How Do Programmers Use Optional Typing? An Empirical Study

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Abstract

The recent popularization of dynamically typed languages, such as Ruby and JavaScript, has brought more attention to the discussion about the impacts of typing strategies over development. Types allow the compiler to find type errors sooner and potentially improve the readability and maintainability of a program. On the other hand, "untyped" code may be easier to change and require less work. This paper tries to identify the programmers' points of views about these tradeoffs. An analysis of the source code of 6638 projects written in Groovy, a programming language which features optional typing, shows in which scenarios programmers prefer typing or not their declarations. Results show that types are popular in the definition of module interfaces, but are less used in scripts, test classes and frequently changed code. There is no correlation between the size and age of projects and how they are typed. Finally, we also found evidence that the background of programmers has influence on how they use types.

Categories and Subject Descriptors D.2.3 [*Software Engineering*]: Cooding Tools and Techniques

General Terms Experimentation, Language

Keywords Type systems, static analysis, Groovy

1. Introduction

When choosing a programming language for a project, a developer considers several characteristics of that language. One of the most important of these characteristics is its type system, which can be static or dynamic. The type system determines when the type of a statement is defined [12]. Statically typed languages, such as Java and C#, require programmers to define the type of a declaration, which can then be used by the compiler to check for type errors. On the other hand, in dynamically typed languages, such as Ruby and JavaScript, the definition of the type of a statement only happens at run time.

Discussions about what is the best type system for a particular situation have become increasingly important in recent years due to the rapid popularization of dynamically typed languages.

According to the TIOBE Programming Community Index [1], a well-known ranking that measures the popularity of programming languages, 27% of the programming languages used in industry are dynamically typed. A decade ago, this number was only 17%. Among the 10 languages on top of the ranking, four are dynamically typed: JavaScript, Perl, Python and PHP. None of these languages were among the top 10 rank until 1998.

Several factors may be considered when choosing between a dynamically or statically typed language. Dynamically typed languages they tend to allow programmers to code faster [12] and adapt to frequently changing requirements more easily [14]. Also, by removing the repetitive work of defining types, these languages allow programmers to focus on the problem to be solved rather than on the rules of the language [13].

Statically typed languages also have their advantages. They allow compilers to find type errors statically [10]. Typed declarations increase the maintainability of systems because they implicitly document the code, telling programmers about the nature of statements [5, 11]. Systems built with these languages tend to be more efficient since they do not need to perform type checking during execution [3, 6]. Finally, modern development environments, such as Eclipse and IDEA, are able to assist programmers with functionalities such as code completion based on the information provided by statically typed declarations [4].

Some languages try to combine characteristics from both static and dynamic type systems. Groovy [2] is one of these languages. Although Groovy is mostly a dynamically typed language, it gives programmers the option to use type annotations as a means to document their code. It is also possible to turn static type checking on so the compiler can find type errors before execution. This allows developers to choose the most appropriate paradigm for each situation.

Understanding the point of view of programmers about the use of types is an important matter. Programming language developers can consider this information in their design so they can develop the most appropriate features for their target audience. Tools can be created or improved to overcome weaknesses of languages. Finally, programmers can benefit from this knowledge when choosing programming languages or typing paradigms for a given context.

This paper presents a large scale empirical study about how programmers use optional typing in Groovy. Through the analysis of a massive dataset with almost seven thousand Groovy projects, we were able to identify when programmers preferred to typed or not their declarations. Our results bring more visibility about what is the point of view of programmers about the use of types. This analysis complements, with a different point of view, existing studies based on controlled experiments.

The remainder of this paper is organized as follows. Section 2 introduces the main concepts of the Groovy programming language

and Section 3 presents the study settings. Section 4 describes the results of the study, which are then discussed in Section 5. Threats to the validity and related work are presented in Sections 6 and 7. Finally, Section 8 concludes this study and suggests future work.

2. The Groovy Language

Groovy is a dynamically typed programming language designed to run on the Java Virtual Machine. Its adoption has grown remarkably over the last years. According to the TIOBE Programming Index, Groovy is the 22nd most popular language in the software industry [1], ahead of languages like Prolog, Haskell and Scala. It builds upon the strengths of Java, but has additional features inspired by dynamic languages such as Python and Ruby. Like Java, Groovy code is compiled to bytecode, allowing it to seamlessly integrate with existing Java classes and libraries. These factors have attracted a large number of Java programmers who want to use Groovy's dynamic functionality without having to learn a completely different language or change the execution platform of their systems.

When Groovy was first launched, in 2007, it was a purely dynamically typed language. However, it allowed programmers to optionally type their declarations. Examples of typed and untyped declarations combined in the same file are shown in Listing 1. This kind of typing should not be confused with static typing since the Groovy compiler does not use these type annotations to look for errors. For example, the snippet of code shown in Listing 2 compiles without any errors. During runtime, the *string* variable references an instance of the *Integer* class. However, an exception is thrown when the method *toUpperCase* is invoked since the *Integer* class does not have such method.

Listing 1 Groovy is a dynamic language

```
1  class DynamicTyping {
2    private String typedField
3    private untypedField
4
5    DynamicTyping(typedParam) {}
6
7    def untypedMethod(untypedParam, int
         typedParam) {
8      def untypedVariable = 1.0
9      return untypedVariable
10   }
11
12   int typedMethod() {
13     String typedVariable = ""
14     return typedVariable
15   }
16 }
```

Listing 2 A class written in Groovy

```
1  String string = new Integer(1)
2  string.toUpperCase()
```

Since version 2.0, Groovy allows programmers to explicitly activate static typing with the usage of the *@TypeChecked* annotation. This makes Groovy a gradually typed language [15–19]. In this mode, the Groovy compiler looks for type errors and fails if it finds any. Listing 3 shows an example of static typing in Groovy. Trying to compile the class *TypeCheckedGroovyClass* produces an error since the method *sum* is supposed to receive two parameters

of the type *int*, but it is actually called with two parameters of the type *String*.

Listing 3 A class written in Groovy

```
1  @TypeChecked
2  class TypeCheckedGroovyClass {
3
4    static int sum(int a, int b) {
5      a + b
6    }
7
8    public static void main(String[] args) {
9      println sum("1", "2")
10   }
11 }
```

The *@TypeChecked* annotation is reasonably recent and most Groovy programmers still do not use it. Typing annotations on the other hand are very popular. Although they do not provide static type checking, they are capable of documenting the code and aiding in the integration with development tools. In the remainder of this text, we refer to declarations with type annotations as "typed", while the word "untyped" is used for declarations with no type annotations.

3. Study Settings

The study presented in this paper consists in the static analysis of the source code of a corpus of 6638 Groovy projects. Its goal is to find in which contexts, Groovy programmers type or not their declarations. In this section we present five research questions that guide our analysis, the data collection and analysis procedures as well as the characterization of the studied dataset.

