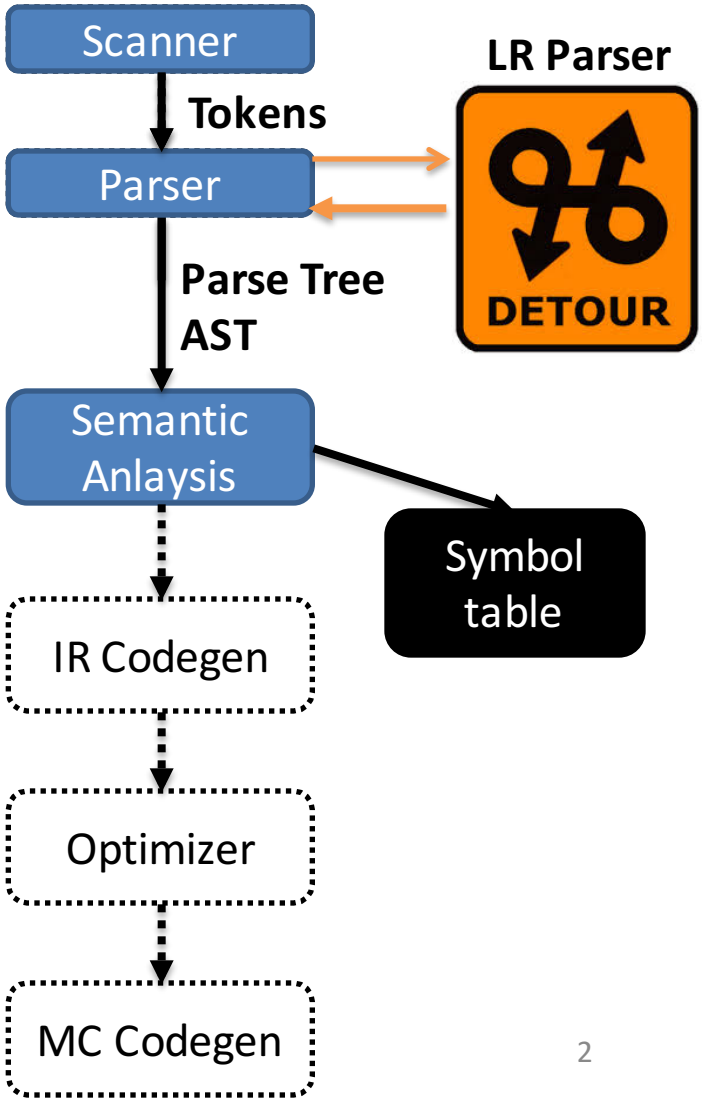
CS536

Types

Roadmap

- Back from our LR Parsing Detour
- Name analysis
  - Static v dynamic
  - Scope
- Today
  - Type checking



Lecture Outline

- Type Safari
  - Type system concepts
  - Type system vocab
- YES
  - 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 which a variable can possess
  - Operations that can be done on member values
  - A representation (perhaps in memory)

Type Intuition

You can't do this:

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

… or can you?

