07-0: **Syntax Errors/Semantic Errors**

- A program has *syntax* errors if it cannot be generated from the Context Free Grammar which describes the language
- The following code has no *syntax* errors, though it has plenty of *semantic* errors:

```
void main() {
   if (3 + x - true)
       x.y.z[3] = foo(z)
}
```

- Why don't we write a CFG for the language, so that all syntactically correct programs also contain no semantic errors?

07-1: **Syntax Errors/Semantic Errors**

- Why don't we write a CFG for the language, so that all syntactically correct programs also contain no semantic errors?
- In general, we can't!
    - In simpleJava, variables need to be declared before they are used
    - The following CFG:
        - $L = \{ww | w \in \{a, b\}\}$

      is *not* Context-Free – if we can't generate this string from a CFG, we certainly can't generate a simpleJava program where all variables are declared before they are used.

07-2: **yacc & CFGs**

- Yacc allows actions – arbitrary C code – in rules
- We could use yacc rules to do type checking
- Why don't we?

07-3: **yacc & CFGs**

- Yacc allows actions – arbitrary C code – in rules
- We could use yacc rules to do type checking
- Why don't we?
    - Yacc files become very long, hard to follow, hard to debug
    - Not good software engineering – trying to do too many things at once

07-4: **Semantic Errors/Syntax Errors**

- Thus, we only build the Abstract Syntax Tree in yacc (not worrying about ensuring that variables are declared before they are used, or that types match, and so on)
- The next phase of compilation – *Semantic Analysis* – will traverse the Abstract Syntax Tree, and find any semantic errors – errors in the *meaning* (semantics) of the program

- Semantic errors are all compile-time errors other than syntax errors.

07-5: **Semantic Errors**

- Semantic Errors can be classified into the following broad categories:
- **Definition Errors**
- Most strongly typed languages require variables, functions, and types to be defined before they are used with some exceptions –
  - Implicit variable declarations in Fortran
  - Implicit function definitions in C

07-6: **Semantic Errors**

- Semantic Errors can be classified into the following broad categories:
- **Structured Variable Errors**
  - x.y = A[3]
    - x needs to be a class variable, which has an instance variable y
    - A needs to be an array variable
  - x.y[z].w = 4
  - x needs to be a class variable, which has an instance variable y, which is an array of class variables that have an instance variable w

07-7: **Semantic Errors**

- Semantic Errors can be classified into the following broad categories:
  - **Function and Method Errors**
    - foo(3, true, 8)
      - foo must be a function which takes 3 parameters:
      - integer
      - boolean
      - integer

07-8: **Semantic Errors**

- Semantic Errors can be classified into the following broad categories:
  - **Type Errors**
  - Build-in functions – /, *, ||, &&, etc. – need to be called with the correct types
    - In simpleJava, +, -, *, / all take integers
    - In simpleJava, || &&, ! take booleans
    - Standard Java has polymorphic functions & type coercion

07-9: **Semantic Errors**

- Semantic Errors can be classified into the following broad categories:

  - **Type Errors**
  - Assignment statements must have compatible types
  - When are types compatible?

07-10: **Semantic Errors**

- Semantic Errors can be classified into the following broad categories:
  - **Type Errors**
  - Assignment statements must have compatible types
    - In Pascal, only *Identical* types are compatible

07-11: **Semantic Errors**

- Semantic Errors can be classified into the following broad categories:
  - **Type Errors**
  - Assignment statements must have compatible types
    - In C, types must have the same structure
    - Coerceable types also apply

```
struct {          struct {
   int x;            int z;
   char y;           char x;
} var1;           } var2;
```

07-12: **Semantic Errors**

- Semantic Errors can be classified into the following broad categories:
  - **Type Errors**
  - Assignment statements must have compatible types
    - In Object oriented languages, can assign superclass value to a subclass variable

07-13: **Semantic Errors**

- Semantic Errors can be classified into the following broad categories:
  - **Access Violation Errors**
  - Accessing private / protected methods / variables
  - Accessing local functions in block structured languages
  - Separate files (C)

07-14: **Environment**

- Much of the work in semantic analysis is managing environments
- Environments store current definitions:
  - Names (and structures) of types
  - Names (and types) of variables

  - Names (and return types, and number and types of parameters) of functions

- As variables (functions, types, etc) are declared, they are added to the environment. When a variable (function, type, etc) is accessed, its definition in the environment is checked.

