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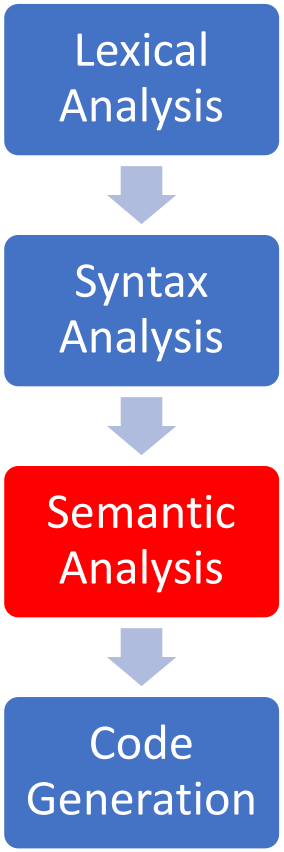
# Experiment in Compiler Construction

## Semantic Analysis (1)

# Content

- Overview
- Symbol table
- Static semantic analysis

# What is semantic analysis?




- Syntax analysis checks only grammatical correctness of a program
- There are a number of correctness that are deeper than grammar
  - Is “x” a variable or a function?
  - Is “x” declared?
  - Which declaration of “x” does a given use reference?
  - Is the assign statement “c:=a+b” type consistent?
  - …
- Semantic Analysis answers those questions and gives direction to a correct code generation.

# Tasks of a semantic analyzer

- Maintaining information about identifiers
  - Constants
  - Variables
  - Types
  - Scopes (program, procedures, and functions)
- Checking semantic rules
  - Scoping rules
  - Typing rules
- Invoking code generation routines

# Symbol table

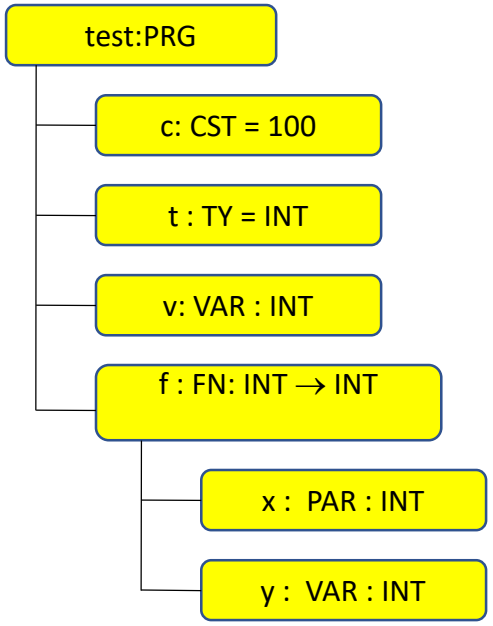
- It maintains all declarations and their attributes
  - Constants: {name, type, value}
  - Types: {name, actual type}
  - Variables: {name, type}
  - Functions: {name, parameters, return type, local declarations}
  - Procedures: {name, parameters, local declarations)
  - Parameters: {name, type, call by value/call by reference}

# Symbol table

- In a KPL compiler, the symbol table is represented as a hierarchical structure

```
PROGRAM test;
CONST c = 100;
TYPE t = Integer;
VAR v : t;
FUNCTION f(x : t) : t;
  VAR y : t;
BEGIN
  y := x + 1;
  f := y;
END;

BEGIN
  v := 1;
  WriteI (f(v));
END.
```



# Symbol table implementation

- Elements of the symbol table

```
// symbol table
struct SymTab_ {
  // main program
  Object* program;

  // current scope
  Scope* currentScope;

  // Global objects such as
  // WRITEI, WRITEC, WRITELN
  // READI, READC
  ObjectNode *globalObjectList;
};
```

```
// Scope of a block
struct Scope_ {
  // List of block's objects
  ObjectNode *objList;

  // Function, procedure or program that
  //block belongs to
  Object *owner;

  // Outer scope
  struct Scope_ *outer;
};
```

# Symbol table implementation

- Symbol table has `currentScope` tell current block
- Update `currentScope` whenever beginning parsing a procedure/function

```
void enterBlock(Scope* scope);
```

- Return `currentScope` to outer block whener a procedure/function has been analysed

```
void exitBlock(void);
```

- Declare a new object in current block

```
void declareObject(Object* obj);
```

# Constant and Type

```
// Type classification

enum TypeClass {
  TP_INT,
  TP_CHAR,
  TP_ARRAY
};

struct Type_ {
  enum TypeClass
   typeClass;

  // Use for type Array
  int arraySize;

  struct Type_
   *elementType;
};
```

```
// Constant

struct ConstantValue_ {
  enum TypeClass type;
  union {
    int intValue;
    char charValue;
  };
};
```