3.1 Research Questoins

We propose the following research questions about the usage of types by Groovy programmers:

- **Question Q1: Do programmers use types more often in the interface of their modules?** We believe that the benefits of the use of types are more clear in declarations that define the interface of modules. In such cases programmers are specifying how the rest of the program should interact with a module, potentially improving the readability and maintainability. On the other hand, in declarations that are hidden from external modules, we expect programmers to opt for the simplicity and flexibility offered by untyped declarations more often.

- **Question Q2: Do programmers use types less often in test classes and scripts?** Many studies analyze typing paradigms in the main classes of a program. However, little is known about this question in scripts or test classes. We want to understand if programmers consider different typing strategies in these scenarios.

- **Question Q3: Does the previous experience of programmers with other languages influence their choice for typing their code?** We believe that programmers familiar with a dynamically typed language are more confortable with the lack of types and end up using types less often in Groovy.

- **Question Q3: Does the size, age or level of activity have any influence on the usage of types?** We hypothesize that as these metrics grow, there is an increased concern about keeping code more maintainable. This can lead programmers to use types more often as a means to improve code readability.

- **Question Q5: In frequently changed code, do developers prefer typed or untyped declarations?** It makes sense to assume that developers try to increase the maintainability of frequently changed code. One way to achieve that is improving the readability of such code with the use of types. On the other hand, the flexibility of untyped declarations is capable of increasing the changeability of those files. We want to understand which one of these strategies is actually preferred by developers in the end.

3.2 Data Collection Procedure

The projects used in this study were obtained from GitHub, a popular source control service based on Git. For each project, it was necessary to retrieve its source code, metadata, commit history, and the metadata of all of its developers. GitHub does not offer a listing of all hosted projects, but it offers two search mechanisms, a REST API and a web based search page. Unfortunately the GitHub API is too limited for our requirements. It imposes a limit of one thousand results and does not allow filtering projects by their programming language.

In order to retrieve an extensive dataset, it was necessary to write a bot to simulate human interactions with the GitHub webpage and search for projects. Some special care was necessary to make this work. For instance, because the number of results is limited to 1 thousand projects, we had to segment the queries. Multiple requests were made, each of them asking for the name of all projects created on a given month. Results were then combined into a single list. Another problem faced was that GitHub denies excessive requests from the same client. By adding artificial delays between requests, it was possible to overcome this limitation.

With the name of all projects in hands, it was then possible to use the GitHub REST API to query their metadata. That metadata also contains the identifiers of the developers and of the commits of that project. Using those identifiers we once again used GitHub REST API and obtained the background of all developers and the file changes of all projects.

3.3 Dataset

Our dataset consists of 6638 projects with almost 9.8 million lines of code. Table 1 shows descriptive statistics for the size, age and number of commits of these projects. There are more than 1.5 million declarations of all types and visibilities in our dataset. More details about these declarations are shown in Table 2 and 3. Note that most fields are declared with private visibility while most methods are public. This is explained by the fact that, different from Java, in Groovy, the default visibilities for fields and methods are private and public respectively.

	Mean	Median	Sd	Max	Total
Size (LoC)	1471	529	4545	149933	9770783
Commits	31	5	175	6545	203375
Age (Days)	361	280	333	1717	2395441

Table 1. Characterization of Projects

More than 4 thousand developers were involved in the projects in our dataset. While 96% of the projects were developed by small groups of 3 people or less, there were projects with up to 58 people. These developers have different backgrounds. Figure 1 shows what are the most popular languages used by these developers in other GitHub projects. Java is the most popular among them. About 40% of the developers of projects in our dataset also have Java projects hosted on GitHub.
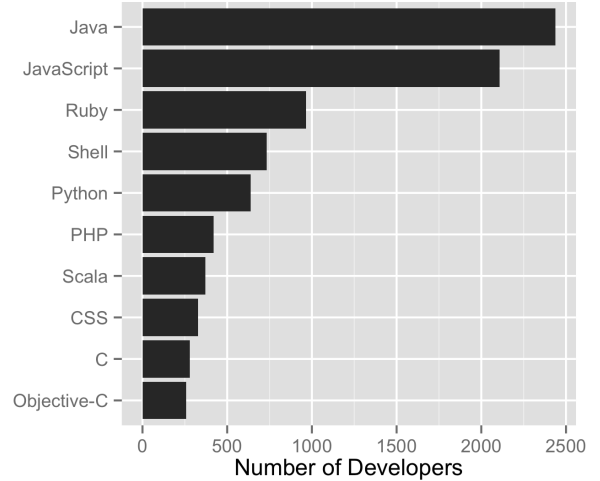

Figure 1. Most popular languages among Groovy developers

	Mean	Median	Sd	Max	Total
Field	54	19	163	5268	366148
Constructor Parameter	3	0	16	933	18956
Method Parameter	30	6	110	3554	202617
Method Return	53	15	165	4893	357997
Local Variable	88	21	361	16427	602645
Public	74	20	239	7942	507296
Protected	6	0	32	1394	42646
Private	58	21	178	5268	395776
All Declarations	227	71	744	29862	1548363

Table 2. Number of Declarations per Project

	Private	Protected	Public
Field	346462	2996	16690
Constructor Parameter	680	246	18030
Method Parameter	27174	10897	164546
Method Return	21460	28507	308030

Table 3. Number of Declarations by Visibility

3.4 Analysis

In order to understand where programmers use types, we developed a static code analyzer based on the Groovy metaprogramming library. It is capable of retrieving the declaration information of parameters and returns of methods, parameters of constructors, fields and local variables. In addition, the analyzer can tell if a declaration is part of a test class or a script and what is its visibility.

A relevant decision we made was not to compile projects, which would require all dependencies to be resolved. This is not feasible given the size of our dataset. Instead, we generated the AST for each file using the $CONVERSION$ phase of the Groovy com-

piler. At this phase, the compiler has not tried to resolve any dependencies yet, but it is capable of generating an AST with enough information to determine if a a declaration is typed or not. This makes it possible to analyze each Groovy file separately without having to compile the whole project.

The downside of the approach described above is that we can not analyze Groovy code in conjunction with its dependencies. For example, it is impossible to determine whether programmers tend to type code that interacts with other typed modules since we have not resolved any dependencies to these modules. However, our choice was fundamental in order to execute a study with such an extensive dataset.

4. Results

This sections presents the data obtained form our analysis and its statistical treatment. We show how the usage of types varies according to kind and visibility of declarations, nature of code, programmers' background, project maturity and frequency of changes. The interpretation of these results is left to Section 5, which answers the proposed research questions based on this data and raises new research questions.