07-15: **Environments & Name Spaces**

- Types and variables have different name spaces in simpleJava, C, and standard Java:

```
simpleJava:

class foo {
   int foo;
}

void main() {
   foo foo;
   foo = new foo();
   foo.foo = 4;
   print(foo.foo);
}
```

07-16: **Environments & Name Spaces**

- Types and variables have different name spaces in simpleJava, C, and standard Java:

```
C:
#include <stdio.h>

typedef int foo;
  int main() {
  foo foo;
  foo = 4;
  printf("%d", foo);
  return 0;
}
```

07-17: **Environments & Name Spaces**

- Types and variables have different name spaces in simpleJava, C, and standard Java:

```
Java:

class EnviornTest {

   static void main(String args[]) {

      Integer Integer = new Integer(4);
      System.out.print(Integer);
    }
}
```

07-18: **Environments & Name Spaces**

- Variables and functions in C share the same name space, so the following C code is **not** legal:

```
int foo(int x) {
  return 2 * x;
}

int main() {
  int foo;
  printf("%d\n",foo(3));
  return 0;
}
```

- The variable definition `int foo;` masks the function definition for `foo`

07-19: **Environments & Name Spaces**

- Both standard Java and simpleJava use different name spaces for functions and variables
- Defining a function and variable with the same name will not confuse Java or simpleJava in the same way it will confuse C
  - *Programmer* might still get confused ...

07-20: **simpleJava Environments**

- We will break simpleJava environment into 3 parts:
  - **type environment** Class definitions, and built-in types int, boolean, and void.
  - **function environment** Function definitions – number and types of input parameters and the return type
  - **variable environment** Definitions of local variables, including the type for each variable.

07-21: **Changing Environments**

```
int foo(int x) {
  boolean y;

  x = 2;
  y = false;
  /* Position A */
  {  int y;
     boolean z;

     y = 3;
     z = true;
  /* Position B */
  }
  /* Position C */
}
```

07-22: **Implementing Environments**

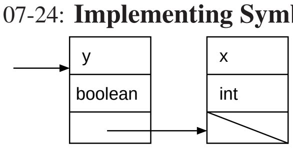
- Environments are implemented with Symbol Tables

- Symbol Table ADT:
  - Begin a new scope.
  - Add a key / value pair to the symbol table
  - Look up a value given a key. If there are two elements in the table with the same key, return the most recently entered value.
  - End the current scope. Remove all key / value pairs added since the last begin scope command

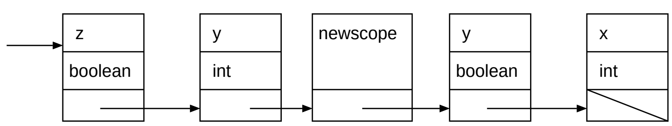
07-23: **Implementing Symbol Tables**

- Implement a Symbol Table as a list
  - Insert key/value pairs at the front of the list
  - Search for key/value pairs from the front of the list
  - Insert a special value for "begin new scope"
  - For "end scope", remove values from the front of the list, until a "begin scope" value is reached

07-24: **Implementing Symbol Tables**



a



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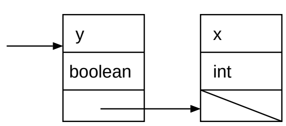


c

07-25: **Implementing Symbol Tables**

- Implement a Symbol Table as an open hash table
  - Maintain an array of lists, instead of just one
  - Store (key/value) pair in the front of `list[hash(key)]`, where `hash` is a function that converts a key into an index
  - If:
    - The hash function distributes the keys evenly throughout the range of indices for the list
    - # number of lists = Θ(# of key/value pairs)

    Then inserting and finding take time $\Theta(1)$

07-26: **Hash Functions**

```
long hash(char *key, int tableSize) {
   long h = 0;
   long g;
   for (;*key;key++) {
      h = (h << 4) + *key;
      g = h & OxF0000000;
      if (g) h ^= g >> 24
      h &= g
   }
   return h % tableSize;
}
```

07-27: **Implementing Symbol Tables**

- What about `beginScope` and `endScope`?
- The key/value pairs are distributed across several lists – how do we know which key/value pairs to remove on an `endScope`?