# Constant and Type

- To make type

```
Type* makeIntType(void);
Type* makeCharType(void);
Type* makeArrayType(int arraySize, Type* elementType);
Type* duplicateType(Type* type)
```

- To make constant value

```
ConstantValue* makeIntConstant(int i);
ConstantValue* makeCharConstant(char ch);
ConstantValue*
    duplicateConstantValue (ConstantValue* v);
```

# Object

```
// Object
// classification

enum ObjectKind {
  OBJ_CONSTANT,
  OBJ_VARIABLE,
  OBJ_TYPE,
  OBJ_FUNCTION,
  OBJ_PROCEDURE,
  OBJ_PARAMETER,
  OBJ_PROGRAM
};
```

```
// Objects' attributes in symbol
// table

struct Object_ {
  char name[MAX_IDENT_LEN];
  enum ObjectKind kind;
  union {
    ConstantAttributes* constAttrs;
    VariableAttributes* varAttrs;
    TypeAttributes* typeAttrs;
    FunctionAttributes* funcAttrs;
    ProcedureAttributes* procAttrs;
    ProgramAttributes* progAttrs;
    ParameterAttributes* paramAttrs;
  };
};
```

# Object – Object's attributes

```
struct ConstantAttributes_ {
  ConstantValue* value;
};
struct VariableAttributes_ {
  Type *type;
  // Scope of variable (for code generation)
  struct Scope_ *scope;
};
struct TypeAttributes_ {
  Type *actualType;
};
struct ParameterAttributes_ {
  // Call by value or call by reference
  enum ParamKind kind;
  Type* type;
  struct Object_ *function;
};
```

# Object – Object's attributes

```
struct ProcedureAttributes_ {
  struct ObjectNode_ *paramList;
  struct Scope_* scope;
};

struct FunctionAttributes_ {
  struct ObjectNode_ *paramList;
  Type* returnType;
  struct Scope_ *scope;
};

struct ProgramAttributes_ {
  struct Scope_ *scope;
};

// Note: parameter objects are declared in list of parameters
  (paramList) as well as in list of objects declared inside
  current block (scope->objList)
```

# Object

- Create a constant object

```
Object* createConstantObject(char *name);
```

- Create a type object

```
Object* createTypeObject(char *name);
```

- Create a variable object

```
Object* createVariableObject(char *name);
```

- Create a parameter object

```
Object* createParameterObject(char *name
                              enum ParamKind kind;
                              Object* owner;);
```

# Object

- Create a function object

```
Object* createFunctionObject(char *name);
```

- Create a procedure object

```
Object* createProcedureObject(char *name);
```

- Create a program object

```
Object* createProgramObject(char *name);
```

# Free the memory

- Free a type

```
void freeType(Type* type);
```

- Free an object

```
void freeObject(Object* obj)
```

- Free a list of object

```
void freeObjectList(ObjectNode* objList)
void freeReferenceList(ObjectNode* objList)
```

- Free a block

```
void freeScope(Scope* scope)
```

# Debugging

- Display type's information

```
void printType(Type* type);
```

- Display object's information

```
void printObject(Object* obj, int indent)
```

- Display object list's information

```
void printObjectList(ObjectNode* objList, int
indent)
```

- Display block's information

```
void printScope(Scope* scope, int indent)
```

# Semantic analyzer - organization

| # | File name | Task |
|---|---|---|
| 1 | makefile | Project |
| 2 | symtab.c, symtab.h | Symbol table implementation |
| 3 | debug.c, debug.h | Debugging |
| 4 | main.c | Main program |

# Assignment 1

- Implement symbol table: Complete *TODO* function in *symtab.c*

# Experiment in Compiler Construction

## Semantic Analysis (2)

# Implement symbol table for KPL

- Initialize and Clean symbol table
- Constant declaration
- Type declaration
- Variable declaration
- Function/Procedure declaration
- Parameter declaration

# Initialize & Clean a symbol table

```
int compile(char *fileName) {
  …
  // Initialize a symbol table
  initSymTab();
  // Compile the program
  compileProgram();
  // Display result for checking
  printObject(symtab->program,0);
  // Clean symbol table
  cleanSymTab();
  …
}
```

# Initialize program

- The program object is initialized by

```
void compileProgram(void);
```

- After program initialization, we enter the outermost block by `enterBlock()`
- When program is completely analysed, we exit by `exitBlock()`

# Constant declaration

- Constant objects are created and declared inside the function `compileBlock()`
- During analysing process, constants' values are filled by

```
ConstantValue* compileConstant(void)
```

*In case a constant's value is identifier constant, refer to symbol table to find actual value.*

