CS 412
Introduction to Compilers

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Lecture 10: Types and type checking
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Administration

- HW2 due now

Review

- Semantic analysis performed on representation of program as AST
- Implemented as a recursive traversal of abstract syntax tree

Semantic Analysis

- Catching errors in a syntactically valid program
  - Identifier errors: unknown identifier, duplicate identifier, used before declaration
  - Flow control errors: unreachable statements, invalid goto/break/continue statements
  - Expressions have proper type for using context
- This lecture:
  - What kinds of checks are done (particularly type chks)
  - How to implement types
  - Not covered in Appel or Dragon Book

Type checking

- Bulk of semantic checking
- Operators (e.g. +, !, [ ]) must receive operands of the proper type
- Functions must be called w/ right number & type of arguments
- Return statements must agree w/ return type
- In assignments, assigned value must be compatible with type of variable on LHS.
- Class members accessed appropriately

Static vs. Strong Typing

- Many languages statically typed (e.g. C, Java, but not Scheme, Dylan): expressions, variables have a static *type*
- Static type is a predicate on values might occur at run time. int x; in Java means x $\in [-2^{31}, 2^{31})$. Types ≈ efficiently decidable predicates
- Strongly typed language: operations unsupported by a value never performed *at run time.*
- In strongly typed language with sound static type system: run-time values of expressions, variables characterized conservatively by static type

Type safety

	Strongly typed	Not strongly typed
Statically typed	ML Pascal Iota Java Modula-3 Iota$^+$	C C++
Not statically typed	Scheme PostScript Smalltalk SELF Dylan CLOS	FORTH assembly code

Why Static Typing?

- Compiler can reason more effectively
- Allows more efficient code: don't have to check for unsupported operations
- Allows error detection by compiler
- But:
  - – requires at least some *type declarations*
  - – type decls often can be inferred (ML)

Dynamic checks

- Even statically-typed languages have some dynamic checking
  - – Array index out of bounds
  - – null in Java, null pointers in C
  - – Inter-module type checking in Java
- Sometimes can be eliminated through static analysis
  - – harder than type checking: undecidable
  - → theorem proving
  - → can't always eliminate these checks

Type Systems

- Type is predicate on values
- Arbitrary predicates: type checking intractable (theorem proving)
- Languages have *type systems* that define what types can be expressed and what static types expressions have
- Types described in program by *type expressions*: int, string, array[int], Object, InputStream[ ], Vector<int>

Example: Iota type system

- Language type systems have *primitive types* (also: *basic types, base types, ground types*)
- Iota: int, string, bool
- Also have *type constructors* that operate on types to produce other types
- Iota: for any type *T,* array[*T*] is a type. Java: *T* [ ] is a type for any *T*

Type expressions: aliases

- Some languages (not Java) allow type aliases (type definitions, equates)
  - – C: typedef int int_array[ ];
  - – Modula-3: type int_array = array of int;
- int_array is type expression denoting same type as int [ ] -- not a type constructor
- Different type expressions may denote the same type

Type Expressions: Arrays

- Different languages have various kinds of array types
- w/o bounds: array(T)
  - C, Java: *T* [ ], Modula-3: array of *T*
- size: array(T, L) (may be indexed 0..L-1)
  - C: *T*[*L*], Modula-3: array[*L*] of *T*
- upper & lower bounds: array(T,L,U)
  - Pascal, Modula-3: indexed L..U
- Multi-dimensional arrays (FORTRAN)

Records/Structures

- More complex type constructor
- Has form $\{id_1: T_1, id_2: T_2, \ldots\}$ for some ids and types T_i
- Supports access operations on each field, with corresponding type
- C: struct { int a; float b; } corresponds to type {a: **int**, b: **float**}
- Class types (e.g. Java) extension of record types

Functions

- Some languages have first-class function types (C, ML, Modula-3, Pascal, not Java)
- Function value can be invoked with some argument expressions with types T_i, returns return type T_r.
- Type: $T_1 \times T_2 \times \ldots \times T_n \rightarrow T_r$
- C: int f(float x, float y)
  - f: **float** × **float** → **int**
- Function types useful for describing methods, as in Java, even though not values
  - extensions needed for exceptions.

