06-0: **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?

06-1: **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.

06-2: **JavaCC & CFGs**

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

06-3: **JavaCC & CFGs**

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

06-4: **Semantic Errors/Syntax Errors**

- Thus, we only build the Abstract Syntax Tree in JavaCC (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.

06-5: **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

06-6: **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

06-7: **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

06-8: **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

06-9: **Semantic Errors**

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

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

06-10: **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

06-11: **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;
```

06-12: **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 subclass value to a superclass variable

06-13: **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)

06-14: **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.

06-15: **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);
}
```

06-16: **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;
}
```

06-17: **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);
    }
}
```

06-18: **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`

06-19: **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 ...

06-20: **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.

06-21: **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 */
}
```

06-22: **Implementing Environments**

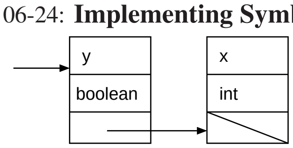
- Environments are implemented with Symbol Tables

- 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

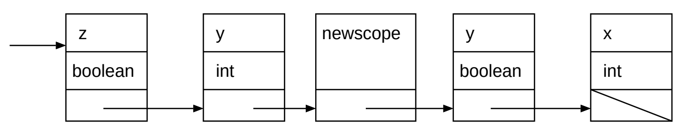
06-23: **Implementing Symbol Tables**

- 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

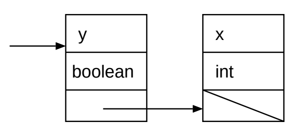
06-24: **Implementing Symbol Tables**




**a**




**b**




**c**

06-25: **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 = $\Theta$(# of key/value pairs)

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

06-26: **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;
}
```

06-27: **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`?

06-28: **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?

06-29: **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

06-30: **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)

06-31: **Built-In Types**

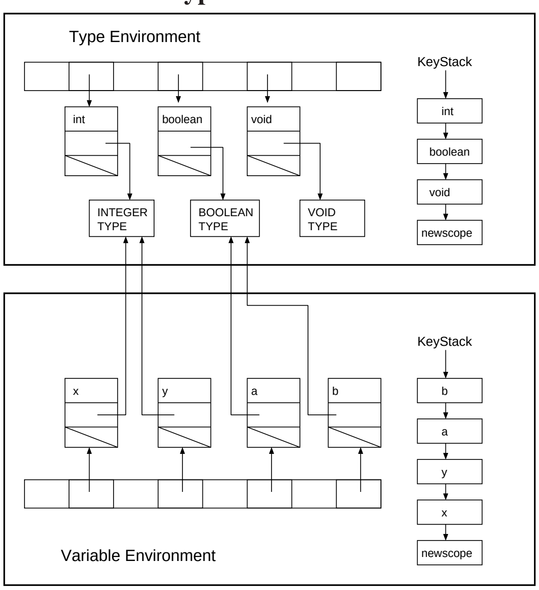
- No auxiliary information required for built-in types int and boolean (an int is and int is an int)
- All types will be represented by pointers to type objects
- We will only allocate *one* block of memory for *all* integer types, and *one* block of memory for *all* boolean types

06-32: **Built-In Types**

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

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

06-33: **Built-In Types**




06-34: **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?

06-35: **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?

06-36: **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!

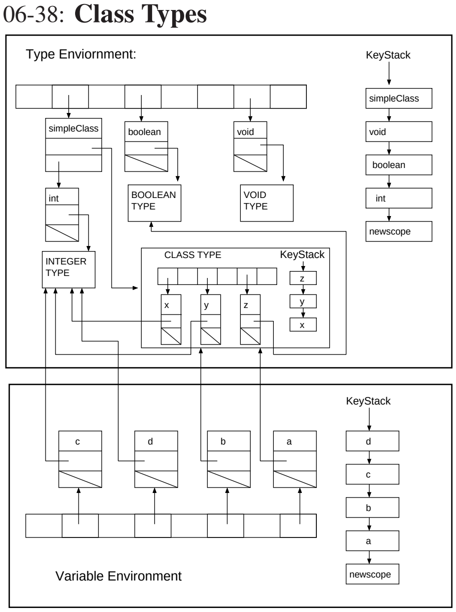
06-37: **Class Types**

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

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

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

06-38: **Class Types**




06-39: **Array Types**

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

06-40: **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

06-41: **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!)

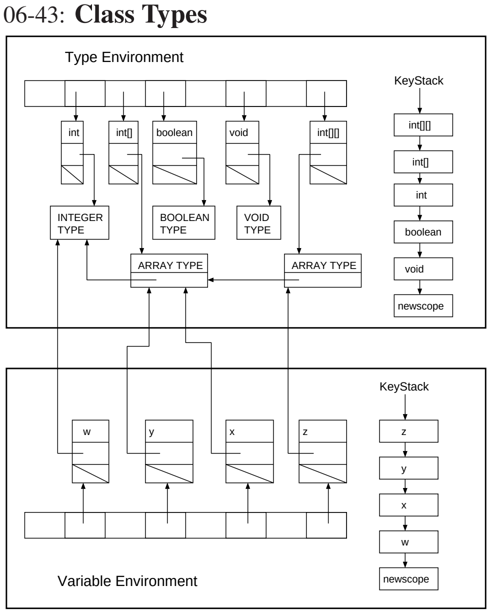
06-42: **Array Types**

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

  /* Body of main program */

}
```

06-43: **Class Types**




06-44: **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

06-45: **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`?

06-46: **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++;`

06-47: **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)

06-48: **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`

06-49: **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`

06-50: **Array Declarations**

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

06-51: **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[]`

06-52: **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

06-53: **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[][][]

06-54: **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[][][]

06-55: **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[]

06-56: **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[][]

06-57: **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)

06-58: **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]);
}
```