4.1 Overall Result

Figure 2 shows a histogram and the descriptive statistics for the relative usage of types in declarations of projects. This value can vary from 0 (a project does not declare any types) to 1 (all declarations of a project are typed). All declarations are considered. Note that there is a significant number of projects for which the relative usage of types is either approximately 0 or 1. These are mostly small projects. About 95% of them have less than 1000 lines of code and 22% of them have less than 100 lines of code. In such projects, it is easier to be consistent on the typing strategy since there are fewer declarations. We initially considered not to include these projects in the rest of our analysis since they could not represent well the entire population of Groovy projects. However, doing so did not alter the results significantly and we decided to include all projects in our analysis regardless of their size. In the rest of this section, this data will be presented in more details so we can understand which factors lead programmers to use types or not.
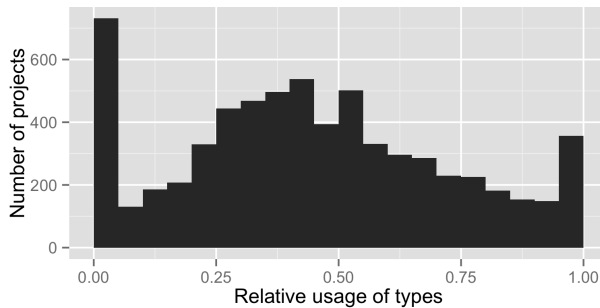

n	mean	std. dev.	Quartiles			
			1st	2nd	3rd	4th
6638	0.45	0.28	0.25	0.42	0.64	1.00

Figure 2. Usage of types in all declarations of all projects

4.2 Declaration Type

This section investigates whether programmers use types differently depending on the type of the declaration. For each project, we measured the relative usage of types by declaration type, which can be a field, a constructor parameter, the return or a parameter

of a method or a local variable. These results are displayed in box plots in Figure 3 along with the corresponding descriptive statistics. Note that the size of each sample, n, is different since not all projects have all types of declarations. For instance, there are only 1670 out of 6638 projects with declarations of constructor parameters. Meanwhile, 6000 projects have declarations of fields.
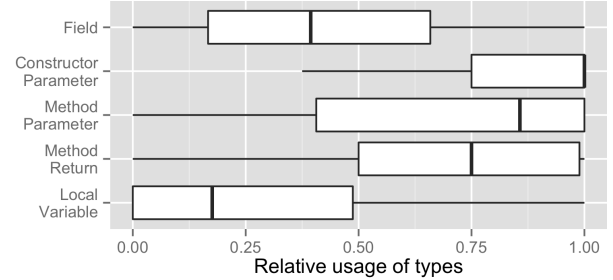
Declaration Type	n	mean	median	std. dev.
Field	6000	0.43	0.39	0.33
Constructor Parameter	1670	0.80	1.00	0.35
Method Parameter	4867	0.67	0.86	0.36
Method Return	5881	0.68	0.75	0.31
Local Variable	5845	0.29	0.18	0.32

Figure 3. Usage of types in all declarations by type of declaration

The results presented in Figure 3 suggest that programmers use types differently depending on the type of a declaration. Local variables, for example, are typed less often. Half of the projects have only 18% or less of their local variables typed. Conversely, methods and constructors are typed in most of the cases. Note that the median for constructor parameters is equal to 1.00, which means that, at least, half of the projects with constructor parameters type all declarations of this kind.

The box plot graph and the descriptive statistics are not enough to determine whether the difference in the usage of types in any two kinds of declaration is significant. In order to do that, a significance test should be applied. We start by defining a hypothesis below, which can then be rejected or accepted.

H0 The data of the two samples are drawn from the same population, i.e., there is no difference in how programmers type different kinds of declarations

H1 Programmers type their declarations differently depending on the kind of the declaration

The appropriate significance test should be chosen carefully. We can not assume that the data presented in Figure 3 follows any particular distribution. In fact, an analysis of the box plots for declarations of local variables, methods and constructors shows that these samples are heavily skewed and thus do not follow a Normal distribution. Because of this, parametric tests such as the *t-test* can not be applied.

A valid alternative for our scenario is the paired Mann-Whitney U test, which works on ranks and does not require an underlying Normal distribution. It computes a *p-value* indicating whether two samples are significantly different from each other. The smaller the value of *p*, the "more significant" is the difference and, consequently, the stronger the rejection of the null hypothesis. Typically values of 0.05 and 0.01 are used to determine if the null hypothesis can be rejected or not. In this study, we use 0.001 for this purpose. This value might seem too small at first, which would require the difference between two samples to be unnecessarily high in order to considered significant. However, due to the large size of our dataset,

this *p-value* seems reasonable [21]. In addition to the *p* value, the Mann-Whitney U test also reports a confidence interval describing the difference of the medians of the two populations. This interval can be used to measure how different are two samples. All of the confidence intervals in this study are calculated with a confidence of 99%.

|		p	conf. interval
	Constructor Parameter	0.0000	(-0.50, -0.44)
Field	Method Parameter	0.0000	(-0.32, -0.27)
	Method Return	0.0000	(-0.30, -0.26)
	Local Variable	0.0000	(0.13, 0.17)
	Field	0.0000	(0.44, 0.50)
Constructor	Method Parameter	0.0000	(0.06, 0.09)
Parameter	Method Return	0.0000	(0.08, 0.13)
	Local Variable	0.0000	(0.62, 0.67)
	Field	0.0000	(0.27, 0.32)
Method	Constructor Parameter	0.0000	(-0.09, -0.06)
Parameter	Method Return	0.0054	(0.00, 0.00)
	Local Variable	0.0000	(0.44, 0.50)
	Field	0.0000	(0.26, 0.30)
Method	Constructor Parameter	0.0000	(-0.13, -0.08)
Return	Method Parameter	0.0054	(0.00, 0.00)
	Local Variable	0.0000	(0.44, 0.47)
	Field	0.0000	(-0.17, -0.44)
Local	Constructor Parameter	0.0000	(-0.67, -0.27)
Variable	Method Parame	0.0000	(-0.50, -0.26)
	Method Return	0.0000	(-0.47, 0.17)

Table 4. Mann-Whitney U Test results for the comparison between the usage of types by type of declaration

The significance test results are displayed in Table 4. It shows the *p* value and confidence interval reported by the Mann-Whitney U test for every two declaration types. There are only two types of declaration for which *p* values different from zero are reported, parameters and returns of methods. This means that there is no significant difference in how programmers use types in these two kinds of declaration. This is reasonable since returns and parameters of methods are declared together as part of a method signature. All other declaration types, however, can be considered significantly different from each other. This includes parameters of methods and constructors. Although these are essentially the same type of declaration in Groovy, they seem to be perceived differently by programmers when it comes to typing. Nevertheless, the difference between these two declaration types reported by the confidence interval is relatively small, $(-0.09, -0.06)$. Other interesting insights provided by these results are that local variables are the least typed declarations while constructor parameters are the most typed ones.

