

# Type Checking

- Primarily applies to statically typed languages — every definition of an object (constants, variables, subroutines) must specify that object's type
- Contexts in which an object may appear can also be viewed as typed, since they constrain the acceptable types for that object
- Three core concepts: *type equivalence* (when are two types the same), *type compatibility* (when can a type be used), and *type inference* (what is the type of an expression, given the types of its subexpressions)

# Type Equivalence

- *Structural equivalence*: equivalent if built in the same way (same parts, same order)
- *Name equivalence*: distinctly named types are always different (“They’re different because the programmer said so; if they’re the same, then the programmer won’t define two types for them.”)
- Structural equivalence questions
  - ◆ What parts constitute a structural difference? Storage? Naming of storage? Field order?
  - ◆ How to distinguish between intentional vs. incidental structural similarities?

# Structural Equivalence

## Design Issues

- Would record types with identical fields, but different name order, be structurally equivalent?

```
type PascalRec = record a : integer; b : integer end;  
val MLRec = { a = 1, b = 2 };  
val OtherRec = { b = 2, a = 1 };
```

- When are arrays with the same number of elements structurally equivalent? — moot point for languages that don't allow variations in array indices

```
type str = array [1..10] of integer;  
type str = array [1..2 * 5] of integer;  
type str = array [0..9] of integer;
```

## Alias Types, Name Equivalence

- *Alias types* are types that purely consist of a different name for another type

```
TYPE Stack_Element = INTEGER;    TYPE Celsius = REAL;  
TYPE Level = INTEGER;           TYPE Fahrenheit = REAL;
```

- ◆ Should INTEGERS be assignable to a Stack\_Element? How about Levels?
- ◆ On the flip side, can a Celsius and Fahrenheit be assigned to each other?

- *Strict name equivalence*: aliased types are distinct
- *Loose name equivalence*: aliased types are equivalence

- ◆ Ada allows additional explicit equivalence control:

```
subtype Stack_Element is integer;    type Celsius is new real;  
                                     type Fahrenheit is new real;
```

- ◆ Modula-3's **BRANDED** keyword explicitly marks a type as distinct at all times, regardless of structural equivalence

# Type Conversion

- Certain contexts in certain languages may require exact matches with respect to types:

```
aVar := anExpression  
value1 + value2  
foo(arg1, arg2, arg3, ... , argN)
```

- *Type conversion* seeks to follow these rules while allowing some flexibility in the values used
  - ◇ Using structurally-equivalent types in a name-equivalent language
  - ◇ Types whose value ranges may be distinct but intersect (e.g. subranges)
  - ◇ Distinct types with sensible/meaningful corresponding values (e.g. integers and floats)

- Explicit conversions are typically called *type casts*
- Type conversions may sometimes add code to a program:
  - ◇ Code to actually perform the conversion
  - ◇ Code to perform semantic checks on the conversion result

Ada	<pre>n : integer; r : real; ... r := real(n);</pre>
C/C++/Java	<pre>// Sample is specific to Java, but shares common syntax. Object n; String s; ... s = (String)n;</pre>
SQL (some flavors)	<pre>-- timestamp is a built-in data type -- charField is a varchar (string) field select charField::timestamp from ...</pre>

# Nonconverting Type Casts

- Type casts that explicitly preserve the internal bit-level representation of values
- Common in manipulating allocated blocks of memory
  - ◊ Same block of memory may be viewed as arrays of characters, integers, or even records/structures
  - ◊ Block of memory may be read from a file or other external source that is initially viewed as a “raw” set of bytes

## Type Casting Examples

- **Ada:** explicit *unchecked\_conversion* subroutine

```
function cast_float_to_int is
  new unchecked_conversion(float, integer);
```

- **C/C++ (but not Java!):** pointer games

```
void *block; // Gets loaded up with some data, say from a file.
Record *header = (Record *)block; // Record is some struct type.
```

- **C++:** explicit cast types *static\_cast*, *reinterpret\_cast*, *dynamic\_cast*

```
int i = static_cast<int>(d); // Assume d is declared as double.
Record *header = reinterpret_cast<Record *>(block);
Derived *dObj = dynamic_cast<Derived *>(baseObj); // Derived is a subclass of Base.
```

# Type Compatibility

- Sometimes absolute type equivalence is too strict; *type compatibility* is sufficient
- Type equivalence vs. type compatibility in Ada (strict):
  - ◇ Types must be equivalent
  - ◇ One type must be a subtype of another, or both are subtypes of the same base type
  - ◇ Types are arrays with the same sizes and element types in each dimension
- Pascal extends slightly, also allowing:
  - ◇ Base and subrange types are cross-compatible
  - ◇ Integers may be used where a real is expected

# Type Coercion

- *Type coercion* is an automatic, implicit type conversion that allows a value of one type to be used in a context that expects another
- Requires run-time code to either:
  - ◇ Perform a dynamic semantic check
  - ◇ Convert between low-level representations
- Languages implement different rules as to when to do which, as well as when type coercion is even allowed

