

Type systems

The INFDEV team

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Introduction

Type systems

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Lecture topics

- Issues with Python
- Issues with Python and possible solutions
- Static typing

Issues with Python

Lack of...

- Lack of constraints: how can we specify that a function only takes integers as input
- Lack of structure: how can we specify that a variable will certainly support some methods
- Lack of assurances: how can we guarantee that programs with evident errors are not run

What is wrong with this?

```
1 def f(x):  
2     return (x * 2)  
3 f("nonsense")
```

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```
1 def f(x):  
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```

The function clearly works with integers, but is given a string

What is wrong with this?

```
1 x = input()
2 if (x > 100):
3     print("dumb")
4 else:
5     print("dumber")
```


What is wrong with this?

```
1 x = input()
2 if (x > 100):
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```

The comparison is nonsensical if `x` is not a number

What is wrong with this?

```
1 def g(car):  
2     return car.drive(2)  
3 g(-1)
```

What is wrong with this?

```
1 def g(car):  
2     return car.drive(2)  
3 g(-1)
```

We expect something with a `drive` method, but get an integer instead

Possible solutions

Testing?

- Testing the program should be enough

Testing?

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- Right?

Testing?

- Testing the program should be enough
- Right?
- No. The number of possible execution paths is immense (order of billions), and each test only takes one.
- Testing can only guarantee presence of bugs, but not their absence!

How many times would we need to test to be sure there is no error?

```
1 if (randint(0,100000) > 99999):  
2     g(-1)  
3 else:  
4     g(mercedesSL500)
```


How many times would we need to test to be sure there is no error?

```
1 if (randint(0,100000) > 99999):  
2     g(-1)  
3 else:  
4     g(mercedesSL500)
```

100000

Testing?

- We want our programming languages to perform checks for us
- Clearly nonsensical programs should be rejected before we can even run them
- It is safer and easier to spend more time "talking" with the IDE than hoping to find all errors at runtime

Static typing

Introduction

- The language verifies^a, before running code, that all variables are correctly used
- "Correctly used" means that they are guaranteed to support all operations used on them
- This is by far and large the most typical solution to increase safety and productivity

^aBy means of the **compiler**.

What is static typing?

- When declaring a variable, we also specify what sort of data it will contain
- The **sort** of data contained is called **TYPE** of the variable
- Types can be either primitives (int, string, etc.), custom (classes), or compositions (functions, list of elements of a given type, etc.)

What is static typing?

- Especially in mainstream languages, the specification of the type of a variable is done by hand by the programmer
- In other languages (mostly functional languages like F#, Haskell, etc.) the type of variables is automatically guessed by the compiler
- In our case our programs will become a bit more verbose but better specified
- Still, static typing is not necessarily connected with verbosity

Static typing

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```
1 def f(x):  
2     return (x * 2)
```

Becomes, typed:

What has improved and why?

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```
1 def f(x):  
2     return (x * 2)
```

Becomes, typed:

What has improved and why?

The second definition encodes information about what goes in and what comes out of the function

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Is this still possible to write (as it was in Python)?

Is this still possible to write (as it was in Python)?

No: we get a compiler error because a string cannot be used where a number is expected

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```
1 x = input()  
2 if (x > 100):  
3     print("dumb")  
4 else:  
5     print("dumber")
```

Becomes, typed:

What has improved and why?

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```
1 x = input()
2 if (x > 100):
3     print("dumb")
4 else:
5     print("dumber")
```

Becomes, typed:

What has improved and why?

The variable declaration specifies what is allowed (and what is not) inside the variable.

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```
1 def g(car):  
2     return car.drive(2)  
3 g(-1)
```

Becomes, typed:

What has improved and why?

```
1 def g(car):  
2     return car.drive(2)  
3 g(-1)
```

Becomes, typed:

What has improved and why?

The function declaration specifies available methods of extttcar. We will thus get a compiler error.

Typing rules and semantic rules

Typing rules and semantic rules

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How do we describe them?

- How do we describe such relations clearly?
- We use the so-called **typing rules**, which specify what may be done and what not
- Typing rules are quite intuitive: they state that if one or more premises are true, then the conclusion is true as well

Typing rules and semantic rules

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$$\frac{A \wedge B}{C}$$

If A and B are true, then we can conclude C

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$$\frac{\text{I wish to buy a pretty car} \wedge \text{I have 120000 euros}}{\text{I buy a Mercedes SL500}}$$

How do we read this rule?

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Typing rules and semantic rules

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$$\frac{\text{I wish to buy a pretty car} \wedge \text{I have 120000 euros}}{\text{I buy a Mercedes SL500}}$$

How do we read this rule?

If I have 120000 euros and I wish to buy a pretty car, then I buy a Mercedes SL500

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$$\frac{\text{I have my umbrella with me} \wedge \text{It is raining}}{\text{I open my umbrella}}$$

How do we read this rule?

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Typing rules and semantic rules

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$$\frac{\text{I have my umbrella with me} \wedge \text{It is raining}}{\text{I open my umbrella}}$$

How do we read this rule?

If I have my umbrella with me, and it is raining, then I open my umbrella

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Reading typing rules

Let us apply this machinery to programming languages

Reading typing rules

- Let us apply this machinery to programming languages
- We will effectively give the specification of a modern compiler
- This looks like a “broadly scoped” execution of the program, and it is indeed such
- Instead of having a coupling of the variables with values in the stack and the heap, we maintain a coupling of the variables with their declared type

Typing rules and semantic rules

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- We want to specify this in the typing rule notation
- The typing rules manipulate a stack of declarations
- $x : \text{int}$

$$\frac{c : \text{Boolean} \wedge a : \text{void} \wedge b : \text{void}}{\text{if } c \text{ then } a \text{ else } b : \text{void}}$$

If a part of a program does not have a type derived through the typing rules (also void is fine), then the whole program cannot be run and we get a compiler error

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This is it!

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The best of luck, and thanks for the
attention!