06-59: **Function Prototypes**

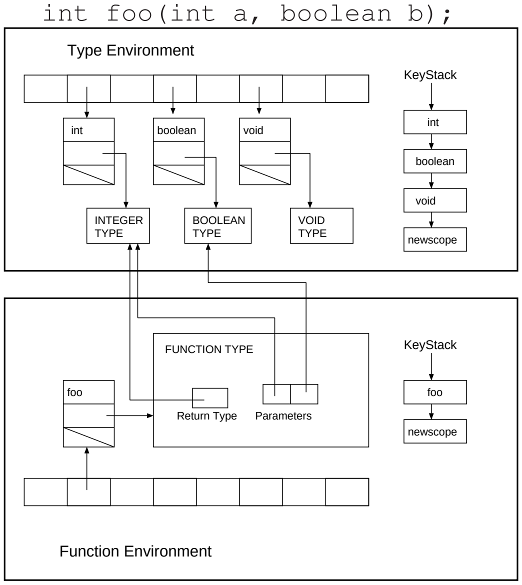
- `int foo(int a, boolean b);`
- Add a description of this function to the function environment

06-60: **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

06-61: **Function Prototypes**

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




06-62: **Function Prototypes**

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

06-63: **Class Definitions**

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

06-64: **Class Definitions**

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

- Create a new variable environment

06-65: **Class Definitions**

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

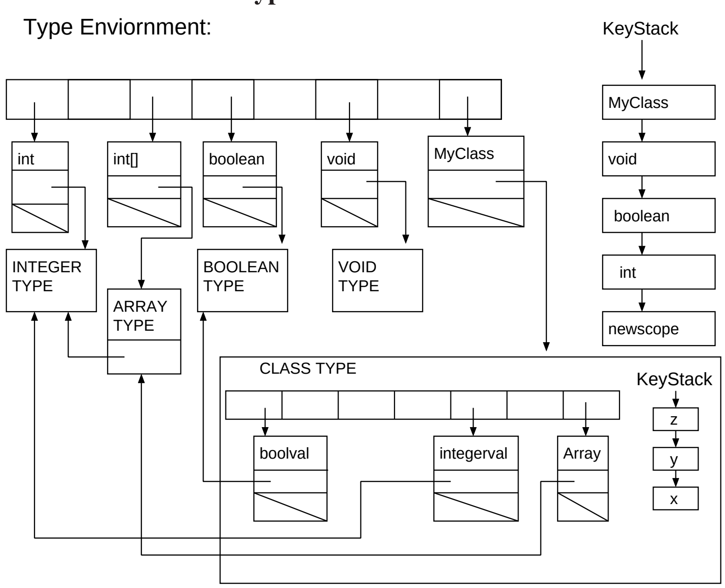
- Create a new variable environment
- Add integerval, Array, and boolval to this environment (possibly adding int[] to the type environment)

06-66: **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

06-67: **Function Prototypes**




06-68: **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

06-69: **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)

06-70: **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 boolean

06-71: **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

06-72: **Expressions**

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

06-73: **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

06-74: **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];
  ```

06-75: **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];
  ```

06-76: **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]];
  ```

06-77: **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]]];
  ```

06-78: **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`.

06-79: **Instance Variables**

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

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

Complete example: Create Type Env, Show AST, Cover Analysis 06-80: **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];
}
```

Complete example: Create Type Env, Show AST, Cover Analysis 06-81: **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)

06-82: **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!

06-83: **Statements**

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

06-84: **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.

06-85: **Types in Java**

- Each type will be represented by a class
- All types will be subclasses of the “type” class:

```
class Type {  }
```

06-86: **Built-in Types**

- Only one internal representation of each built-in type
  - All references to INTEGER type will be a pointer to the same block of memory
- How can we achieve this in Java?
  - *Singleton* software design pattern

06-87: **Singletons in Java**

- Use a singleton when you want only one instantiation of a class

- Every call to “new” creates a new instance
- – prohibit calls to “new”!
  - Make the constructor private
  - Obtain instances through a static method

06-88: **Singletons in Java**

```
public class IntegerType extends Type {

    private IntegerType() { }

    public static IntegerType instance() {
        if (instance_ == null) {
           instance_ = new IntegerType();
        }
        return instance_;
    }
    static private IntegerType instance_;
}
```

06-89: **Singletons in Java**