07-28: **Implementing Symbol Tables**

- What about `beginScope` and `endScope`?
- The key/value pairs are distributed across several lists – how do we know which key/value pairs to remove on an `endScope`?
  - If we knew exactly which variables were inserted since the last `beginScope` command, we could delete them from the hash table
  - If we always enter and remove key/value pairs from the beginning of the appropriate list, we will remove the correct items from the environment when duplicate keys occur.
  - How can we keep track of which keys have been added since the last beginScope?

07-29: **Implementing Symbol Tables**

- How can we keep track of which keys have been added since the last beginScope?
- Maintain an auxiliary stack
  - When a key/value pair is added to the hash table, push the key on the top of the stack.
  - When a "Begin Scope" command is issued, push a special begin scope symbol on the stack.
  - When an "End scope" command is issued, pop keys off the stack, removing them from the hash table, until the begin scope symbol is popped

07-30: **Type Checking**

- **Built-in types** ints, floats, booleans, doubles, etc. simpleJava only has the built-in types int and boolean
- **Structured types** Collections of other types – arrays, records, classes, structs, etc. simpleJava has arrays and classes
- **Pointer types** int *, char *, etc. Neither Java nor simpleJava have explicit pointers – no pointer type. (Classes are represented internally as pointers, no explicit representation)
- **Subranges & Enumerated Types** C and Pascal have enumerated types (enum), Pascal has subrange types. Java has neither (at least currently – enumerated types may be added in the future)

07-31: **Built-In Types**

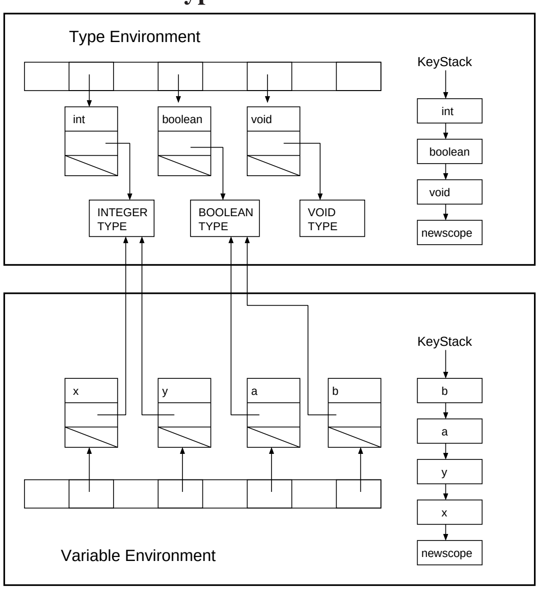
- No auxiliary information required for built-in types int and boolean (an int is and int is an int)
- All types will be represented by pointers to type objects
- We will only allocate *one* block of memory for *all* integer types, and *one* block of memory for *all* boolean types

07-32: **Built-In Types**

```
void main() {
  int x;
  int y;
  boolean a;
  boolean b;

  x = y;
  x = a;   /* Type Error */
}
```

07-33: **Built-In Types**



07-34: **Class Types**

- For built-in types, we did not need to store any extra information.
- For Class types, what extra information do we need to store?

07-35: **Class Types**

- For built-in types, we did not need to store any extra information.
- For Class types, what extra information do we need to store?
  - The name and type of each instance variable
- How can we store a list of bindings of variables to types?

07-36: **Class Types**

- For built-in types, we did not need to store any extra information.
- For Class types, what extra information do we need to store?
    - The name and type of each instance variable
- How can we store a list of bindings of variables to types?
    - As an environment!

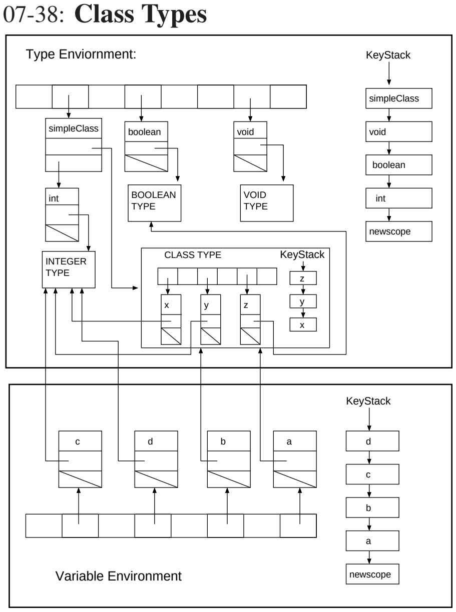
07-37: **Class Types**

```
class simpleClass {
  int x;
  int y;
  boolean z;
}

void main() {
  simpleClass a;
  simpleClass b;
  int c;
  int d;

  a = new simpleClass();
  a.x = c;
}
```

07-38: **Class Types**



07-39: **Array Types**

- For arrays, what extra information do we need to store?