- When a constant has been analysed, he has to be declared in current block by function `declareObject`

# User-defined type declaration

- Type objects are created and declared inside the function

  `compileBlock2()`

- Actual type is learned during the analysing by function

  `Type* compileType(void)`

  - If we meet identifier type, refer to symbol table to find actual type

- When a user-defined type has been analysed, he has to be declared in current block by function `declareObject`

# Variable declaration

- Variable objects are created and declared inside function

  `compileBlock3()`

- Type of a variable is filled when analysing type by using function

  `Type* compileType(void)`

- For later code generation, one of variable object's attributes should be the current scope.
- When a variable object is analysed, he has to be declared in current block by function `declareObject`

# Function declaration

- Function objects are created and declared in function `compileFuncDecl()`
- Attributes of a function object need to be filled include:
  - List of parameters, in function `compileParams`
  - Return type, in function `compileType`
  - Function's scope
- Note:The function object has to be declared in current block

  Update function scope as currentScope before deal with function local object.

# Procedure declaration

- Function objects are created and declared in function `compileProcDecl()`
- Attributes of a function object need to be filled include:
  - List of parameters, in function `compileParams`
- Note:The function object has to be declared in current block

  Update function scope as currentScope before deal with function local object.

# Parameter declaration

- Parameter objects are created and declared in function `compileParam()`
- Parameter objects' attributes:
  - Data type of parameter: a basic type
  - Kind of parameter: Call by value (PARAM_VALUE) or call by reference (PARAM_REFERENCE)
- Note: parameter objects should be declared in both
  - Current function's list of parameter (`paramList`)
  - Current function's list of local objects (`objectList`).

# Project organization

| # | Filename | Task |
|---|---|---|
| 1 | Makefile | Project |
| 2 | scanner.c, scanner.h | Token reader |
| 3 | reader.h, reader.c | Read character from source file |
| 4 | charcode.h, charcode.c | Classify character |
| 5 | token.h, token.c | Recognize and classify token, keywords |
| 6 | error.h, error.c | Manage error types and messages |
| 7 | parser.c, parser.h | Parse programming structure |
| 8 | debug.c, debug.h | Debugging |
| 9 | symtab.c symtab.h | Symbol table construction |
| 10 | main.c | Main program |

# Assignment 2

- Observe the structure of parser (modified)
- Complete *TODO* function
- Test on provided examples

# Example

- Insert information of a constant
- Assignment 1

```
obj = createConstantObject("c1");
obj->constAttrs->value = makeIntConstant(10);
declareObject(obj);
```

# void compileBlock(void)

```
{  Object* constObj;
 ConstantValue* constValue;
 if (lookAhead->tokenType == KW_CONST) {
   eat(KW_CONST);
   do {
     eat(TK_IDENT);
        constObj = createConstantObject(currentToken->string);
     eat(SB_EQ);
        constValue = compileConstant();
         constObj->constAttrs->value = constValue;
     declareObject(constObj);
     eat(SB_SEMICOLON);
   } while (lookAhead->tokenType == TK_IDENT);
   compileBlock2();
 }
 else compileBlock2();
}
```

```
obj = createConstantObject("c1");
  obj->constAttrs->value =
makeIntConstant(10);
  declareObject(obj);
```

# Experiment in Compiler Construction

## Semantic Analysis (3)

# Overview

- Checking duplicate object declaration
- Checking reference to object

# Checking fresh identifier

- A fresh identifier is an identifier that is new (has not been used) in current scope
- Checking fresh identifier is task of function

```
void checkFreshIdent(char *name);
```

# Checking fresh identifier

- Checking fresh identifier is performed in
  - Constant declaration
  - User-defined type declaration
  - Variable declaration
  - Parameter declaration
  - Function declaration
  - Procedure declaration

# Checking declared constant

- Performed when there is a reference to a constant, e.g:
  - When analysing an unsigned constant
  - When analysing an constant
- If a constant is not declared in current block, search in outer blocks.
- The value of declared constant will be the value of the constant that we are dealing with
  - Share the value
  - Do not share the value → `duplicateConstantValue`

# Checking declared type

- Performed when there is a reference to a type, e.g: when analysing a type in function `compileType`
- If a type is not declared in current block, search in outer blocks
- The actual type of refered type name will be used to create the type we are dealing with
  - Share type
  - Do not share type → `duplicateType`

# Checking declared variable

- Performed when there is a reference to a variable, e.g:
  - In for statement
  - When analysing factor
- If a variable is not declared in current block, search in outer blocks.