4.3 Declaration Visibility

This sections presents an analysis about how programmers type their declarations according to the their visibilities. We follow the same approach from the previous section. Figure 4 shows box plots for the usage of types per declaration type along with the descriptive statistics. Declarations of fields, parameters and returns of methods and parameters of constructors of all projects are considered. Mann-Whitney U test results are presented in Table 5.

The null hypothesis can be rejected for all cases since the reported *p* values are always equal to 0. Protected declarations are those typed most often. Notice how skewed is the distribution for
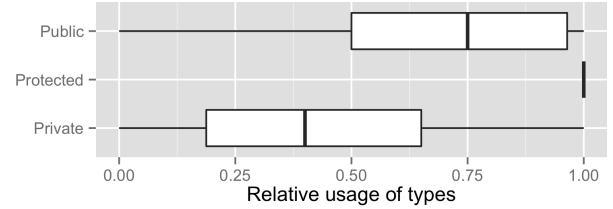
Declaration Visibility	n	mean	median	std. dev.
Public	5852	0.69	0.75	0.29
Protected	2387	0.93	1.00	0.19
Private	6023	0.43	0.40	0.32

Figure 4. Usage of types in all declarations by type of declaration

these elements in Figure 4. Almost all 2387 projects which use protected visibility in their declarations have all of their protected fields, methods and constructors typed. The confidence intervals reported by the U tests show a large difference between these declarations and those with either private or public visibility. Although public declarations are not typed as much, they are also typed very often. At least half of the projects type 75% or more of their declarations. Conversely private declarations are those with the smallest relative use of types.

|		p	conf. interval
Public	Protected	0.0000	(-0.22, -0.18)
	Private	0.0000	(0.28, 0.31)
Protected	Public	0.0000	(0.18, 0.22)
	Private	0.0000	(0.54, 0.57)
Private	Public	0.0000	(-0.31, -0.28)
	Protected	0.0000	(-0.57, -0.54)

Table 5. Mann-Whitney U Test results for the comparison between the usage of types by visibility of declaration

4.4 Test Classes and Main Classes

We now analyze the use of types in test classes in comparison to main classes. A simple heuristic to determine if a class was written as a test class or a main class is used. In Groovy, like in Java, it is common to organize test classes and main classes in different source folders. The convention adopted by popular build tools among Groovy programmers, such as Gradle and Maven, assumes that test classes and main classes are in the *src/test/groovy* and *src/main/groovy* directories respectively. Based on these conventions, we can assume that any classes inside a *test* directory, but not in a *main* directory, are test classes.

For every project, we measured the usage of types in test classes and main classes. Script files are not considered in this analysis. We found test classes in 4350 of the 6638 projects in our dataset. Results are displayed in Figure 5 and show the relative usage of types by declaration type. White and gray box plots correspond to test classes and main classes respectively. We also applied the Mann Whitney U test, but this time however we are not comparing declaration types to each other. Instead, we are comparing declarations in test classes to declarations of the same kind in main classes. Results for the U test are shown in Table 6. We do not show results by visibility since this is usually not a concern when writing test classes.

According to Figure 5 and Table 6, the usage of types in test classes is very different for declarations of local variables and
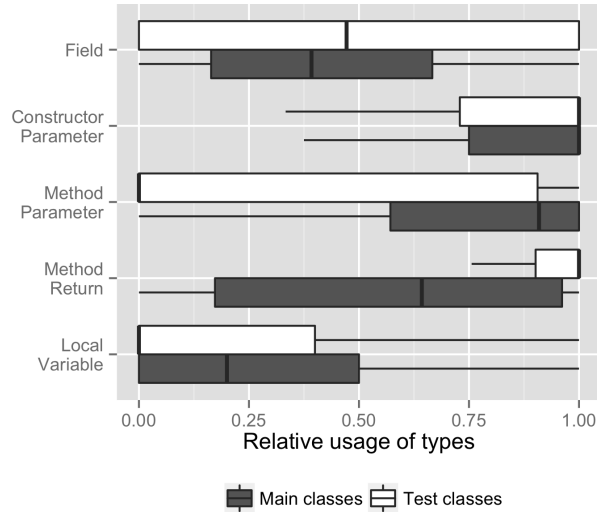
Declaration Type	Class Type	n	mean	median	std. dev.
Field	Test	1769	0.48	0.47	0.43
	Main	5857	0.43	0.39	0.33
Constructor Parameter	Test	124	0.77	1.00	0.41
	Main	1623	0.80	1.00	0.34
Method Parameter	Test	1524	0.34	0.00	0.43
	Main	4593	0.71	0.91	0.35
Method Return	Test	4334	0.85	1.00	0.31
	Main	5299	0.54	0.60	0.39
Local Variable	Test	2842	0.23	0.00	0.35
	Main	5548	0.30	0.19	0.32

Figure 5. Usage of types by declaration type in test classes and main classes

methods. While local variables in main classes are not typed very often, they are typed even less in test classes. At least half of the projects type none of the declarations of this kind in test classes. The difference in declarations of parameters of methods is even more evident since they are often typed in main classes, but almost never typed in test classes. The confidence interval reported by the U test in this case is $(-0.533, -0.420)$. The large width of the box plots for fields and method parameters is noteworthy. This indicates that many projects type either almost all or none of these declarations.

Curiously, method returns are significantly more typed in test classes. The difference reported by the confidence interval in Table 6 for this case is $(0.200, 0.250)$. At least half of the projects type all of their method returns in test classes. Although counter intuitive this result can be easily explained. Automated testing frameworks usually enforce a certain method signature for test methods. JUnit for example, which is used in 2525 of the 4350 projects with test classes, requires test methods to be typed as *void*. Other popular test frameworks, such as TestNG, have similar requirements. This implies that, in this case, developers type their methods not because they want to, but because they need to.

4.5 Script Files and Class Files

This section investigates how programmers type their code in script files. Similar to what was done in the previous section, we measured the usage of types in script files and class files in all projects and compared the obtained data. Determining whether a file corre-

Declaration Type	p	conf. interval
Field	0.0020	(0.000, 0.000)
Constructor Parameter	0.4389	(0.000, 0.000)
Method Parameter	0.0000	(-0.533, -0.420)
Method Return	0.0000	(0.200, 0.250)
Local Variable	0.0000	(-0.070, -0.032)

Table 6. Mann-Whitney U Test results for the comparison between the usage of types by test classes and main classes

sponds to a script or a class is fairly simple. In Groovy, a script file is compiled into a class extending *groovy.lang.Script*. We consider all classes extending this class to be scripts.