07-40: **Array Types**

- For arrays, what extra information do we need to store?
  - The base type of the array
  - For statically declared arrays, we might also want to store range of indices, to add range checking for arrays
    - Will add some run time inefficiency – need to add code to dynamically check each array access to ensure that it is within the correct bounds
    - Large number of attacks are based on buffer overflows

07-41: **Array Types**

- Much like built-in types, we want only one instance of the internal representation for `int[]`, one representation for `int[][]`, and so on
  - So we can do a simple pointer comparison to determine if types are equal
  - Otherwise, we would need to parse an entire type structure whenever a type comparison needed to be done (and type comparisons need to be done *frequently* in semantic analysis!)

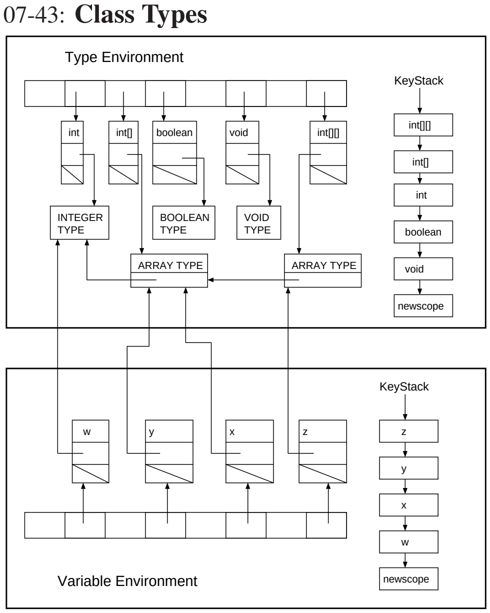
07-42: **Array Types**

```
void main () {
  int w;
  int x[];
  int y[];
  int z[][];

  /* Body of main program */

}
```

07-43: **Class Types**



07-44: **Semantic Analysis Overview**

- A Semantic Analyzer traverses the Abstract Syntax Tree, and checks for semantic errors
  - When declarations are encountered, proper values are added to the correct environment

07-45: **Semantic Analysis Overview**

- A Semantic Analyzer traverses the Abstract Syntax Tree, and checks for semantic errors
  - When a statement is encountered (such as `x = 3`), the statement is checked for errors using the current environment
    - Is the variable `x` declared in the current scope?
    - Is it `x` of type `int`?

07-46: **Semantic Analysis Overview**

- A Semantic Analyzer traverses the Abstract Syntax Tree, and checks for semantic errors
  - When a statement is encountered (such as if (x > 3) x++;), the statement is checked for errors using the current environment
    - Is the expression `x > 3` a valid expression (this will require a recursive analysis of the expression `x > 3`)
    - Is the expression `x > 3` of type `boolean`?
    - Is the statement `x++` valid (this will require a recursive analysis of the statement `x++;`

07-47: **Semantic Analysis Overview**

- A Semantic Analyzer traverses the Abstract Syntax Tree, and checks for semantic errors
  - When a function definition is encountered:
    - Begin a new scope
    - Add the parameters of the functions to the variable environment
    - Recursively check the body of the function
    - End the current scope (removing definitions of local variables and parameters from the current environment)

07-48: **Variable Declarations**

- `int x;`
  - Look up the type `int` in the type environment.
    - (if it does not exists, report an error)
  - Add the variable `x` to the current variable environment, with the type returned from the lookup of `int`

07-49: **Variable Declarations**

- `foo x;`
  - Look up the type `foo` in the type environment.
    - (if it does not exists, report an error)
  - Add the variable `x` to the current variable environment, with the type returned from the lookup of `foo`

07-50: **Array Declarations**

- `int A[];`
  - Defines a variable `A`
  - *Also* potentially defines a type int[]

07-51: **Array Declarations**

- `int A[];`
  - look up the type int[] in the type environment
  - If the type exists:
    - Add `A` to the variable environment, with the type returned from looking up `int[]`

