

Types

A Type is a Set of Values

Consider the statement:

```
let mut n : i32;
```

Here we declare `n` to be a variable of type `i32`; what we mean, `n` can take on any value from the set of all 32 bit integer values.

Types

Def: A type is a set of values.

Def: A primitive type is a type a programmer can use but not define.

Def: A constructed type is a user defined type.

Example: Java, primitive type

<code>float q;</code>	}	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.
<u>float</u>		
type float \Rightarrow set of all possible floating point values		

Types

Example: Java, constructed type

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

```
Rectangle r = new Rectangle();
```



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

Types

Example: Rust, constructed type

```
1  #[allow(dead_code)]
2
3  struct Rectangle {
4      xdim : i32,
5      ydim : i32
6  }
7
8  fn main() {
9      let _r: Rectangle = Rectangle {xdim:3, ydim:4};
10 }
```

an element of
type Rectangle.

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}`

Example: Rust, constructed type

let a : [i64;3] = ...;

the variable a will accept values
which are arrays of 3 i64 integers.

Subtypes

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

Example: Java

The notation $A \rightarrow B$ means
A is a subtype of B.

Short is a subtype of int: $\text{short} \rightarrow \text{int}$

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)

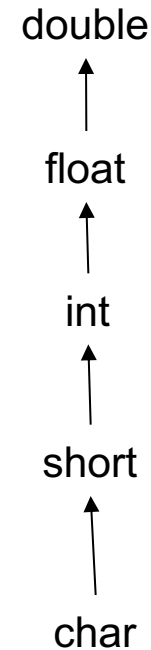
Example: Java

$\text{float} \rightarrow \text{double}$

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

Subtypes & Type Hierarchies

- Here the arrow means “subtype of”, e.g., int is a subtype of float.
- 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 ✗



Subtypes

- Rust does NOT have subtypes
 - Therefore, it does NOT support automatic type coercion
 - It is an error in Rust to do:

```
let x : i64 = 3;  
let i : f64 = x;
```
 - You would have to explicitly cast the integer variable as a floating point:

```
let x : i64 = 3;  
let i : f64 = x as f64;
```


Function Types

Rust and Haskell (as we will see) treat functions as just another data type that can be manipulated in a very elegant way.

- ☞ Functions can be passed as values; just as values that belong to other data types
- ☞ Functions belong to **function types**

Example: in Rust consider the function type

$x: \text{fn}(f64) \rightarrow f64$

This type represents the set of all functions from f64 to f64.

Looking at the Rust standard library `std::f64` we can find some examples from this set of functions

floor: $\text{fn}(f64) \rightarrow f64$


ceil: $\text{fn}(f64) \rightarrow f64$

round: $\text{fn}(f64) \rightarrow f64$

Function Types

Example: Functions as values

```
1  fn myround (x:f64) -> i64 {  
2    x.round() as i64  
3  }  
4  
5  fn main () {  
6    let foo: fn(f64)->i64 = myround;  
7    let v : i64 = foo(3.4);  
8    println!("{}", v);  
9  }
```

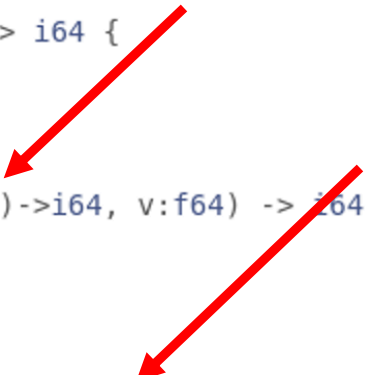


☞ A function is just an element of a particular function set.

Function Types

Example: Functions as function arguments

```
1  fn myfloor (x:f64) -> i64 {
2    x.floor() as i64
3  }
4
5  fn myceil (x:f64) -> i64 {
6    x.ceil() as i64
7  }
8
9  fn myfun (x: fn(f64)->i64, v:f64) -> i64 {
10     x(v)
11  }
12
13 fn main () {
14     println!("{}", myfun(myfloor, 3.4));
15     println!("{}", myfun(myceil, 3.4));
16 }
```



☞ A function is just an element of a particular function set.

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 Rust:

```
let x : i64 = 3;  
let y : i64 = 2 * x;
```

- We want to make sure that all the assignments are legal.
- We will use the type notation ' $3.\{i64\}$ ' indicating that this syntactic unit has the type `i64`.

Type Inference

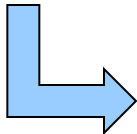
- We start at the primitives on the right side of the assignments starting with the first statement and then stepping through all the remaining statements

Type Inference

```
let x : i64 = 3.{i64};  
let y : i64 = 2 * x;
```



```
let x : i64 = 3.{i64}; ✓  
let y : i64 = 2 * x;
```



```
let x : i64 = 3; ✓  
let y : i64 = 2.{i64} * x;
```



```
let x : i64 = 3; ✓  
let y : i64 = 2.{i64} * x.{i64};
```



```
let x : i64 = 3; ✓  
let y : i64 = 2 * .{fn(i64,i64)->i64} x;
```



```
let x : i64 = 3; ✓  
let y : i64 = 2 * .{fn(i64,i64)->i64} x; ✓
```



```
let x : i64 = 3; ✓  
let y : i64 = 2 * x; ✓
```

Type Inference

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

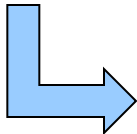
```
let x : i64 = 3;  
let y : f64 = 2 * x;
```

Type Inference

```
let x : i64 = 3.{i64};  
let y : f64 = 2 * x;
```



```
let x : i64 = 3.{i64}; ✓  
let y : f64 = 2 * x;
```



```
let x : i64 = 3; ✓  
let y : f64 = 2.{i64} * x;
```



```
let x : i64 = 3; ✓  
let y : f64 = 2.{i64} * x.{i64};
```



```
let x : i64 = 3; ✓  
let y : f64 = 2 *.{fn(i64,i64)->i64} x;
```



```
let x : i64 = 3; ✓  
let y : f64 = 2 *.{fn(i64,i64)->i64} x; ✗
```



```
let x : i64 = 3; ✓  
let y : f64 = 2 * x; ✗
```

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

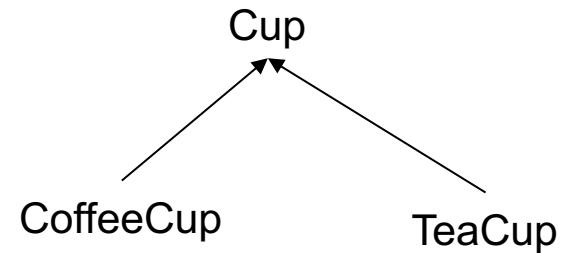
Types & Objects

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:

$A \rightarrow B$ 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 $\{-1, -2, -3, -4, \dots\}$, call this type Q .
- Describe the type associated with the set of values $\{-2, -4, -6, -8, \dots\}$, 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?
- Describe the type associated with set $\text{fn}(Q) \rightarrow P$.

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 as 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