Types

Roadmap

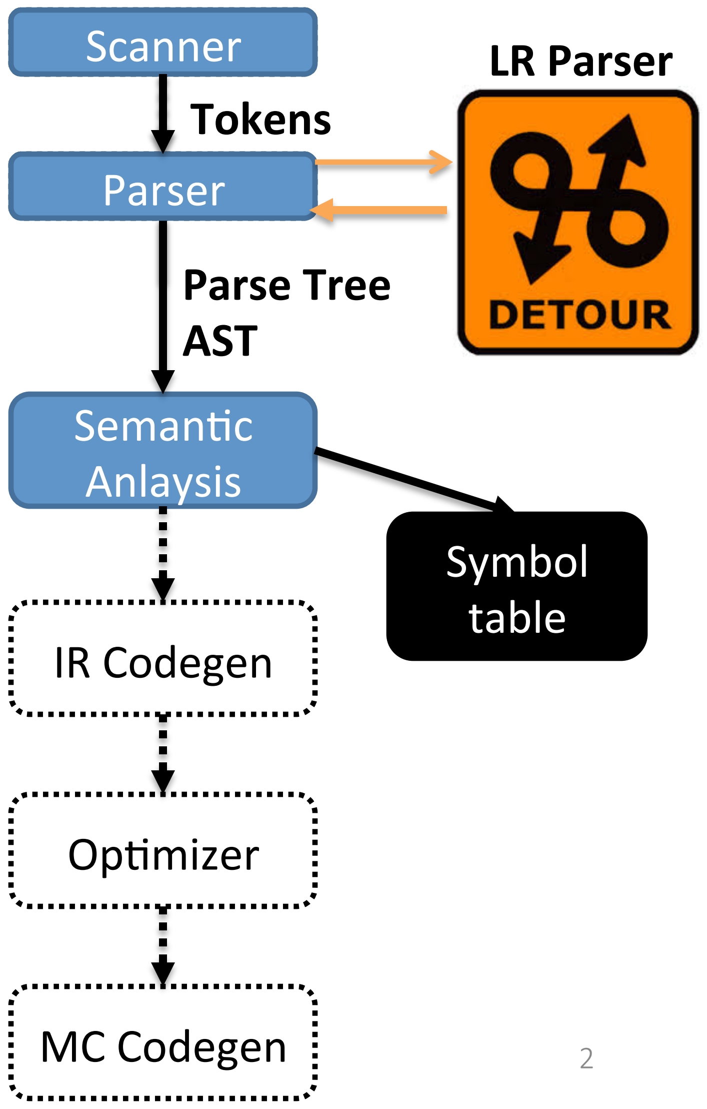
Back from LR Parsing Detour

Name analysis

- Static vs dynamic
- Scope

Today

- Type checking



Lecture Outline

Type Safari
- Type system concepts
- Type system vocabulary

For our language
- 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 + operators for building more complex 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;
```
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)

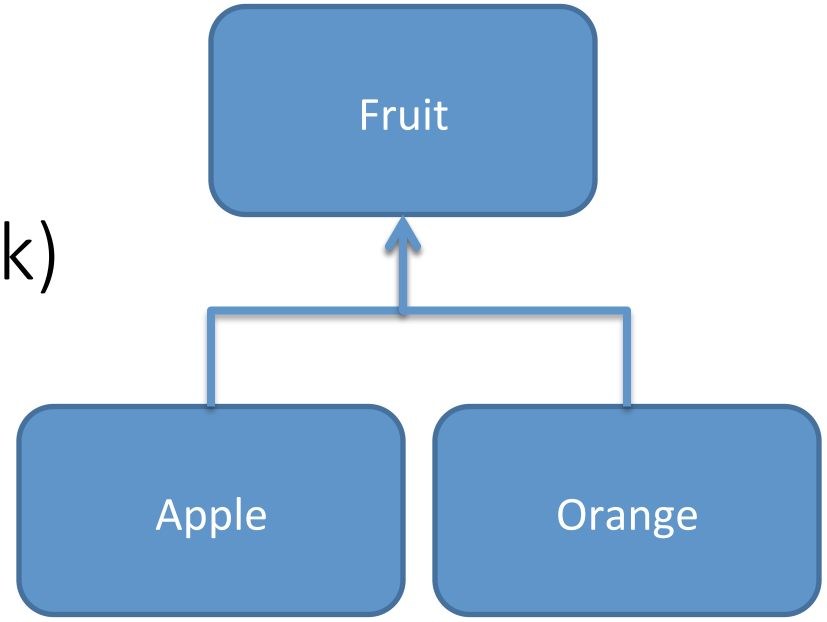
Example: Casting

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
- Runtime failuires

Duck Typing

Type is defined by the methods and properties

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

How do we check?

– Runtime modifications to allow duck typing (Duck punching)

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;
```