07-52: **Array Declarations**

- `int A[];`
  - look up the type int[] in the type environment
  - If the type does not exist:
    - Check to see if `int` appears in the type environment. If it does not, report an error
    - If `int` does appear in the type environment
      - Create a new Array type (using the type returned from `int` as a base type)
      - Add new type to type environment, with key `int[]`
      - Add variable `A` to the variable environment, with this type

07-53: **Multidimensional Arrays**

- For multi-dimensional arrays, we may need to repeat the process
- For a declaration int x[][][], we may need to add:
  - int[]
  - int[][]
  - int[][][]

  to the type environment, before adding x to the variable environment with the type int[][][]

07-54: **Multidimensional Arrays**

```
void main() {
   int A[][][];
   int B[];
   int C[][];

   /* body of main */
}
```

- For `A[][][]`:
  - Add int[], int[][], int[][][] to type environment
  - add A to variable environment with type int[][][]

07-55: **Multidimensional Arrays**

```
void main() {
   int A[][][];
   int B[];
   int C[][];

   /* body of main */
}
```

- For `B[]`:
  - int[] is already in the type environment.
  - add B to variable environment, with the type found for int[]

07-56: **Multidimensional Arrays**

```
void main() {
   int A[][][];
   int B[];
   int C[][];

   /* body of main */
}
```

- For `C[][]`:
  - int[][] is already in the type environment
  - add C to variable environment with type found for int[][]

07-57: **Multidimensional Arrays**

- For the declaration `int A[][][]`, why add types int[], int[][], and int[][][] to the type environment?
- Why not just create a type int[][][], and add `A` to the variable environment with this type?
- In short, why make sure that all instances of the type int[] point to the same instance?
  (examples)

07-58: **Multidimensional Arrays**

```
void Sort(int Data[]);

void main() {
  int A[];
  int B[];
  int C[][];

  /* Code to allocate space for A,B & C, and
     set initial values */

  Sort(A);
  Sort(B);
  Sort(C[2]);
}
```

07-59: **Function Prototypes**

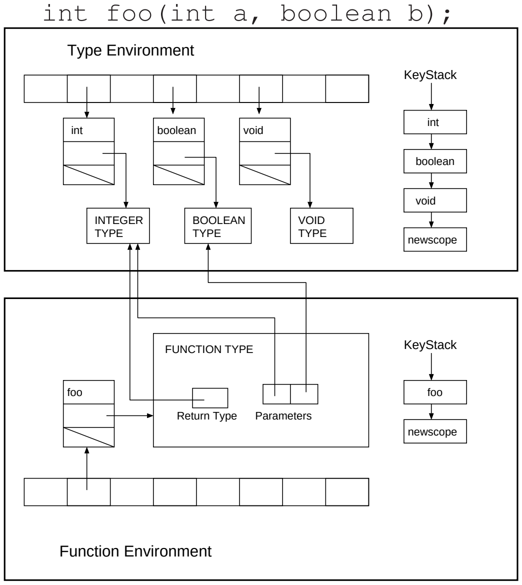
- `int foo(int a, boolean b);`
- Add a description of this function to the function environment

07-60: **Function Prototypes**

- `int foo(int a, boolean b);`
- Add a description of this function to the function environment
  - Type of each parameter
  - Return type of the function

07-61: **Function Prototypes**

`int foo(int a, boolean b);`



07-62: **Function Prototypes**

- `int PrintBoard(int board[][]);`
- Analyze types of input parameter
  - Add int[] and int[][] to the type environment, if not already there.

07-63: **Class Definitions**

```
class MyClass {
   int integerval;
   int Array[];
   boolean boolval;
}
```

07-64: **Class Definitions**

```
class MyClass {
   int integerval;
   int Array[];
   boolean boolval;
}
```

- Create a new variable environment

07-65: **Class Definitions**

```
class MyClass {
   int integerval;
   int Array[];
   boolean boolval;
}
```