Components of a type system

- Primitive types + means of building aggregate types
  - int, bool, void, class, function, struct
- Means of determining if types are compatible
  - Can disparate types be combined? How?
- Rules for inferring 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;
```

Legal in Java, C++

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 v cross-casting)

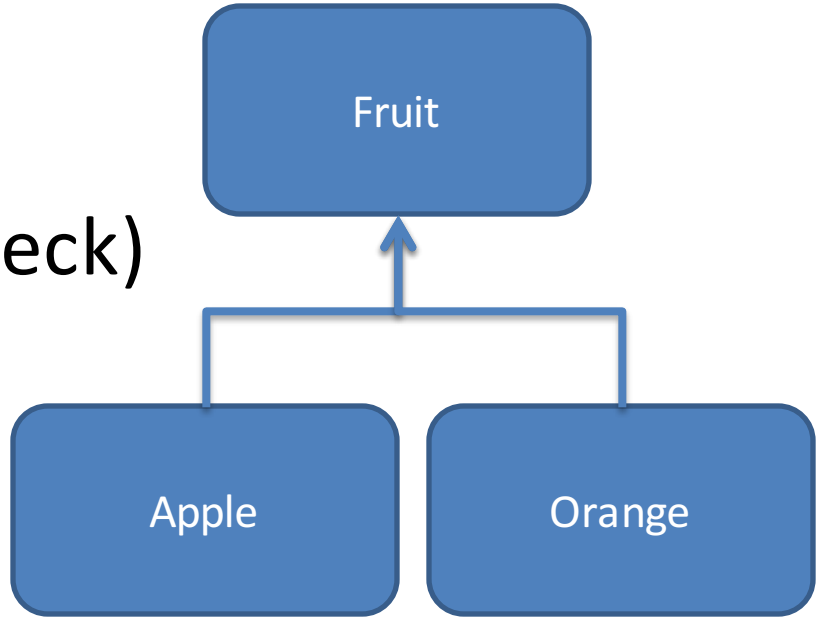
Example: Casting

- 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 v Dynamic Tradeoffs

- Statically typed
  - Compile-time optimization
  - Compile-time error checking
- Dynamically typed
  - Avoid dealing with errors that don't matter
  - Some added flexibility

Duck Typing

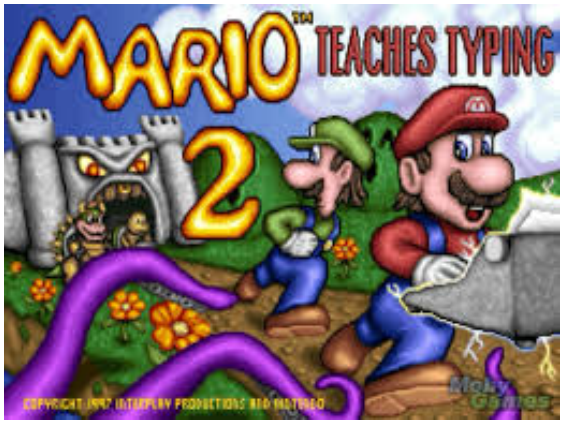
- Type is defined by the methods and properties

```
class bird:
    def quack(): print("quack!")
class mechaBird:
    def quack(): print("101011…")
```

- Duck Punching
  - Runtime modifications to allow duck typing

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 v 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

Strong v Weak Example

- C (weaker)

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

- SML (stronger)

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

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;
}
```

Type System of YES

YES

YES 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)

YES 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

YES 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 boolean

YES Type Errors III

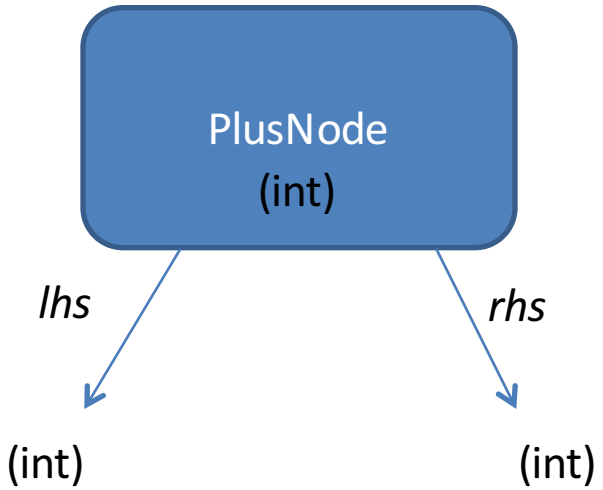
- Invoking (aka calling) something that's not a function
- Invoking a function with
  - Wrong number of args
  - Wrong types of args
    - Also will not allow struct or functions as args
- Returning a value from a void function
- Not returning a value in a non-void function function
- Returning wrong type of value in a non-void function

