Ch 12 Semantic Analysis II

(Type Checking)

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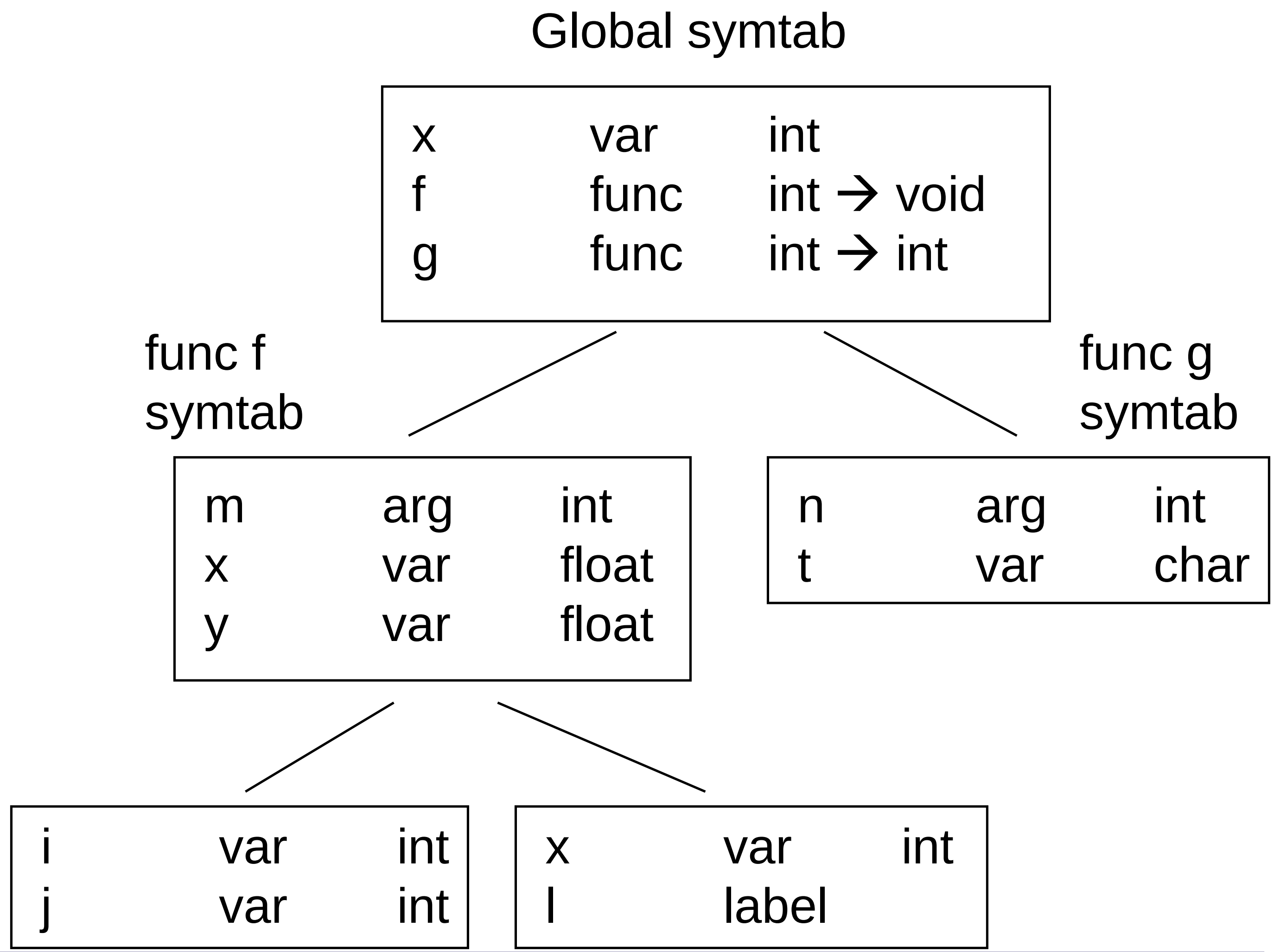
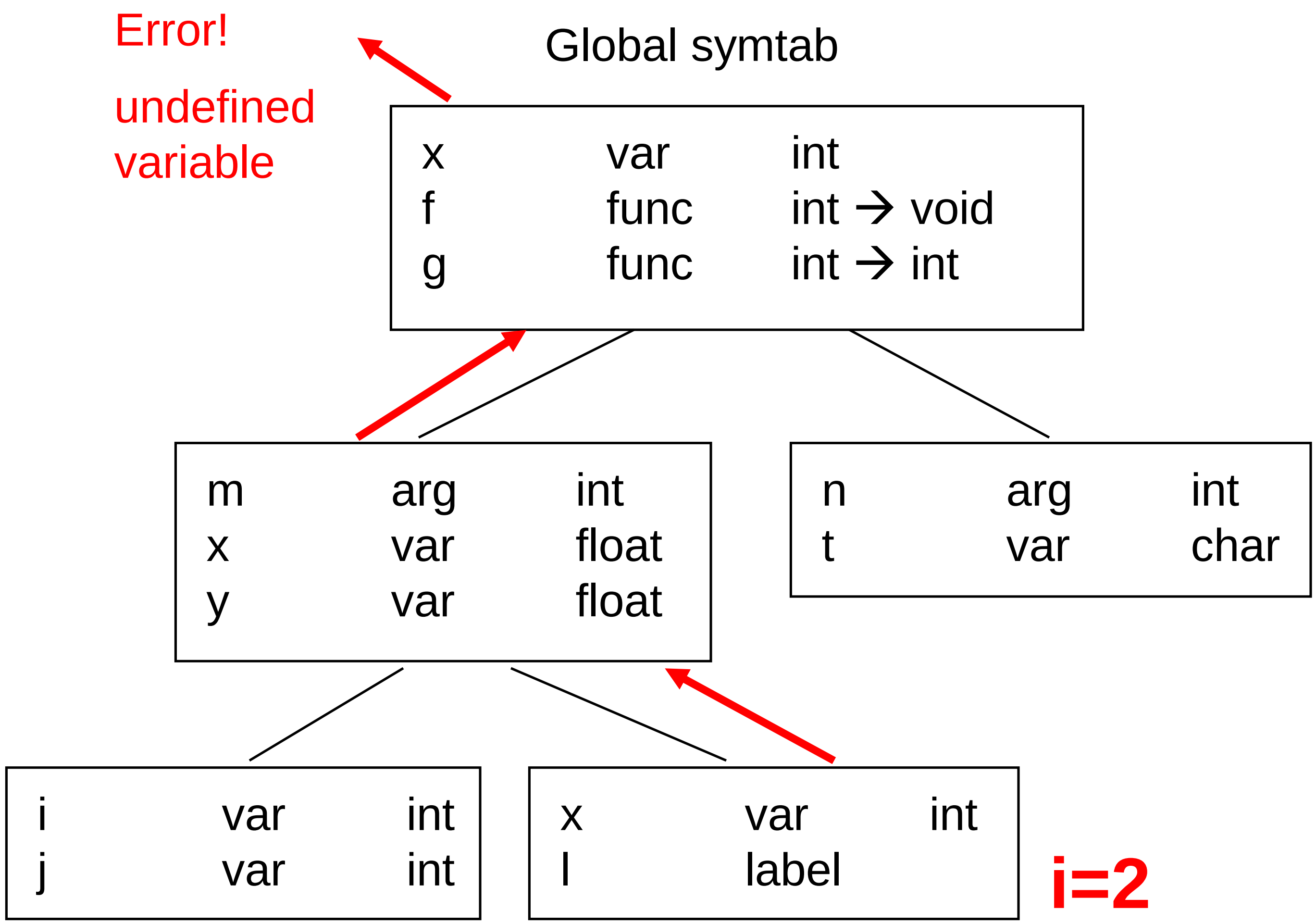
From Last Time – Hierarchical Symbol Table

```
int x;

void f(int m) {
    float x, y;
    ...
    {int i, j; ....; }
    {int x; l: ...; }
}

int g(int n) {
    char t;
    ... ;
}
```