Representing types

- Type-checking routine returned a Type object – what is it?

```
Type typeCheck(SymTab s)
```

Option 1: make Type an AST node

```
abstract class Type extends Node
      { abstract boolean equals(Type t); }
class IdType extends Type { String name; }
class ArrayType extends Type { Type elemType;...}
class FunctionType extends Type { ... }
```

- Type equality requires tree comparisons
- Must look in symbol table to interpret IdType; must make sure the right symbol table is available!

Creating Type AST nodes

non terminal Type type_expr
or Type parseType();

```
type ::= ID:id
             {: RESULT = new IdType(id); :}
       |  ARRAY LBRACKET type:t RBRACKET
             {: RESULT = new ArrayType(t); :}
```

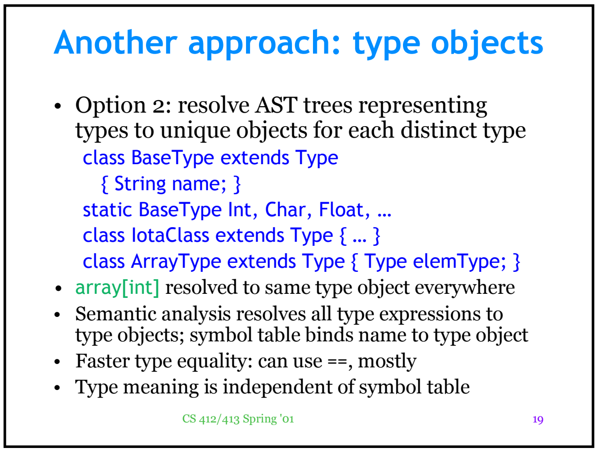
Processing type declarations

- Type aliases, class definitions must be added to symbol table (usu. top-level) during semantic analysis

```
class_defn ::= CLASS ID:id { decls:d }
```

- AST for class_defn should be checked once for validity – mutual references can require multiple passes over AST to collect legal names
- Sem. analysis binds (in ST) class names to objects representing checked type definitions:

```
class IotaClass { String name; SymTab decls; ... }
```

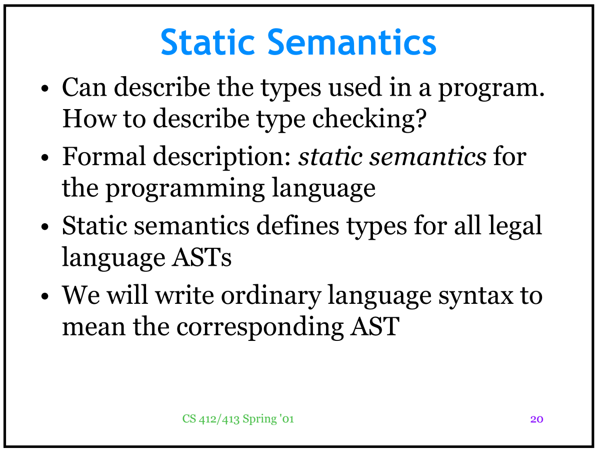


Another approach: type objects

- Option 2: resolve AST trees representing types to unique objects for each distinct type

```
class BaseType extends Type
   { String name; }
static BaseType Int, Char, Float, …
class IotaClass extends Type { … }
class ArrayType extends Type { Type elemType; }
```

- array[int] resolved to same type object everywhere
- Semantic analysis resolves all type expressions to type objects; symbol table binds name to type object
- Faster type equality: can use ==, mostly
- Type meaning is independent of symbol table



Static Semantics

- Can describe the types used in a program. How to describe type checking?
- Formal description: *static semantics* for the programming language
- Static semantics defines types for all legal language ASTs
- We will write ordinary language syntax to mean the corresponding AST