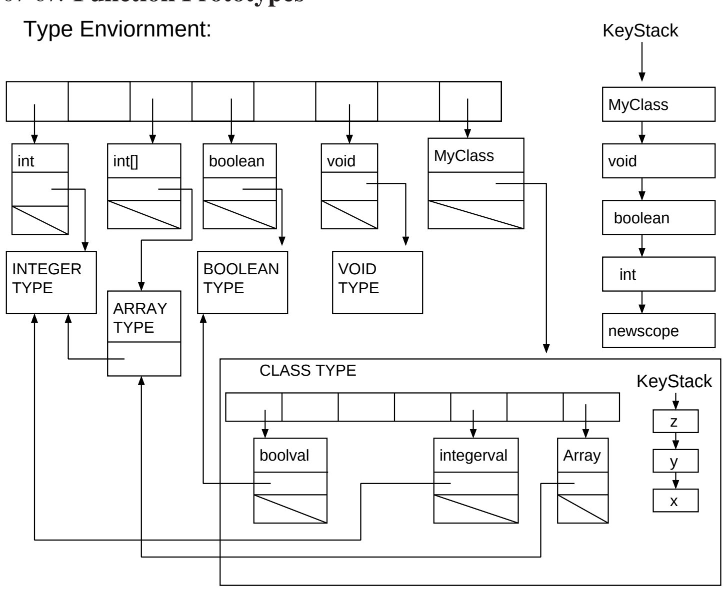
- Create a new variable environment
- Add integerval, Array, and boolval to this environment (possibly adding int[] to the type environment)

07-66: **Class Definitions**

```
class MyClass {
   int integerval;
   int Array[];
   boolean boolval;
}
```

- Create a new variable environment
- Add integerval, Array, and boolval to this environment (possibly adding int[] to the type environment)
- Add entry in type environment with key MyClass that stores the new variable environment

07-67: **Function Prototypes**



07-68: **Function Definitions**

- Analyze formal parameters & return type. Check against prototype (if there is one), or add function entry to function environment (if no prototype)
- Begin a new scope in the variable environment
- Add formal parameters to the variable environment
- Analyze the body of the function, using modified variable environment
- End current scope in variable environment

07-69: **Expressions**

- To analyze an expression:
  - Make sure the expression is well formed (no semantic errors)
  - Return the type of the expression (to be used by the calling function)

07-70: **Expressions**

- Simple Expressions
  - 3 (integer literal)
    - This is a well formed expression, with the type int
  - true (boolean literal)
    - This is a well formed expression, with the type int

07-71: **Expressions**

- Operator Expressions
  - 3 + 4
    - Recursively find types of left and right operand
    - Make sure the operands have integer types
    - Return integer type
  - x ¿ 3
    - Recursively find types of left and right operand
    - Make sure the operands have integer types
    - Return boolean type

07-72: **Expressions**

- Operator Expressions
  - (x ¿ 3) —— z
    - Recursively find types of left and right operand
    - Make sure the operands have boolean types
    - Return boolean type

07-73: **Expressions – Variables**

- Simple (Base) Variables – x

  - Look up `x` in the variable environment
  - If the variable was in the variable environment, return the associated type.
  - If the variable was *not* in the variable environment, display an error.
    - Need to return *something* if variable is not defined – return type integer for lack of something better

07-74: **Expressions – Variables**

- Array Variables – `A[3]`
  - Analyze the index, ensuring that it is of type int
  - Analyze the base variable. Ensure that the base variable is an Array Type
  - Return the type of an element of the array, extracted from the base type of the array
- ```
  int A[];

  /*  initialize A, etc. */
  x =  A[3];
  ```

07-75: **Expressions – Variables**

- Array Variables
  - Analyze the index, ensuring that it is of type int
  - Analyze the base variable. Ensure that the base variable is an Array Type
  - Return the type of an element of the array, extracted from the base type of the array
- ```
  int B[][];

  /*  initialize B, etc. */
  x =  B[3][4];
  ```

07-76: **Expressions – Variables**

- Array Variables
  - Analyze the index, ensuring that it is of type int
  - Analyze the base variable. Ensure that the base variable is an Array Type
  - Return the type of an element of the array, extracted from the base type of the array
- ```
  int B[][];
  int A[];

  /*  initialize A, B, etc. */
  x =  B[A[4]][A[3]];
  ```

07-77: **Expressions – Variables**

- Array Variables
  - Analyze the index, ensuring that it is of type int
  - Analyze the base variable. Ensure that the base variable is an Array Type
  ```

- Return the type of an element of the array, extracted from the base type of the array

- ```
  int B[][];
  int A[];