Figure 6 and Table 7 show the results of our analysis. Note that constructors and fields are not considered since there is no way to declare those elements in scripts. Also, we do not present an analysis of declarations grouped by visibility since, although allowed, defining the visibility of a declaration inside a script does not make any sense.
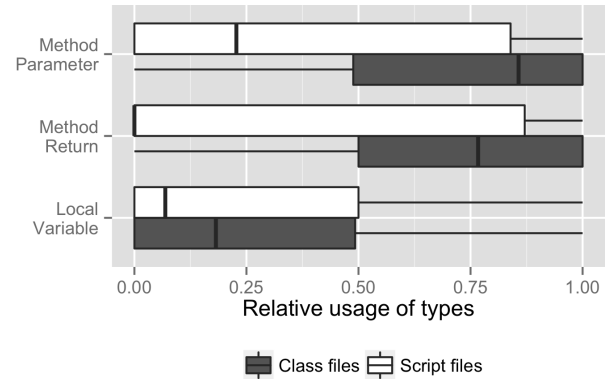
Declaration Type	File Type	n	mean	median	std. dev.
Method Parameter	Script	504	0.40	0.23	0.42
	Class	4647	0.69	0.86	0.35
Method Return	Script	583	0.34	0.00	0.43
	Class	5662	0.70	0.77	0.30
Local Variable	Script	1775	0.28	0.07	0.37
	Class	5246	0.30	0.18	0.32

Figure 6. Usage of types by declaration type in script files and class files

Programmers type all kinds of declarations differently in scripts. According to the p values shown in Table 7, the null hypothesis can be rejected for all cases. The confidence interval reported for local variable declarations though is relatively small. This indicates a small difference for this type of declaration between scritps and classes. On the other hand, declarations of methods present a very different behavior. Unlike in classes, most of these declarations are not typed in scripts. This is even more clear in method returns, where most of projects do not type any of these declarations in script files. Note however that the value for the last quartile of these declarations is very high, superior to 0.8. This indicates that, although most projects prefer not to use types in these declarations, there are a few projects that consistently type most of them.

Declaration Type	p	conf. interval
Method Parameter	0.0000	(-0.385, -0.234)
Method Return	0.0000	(-0.500, -0.400)
Local Variable	0.0000	(-0.021, 0.000)

Table 7. Mann-Whitney U Test results for the comparison between the usage of types in script files and class files

### 4.6 Programmers' Background

In this section, we analyze how programmers use types in their declarations according to their backgrounds. Projects are distributed in three groups based on the type system of the languages their developers have used on GitHub. The first group comprises those projects of programmers who developed only in statically typed languages, such as Java or C#. The projects of those who developed only in dynamically typed languages, such as Ruby or JavaScript, comprise the second group. Finally, the third group is formed by the projects of those programmers with both dynamically and statically typed languages in their portfolio. Figures 7 and 8 show results by declaration type and visibility respectively. Results for the Mann-Whitney U test are reported in Tables 8 and 9. Notice that these tables are divided in three groups, each one corresponding to the comparison between the data of two of the three different groups.

	Declaration Type	p	conf. interval
Static vs. Static and Dynamic	Field	0.0000	(0.073, 0.163)
	Constructor Parameter	0.7281	(0.000, 0.000)
	Method Parameter	0.0000	(0.000, 0.036)
	Method Return	0.0000	(0.000, 0.067)
	Local Variable	0.0000	(0.038, 0.100)
Static vs. Dynamic	Field	0.0000	(0.139, 0.228)
	Constructor Parameter	0.9347	(0.000, 0.000)
	Method Parameter	0.0000	(0.005, 0.076)
	Method Return	0.0000	(0.000, 0.062)
	Local Variable	0.0000	(0.057, 0.126)
Static and Dynamic vs. Dynamic	Field	0.0000	(0.000, 0.050)
	Constructor Parameter	0.7531	(0.000, 0.000)
	Method Parameter	0.0032	(0.000, 0.013)
	Method Return	0.5269	(0.000, 0.000)
	Local Variable	0.0071	(0.000, 0.005)

Table 8. Mann-Whitney U Test results for the comparison between the usage of types by declaration type and programmers background

The usage of types by programmers with both statically and dynamically typed languages in their portfolio is similar to that of programmers with dynamically languages only. According to Tables 8 and 9, the only significant differences in the usage of types are in declarations of fields or in those with public visibility. Still, the difference indicated by the confidence interval in these cases is arguably small, between 0 and 0.05 in both cases.

Programmers with only statically typed languages in their portfolio tend to use more types than the others. There are only two situations where the *p* value reported by the Mann-Whitney U test is big enough so the null hypothesis can not be rejected, protected declarations and declarations of constructor parameters. In all other cases, these programmers use type more often than the others.
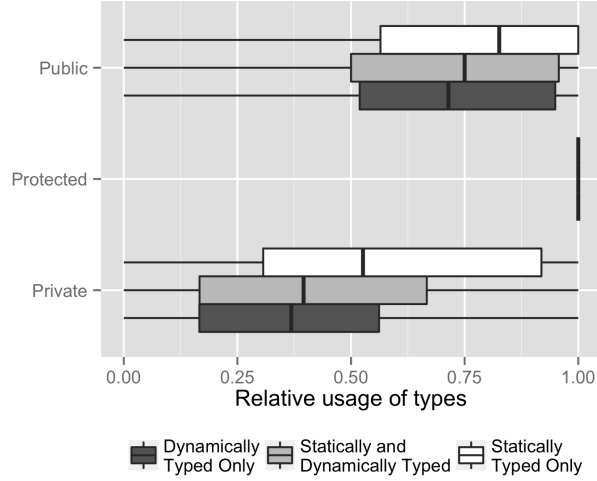

Figure 7. Usage of types by declaration type and programmer background
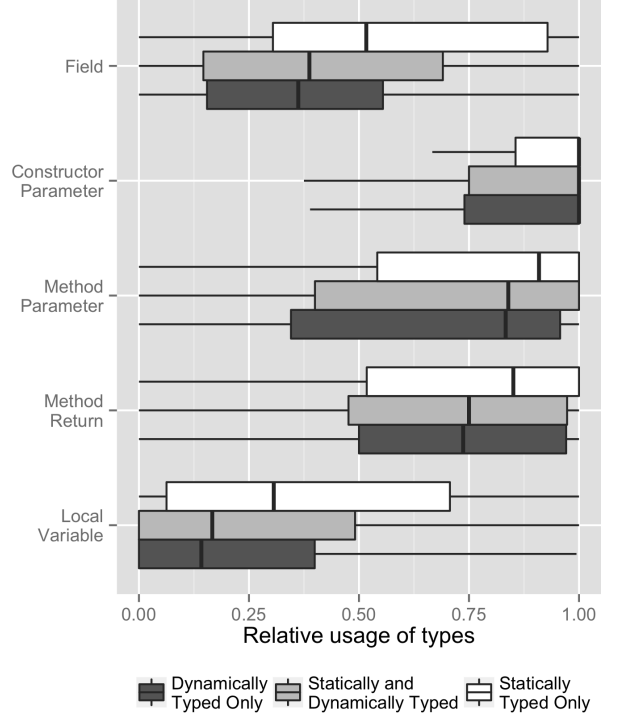
Declaration Type	Background	N	Mean	Median	Std. Dev.
Field	Static	782	0.56	0.52	0.35
	Both	3183	0.43	0.39	0.34
	Dynamic	2035	0.38	0.36	0.29
Constructor Parameter	Static	224	0.83	1.00	0.33
	Both	991	0.80	1.00	0.35
	Dynamic	455	0.80	1.00	0.34
Method Parameter	Static	662	0.73	0.91	0.34
	Both	2694	0.67	0.84	0.36
	Dynamic	1511	0.65	0.83	0.37
Method Return	Static	764	0.73	0.85	0.30
	Both	3205	0.66	0.75	0.32
	Dynamic	1912	0.68	0.74	0.29
Local Variable	Static	798	0.39	0.31	0.36
	Both	3230	0.28	0.17	0.32
	Dynamic	1817	0.25	0.14	0.30