# Checking declared LHS

- An identifier that appears in the left-hand side of an assign statement or in a factor possibly is:
  - Current function
  - A declared variable
    - If the variable's type is array type, the array index must follow the variable's name.
- Variable is different from parameters and current function.

# Checking declared function

- Performed when a function is referred, e.g
  - As left-hand side of assign statement (current function)
  - In a factor (a list of parameters will follows function's name)
- If a function is not declared in current block, search in outer blocks.
- Global functions: READC, READI

# Checking a declared procedure

- Performed when a procedure is referred, e.g:
  - In CALL statement
- If a procedure is not declared in current block, search in outer blocks.
- Global procedures: WRITEI, WRITEC, WRITELN

# List of error codes

- ERR_UNDECLARED_IDENT
- ERR_UNDECLARED_CONSTANT
- ERR_UNDECLARED_TYPE
- ERR_UNDECLARED_VARIABLE
- ERR_UNDECLARED_FUNCTION
- ERR_UNDECLARED_PROCEDURE
- ERR_DUPLICATE_IDENT

# Project organization

| # | Filename | Task |
|---|---|---|
| 1 | Makefile | Project |
| 2 | scanner.c, scanner.h | Token reader |
| 3 | reader.h, reader.c | Read character from source file |
| 4 | charcode.h, charcode.c | Classify character |
| 5 | token.h, token.c | Recognize and classify token, keywords |
| 6 | error.h, error.c | Manage error types and messages |
| 7 | parser.c, parser.h | Parse programming structure |
| 8 | debug.c, debug.h | Debugging |
| 9 | symtab.c symtab.h | Symbol table construction |
| 10 | semantics.c. semantics.h | Analyse the program's semantic |
| 11 | main.c | Main program |

# Assignment 3

- Implement the following function in *semantics.c*
  - `checkFreshIdent`
  - `checkDeclaredIdent`
  - `checkDeclaredConstant`
  - `checkDeclaredType`
  - `checkDeclaredVariable`
  - `checkDeclaredProcedure`
  - `checkDeclaredLValueIdent`
- Test on provided examples

# Experiment in Compiler Construction

## Semantic Analysis (4)

# Overview

- Type checking
- Checking the consistency between the declaration and usage of arrays.
- Checking the consistency between the declaration and usage of functions.
- Checking the consistency between the declaration and calling of procedures.
- Checking the consistency in reference usage

# Type checking

- Type comparison
  - checkIntType
  - checkCharType
  - checkArrayType
  - checkTypeEquality

# Type checking

- Constant:
  - [+/-] <constant>
  - The type of <constant> is integer

# Type checking

- Assign statement
  - <LValue> := <Expr>;
  - Basic types of <Lvalue> and <Expr> must be the same

# Type checking

- For statement:
  - For <var> := <exp1> To <exp2> do <stmt>
  - Basic types of <var>, <exp1>, and <exp2> must be the same

# Type checking

- Function and procedure:
  - Types of declared parameter and actual parameter (argument)must be the same
  - The corresponding actual parameter (argument) of a variable declared parameter must be a LValue.

# Type checking

- Condition:
- <exp1> <op> <exp2>
  - The basic types of <exp1> and <exp2> must be the same

# Type checking

- Expression:

  [+|-] <exp> → <exp> : integer

  [*|/] <term> → <term> : integer

# Type checking

- Index:
- (. <exp> .) → <exp> : integer
- The number of dimension of the array must be considered

# Project organization

| # | Filename | Task |
|---|---|---|
| 1 | Makefile | Project |
| 2 | scanner.c, scanner.h | Token reader |
| 3 | reader.h, reader.c | Read character from source file |
| 4 | charcode.h, charcode.c | Classify character |
| 5 | token.h, token.c | Recognize and classify token, keywords |
| 6 | error.h, error.c | Manage error types and messages |
| 7 | parser.c, parser.h | Parse programming structure |
| 8 | debug.c, debug.h | Debugging |
| 9 | symtab.c symtab.h | Symbol table construction |
| 10 | semantics.c. semantics.h | Analyse the program's semantic |
| 11 | main.c | Main program |

# Assignment 4

- Implement the following function in *semantic.c*
  - `void checkIntType(Type* type);`
  - `void checkCharType(Type* type);`
  - `void checkArrayType(Type* type);`
  - `void checkBasicType(Type* type);`
  - `void checkTypeEquality(Type* type1, Type* type2);`

# Structure for types

```
struct Type_ {
  enum TypeClass typeClass;
  int arraySize;
  struct Type_ *elementType;
};

enum TypeClass {
  TP_INT,
  TP_CHAR,
  TP_ARRAY
};
```

# Assignment 4

- Update *parser.c* with the implementation of described type checking rules
- Test on provided examples