  /*  initialize A, B, etc. */
  x =  B[A[4]][B[A[3],A[4]]];
  ```

07-78: **Expressions – Variables**

- Instance Variables – `x.y`
  - Analyze the base of the variable (`x`), and make sure it is a class variable.
  - Look up `y` in the variable environment *for the class x*
  - Return the type associated with `y` in the variable environment for the class `x`.

07-79: **Instance Variables**

```
class foo {
 int x;
 boolean y;
}

int main() {
   foo x;
   int y;
   ...
   y = x.x;
   y = x.y;
}
```

07-80: **Instance Variables**

```
class foo {
 int x;
 boolean y[];
}

int main() {
   foo A[];
   int a;
   boolean b;
   ...
   w = A[3].x;
   b = A[3].y[4];
   b = A[3].y[A[3].x];
}
```

07-81: **Statements**

- If statements
  - Analyze the test, ensure that it is of type boolean
```

- Analyze the “if” statement
- Analyze the “else” statement (if there is one)

07-82: **Statements**

- Assignment statements
  - Analyze the left-hand side of the assignment statement
  - Analyze the right-hand side of the assignment statement
  - Make sure the types are the same
    - Can do this with a simple pointer comparison!

07-83: **Statements**

- Block statements
  - Begin new scope in variable environment
  - Recursively analyze all children
  - End current scope in variable environment

07-84: **Statements**

- Variable Declaration Statements
  - Look up type of variable
    - May involve adding types to type environment for arrays
  - Add variable to variable environment
  - If there is an initialization expression, make sure the type of the expression matches the type of the variable.

07-85: **Types in C**

- Three different kinds of types:
  - Builtins (int, boolean, void)
  - Array
    - Base type
  - Class
    - Name (and types) of all instance variables
    - – *environment*

07-86: **Types in C**

```
typedef struct type_ *type;

struct type_ {
  enum {integer_type, boolean_type, void_type,
        class_type, array_type} kind;
  union {
    type array;
    struct {
      environment instancevars;
    } class;
  } u;
};
```

07-87: **Built-in Types**

- *One* instance of each of the base types
- Each call to constructor to return the *same* instance:

```
type t1,t2;
t1 = IntegerType();
t2 = IntegerType();
if (t1 == t2) {
    ...
}
```

- if test should always be true

07-88: **Built-in Types**

```
type integerType_ = NULL;

type IntegerType() {
   if (integerType_ == NULL) {
       integerType_ = (type) malloc(sizeof(type_));
       integerType_-> kind = integer_type;
   }
   return integerType_;
}
```

07-89: **Array Types**

- int A[];
  - Create the type with ArrayType(IntegerType());
- int A[][];
  - Create the type with ArrayType(ArrayType(IntegerType()));

07-90: **Environments**

- File environment1.h

```
typedef struct environment_ *environment;
typedef struct envEntry_ *envEntry;

environment Environment();
void AddBuiltinTypes(environment env);
void AddBuiltinFunctions(environment env);

void beginScope(environment env);
void endScope(environment env);
void enter(environment env, char * key, envEntry entry);
envEntry find(environment env, char *key);
```

07-91: **Environments**

- File environment2.h

```
envEntry VarEntry(type typ);
envEntry FunctionEntry(type returntyp, typeList formals);
envEntry TypeEntry(type typ);
struct envEntry_ {
  enum {Var_Entry, Function_Entry,Type_Entry} kind;
  union {
    struct {
      type typ;
    } varEntry;
    struct {
      type returntyp;
      typeList formals;
    } functionEntry;
    struct {
      type typ;
    } typeEntry;
  } u;
};
```

07-92: **Class Types**

- Create the type for the class:

```
class foo {
   int x;
   boolean y;
}
```

- with the C code:

```
type t4;
environment instanceVars = Environment();
enter(instanceVars, "x",
      VariableEntry(IntegerType()));
enter(instanceVars, "y",
      VariableEntry(BooleanType()));
t4 = ClassType(instanceVars);
```

07-93: **Reporting Errors**

- Function Error:

```
char *name;
int intval;

Error(3, "Variable %s not defined", name);
Error(15, "Function %s requires %d input parmeters",
      name, intval);
```

07-94: **Reporting Errors**

- File errors.h

```
void Error(int linenum, char *message, ...);
int anyerrors();
int numerrors();
```

07-95: **Traversing the AST**

- Write a suite of functions to traverse the tree
  - Function for each type of tree node

- function for ASTprogram analyzes an ASTprogram
- function for ASTstatement analyzes an ASTstatement
- ... etc.