Catching Semantic Errors

```
int x;
void f(int m) {
    float x, y;
    ...
    {int i, j; x=1; }
    {int x; l: i=2; }
}

int g(int n) {
    char t;
    x=3;
}
```



Symbol Table Operations

- **Two operations:**
  - To build symbol tables, we need to insert new identifiers in the table
  - In the subsequent stages of the compiler we need to access the information from the table: use lookup function
- **Cannot build symbol tables during lexical analysis**
  - Hierarchy of scopes encoded in syntax
- **Build the symbol tables:**
  - While parsing, using the semantic actions
  - After the AST is constructed

Forward References

- Use of an identifier within the scope of its declaration, but before it is declared
- Any compiler phase that uses the information from the symbol table must be performed after the table is constructed
- Cannot type-check and build symbol table at the same time
- Example

```
class A {
    int m() {return n(); }
    int n() {return 1; }
}
```

Back to Type Checking

- **What are types?**
  - They describe the values computed during the execution of the program
  - Essentially they are a predicate on values
    - E.g., “int x” in C means $-2^{31} <= x < 2^{31}$
- **Type Errors: improper or inconsistent operations during program execution**
- **Type-safety: absence of type errors**

How to Ensure Type-Safety

- **Bind (assign) types, then check types**
- **Type binding: defines type of constructs in the program (e.g., variables, functions)**
  - Can be either explicit (int x) or implicit (x=1)
  - Type consistency (safety) = correctness with respect to the type bindings
- **Type checking: determine if the program correctly uses the type bindings**
  - Consists of a set of type-checking rules

Type Checking

- **Semantic checks to enforce the type safety of the program**
- **Examples**
  - Unary and binary operators (e.g. +, ==, [ ]) must receive operands of the proper type
  - Functions must be invoked with the right number and type of arguments
  - Return statements must agree with the return type
  - In assignments, assigned value must be compatible with type of variable on LHS
  - Class members accessed appropriately

