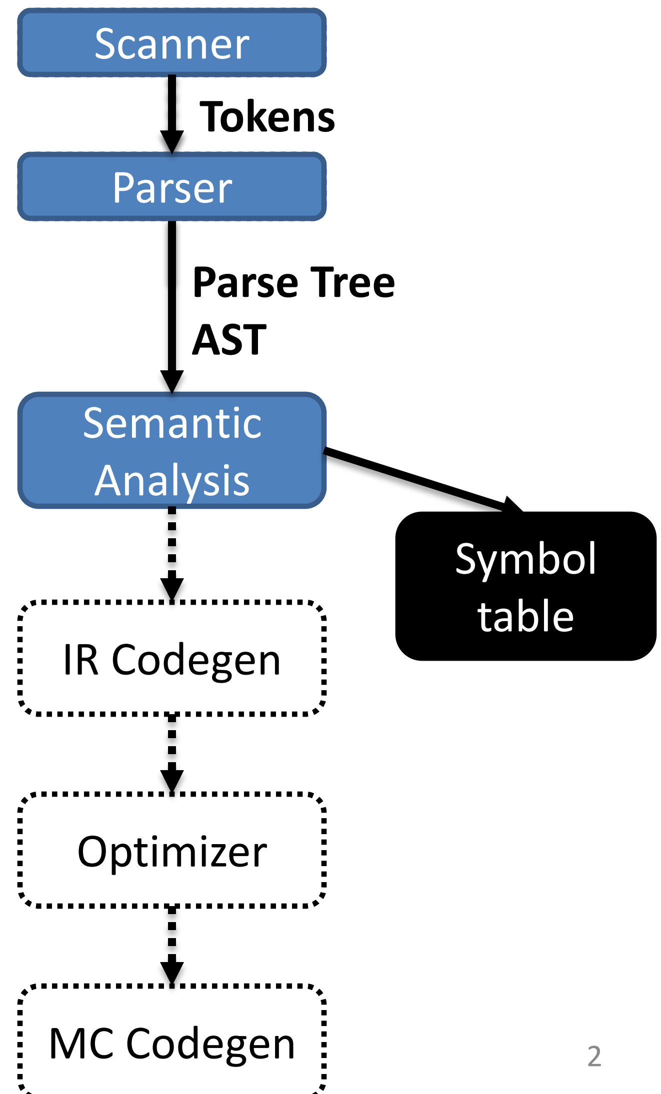
Introduction to Compiler Design

Lesson 12:

Types - Type Checking

Roadmap

- Back from LR Parsing Detour
- Name analysis
  - Static scoping
  - Tree traversal, with symbol-table operations (new, insert, lookup)
- Today
  - Type checking



Lecture Outline

- Type Safari
  - Type-system concepts
  - Type-system vocabulary
- C--
  - Type rules
  - How to apply type rules
- Data representation
  - Moving towards actual code generation
  - Brief comments about types in memory

Say, What *is* a Type?

- Short for “data type”
  - Classification identifying kinds of data
  - A set of possible values that a variable can possess
  - Operations that can be done on member values
  - A representation (perhaps in memory)

Type Intuition

The language does not allow you to do the following:

```
int a = 0;
int * pointer  = &a;
float fraction = 1.2;
a = pointer + fraction;
```

… or does it?

Components of a Type System

- Primitive types + operators for building more complex types
  - int, bool, void, class, function, struct
- Means of determining if types are compatible
  - Can values with different types be combined?
  - If so, how?
- Rules for inferring the type of an expression

Type Rules

- For every operator (including assignment)
  - What types can the operand have?
  - What type is the result?

- Examples

```
double a;
int b;
a = b;
b = a;
```

`a = b;` *Legal in Java, C++*

`b = a;` *Legal in C++, **not** in Java*

Type Coercion

- Implicit cast from one data type to another
  – Float to int

- Narrow form: type promotion
  - When the destination type can represent the source type
  - float to double

Types of Typing I: **When** do we check?

- Static typing
  - Type checks are made before execution of the program (compile-time)
- Dynamic typing
  - Type checks are made during execution (runtime)
- Combination of the two
  - Java (downcasting vs cross-casting)

