Programming Paradigms

Type Systems (Part 1)

Prof. Dr. Michael Pradel

Software Lab, University of Stuttgart

Summer 2020

Quiz

What values do these JavaScript expressions evaluate to?

```
''      ==   '0'
0       ==   ''
0       ==   '0'
false   ==   'false'
```

Please vote via Ilias.

Quiz

What values do these JavaScript expressions evaluate to?

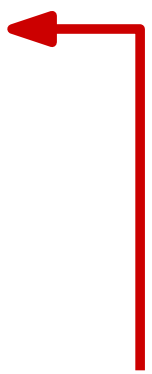
```
''      ==   '0'          // false
0       ==   ''           // true
0       ==   '0'          // true
false   ==   'false'      // false
```

Please vote via Ilias.

Quiz

What values do these JavaScript expressions evaluate to?

```
''      ==   '0'          // false
0       ==   ''           // true
0       ==   '0'          // true
false   ==   'false'      // false
```



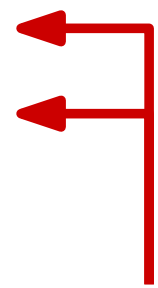
Two strings that are not the same

Please vote via Ilias.

Quiz

What values do these JavaScript expressions evaluate to?

```
''      ==   '0'          // false
0       ==   ''           // true
0       ==   '0'          // true
false   ==   'false'      // false
```



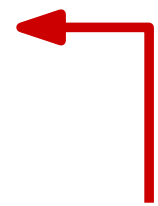
Number and string: String is coerced into a number (here: 0)

Please vote via Ilias.

Quiz

What values do these JavaScript expressions evaluate to?

```
''      ==   '0'          // false
0       ==   ''           // true
0       ==   '0'          // true
false   ==   'false'      // false
```



Boolean and another type:

- **Boolean gets coerced to a number (here: 0)**
- **String also get coerced to a number (here: NaN)**
- **The two numbers differ**

Please vote via Ilias.

Overview

- Introduction 
- Types in Programming Languages
- Polymorphism
- Type Equivalence
- Type Compatibility
- Formally Defined Type Systems

Types

- **Most PLs: Expressions and memory objects have types**
- **Examples**
  - Assignment `x=4` (implicitly) says `x` has a number type
  - Declaration `int n;` says `n` has integer type
  - Expression `a+b` has a type, which depends on the type of `a` and `b`
  - `new X()` has a type

Why Do We Need Types?

Reason 1: Provide context for operations

- Meaning of `a+b` depends on types of `a` and `b`
  - E.g., addition vs. string concatenation
- Meaning of `new x` depends in the type of `x`
  - E.g., which initialization code to call?

PL implementation uses this context information

Why Do We Need Types?

Reason 2: Limit valid operations

- Many syntactically valid operations don't make any sense
  - Adding a character and a record
  - Computing the logarithm of a set

Helps developers find bugs early

Why Do We Need Types?

Reason 3: Code readability and understandability

- Types = stylized documentation
- Makes maintaining and extending code easier

But: Sometimes, types make code harder to write

Why Do We Need Types?

Reason 4: Compile-time optimizations

- Compiler knows that some behavior is impossible
  - E.g., assignment of type T1 may not influence values of type T2

Works both for explicitly specified and implicitly inferred types

Bits Are Untyped

- **(Most) hardware stores and computes on raw bits**
  - Bits may be code, integer data, addresses, etc.
- **(Most) assembly languages are untyped**
  - Operation of any kind can be applied to values at arbitrary locations

Type Systems

- **Definition of types and their association with PL constructs**
  - Every PL construct that has/refers to a value has a type (e.g., named constants, variables, record fields, functions)
- **Rules for**
  - Type equivalence
  - Type compatibility
  - Type inference

Type Checking

Ensure that program obeys the type compatibility rules

Example (Java):

```
int a = 3;
String b = a - 2;
```

Type Checking

Ensure that program obeys the type compatibility rules

Example (Java):

```
int a = 3;
String b = a - 2;
```

Type error: Can't assign int value to String variable