continued)

- In practice, the syntax of most programming languages can be defined, or at least closely approximated, by an LL(1) grammar.
  - e.g., by using grammar transformations such as eliminating left recursion
- The phrase "recursive descent" refers to the fact that we descend (top-down) the parse tree using recursive method/function calls.

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Recursive Decent Parsing

- The "recursive" part of the phrase "recursive descent" comes from the use of recursive method calls in the parser; e.g., to parse nested loop statements.

```
parseLoop()         // called when parsing the outer loop
   ...
   parseStatements()
      ...
      parseLoop()   // called when paring the inner loop
```

- For the "descent" part of "recursive descent", consider a portion of the parse tree for a simple CPRL program.

```
var x : Integer;
begin
   ...
end.
```


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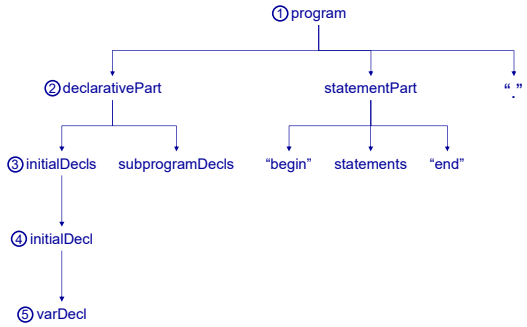
Recursive Decent Parsing (continued)



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Recursive Decent Parsing (continued)

- The numbers on the left side of the parse tree correspond to the order of calls to parsing methods; i.e., these are the first five paring methods called when parsing the program.

```
parseProgram()
parseDeclarativePart()
parseInitialDecls()
parseInitialDecl()
parseVarDecl()
```


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Developing a Parser

Three major versions of the parser for the compiler project:

- Version 1: Language recognition based on a context-free grammar (with minor checking of language constraints)
- Version 2: Add error-recovery
- Version 3: Add generation of abstract syntax trees

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Developing a Parser for CPRL Version 1: Language Recognition

- Use the parsing refinements discussed earlier.
- Verify that the grammar restrictions (in terms of first and follow sets) are satisfied by the grammar for CPRL.
- Use the grammar to develop version 1 of the parser.
  - requires grammar analysis
  - computation of first and follow sets

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Variables versus Named Values

- From the perspective of the grammar, there is no real distinction between a variable and a named value.

```
variable = ( varId | paramId ) ( "[" expression "]" )* .
namedValue = variable .
```

- Both are parsed similarly, but we make a distinction based on the context where the identifier appears.
- For example, consider the assignment statement

```
x := y;
```

The identifier “x” represents a variable, and the identifier “y” represents a named value.

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Variables versus Named Values (continued)

- Loosely speaking, it’s a variable if it appears on the left side of an assignment statement, and it’s a named value if it is used as an expression.
- The distinction between a variable and a named value will become important later when we consider the topics of error recovery and code generation − the error recovery and code generation are different for a variable than for a named value.

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Handling Grammar Limitations

- As given, the grammar for CPRL is “not quite” LL(1)
- Example: Parsing a statement.

```
statement = assignmentStmt | ifStmt | loopStmt | exitStmt
          | readStmt | writeStmt | writelnStmt
          | procedureCallStmt | returnStmt .
```

- Use the lookahead symbol to select the parsing method.
  - “if” → parse an “if” statement
  - “while” → parse a loop statement
  - “loop” → parse a loop statement
  - identifier → parse either an assignment statement or procedure call statement (which one?)
- An identifier is in the first set of both an assignment statement and a procedure call statement.

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Handling Grammar Limitations (continued)

- A similar problem exists when parsing a factor.

```
factor = "not" factor | constValue | namedValue
       | functionCall | "(" expression ")" .
```

- An identifier is in the first set of `constValue`, `namedValue`, and `functionCall`.

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Possible Solutions

1. Use additional token lookahead – LL(2)
   - If the symbol following the identifier is "[" or ":=", parse an assignment statement.
   - If it is "(" or ";", parse a procedure call statement.
2. Redesign/factor the grammar; e.g., replace "`s = i x | i y .`" with "`s = i ( x | y ) .`"
3. Use an identifier table to store information about how the identifier was declared, and then later use the declaration information to determine if the identifier is a constant, variable, procedure name, etc.