4.7 Project Size, Age and Number of Commits

This section investigates whether programmers use types differently in their code depending on the project characteristics. We analyze three metrics: age, number of lines of code and number of commits. We start by analyzing the correlation between these metrics and the relative use of types in declarations by type and visibility. The Spearman rank correlation coefficient is used for this purpose. This coefficient, which can go from -1 to 1, is a measure of the dependence between two variables. A positive value means that two variables are correlated, i.e, as the value of one grows, so does the value of the other. A negative value means an inverse correlation. Values close to 1 or -1 indicate very strong relationships

Figure 8. Usage of types by declaration visibility and programmer background

Declaration Type/Visibility	Size	Age	Commits
Field	0.221	-0.063	0.153
Constructor Parameter	-0.072	-0.132	-0.053
Method Parameter	-0.123	-0.079	-0.004
Method Return	-0.071	0.168	-0.027
Local Variable	0.057	-0.049	0.112
Public	-0.063	0.119	-0.024
Protected	-0.286	-0.020	-0.165
Private	0.213	-0.068	0.160

Table 10. Spearman Correlation between the usage of types and the size, age and number of commits of projects

	mean	median	std. dev.	max	total
Size (LoC)	9947	5627	14594	149933	2218189
Commits	487	213	800	6545	108583
Age (Days)	600	574	350	1469	133697

Table 11. Descriptive statistics for mature projects

Declaration Type	Background	n	mean	median	std. dev.
Public	Static	757	0.73	0.83	0.29
	Both	3191	0.68	0.75	0.30
	Dynamic	1904	0.69	0.71	0.27
Protected	Static	287	0.92	1.00	0.20
	Both	1275	0.94	1.00	0.18
	Dynamic	825	0.93	1.00	0.20
Private	Static	787	0.56	0.53	0.34
	Both	3196	0.43	0.40	0.33
	Dynamic	2040	0.38	0.37	0.28

types. A possibility is that this influence appears only in the most mature projects, where the values of all of these three metrics are high enough. In order to determine whether this is true, we conduct now a comparison between mature projects and the rest of the dataset. We define a mature project as a project that is 100 days old or more and has, at least, 2KLoC and 100 commits. These numbers were defined by manually inspecting our dataset and finding that there are popular and mature projects that barely exceed these three metrics. According to our criteria, there are 223 mature projects in our dataset, which are detailed in Table 11.

Figures 9 and 10 show the box plots for the usage of types in mature projects and others by declaration type and visibility respectively. Mann-Whitney U test results for the samples presented in these graphs are displayed in Table 12. There are significant differences in the usage of types only in two cases, declarations of fields and protected declarations. For private declarations, although the value of p is 0, the confidence interval for the difference of medians is negligible. These differences are too small, specially when compared to the differences found when analyzing programmers' background, script files and test classes. Hence, we can not conclude that programmers type their declarations differently in mature projects, at least, when considering our definition of maturity.

	Declaration Visibility	p	conf. interval
Static vs. Static and Dynamic	Public	0.0000	(0.000, 0.058)
	Protected	0.1287	(0.000, 0.000)
	Private	0.0000	(0.082, 0.167)
Static vs. Dynamic	Public	0.0000	(0.000, 0.065)
	Protected	0.1130	(0.000, 0.000)
	Private	0.0000	(0.143, 0.229)
Static and Dynamic vs. Dynamic	Public	0.0000	(0.000, 0.051)
	Protected	0.8260	(0.000, 0.000)
	Private	0.8328	(0.000, 0.000)

Table 9. Mann-Whitney U Test results for the comparison between the usage of types by declaration visibility and programmers background

while values above 0.5 or below -0.5 can be considered strong correlations.

Table 10 shows the Spearman correlation coefficient between the usage of types and the age, size and number of commits of a project. Most of values in this table are close to 0. There are only a few which could indicate a very weak relationship, such as *Size* vs. *protected* or *commits* vs. *private*. All in all, we can not say that there is a correlation between the metrics and the usage of types in Groovy projects.

The lack of correlation between usage of types and these metrics does not necessarily imply that they no influence on the usage of

Declaration Type/Visibility	p	conf. interval
Field	0.0000	(0.053,0.173)
Constructor Parameter	0.3203	(0.000,0.000)
Method Parameter	0.0794	(-0.051,0.002)
Method Return	0.9373	(-0.031,0.051)
Local Variable	0.0002	(0.012,0.078)
Public	0.8540	(-0.031,0.045)
Private	0.0000	(0.000,0.000)
Protected	0.0000	(0.055,0.169)

Table 12. Mann-Whitney U Test results for the comparison between the usage of types by mature projects and others
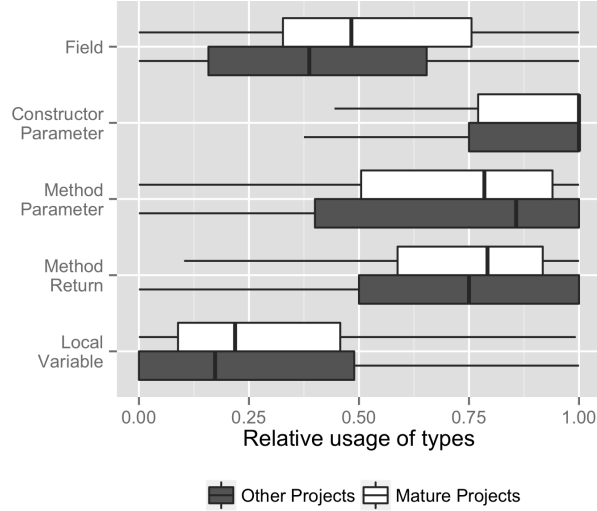
Declaration Type	Project Type	n	mean	median	std. dev.
Field	Mature	221	0.53	0.48	0.27
	Other	5779	0.43	0.39	0.33
Constructor Parameter	Mature	172	0.83	1.00	0.30
	Other	1498	0.80	1.00	0.35
Method Parameter	Mature	222	0.69	0.78	0.29
	Other	4645	0.67	0.86	0.37
Method Return	Mature	222	0.72	0.79	0.24
	Other	5659	0.68	0.75	0.32
Local Variable	Mature	223	0.32	0.22	0.28
	Other	5622	0.29	0.17	0.32

Figure 9. Usage of types in projects by declaration type and project maturity

4.8 Frequency of changes

This section investigates whether programmers prefer to type their declarations in frequently changed code or not. Only the mature projects defined in the previous section are considered since we would not be able to obtain meaningful results from small and young projects.