07-96: **Traversing the AST**

```
void analyzeProgram(ASTprogram program) {
  environment typeEnv;
  environment functionEnv;
  environment varEnv;

  typeEnv = Environment();
  functionEnv = Environment();
  varEnv = Environment();

  AddBuiltinTypes(typeEnv);
  AddBuiltinFunctions(functionEnv);

  analyzeClassList(typeEnv, functionEnv, varEnv, program->classes);
  analyzeFunctionDecList(typeEnv,functionEnv,varEnv, program->functiondecs);
}
```

07-97: **Analyzing Expressions**

- Functions that analyze expressions will return a type
  - Type of the expression that was analyzed
- The return value will be used to do typechecking “upstream”

07-98: **Analyzing Expressions**

```
void analyzeExpression(typeEnvironment typeEnv,
                       functionEnvironment functionEnv,
                       variableEnvironment varEnv, ASTexpression expression) {
  switch(expression->kind) {
  case ASTvariableExp:
    return analyzeVariable(varEnv,exp->u.var);
  case ASTintegerLiteralExp:
    return IntegerType();
  case ASTbooleanLiteral:
    return BooleanType();
  case ASToperatorExp:
    return analyzeOperatorExpression(typeEnv,functionEnv,varEnv, expression);
  case ASTcallExp:
    return analyzeCallExpression(typeEnv,functionEnv,varEnv, expression);
  }
}
```

07-99: **Analyzing Variables**

- Three different types of variables
  - (Base, Array, Class)
- Examine the “kind” field to determine which kind
- Call appropriate function

07-100: **Base Variables**

- To analyze a base variable
  - Look up the name of the base variable in the variable environment
  - Output an error if the variable is not defined
  - Return the type of the variable
    - (return *something* if the variable not declared. An integer is as good as anything.

07-101: **Base Variables**

```
type analyzeBaseVariable(variableEnvironment varEnv, ASTVariable var) {
    envEntry base;
    base = find(varEnv, var->u.baseVar.name);
    if (base == NULL) {
      Error(var->line,"Variable %s not defined",var->u.baseVar.name);
      return IntegerType();
    }
    return base->u.typeEntry.typ;
}
```

07-102: **Analyzing Statements**

- To analyze a statement
  - Recursively analyze the pieces of the statement
  - Check for any semantic errors in the statement
  - Don't need to return anything (yet!) – if the statement is correct, don't call the Error function!

07-103: **Analyzing Statements**

```
void analyzeStatement(environment typeEnv, environment functionEnv,
      environment varEnv, ASTstatement statement) {

  switch(statement->kind) {
  case AssignStm:
    analyzeAssignStm(typeEnv, functionEnv, varEnv, statement);
    break;
  case IfStm:
    analyzeIfStm(typeEnv, functionEnv, varEnv, statement);
    break;

 /* lots of other statements */

  case EmptyStm:
    break;
  default:
    Error(statement->line,"Bad Statement");
  }
}
```

07-104: **Analyzing If Statements**

- To analyze an if statement we:

07-105: **Analyzing If Statements**

- To analyze an if statement we:
  - Recursively analyze the "then" statement (and the "else statement, if it exists)
  - Analyze the test
  - Make sure the test is of type boolean

07-106: **Analyzing If Statements**

```
void analyzeIfStm(environment typeEnv, environment varEnv,
                  environment functionEnv, ASTstatement statement) {
   type testType;
   type test = analyzeExpression(typeEnv, functionEnv, varEnv,
                                 statement->u.ifStm.test);
   if (test != BooleanType()) {
      Error(statement->line,"If test must be a boolean");
   }
   analyzeStatement(typeEnv, functionEnv, varEnv, statement->u.ifStm.thenstm);
   analyzeStatement(typeEnv, functionEnv, varEnv, statement->u.ifStm.elsestm);
}
```

07-107: **Project Hints**

- This project will take *much* longer than the previous projects. You have 3 weeks (plus Spring Break) – start *NOW*.

- The project is pointer intensive. Spend some time to understand environments and type representations before you start.
- Start early. This project is longer than the previous three projects.
- Variable accesses can be tricky. Read the section in the class notes closely before you start coding variable analyzer.
- Start early. (Do you notice a theme here? I'm not kidding. Really.)