We will use the third approach.

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Class `IdTable` (Version 1)

- We will create a preliminary version class `IdTable` to help track identifiers that have been declared and to assist with basic constraint analysis of scope rules.
- Types of Identifiers

```
enum class IdType
  {
    constantId,  variableId, arrayTypeId,
    procedureId, functionId
  }
```

Class `IdTable` will be extended in subsequent assignments to perform a more complete analysis of CPRL scope rules.

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Procedure Example – Scope

```
var x : Integer;
var y : Integer;

procedure p is
   var x : Integer;
   var n : Integer;
begin
   x := 5;     // which x?
   n := y;     // which y?
end p;

 begin
    x := 8;    // which x?
 end.
```


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Handling Scopes within Class `IdTable`

- Variables and constants can be declared at the program level or at the subprogram level, introducing the concept of scope.
- Class `IdTable` will need to search for names both within the current scope and possibly in enclosing scopes.
- Class `IdTable` is implemented as a stack of maps from identifier strings to their `IdType`.
  - When a new scope is opened, a new map is pushed onto the stack.
  - Searching for a declaration involves searching within the current level (top map in the stack) and then within enclosing scopes (maps under the top).

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Selected Methods in `IdTable`

```
/**
 * Opens a new scope for identifiers.
 */
fun openScope()

/**
 * Closes the outermost scope.
 */
fun closeScope()

/**
 * Add a token and its type at the current scope level.
 * @throws ParserException if the identifier token is already
 *                         defined in the current scope.
 */
fun add(idToken : Token, idType : IdType)
```


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Selected Methods in `IdTable` (continued)

```
/**
 * Returns the IdType associated with the identifier
 * token's text.  Returns null if the identifier is not found.
 * Searches enclosing scopes if necessary.
 */
operator fun get(idToken : Token) : IdType?
```


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Adding Declarations to `IdTable`

- When an identifier is declared, the parser will attempt to add its token and `IdType` to the table within the current scope.
  - throws an exception if an identifier with the same name (same token text) has been previously declared in the current scope.
- Example from method `parseConstDecl()`

```
idTable.add(constId, IdType.constantId)
```

Throws a `ParserException` if the identifier is already defined in the current scope

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Using `IdTable` to Check Applied Occurrences of Identifiers

When an identifier is encountered in the statement part of the program or a subprogram, the parser will

- check that the identifier has been declared
- use the information about how the identifier was declared to facilitate correct parsing (e.g., you can't assign a value to an identifier that was declared as a constant.)

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Example Using `IdTable` to Check Applied Occurrences of Identifiers

```
// in method parseFactor()
scanner.symbol == Symbol.identifier ->
  {
    // Handle identifiers based on whether they are
    // declared as variables, constants, or functions.
    val idToken = scanner.token
    val idType = idTable[idToken]

    if (idType != null)
      {
        when (idType)
          {
            IdType.constantId -> parseConstValue()
            IdType.variableId -> parseNamedValue()
            IdType.functionId -> parseFunctionCall()
```

(continued on next page)

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Example Using `IdTable` to Check Applied Occurrences of Identifiers (continued)

```
          else              ->
              throw error("Identifier \"${scanner.token}\""
                        + " is not valid as an expression.")
          }
      }
    else
        throw error("Identifier \"${scanner.token}\" has not "
                  + "been declared.")
  }
```


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Example: Parsing a Procedure Declaration

```
// procedureDecl = "procedure" procId ( formalParameters )?
//      "is" initialDecls statementPart procId ";" .
match(Symbol.procedureRW)
val procId = scanner.token
match(Symbol.identifier)
idTable.add(procId, IdType.procedureId)
idTable.openScope()

if (scanner.getSymbol() == Symbol.leftParen)
    parseFormalParameters()

match(Symbol.isRW)
parseInitialDecls()
parseStatementPart()
idTable.closeScope()
```

Note that the procedure name is defined in the outer (program) scope, but its parameters and initial declarations are defined within the scope of the procedure.