We found that in most of the mature projects programmers prefer untyped declarations in frequently changed code. We calculated the Spearman correlation coefficient between the frequency of changes of a file and the usage of types in that file for all mature projects. In projects where programmers prefer the usage of types in frequently changed files, this coefficient is positive, and negative in case programmers prefer untyped declarations. Figure 11 displays the cumulative distribution of this coefficient across the mature projects dataset. It shows that 65% of them present a negative Spearman correlation coefficient and that almost half of these present strong correlations, i.e., inferior to -0.5. On the other hand, it can be said that only 10% of the mature projects present strong positive correlations.

5. Discussion

In this section, we discuss the results of our study in order to try and answer the research questions proposed in Section 3.1. Although we were able to get a good understanding of the usage of types in different contexts, the cause for such results is still unclear in many of them. We provide several hypothesis with the goal of identifying
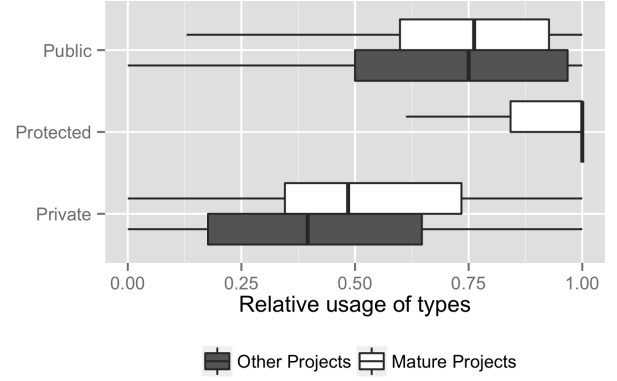

Declaration Type	Project Type	n	mean	median	std. dev.
Public	Mature	223	0.72	0.76	0.24
	Other	5629	0.69	0.75	0.29
Protected	Mature	183	0.88	1.00	0.21
	Other	2204	0.94	1.00	0.19
Private	Mature	221	0.53	0.48	0.26
	Other	5802	0.43	0.40	0.32

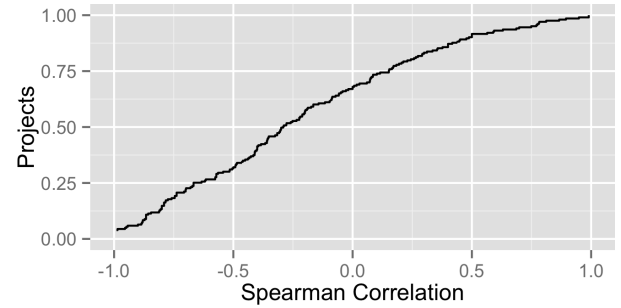**Figure 10.** Usage of types in projects by declaration visibility and project maturity

Figure 11. Spearman ranking for the correlation between frequency of changes of files and the usage of types in mature projects

future research topics that can provide more detailed insights about such causes.

Q1: Do programmers use types more often in the interface of their modules?

The analysis of the usage of types by kind and visibility of declarations, presented in Sections 4.2 and 4.3, shows evidence that the answer for Q1 is affirmative. Methods and constructors are the most typed declarations. In particular, constructors, which are extremely important members of a module definition, have their parameters always typed in most projects. Fields can also be part of a module definition, but are significantly less typed than methods and constructors. This can be explained by the fact that, in Groovy, similar to what happens with Java, interactions with fields of other modules usually happen through accessor methods. This is supported by Section 3.3, which shows that the great majority of field declarations is private.

Public and protected declarations, which compose the interface of a module, are typed more often than private declarations It is interesting to notice that protected declarations are typed with a

frequency much higher than public declarations. These declarations give subclasses and other classes in the same package access to internal elements of a class, forming a tightly coupled relationship [28]. In addition, protected methods are frequently designed to be overwritten by subclasses.

While it is clear that module definitions are typed more often, the cause for such phenomena is still open to discussion. We believe that the main motivation for this is the implicit documentation provided by types. In these scenarios, types provide useful hints about the behavior of modules [36] and define pre and post condition of contracts [22–27]. Users of an well defined module learn how to use it faster and do not need to read its implementation to understand how to use it. Programmers may consider that delicate contracts, such as those defined by protected methods, should be well documented and thus are typed more often.

We can also speculate that declarations that are not part of a module definition, local variables or those with private visibility, require less documentation and thus are typed less often. Programmers can easily find all the references to these elements. Local variables are only used inside the block of code where they were declared, while all the references to elements declared privately are in the same file. This makes it easier for them to infer the types of such declarations even when it is not explicitly defined.

Documentation may not be the only reason why programmers type declarations in modules interfaces. We can think of at least other two. First, a programmer might type a declaration so he or she can get code assistance from the development environment. For example, typing the declaration of a method parameter allows the development environment to provide code completion for that parameter inside the method. Another possibility is that, even though Groovy is actually a dynamically typed language, programmers might type their declarations thinking that the compiler will check for type errors, which would lead to safer interactions between modules

Q2: Do programmers use types less often in test classes and scripts?

There are notable differences between the usage of types in either test classes or scripts and the main classes of a program. Sections 4.4 and 4.5 show that, in these scenarios, programmers use types less often in declarations of methods and local variables. The only exceptions are declarations of method returns in test classes, which are typed in most cases due to requirements of testing frameworks such as JUnit and TestNG.

If we are right about our hypothesis that programmers type their modules as a means to document their code, than this could explain this less frequent use of types. Scripts and test classes are usually not designed as reusable modules. Test classes have the sole goal of verifying a program's functionality and not interfering with it while scripts can not be instantiated or referenced by other modules. In these scenarios, programmers might perceive documentation as less important. It is curious however that test code itself is usually considered by programmers as a form of documentation [37, 38]. Because of this, we were expecting programmers to actually use more types in test classes as a means to improve the documentation provided by them. Perhaps, although programmers use test classes as documentation, they might not write them with this goal in mind.

An alternative explanation for the fact that scripts and tests are typed less frequently is that most of them are probably simpler than functional classes. As found in the recent work of Hanenberg et al, typed code potentially has positive impacts on the development time of easier tasks [34]. In such case, programmers might not type their declarations in scripts or test classes since this would allow them to finish their tasks faster.

Q3: Does the previous experience of programmers with other languages influence their choice for typing their code?