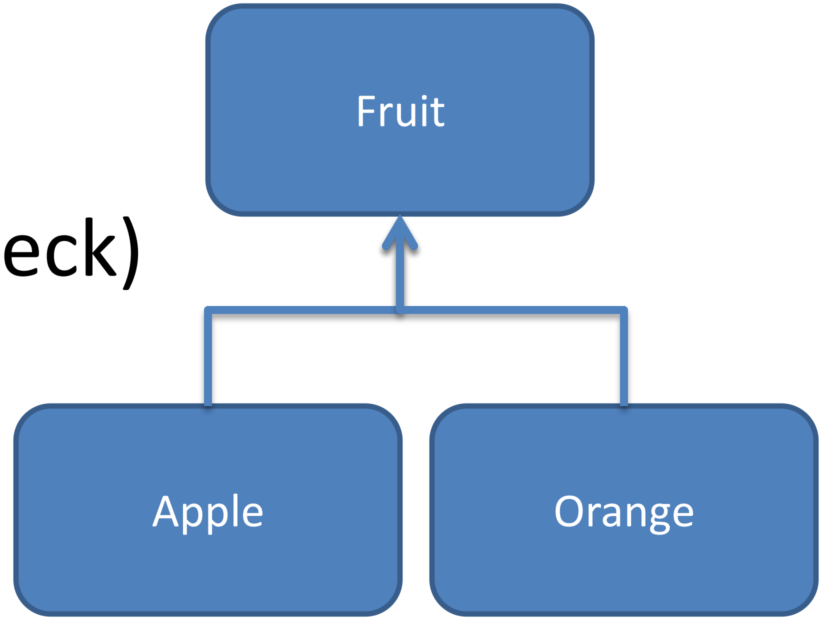
Example: Casting

- Cross-casting (static check)

```
Apple a = new Apple();
Orange o = (Orange)a;
```

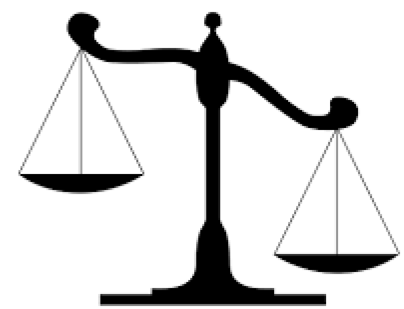
- Downcasting (dynamic check)

```
Fruit f = new Apple();
if ( … ) {
   f = new Orange();
}
Apple two = (Apple)f;
```



Static vs. Dynamic Tradeoffs

- Statically typed
  - Compile-time optimization
  - Compile-time error checking
- Dynamically typed
  - Avoid dealing with errors that don't matter
  - Some added flexibility
  - Failures can happen at runtime
    - . . . in a fielded product
    - Test suites rarely exercise all code under all different runtime situations



Types of Typing II: **What** do we check?

- Strong vs. weak typing
  - Degree to which type checks are performed
  - Degree to which type errors are allowed to happen at runtime
  - Continuum without precise definitions

Strong vs. Weak

- No universal definitions but …
  - Statically typed is often considered stronger (fewer type errors possible)
  - The more implicit casts allowed the weaker the type system
  - The fewer checks performed at runtime the weaker the type system

Strong vs. Weak Example

- C (weaker)

```
union either{
     int i;
     float f;
} u;
u.i = 12;
float val = u.f;
```

StandardML (stronger)

```
real(2) + 2.0
```

Fancier types

- **Dependent types** can be used to reason about computation
- Reverse takes a list of int of length n and returns a list of int of length n
- **Resource types** can be used to reason about program complexity
- The program only type-checks if it runs in poly time
- Very hard to reason about, but strong guarantees

Type Safety

- Type safety
  - All successful operations must be allowed by the type system
  - Java was explicitly designed to be type safe
    - If you have a variable with some type, it is guaranteed to be of that type
  - C is not
  - C++ is a little better

Type-Safety Violations

- C
  - Format specifier

```
printf("%s", 1);
```

  - Memory safety

```
struct big{
    int a[100000];
};
struct big * b = malloc(1);
```

C++

  - Unchecked casts

```
class T1{ char a};
class T2{ int b; };
int main{
    T1 * myT1 = new T1();
    T2 * myT2 = new T2();
    myT1 = (T1*)myT2;
}
```

C-- type system

- Primitive types
  – int, bool, string, void
- Type constructors
  – struct
- Coercion
  – bool cannot be used as an int in our language (nor vice-versa)

C-- Type Errors I

- Arithmetic operators must have **int** operands
- Equality operators **==** and **!=**
  - Operands must have same type
  - Can't be applied to
    - Functions (but CAN be applied to function results)
    - struct name
    - struct variables
- Other relational operators must have **int** operands
- Logical operators must have **bool** operands

C-- Type Errors II

- Assignment operator
  - Must have operands of the same type
  - Can't be applied to
    - Functions (but CAN be applied to function results)
    - struct name
    - struct variables
- For cin >> x;
  - x cannot be function, struct name, struct variable
- For cout << x;
  - x cannot be function, struct name, struct variable
- Condition of if, while must be bool