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 length n

Resource types can be used to reason about program complexity

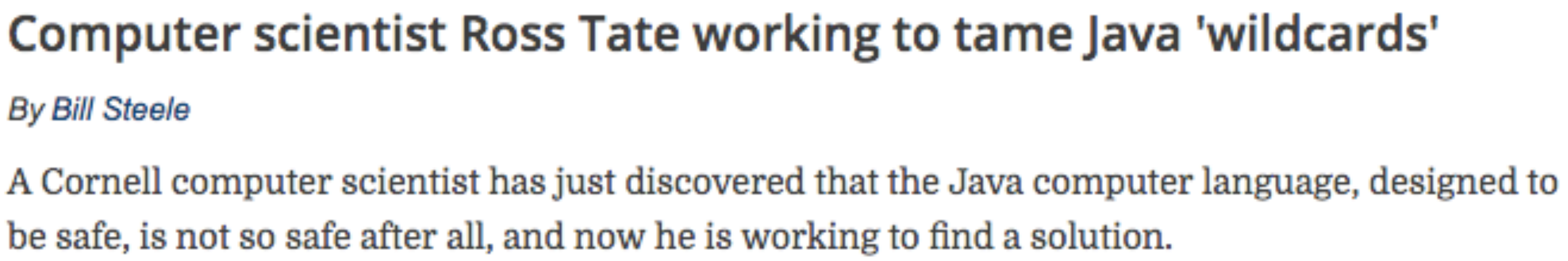
- The program only type-checks if it runs in poly time

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



Computer scientist Ross Tate working to tame Java 'wildcards'

By Bill Steele

A Cornell computer scientist has just discovered that the Java computer language, designed to be safe, is not so safe after all, and now he is working to find a solution.

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 for Our Language

Our 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)

Our 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

Our 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

Our 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

Returning wrong type of value in a non-void function

Type Checking

Structurally similar to nameAnalysis

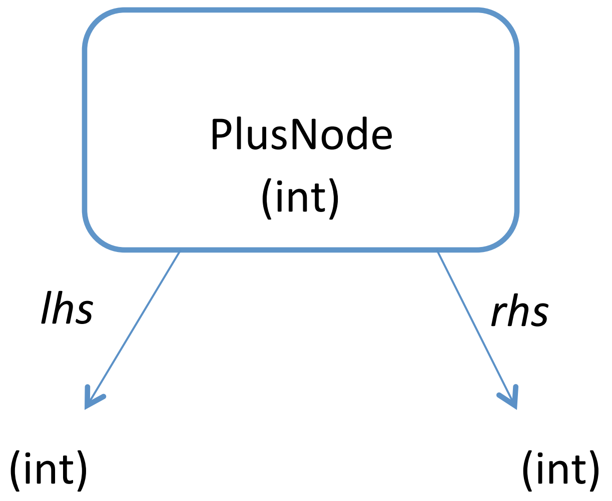
- Historically, intermingled with nameAnalysis and done as part of attribute “decoration”

Add a typeCheck method to AST nodes

- Recursively walk the AST checking types of sub-expressions
- Let’s look at a couple of examples

Type Checking: Binary Operator

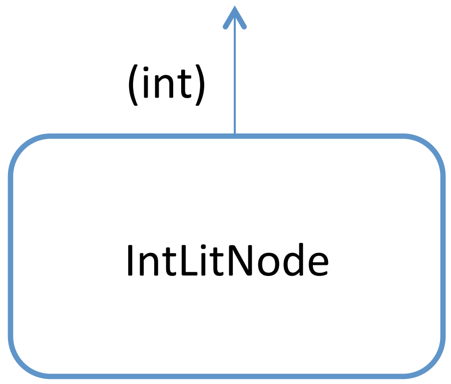
- Get the type of the LHS
- Get the type of the RHS
- Check that the types are compatible for the operator
- Set the *kind* of the node be a value
- Set the *type* of the node to be the type of the operation's result