```
Type t1;
Type t2;
Type t3;

t1 = IntegerType.instance();
t2 = IntegerType.instance();
t3 = IntegerType.instance();
```

- t1, t2, and t3 all point to the same instance

06-90: **Structured Types in Java**

- Built-in types (integer, boolean, void) do not need any extra information)
  - An integer is an integer is an integer
- Structured types (Arrays, classes) need more information
  - An array of *what*
  - What fields does the class have

06-91: **Array Types in Java**

- Internal representation of array type needs to store the element type of the array

```
class ArrayType extends Type {

    public ArrayType(Type type) {
        type_ = type;
    }

    public Type type() {
        return type_;
    }

    public void settype(Type type) {
        type_ = type;
    }

    private Type type_;
}
```

06-92: **Array Types in Java**

- Creating the internal representation of an array of integers:

```
Type t1;
t1 = new ArrayType(IntegerType.instance());
```

- Creating the internal representation of a 2D array of integers:

```
Type t2;
t2 = new ArrayType(new ArrayType(IntegerType.instance()));
```

06-93: **Array Types in Java**

- Creating the internal representation of a 2D array of integers:

```
Type t2;
t2 = new ArrayType(new ArrayType(IntegerType.instance()));
```

- Note that you should not use this exact code in your semantic analyzer
  - Create a 1D array of integers, add this to the type environment
  - Create an array of 1D array of integers, using the previously created type

06-94: **Environments**

- TypeEnvironment.java
- TypeEntry.java
- VariableEnvironment.java
- VariableEntry.java
- FunctionEnvironment.java
- FunctionEntry.Java

06-95: **Class Types**

- Create the type for the class:

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

- with the Java code:

```
Type t4;
VariableEnviornment instanceVars = new VariableEnviornment();

instancevars.insert("x", new VariableEntry(IntegerType.instance()));
instancevars.insert("y", new VariableEntry(BooleanType.instance()));

t4 = new ClassType(instanceVars);
```

06-96: **Reporting Errors**

- Class CompError:

```
public class CompError {

    private static int numberOfErrors = 0;

    public static void message(int linenum, String errstm) {
        numberOfErrors++;
        System.out.println("TstError in line " + linenum + ": "+ errstm);
    }

    public static boolean anyErrors() {
        return numberOfErrors > 0;
    }

    public static int numberOfErrors() {
        return numberOfErrors;
    }
}
```

06-97: **Reporting Errors**

- Using CompError
- Trying to add booleans on line 12 ...

```
CompError.message(12, "Arguments to + must be integers");
```

06-98: **Traversing the AST**

- Write a Visitor to do Semantic Analysis
  - Method for each type of AST node
  - VisitProgram analyzes ASTprogram
  - VisitIfStatement analyzes an ASTstatement
  - ... etc.

06-99: **Setting up the Visitor**

```
public class SemanticAnalyzer implements ASTVisitor {

    private VariableEnvironment variableEnv;
    private FunctionEnvironment functionEnv;
    private TypeEnvironment typeEnv;
    /* May need to add some more ... */


    public SemanticAnalyzer() {
        variableEnv = new VariableEnvironment();
        functionEnv = new FunctionEnvironment();
        functionEnv.addBuiltinFunctions();
        typeEnv = new TypeEnvironment();
    }


}
```

06-100: **Traversing the AST**

```
    public Object VisitProgram(ASTProgram program) {
        program.classes().Accept(this);
        program.functiondefinitions().Accept(this);
        return null;
    }
```

06-101: **Analyzing Expressions**

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

06-102: **Analyzing Expressions**

```
    public Object VisitIntegerLiteral(ASTIntegerLiteral literal) {
        return IntegerType.instance();
    }
```

06-103: **Analyzing Variables**

- Three different types of variables
    - (Base, Array, Class)

```
ASTVariable a, b, c;
Type t;
a = new ASTBaseVariable("x");
b = new ASTArrayVariable(a, new ASTIntegerLiteral(3));
c = new ASTClassVariable(b, "y");

t = (Type) a.Accept(semanticAnalyzer);
t = (Type) b.Accept(semanticAnalyzer);
t = (Type) c.Accept(semanticAnalyzer);
```

06-104: **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.

06-105: **Base Variables**

```
    public Object VisitBaseVariable(ASTBaseVariable base) {
        VariableEntry baseEntry = variableEnv.find(base.name());
        if (basEntry == null) {
            CompError.message(base.line(),"Variable " + base.name()
                              + " is not defined in this scope");
            return IntegerType.instance();
        }  else {
            return baseEntry.type();
        }
    }
```

06-106: **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!

06-107: **Analyzing If Statements**

- To analyze an if statement we:

06-108: **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

06-109: **Analyzing If Statements**

```
public Object VisitIfStatement(ASTIfStatement ifsmt) {

    Type test = (Type) ifsmt.test().Accept(this);

    if (test != BooleanType.instance()) {
        CompError.message(ifsmt.line(),"If test must be a boolean");
    }

    ifsmt.thenstatement().Accept(this);

    if (ifsmt.elsestatement() != null) {
        ifsmt.elsestatement().Accept(this);
    }
    return null;
}
```

06-110: **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.)