Types

A Type is a Set of Values

Consider the Asteroid statement:

```
let n:%integer = 3;
```

Here we constrain n to take on any value from the set of all integer values.

Types

Def: A type is a set of values.

Def: A primitive type is a type that is built into the language, e.g., integer, string.

Def: A constructed type is a user defined type, e.g., any type introduced by the user. In Asteroid this is done through the 'structure' statement.

Example: Java, primitive type

float q;

type float ⇒ set of all possible floating point values

q is of type float, only a value that is a member of the set of all floating point values can be assigned to q.

Types

Example: Java, constructed type

```
class Rectangle { int xdim; int ydim; };

Rectangle r = new Rectangle();
```

Now the variable r only accepts values that are members of type Rectangle;
☞ object instantiations of class Rectangle.

Types

Example: Asteroid, constructed type

```
4  structure Rectangle with
5  ··data xdim.
6  ··data ydim.
7  end
8
9  let r = Rectangle(4,2).
```

an element of
type Rectangle.

Types

In statically typed languages arrays are also considered ‘constructed types’

Example: C, constructed type

int a[3];

the variable a will accept values which are arrays of 3 integers.

e.g.: int a[3] = {1,2,3};
int a[3] = {7,24,9}

That is, ‘int a[3]’ defines the set of all integer arrays of size three.

Subtypes

Def: a subtype is a subset of the elements of a type.

Example: Java

Short is a subtype of int: short < int

The notation A < B means
A is a subtype of B.

Observations:
(1) converting a value of a subtype to a values of the super-type is called widening type conversion. (safe)
(2) converting a value of a supertype to a value of a subtype is called narrowing type conversion. (not safe)

Example: Java

float < double

Subtypes give rise to type hierarchies and type hierarchies allow for automatic type coercion – widening conversions!

Subtypes & Type Hierarchies

- In type hierarchies it is always safe to move from subtype to supertype – widening conversion (coercion)
  - E.g. short < int ✓
- Never the other way around
  - E.g. int < short ✗

char < short < int < float < double

Part of the Java type hierarchy

Subtypes

- The Asteroid type hierarchy
  - boolean < integer < real < string
  - list < string
  - tuple < string
  - none
  - constructed types

Why do we use types?

- Types allow the computer/language system to assist the developer write better programs. Type mismatches in a program usually indicate some sort of programming error.
  - Static type checking – check the types of all statements and expressions at compile time.
  - Dynamic type checking – check the types at runtime.

Type Equivalence

I. Name (nominal) Equivalence – two objects are of the same type if and only if they share the same type name.

Example: Rust

```
1  struct Type1 {x:i64, y:i64}
2  struct Type2 {x:i64, y:i64}
3
4  fn main () {
5      let x: Type1 = Type1{x:1,y:2};
6      let y: Type2 = x;
7      println!("{:?}",y);
8  }
```

Error; even though the types look the same, their names are different, therefore, Rust will not compile.

☞Rust uses name equivalence

Type Equivalence

II. Structural Equivalence – two objects are of the same type if and only if they share the same type structure.

Example: Haskell

```
1  type Type1 = (Integer, Integer)
2  type Type2 = (Integer, Integer)
3
4  x :: Type1
5  y :: Type2
6
7  x = (1,2)
8  y = x
```

Even though the type names are different, Haskell correctly recognizes this statement.

☞ Haskell uses structural equivalence.

Type Inference

- Type inference refers to the automatic detection of the data type of an expression in a programming language.
- To see how this might work let's work through an example.

Type Inference

- Assume we have the following statements in a programming language like Asteroid:

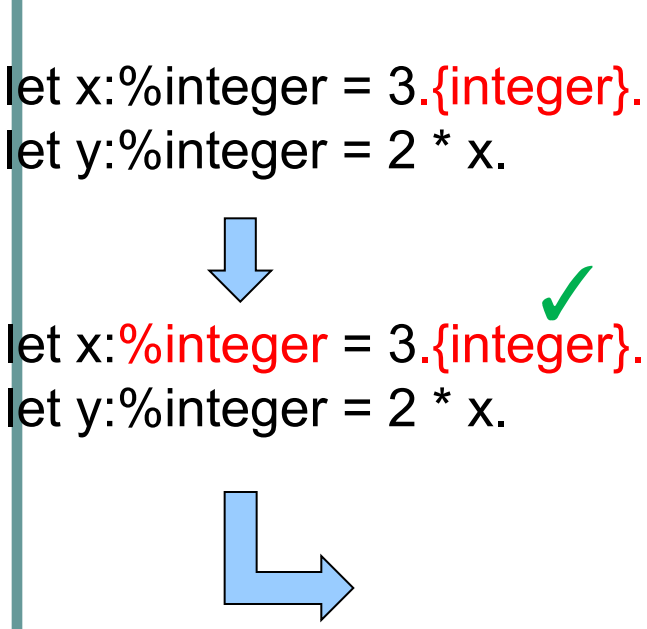
```
let x : integer = 3.
let y : integer = 2 * x.
```