4 Concepts Related to Types/Languages

1. **Static vs dynamic checking**
   - When to check types
2. **Static vs dynamic typing**
   - When to define types
3. **Strong vs weak typing**
   - How many type errors
4. **Sound type systems**
   - Statically catch all type errors

Static vs Dynamic Checking

- **Static type checking**
  - Perform at compile time
- **Dynamic type checking**
  - Perform at run time (as the program executes)
- **Examples of dynamic checking**
  - Array bounds checking
  - Null pointer dereferences

Static vs Dynamic Typing

- **Static and dynamic typing refer to type definitions (i.e., bindings of types to variables, expressions, etc.)**
- **Static typed language**
  - Types defined at compile-time and do not change during the execution of the program
    - C, C++, Java, Pascal
- **Dynamically typed language**
  - Types defined at run-time, as program executes
    - Lisp, Smalltalk

Strong vs Weak Typing

- **Refer to how much type consistency is enforced**
- **Strongly typed languages**
  - Guarantee accepted programs are type-safe
- **Weakly typed languages**
  - Allow programs which contain type errors
- **These concepts refer to run-time**
  - Can achieve strong typing using either static or dynamic typing

Soundness

- **Sound type systems: can statically ensure that the program is type-safe**
- **Soundness implies strong typing**
- **Static type safety requires a conservative approximation of the values that may occur during all possible executions**
  - May reject type-safe programs
  - Need to be expressive: reject as few type-safe programs as possible

Class Problem

Classify the following languages: C, C++, Pascal, Java, Scheme ML, Postscript, Modula-3, Smalltalk, assembly code

	Strong Typing	Weak Typing
Static Typing		
Dynamic Typing		

Why Static Checking?

- **Efficient code**
  - Dynamic checks slow down the program
- **Guarantees that all executions will be safe**
  - Dynamic checking gives safety guarantees only for some execution of the program
- **But is conservative for sound systems**
  - Needs to be expressive: reject few type-safe programs

Type Systems

- **What are types?**
  - They describe the values computed during the execution of the program
  - Essentially they are a predicate on values
    - E.g., “int x” in C means $-2^{31} <= x < 2^{31}$
- **Type expressions: Describe the possible types in the program**
  - E.g., int, char*, array[], object, etc.
- **Type system: Defines types for language constructs**
  - E.g., expressions, statements

Type Expressions

- **Language type systems have basic types (aka: primitive types or ground types)**
  - E.g., int, char*, double
- **Build type expressions using basic types:**
  - Type constructors
    - Array types
    - Structure/object types
    - Pointer types
  - Type aliases
  - Function types

Type Comparison

- **Option 1: Implement a method T1.Equals(T2)**
  - Must compare type trees of T1 and T2
  - For object-oriented languages: also need sub-typing, T1.SubtypeOf(T2)
- **Option 2: Use unique objects for each distinct type**
  - Each type expression (e.g., array[int]) resolved to same type object everywhere
  - Faster type comparison: can use ==
  - Object-oriented: check subtyping of type objects

Creating Type Objects

- **Build types while parsing – use a syntax-directed definition**

```
non terminal Type type
type : INTEGER
          {$$ = new IntType(id); }
        | ARRAY LBRACKET type RBRACKET
          {$$ = new ArrayType($3); } ;
```

- **Type objects = AST nodes for type expressions**

Processing Type Declarations

- **Type declarations add new identifiers and their types in the symbol tables**
- **Class definitions must be added to symbol table:**
  - class_defn : CLASS ID {decls} ;
- **Forward references require multiple passes over AST to collect legal names**
  - class A {B b; }
  - class B { ... }

Type Checking

- **Type checking = verify typing rules**
  - E.g., “Operands of + must be integer expressions; the result is an integer expression”
- **Option 1: Implement using syntax-directed definitions (type-check during the parsing)**

```
expr:     expr PLUS expr {
          if ($1 == IntType && $3 == IntType)
                    $$ = IntType
          else
                    TypeCheckError(“+”);
          }
```

Type Checking (2)

- **Option 2: First build the AST, then implement type checking by recursive traversal of the AST nodes:**

```
class Add extends Expr {
	Type typeCheck() {
		Type t1 = e1.typeCheck(), t2 = e2.typeCheck();
		if (t1 == Int && t2 == Int) return Int
		else TypeCheckError("+");
	}
}
```

Type Checking Identifiers

- **Identifier expressions: Lookup the type in the symbol table**

```
class IdExpr extends Expr {
        Identifier id;
        Type typeCheck() {return id.lookupType(); }
}
```

Next Time: Static Semantics

- **Can describe the types used in a program**
- **How to describe type checking**
- **Static semantics: Formal description for the programming language**
- **Is to type checking:**
  - As grammar is to syntax analysis
  - As regular expression is to lexical analysis
- **Static semantics defines types for legal ASTs in the language**