Type Checking

- Structurally similar to nameAnalysis
  - Historically, intermingled with nameAnalysis and done as part of attribute “decoration”
- Add a typeCheck method to AST nodes
  - Recursively walk the AST checking subtypes
  - Let’s look at a couple of examples

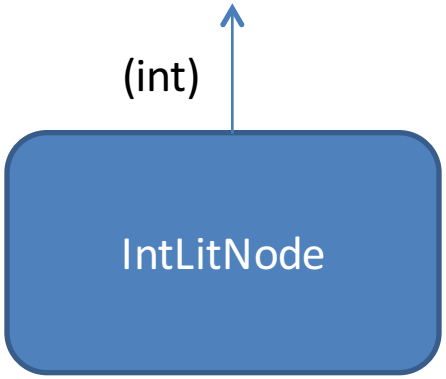
Type Checking: Binary Operator

- 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



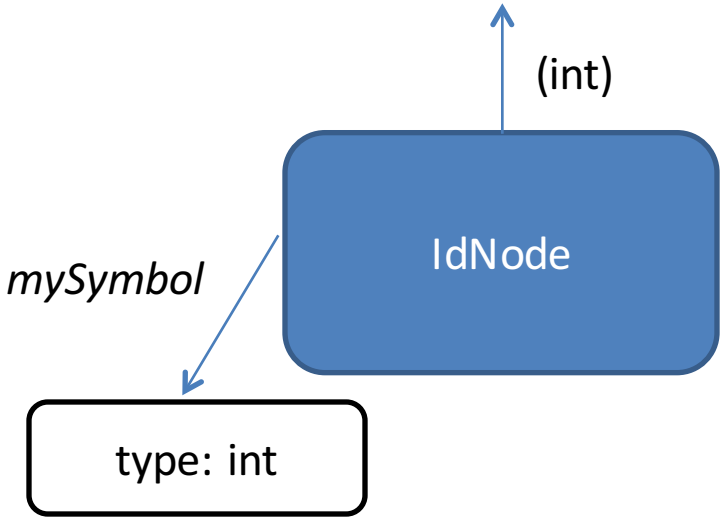
Type “Checking”: Literal

- 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: IdNode

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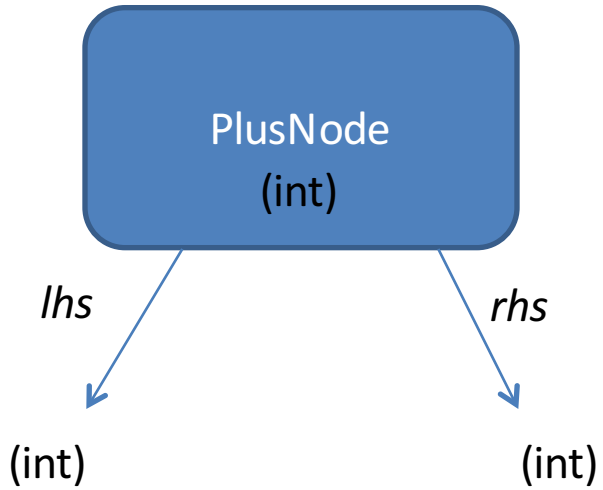