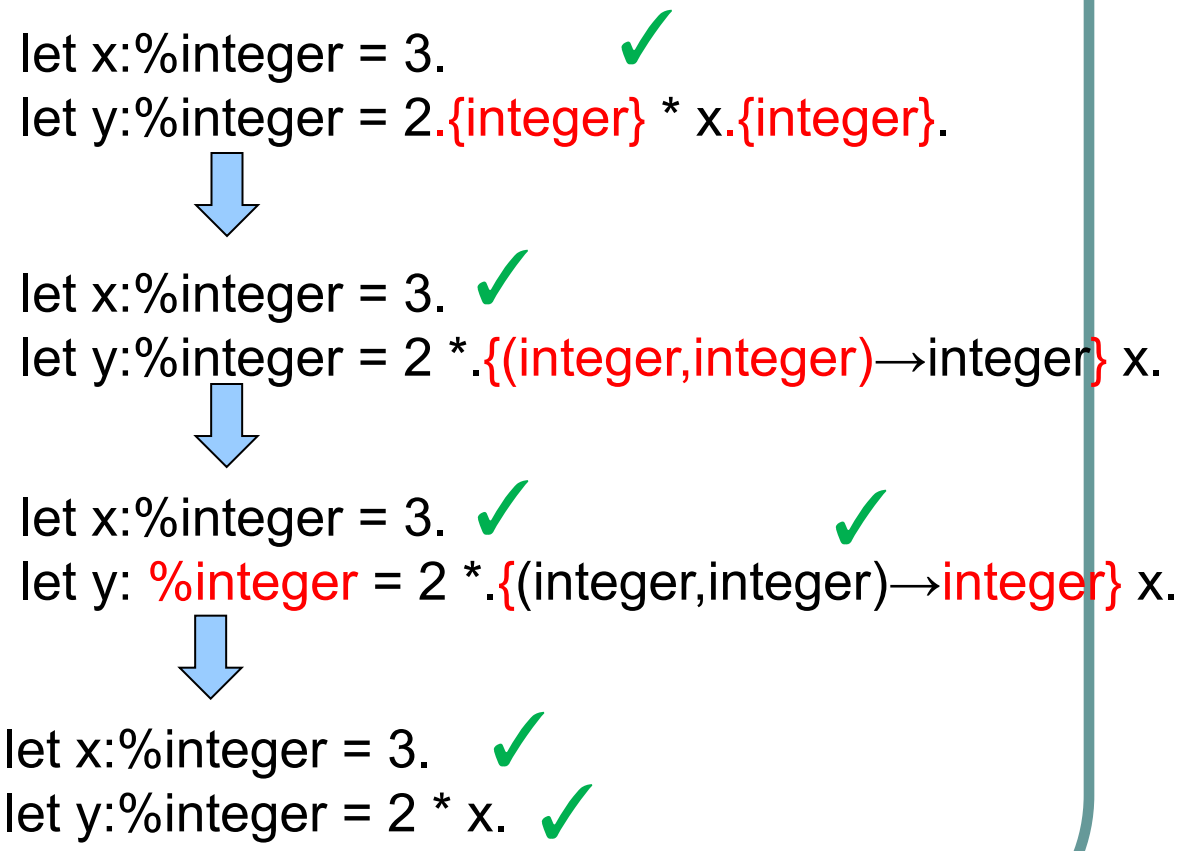
- We want to make sure that all the assignments are legal.
- We will use the type notation ‘3.{integer}’ indicating that this syntactic unit has the type integer.

Type Inference

- We start at the primitives on the right side of the assignments of the first statement and then stepping through all the remaining statements

Type Inference





Type Inference

- Let's try a program with a bug in it:

```
let x:%boolean = 3.
```

Type Inference

let x:%boolean = 3.{integer}.

let x:%boolean = 3.{integer}. ✘

Recall Asteroid's type hierarchy: boolean < integer < real < string

We are not allowed to assign a supertype to a subtype!

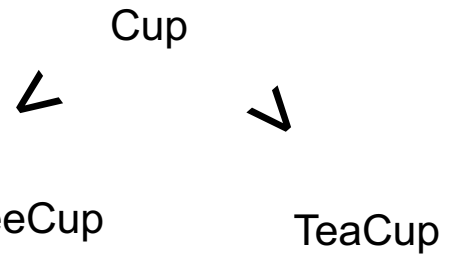
Types & Objects

- In any OO language class definitions create new types
- Objects are the values in those types
- In OO languages that support inheritance, inheritance creates a subtype-supertype relationship in the class hierarchy

Types & Objects

Example: Java

```
class Cup { ... };
class CoffeeCup extends Cup { ... };
class TeaCup extends Cup { ... };
```



Which ones of the following statements are safe and which ones are not?

1. Cup x = new Cup();
2. Cup y = new CoffeeCup();
3. TeaCup z = new Cup();
4. TeaCup t = new TeaCup();
   Cup c = t;

Notation:
A < B means A is subtype of B

Note: Type coercion in type hierarchies gives rise to polymorphic programming in OO - objects can appear in different type contexts.

Exercises

- Describe the type associated with the set of values {-1,-2,-3,-4,…}, call this type Q.
- Describe the type associated with the set of values {-2,-4,-6,-8,…}, call this type P.
- Is there a subtype-supertype relationship between these types? If so, what is it?
- Let x be a variable of type Q and y be a variable of type P, then is the assignment

  x := y

  a safe assignment? Why? Why not?

Hint: A type is a set of values!

Take Away

- Types are sets of values, typically with a common representation and common set of operations.
- Types in programming languages allows compilers and interpreters to check for consistency in your programs.
- Inconsistencies usually show up a type mismatches.
- Type equivalence between constructed types can be established in one of two ways, name equivalence or structural equivalence.
- Class hierarchies in OO languages give rise to subtype-supertype relationships due to inheritance.

Assignments

- Assignment #2 – See BrightSpace