C-- Type Errors III

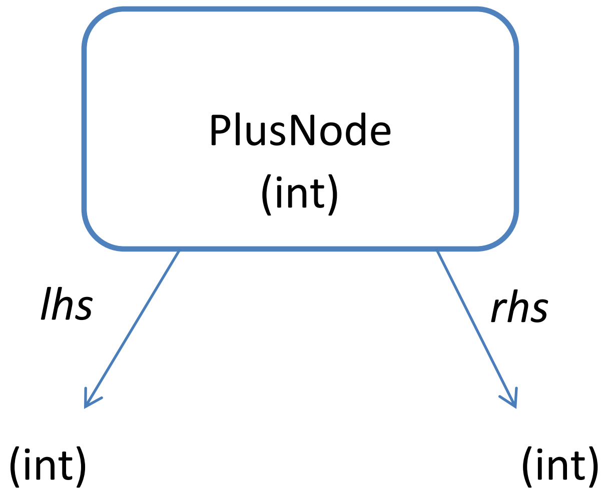
- Invoking (a.k.a. calling) something that is not a function
- Invoking a function with
  - Wrong number of arguments
  - Wrong types of arguments
    - Also will not allow structs or functions as arguments
- Returning a value from a void function
- Not returning a value in a non-void function function
- Returning wrong type of value in a non-void function

Type Checking

- Structurally similar to Name Analysis
  - Sometimes intermingled with Name Analysis and done as part of attribute “decoration”
  - Don’t do that . . .
- Add a typeCheck method to AST nodes
  - Recursively walk the AST checking types of sub-expressions
  - Let’s look at a couple of examples

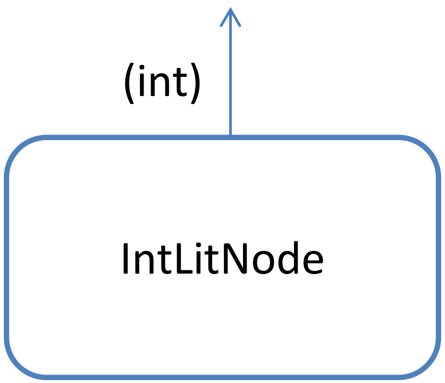
Type Checking: Binary Operator

- Get the type of the LHS
- Get the type of the RHS
- Check that the types are compatible for the operator
- Set the *kind* of the node be a value
- Set the *type* of the node to be the type of the operation's result



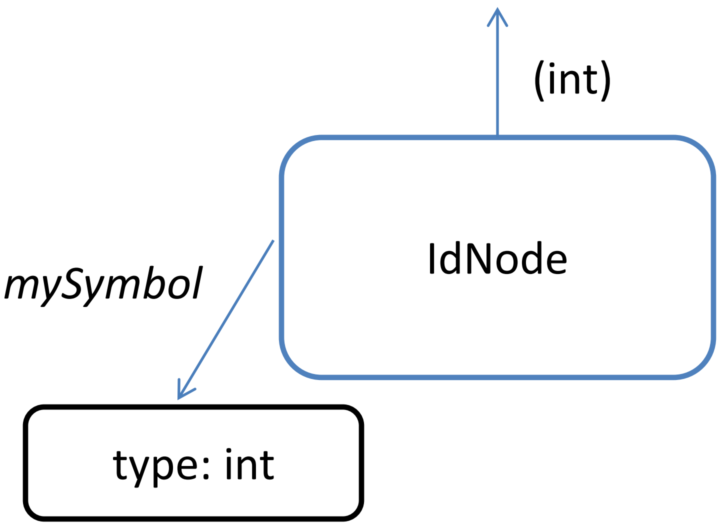
Type “Checking”: Literal

- Cannot be wrong
  - Just pass the type of the literal up the tree



Type Checking: IdNode

- Look up the type of the declaration
  - There should be a symbol “linked” to the node
- Pass symbol type up the tree



Type Checking: Others

- Other node types follow these same principles
  - A call to function f
    - Get the type of each actual parameter of f
    - Match against the type of the corresponding formal parameter of f
      - use the information in the symbol-table entry for f
    - Pass f's return type up the tree
  - Statement s
    - Type check the constituents of s
    - Nothing to pass up the tree: A statement does not produce a value, and hence s has no "return type"

Type Checking: Errors

- Goals
  - Report multiple errors
  - Don't report the same error multiple times (i.e., avoid error cascading)
- We'd like the compiler to report as many *distinct* errors as possible
  - It mustn't give up at the first error
  - Internally, it needs to know if an error has already been reported
- Introduce an internal **error** type
  - When type incompatibility is discovered
    - Report the error
    - Pass **error** up the tree
  - When a type check gets **error** as an operand
    - Don't (re)report an error
    - Again, pass **error** up the tree

Error Example

```
int a;
bool b;
a = true + 1 + 2 + b;
b = 2;
```