Type Checking: Others

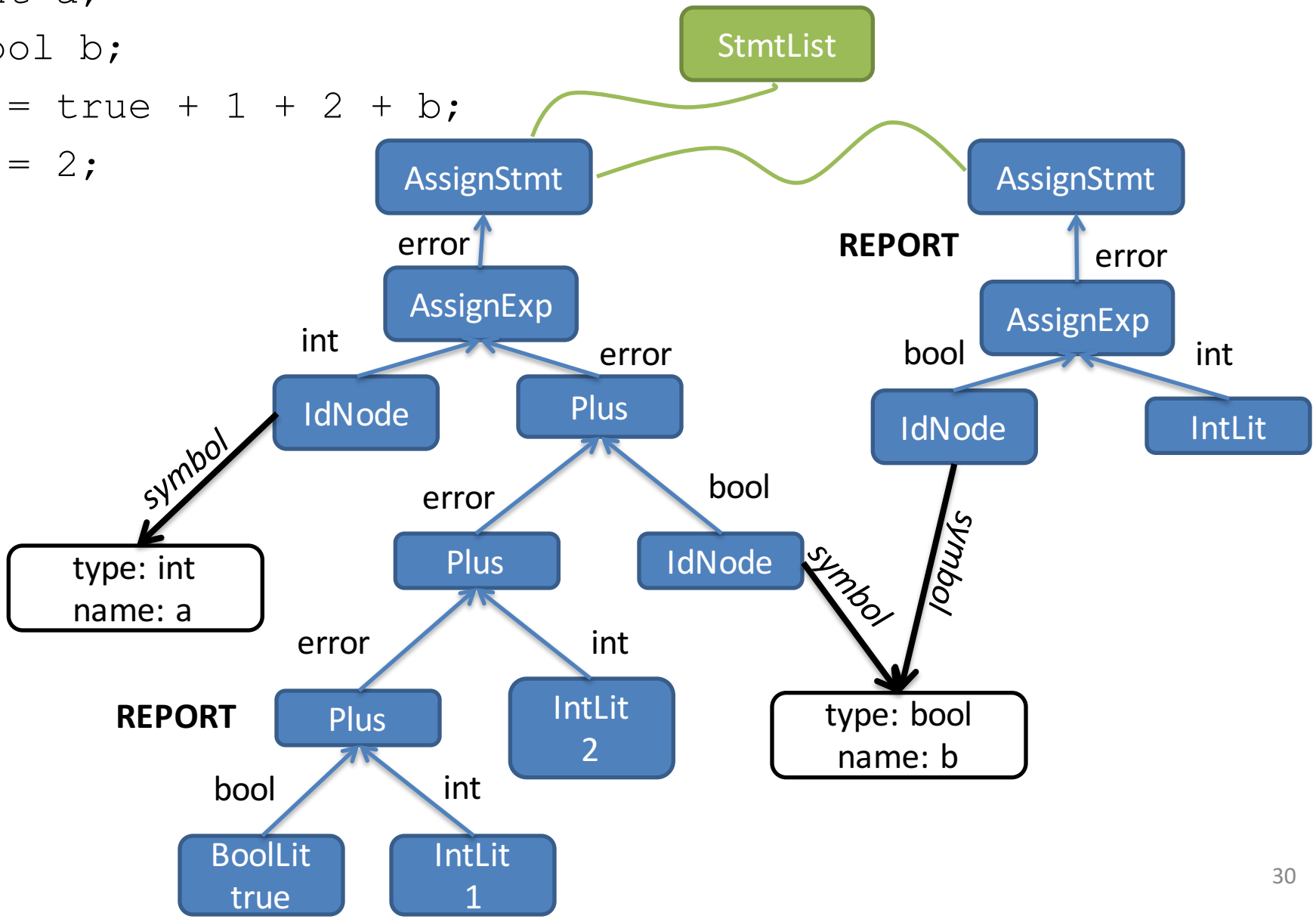
- Other node types follow these same principles
  - Function calls
    - Get type of each actual argument
      - Match against the formal argument (check symbol)
    - Send the return type up the tree
  - Statement
    - No type

Type Checking: Errors

- We'd like all *distinct* errors at the same time
  - Don't give up at the first error
  - Don't report the same error multiple times
- Introduce an internal **error** type
  - When type incompatibility is discovered
    - Report the error
    - Pass **error** up the tree
  - When you get 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;
```



Looking Towards Next Lecture

- Starting Tuesday
  - Look at data (and therefore types) is represented in the machine
  - Start very abstract, won't talk about an actual architecture for awhile
  - Assembly has no intrinsic notion of types. We'll have to add code for type checking ourselves