# Type Coercion Design Issues

## Sometimes viewed as a weakening of type security

- Allows mixing of types without explicit indication of intent
- Opposite end of the spectrum: C and Fortran
  - ◊ Allow interchangeable use of numeric types
  - ◊ Fortran: arithmetic can be performed on entire arrays
  - ◊ C: arrays and pointers are roughly interchangeable
- C++ adds programmer-extensible coercion rules

```
class ctr {
public:
    ctr(int i = 0, char* x = "ctr") { n = i; strcpy(s, x); }
    ctr& operator++(int) { n++; return *this; }
    operator int() { return n; } // Coercion to int
    operator char*() { return s; } // Coercion to char *
private: int n; char s[64];
};
```

- Overloading and type coercion: may feel similar but with real semantic differences (e.g., overloaded “+” vs. coercing “+”)
- How to handle constants — is “5” an *int* or a *float*?  
What is the base type of a *nil* or *NULL* reference?
  - ◊ Constants may be viewed as having more than one possible type (and therefore are overloaded) and coerced as needed
  - ◊ Ada makes this explicit and formal: constants have distinct types from variables (*universal\_integer* vs. *integer*; *universal\_real* vs. *real*) — allows constants in any derived type
- “Generic” objects: *void\** (C/C++), *any* (Clu), *address* (Modula-2), *Object* (Java), *virtually anything* (JavaScript)
  - ◊ Nice for abstraction (e.g., data structures, translation from memory or I/O)
  - ◊ May require self-descriptive entities (type tags) — values “know” about their own type information, allowing runtime checking of type casts

# Type Inference

- *Type inference* refers to the process of determining the type of an arbitrarily complex expression
- Generally not a huge issue — most of the time, the type for the result of a given operation or function is clearly known, and you just “build up” to the final type as you evaluate the expression
- In languages where an assignment is also an expression, the convention is to have the “result” type be the type of the left-hand side

But, there are occasional issues, specifically with subrange and composite types:

- *Subranges* — in languages that can define types as subranges of base types (Ada, Pascal), type inference can be an issue:

```
type Atype = 0..20; Btype = 10..20;  
var a : Atype; b : Btype; c : ???;  
c := a + b;
```

◆ What should c's type be? An easy answer: go back to the base type (integer in this case)

- What if an expression is assigned to a subrange?

```
a := 5 + b; (* Where a and b are defined as above *)
```

- ◆ The primary question is bounds checking — operations on subranges can certainly produce results that break away from their defined bounds
- ◆ Static checks: include code that infers the lowest and highest possible results
- ◆ Dynamic check: static checks are not always possible, so check at runtime as a last resort

# Composite Type Inference

- What is the type of operators on arrays? We know it's an array, but can we be more specific? (particularly for languages where the index range is part of the array definition)
  - ◊ Case in point: strings in languages where strings are exactly character arrays (Pascal, Ada)
- Another tricky composite type: sets. In languages that encode a base type with a set (e.g., set of integer), what is the “type” of unions, intersections, and differences of sets?

## Inferring Combinations of Types

- What if a set is combined with a subrange?

```
var A : set of 1..10;  
    B : set of 10..20;  
    C : set of 1..15;  
    i : 1..30;  
  
...  
  
C := A + B * [1..5, i];
```

- Same as type inferences in subranges: static checks are possible in some cases, but dynamic checks are not completely avoidable

# The ML Type System

- Full-blown type inference
- The “feel” of untyped declarations without losing the checks provided by strong typing

```
fun fib n =  
  let fun fib_helper f1 f2 i =  
        if i = n then f2 else fib_helper f2 (f1 + f2) (i + 1)  
      in  
        fib_helper 0 1 0  
      end;
```

- ML figures out that *fib* is a function that takes an integer and returns an integer through a series of deductions, usually starting with any literals in the code

- The key to ML’s type inference is the absence of inconsistency or ambiguity. Pitfalls include:

- ◆ Arithmetic operations that switch between real and integer operands
- ◆ Functions that can go “either way” — this will require explicit type declarations:

```
fun square x = x * x; (* Defaults to int -> int *)
```

- All this, and the ML type system also accommodates polymorphism. If an operation is polymorphic, then the function is also polymorphic:

- ◆ Easy example: equality has type `'a * 'a -> bool`
- ◆ Not so obvious but works just fine thank you:

```
fun twice f x = f (f x);  
twice (fn x => x / 2.0) 1.0;  
twice (fn x => x ^ "ee") "whoop";
```

# Type Unification

- Part of ML's type inference is *unification* — composing or combining multiple types in a consistent manner

- ◆ Say E1 has type 'a \* int and E2 has type string \* 'b

- ◆ if x then E1 else E2 can be inferred as having type string \* int

- The type system is completely orthogonal with lists

```
fun append l1 l2 =  
  if l1 = nil then l2 else (hd l1) :: append (tl l1) l2;
```

```
fun member x l =  
  if l = nil then false else  
    if x = (hd l) then true else member x (tl l);
```

- Tuple types  $(a, b, c)$  allow functions to be fixed at having a single argument
  - ◆ “Multiple arguments” can be expressed either as a tuple, or
  - ◆ ...by *currying*: functions with arguments are themselves functions, and can be given additional arguments (this is the argument-without-parentheses notation that you have been seeing)
- ML has records  $\{ \text{name} = \text{value}, \dots, \text{name}_n = \text{value}_n \}$  which operate based on structural equivalence, independently of field name order
- New types can be synthesized using *datatype* and a special notation for constructors