Type "Checking": Literal

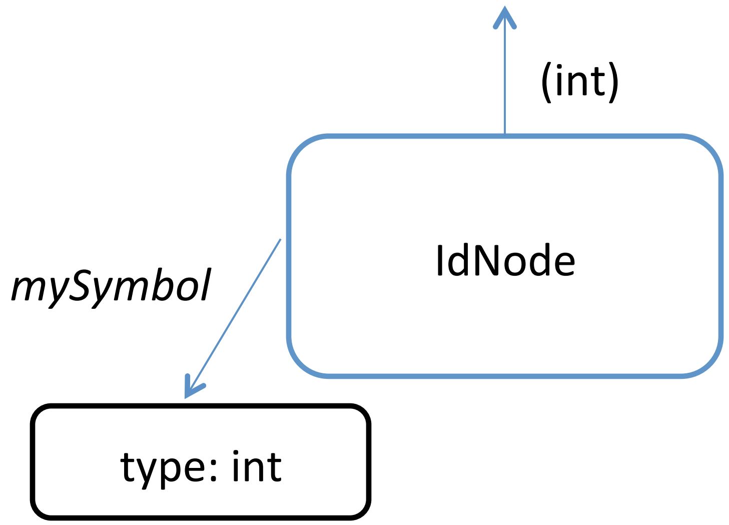
Cannot be wrong

- 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

- 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

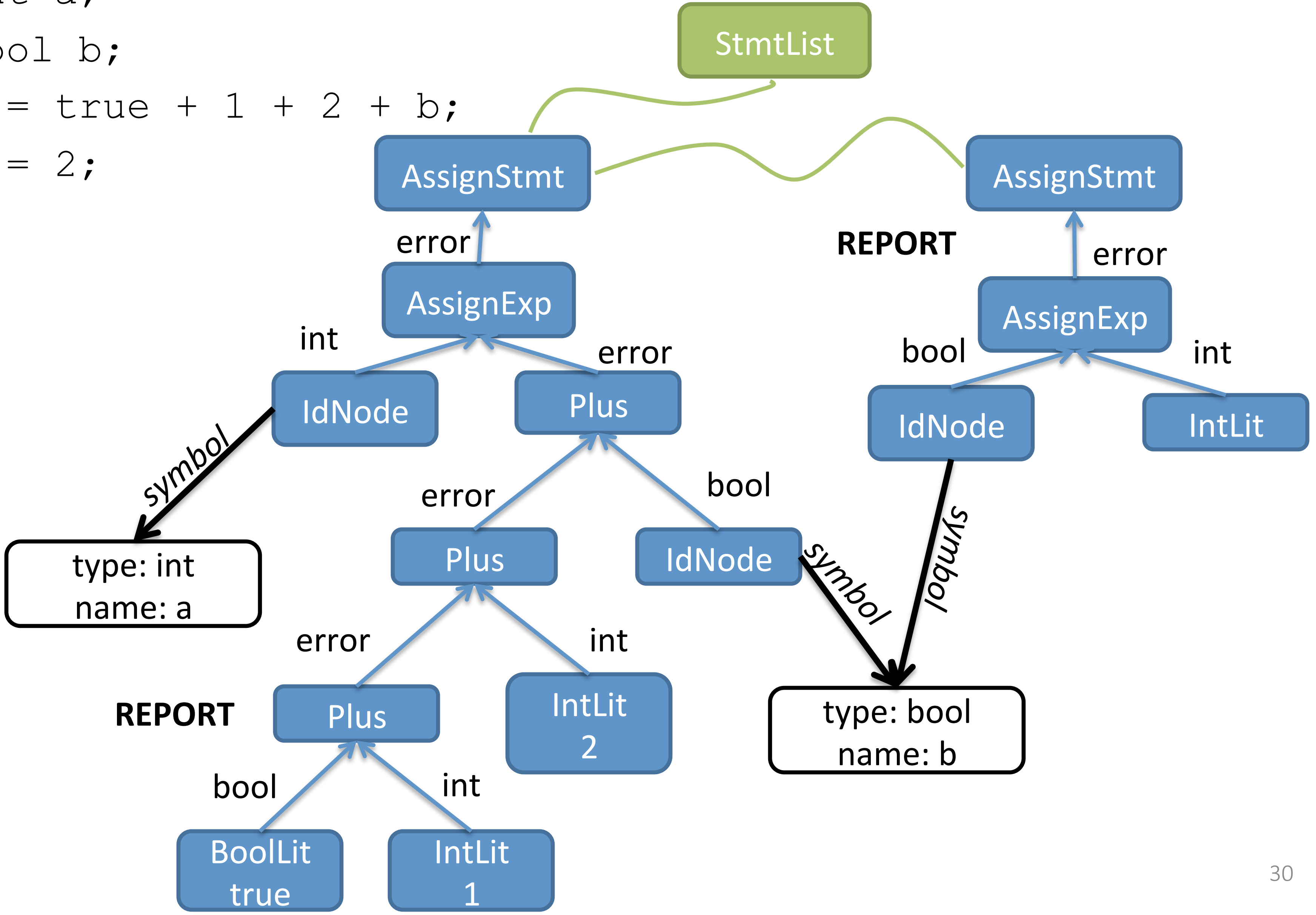
Introduce an internal **error** type

- 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

```
A problem has been detected and windows has been shut down to prevent damage
to your computer.

DRIVER_IRQL_NOT_LESS_OR_EQUAL

If this is the first time you've seen this Stop error screen,
restart your computer. If this screen appears again, follow
these steps:

Check to make sure any new hardware or software is properly installed.
If this is a new installation, ask your hardware or software manufacturer
for any windows updates you might need.

If problems continue, disable or remove any newly installed hardware
or software. Disable BIOS memory options such as caching or shadowing.
If you need to use Safe Mode to remove or disable components, restart
your computer, press F8 to select Advanced Startup Options, and then
select Safe Mode.

Technical information:

*** STOP: 0x000000D1 (0x0000000C,0x00000002,0x00000000,0xF86B5A89)


***       gv3.sys - Address F86B5A89 base at F86B5000, DateStamp 3dd991eb

Beginning dump of physical memory
Physical memory dump complete.
Contact your system administrator or technical support group for further
assistance.
```

Error Example

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



Looking Towards Next Lecture

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