Type Analysis of Python

# Introduction

Python is a dynamically typed, general purpose programming language that supports both object-oriented, imperative and functional programming styles. As opposed to most other programming languages Python is an indented language, with the intention to allow programmers to write more concise code.

Because of its dynamic nature and little tool support it can be difficult to develop and maintain larger programs. In this report we present our work towards developing a conservative type analysis for Python in Scala.

# Dynamic features of Python

As mentioned Python is a dynamically typed language, and therefore has a lot in common with e.g. JavaScript. In this section we present some of its interesting dynamic features, together with a bunch of common runtime errors.

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| 1  2  3  4  5  6  7  8  9  10  11  12  13  14  15  16  18  19 | class Person(object):  def \_\_init\_\_(self, name):  self.name = name  class Student(Person):  pass  s1 = Student('Foo')  s2 = Student('Bar')  def addGrade(self, course, grade):  self.grades[course] = grade  Student.addGrade = addGrade  s1.grades = {}  s1.addGrade('math', 10)  s2.addGrade('math', 7) |
| Fig. 1 | |

Classes are declared using the class keyword, supports multiple inheritance and can be modified further after creation. The code in figure 1 declares an empty Student class that inherits from Person, which in turn inherits from object. In line 14 a function addGrade is added to the Student class and in line 16 the attribute grades is set to an empty dictionary on the s1 object. Therefore we can call the addGrade function on the s1 object without getting a runtime error. However, since we forgot to set the grades attribute on the s2 object, we get the following runtime error from line 19: AttributeError: 'Student' object has no attribute 'grades'.

Notice that the receiver object is given implicitly as a first argument to the addGrade function. In case we had forgot to supply the extra formal parameter self, the following runtime error would result from line 18: TypeError: addGrade() takes exactly 2 arguments (3 given).

Another interesting aspect with regards to parameter passing is that Python supports unpacking of argument lists. For instance we could have provided the arguments to the addGrade function in line 18 by means of a dictionary instead: s1.addGrade(\*\*{ 'course': 'math', grade: 10 }).

Unlike as in JavaScript, we wouldn't be able to change line 16 into s1['grades'] = {}. This would result in the following error: TypeError: 'Student' object does not support item assignment, while trying to access s1['grades'] would result in the following error: TypeError: 'Student' object has no attribute '\_\_getitem\_\_'. Instead it is possible to call the built-in functions getattr(obj,attr) and

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| 1  2  3  4  5  6  7  8  9  10 | class Student(Person):  def \_\_getitem\_\_(self, name):  return self.grades[name]  def \_\_setitem\_\_(self, name, val):  setattr(self, name, val)  def \_\_getattr\_\_(self, name):  if name in self.grades:  return self.grades[name]  else:  return "<no such grade>" |
| Fig. 2 | |

setattr(obj,attr,val).

But Python also allows the programmer to customize the behavior when indexing into an object by supplying special functions \_\_setitem\_\_ and \_\_getitem\_\_, giving the programmer much more control. As an example consider the new Student class in figure 2. With this implementation we could set the grades attribute as in JavaScript: s1['grades'] = {}, and e.g. get the grade of s1 in the math course by calling s1.math or s1['math'].

## Other

* Global variables are read only unless explicitly declared global.
* Multiple inheritance: Different lookup strategies depending on old-style (that does not extend object) or new-style classes (that extends object).

# Control Flow Graph construction

In this section we give examples of how we inductively generate the control flow graph of some essential language features. During this we will present the control flow graph nodes that we use, together with their semantics.

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| While.png |
| Fig. 3 |

In Python, both for and while loops has an else branch, which is executed if the loop terminates normally (i.e. not using break). As a consequence, we generate the control flow graph illustrated in figure 3 for the while fragment.

CFGcond is the control flow graph that results from the condition. If the condition is the boolean True, CFGcond will be the control flow graph consisting of a single node, namely ConstantBooleanNode. Inspired from TAJS, Type Analyzer for JavaScript, our ConstantBooleanNode holds a result register (regcond in figure 3) together with the actual constant value, True in this case.

The other nodes ConstantIntNode, ConstantFloatNode, ConstantLongNode, ConstantComplexNode, ConstantStringNode, ConstantNoneNode, NewListNode, NewDictionaryNode and NewTupleNode work in a similar way to ConstantBooleanNode.

The motivation for introducing registers is that a single expression as e.g. s1.addGrade('math', 10) is evaluated in several steps.

First the function addGrade is looked up in the class of s1. This is done in the control flow graph using ReadPropertyNode, which holds a result register, a base register, i.e. the register where to find the object, and the name of the property to look up. Similar nodes include ReadVariableNode and ReadIndexableNode.

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| Call-example.png |
| Fig. 4 |

Secondly, each argument given to the function is evaluated, and finally the actual call is done. Calls in the control flow graph is modeled using the CallNode, which holds a result register, a function register and a list of arguments registers.

Thus the expression s1.addGrade('math', 10) will result in the control flow graph found in figure 4 (where the numbers to the left represent the result registers of the nodes).

So far we have primarily been concerned with putting constants into registers and reading e.g. variables. In order to support writing we have three different nodes: WriteVariableNode, WritePropertyNode, and WriteIndexableNode. Besides holding a value register, i.e. the register where to find the value being written, WriteVariableNode contains the name of the variable being written to, WritePropertyNode contains a base register and the property being written to, and WriteIndexableNode contains a base and property register (the latter has a register for the property because it is not constant, for instance we could write something like the following: dict[getKey()] = aValue, whereas property in obj.property = aValue must be a string).

## Complete node reference

FunctionDeclNode def f(...):  
ClassDeclNode class c(...):  
ClassEntryNode  
FunctionEntryNode

ExitNode

ConstantBooleanNode  
ConstantIntNode  
ConstantFloatNode  
ConstantLongNode  
ConstantComplexNode  
ConstantStringNode  
ConstantNoneNode None

NewListNode []  
NewDictionaryNode {}  
NewTupleNode ()  
NewSetNode set()

ReadVariableNode x  
ReadPropertyNode regobj.property  
ReadIndexableNode regobj[regindex]

WriteVariableNode x = value  
WritePropertyNode regobj.property = value  
WriteIndexableNode regobj[regindex] = value

DelVariableNode del x

DelPropertyNode del regobj.property  
DelIndexableNode del regobj[regindex]

NoOpNode  
CallNode regfunction(reg1, ..., regn)  
ReturnNode return regvalue

CompareOpNode regleft opcomp regright  
BinOpNode regleft opbinop regright

IfNode if regcond, while regcond:  
ForInNode for ... in ...:

RaiseNode raise regexception  
ExceptNode except (type1, ..., typen):

# Code examples

## Figure 1

class Person(object):

def \_\_init\_\_(self, name):

self.name = name

class Student(Person):

pass

s1 = Student('Foo')

s2 = Student('Bar')

def addGrade(self, course, grade):

self.grades[course] = grade

Student.addGrade = addGrade

s1.grades = {}

s1.addGrade('math', 10)

s2.addGrade('math', 7)

## Figure 2

class Person(object):

def \_\_init\_\_(self, name):

self.name = name

class Student(Person):

def \_\_getitem\_\_(self, name):

return self.grades[name]

def \_\_setitem\_\_(self, name, val):

setattr(self, name, val)

def \_\_getattr\_\_(self, name):

if name in self.grades:

return self.grades[name]

else:

return "<no such grade>"

s1 = Student('Foo')

s2 = Student('Bar')

def addGrade(self, course, grade):

self.grades[course] = grade

Student.addGrade = addGrade

s1.grades = {}

s1.addGrade('math', 10)