The analysis presented in Section 4.6 indicates that the answer for Question Q4 is affirmative. The choice for using types on a language with optional typing, such a Groovy, is in fact influenced by the programmers' experience with other languages. However, this influence is only visible on programmers who have only static languages on their GitHub portfolio. In most cases, these programmers type their declarations more often than others.

The usage of types by those who developed only in dynamically typed languages and those with experience in both typing paradigms is not significantly different. Apparently programmers who develop in a language with a dynamic type system get used to the lack of types, leading them to declare types less often. This hypothesis supports the work of Daly et al which suggests that such programmers have ways of reasoning about types that compensate for the lack of static type information [7].

Q4: Does the size, age or level of activity have any influence on the usage of types?

We initially believed that, as these metrics grow, the maintenance of projects becomes more difficult, leading programmers to use more types as a means to make code more readable. However, the analysis presented in Section 4.7 shows no evidence of such behavior. We consider two hypothesis in order to explain these results. First, the considered metrics might not actually correlate to the need for maintenance of projects. Second, even if these metrics are a good indicative of the necessity of better maintainability, once projects start growing and aging, programmers might not have the opportunity or desire to make their code more maintainable.

Q5: In frequently changed code, do developers prefer typed or untyped declarations?

In frequently changed code, there are arguments in favor and against using types. Since types act as documentation, programmers might use them to make code more maintainable and easier to change [10]. On the other hand, untyped code is simpler and can potentially be changed faster [14]. The results presented in Section 4.8 however show that the latter is considered more often than the first.

In most projects, the usage of untyped declarations grows as the frequency of changes in a file increases. Apparently, programmers understand that untyped code makes maintenance tasks easier. One can argue that the causal relationship is the opposite, i.e., these files have to be changed more often because of problems generated by the use of untyped declarations. However, it is very unlikely that programmers would not notice that untyped declarations would be causing such problems and would not add types to those declarations in order to fix them.

6. Threats to Validity

In this section, we discuss potential threats to validity. As usual, we have arranged possible threats in two categories, internal and external validity [31].

Internal Validity

Perhaps the most relevant internal threat to our study is that in a large scale empirical study such as ours, there might be many confounds which are difficult to identify. In Section 4.6 we consider that the GitHub portfolio of a programmer represents well his experience with other languages and type systems, but this might not be true for all programmers. They may have projects in their portfolio that they have not worked on or projects hosted somewhere else written in other languages. There is still the possibility of a

programmer having multiple GitHub accounts with different languages in each one, causing this programmer to be measured twice with different inferred backgrounds. Due to the large number of programmers considered in our study, we expect these special cases not to have a large influence over the results.

There are other factors which might have influenced programmers besides the ones considered in this study. Some frameworks require programmers to use typed or untyped declarations in some cases. For example, we found that the data collected in test classes is biased by the fact that popular testing frameworks, such as JUnit, require test methods to have their returns declared as *void*. There might be other similar cases that we were not able to indentify.

In our discussion, in Section 5, we avoided providing definitive answers for what caused the behavior we found in our analysis. Instead, we raised many hypothesis to explain these results. It is difficult however to state whether these hypothesis make sense or not. In order to overcome this uncertainty, we are planning a series of controlled and qualitative studies which will complement the findings in this study in order to validate or reject these hypothesis.

External Validity

Although we have analyzed a very extensive number of Groovy projects, it can not be said that we have all possible scenarios covered. By manually inspecting our dataset, we could find only a few projects with characteristics of software developed inside an organization. Most of them were developed by small groups of people or open source communities. Such enterprise projects are probably hosted privately on GitHub or in private servers, hence unavailable to us.

The behavior observed for Groovy projects can be very different in other languages. Most languages are not like Groovy and feature either static or dynamic typing, forcing programmers to choose a single typing strategy for all scenarios in a single project. Even a language with a hybrid typing paradigm might implement different strategies which will be perceived differently by the programmers of that language. Finally, the tools used to code in a given language might influence programmers to chose different type strategies.

7. Related Work

There are multiple studies in the literature which compare different typing strategies. Although we are not aware of any studies that analyze this question using a large scale case study as ours, we know of multiple controlled experiments with significant results. One of the goals of this paper is to complement theses results by providing a a different point of view to their analyses.

In a recent experiment, Hanenberg et al. studied the impact of the use of types on the development time of programmers while performing tasks on an undocumented API [34]. The experiment divided 27 people in two groups. They developed in two languages, one statically typed, Java, and the other dynamically typed, Groovy. Results revealed a positive impact of the use of types when these were used to document design decisions or when a high number of classes had to be identified by programmers. On the other hand, for easier tasks, programmers developed faster in the dynamically typed language. Our analysis suggest that programmers are aware of these tradeoffs and consider them when choosing whether to type or not their declarations. In potentially simpler scenarios, such as scripts and tests, we show a lower usage of types. Conversely, programmers type the interface of their modules very often, probably as a means to document their code. This implicit documentation potentially improves the development time in more complex scenarios, such as those where programmers benefited from types in [34].

In experiments conducted in [7], the authors compare the performance of two groups working on small development tasks. One group used Ruby, a dynamically typed language, while the other used DRuby, a statically typed version of Ruby. Results showed that the DRuby compiler rarely managed to capture any errors that were not already evident for programmers. Most subjects involved in the study had previous experience with Ruby, which suggests that programmers get used to the lack of typing in their declarations. Our analysis of the programmers' backgrounds supports this argument. It shows that those programmers which have worked with dynamically typed languages in fact use types less often.

8. Conclusions and Future Work

In this paper we conducted a large scale case study in order to investigate how types are used in Groovy. Our goal is to find what are the points of views of programmers about what typing strategies are more suitable to which contexts. The main findings of this study are:

- Groovy programmers type declarations that define the interface of modules more often than other declarations
- Types are less popular in test classes and script files
- Those programmers who have developed in at least one dynamically typed language use types less frequently than those who have only worked with statically typed languages
- Apparently, there is no influence of the size, age or level of activity of a project on how programmers use types
- In most projects, the files that change more frequently are also those files with a lower usage of types

We believe that these results are valuable to developers of programming languages and development tools who can base their designs on real user data. Also, programmers can understand the tradeoffs between using or not types in their projects. Our results provide a different point of view and complement previous studies which analyzed typing strategies through the use of controlled experiments. We hope that the questions raised in our discussion can inspire other researchers to analyze our findings in more details.

In future work we want to conduct controlled experiments and qualitative studies in order to evaluate some of our results in more details. In particular, we have started a new study with the goal of finding what are the impacts of the use of the documentation provided by types and the documentation provided by unit tests on the development time of maintenance tasks. Another work in progress is a framework for the analysis of large numbers of source code repositories called ERA (Elastic Repository Analysis). This framework is based on the artifacts we built in order to obtain and process our large dataset. ERA will help other researchers to retrieve large numbers of projects from GItHub as well as process these projects quickly on the cloud using Amazon Web Services.

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