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Example: Parsing a Procedure Declaration (continued)

```
val procId2 = scanner.token
match(Symbol.identifier)

if (procId.text != procId2.text)
    throw error(procId2.position, "Procedure name mismatch.")

match(Symbol.semicolon)
```

Note the check that the procedure names (`procId` and `procId2`) match. Technically, ensuring that the procedure names match goes beyond simple syntax analysis and represents more of a constraint check. As far as the context-free grammar is concerned, they are both just identifiers.

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Example: Parsing a Statement

```
when (scanner.symbol)
  {
    Symbol.identifier  ->
      {
        val idType = idTable[scanner.token]

        if (idType != null)
          {
            if (idType == IdType.variableId)
                parseAssignmentStmt()
            else if (idType == IdType.procedureId)
                parseProcedureCallStmt()
            else
                throw error(...)
          }
        else
            throw error(...)
      }
```


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Example: Parsing a Statement (continued)

```
    Symbol.ifRW      -> parseIfStmt()
    Symbol.loopRW, Symbol.whileRW -> parseLoopStmt()
    Symbol.exitRW    -> stmt = parseExitStmt()
    ...
  }
```


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Object `ErrorHandler`

- Kotlin object (not class) used for consistency in error reporting.
- Implements the singleton pattern (only one instance)

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Two Key Methods in Object `ErrorHandler`

```
/**
 * Returns true if errors have been reported by the
 * error handler.
 */
fun errorsExist() : Boolean

/**
 * Reports the error.  Stops compilation if the maximum
 * number of errors have been reported.
 */
fun reportError(e : CompilerException)
```


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Using `ErrorHandler` for Parser Version 1

- Version 1 of the parser does not implement error recovery. When an error is encountered, the parser will print an error message and then exit.
- In order to ease the transition to error recovery in the next version of the parser, most parsing methods will wrap the basic parsing logic in a `try/catch` block.
- Any parsing method that calls `match()` or the `add()` method of `IdTable` will need to have a `try/catch` block.
- Error reporting will be implemented within the `catch` clause of the `try/catch` block.

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Using ErrorHandler for Parser Version 1 (continued)

```
fun parseAssignmentStmt()
  {
    try
      {
        parseVariable()
        match(Symbol.assign)
        parseExpression()
        match(Symbol.semicolon)
      }
    catch (e : ParserException)
      {
        ErrorHandler.reportError(e)
        exit()
      }
  }
```

wrap the parsing statements in a try/catch block

This approach provides the framework that we will use for error recovery in the next section.

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Implementing methods parseVariable() and parseNamedValue()

- To implement methods `parseVariable()` and `parseNamedValue()` we use a helper method to provide common logic for both methods.
- The helper method does not handle any parser exceptions but instead throws them back to the calling method where they can be handled appropriately.
- An outline of the helper method, `parseVariableExpr()`, is shown on the next couple of slides.
- Both `parseVariable()` and `parseNamedValue()` call the helper method to parse the grammar rule for variable.

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Method parseVariableExpr()

```
// parses the following grammar rule:
// variable = ( varId | paramId ) ( "[" expression "]" )* .
fun parseVariableExpr()
  {
    val idToken = scanner.token
    match(Symbol.identifier)
    val idType = idTable[idToken]

    if (idType == null)
      {
        val errorMsg = "Identifier \"$idToken\" has "
                     + "not been declared."
        throw error(idToken.position, errorMsg)
      }
```

(continued on next slide)

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Method parseVariableExpr() (continued)

```
    else if (idType != IdType.variableId)
      {
        val errorMsg = "Identifier \"$idToken\" is "
                     + "not a variable."
        throw error(idToken.position, errorMsg)
      }

    while (scanner.symbol == Symbol.leftBracket)
      {
        matchCurrentSymbol()
        parseExpression()
        match(Symbol.rightBracket)
      }
  }
```


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Method parseVariable()

- Method `parseVariable()` simply calls the helper method to parse its grammar rule.

```
fun parseVariable()
  {
    try
      {
        parseVariableExpr()
      }
    catch (e : ParserException)
      {
        ErrorHandler.reportError(e)
        exit()
      }
  }
```

Method `parseNamedValue()` is implemented similarly.

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