ABSTRACT
Aspects of frameworks, such as inversion of control and the structure of framework applications, require developers to adjust their debugging strategies as compared to debugging sequential programs. However, the benefits and challenges of framework debugging are not fully understood, and gaining this knowledge could provide guidance in debugging strategies and framework tool design. To gain insight into the process developers use to fix problems in framework applications, we performed two human studies investigating how developers fix applications that use a framework API incorrectly. These studies focused on the Android Fragment class and the ROS framework. We analyzed the results of the studies using a mixed-methods approach, consisting of techniques from grounded theory, qualitative content analysis, and case studies. From our analysis, we produced a theory of the benefits and challenges of framework debugging. This theory states that developers find inversion of control challenging when debugging but find the structure of framework applications helpful. This theory could be used to guide strategies for debugging framework applications and framework tool designs.

CCS CONCEPTS
• Software and its engineering → Development frameworks and environments; Software testing and debugging; • Human-centered computing → HCI theory, concepts and models;

KEYWORDS
Frameworks, Debugging, HCI Theory

ACM Reference Format:
Zack Coker, David Gray Widder, and Claire Le Goues, Christopher Bogart, Joshua Sunshine. 2018. Debugging Framework Applications: Benefits and Challenges. In Proceedings of ACM Conference, Washington, DC, USA, July 2017 (Conference’17), 12 pages.
https://doi.org/10.1145/nmnnmn.nmnnmn

1 INTRODUCTION
Software developers often rely on libraries, structured as functions or classes, to save development time through reuse. When a library provides the central driving event loop of a program, it may be better organized as a framework. Frameworks organize applications via a mechanism known as inversion of control [5]: The core logical component of the framework calls project-specific code of the application, and only when required. This mechanism requires applications conform to a predefined architecture [5] and interact with code through a defined interface. The main benefits of this approach are time saved through reuse and from consistent application structure — the provided high-level application architecture, file organization, and standard application control flow.

Our conjecture is that the aspects that differentiate framework programs from sequential programs that use libraries (the heavy use of inversion of control, object protocols, and declarative artifacts) should present unique debugging challenges [5]. However, how these factors influence a developer’s debugging process is not well understood. Improvements in understanding how these factors influence the debugging process could lead to improved framework design, along with improved strategies and tools for debugging.

We performed an exploratory study to understand how frameworks help and hinder developers during the debugging process. To improve our study’s external validity, we investigated two frameworks with different use cases: Android, a mobile development framework, and the Robotic Operating System (ROS), a robotics framework. We created debugging tasks based on framework directives, statements in framework documentation that specify testable assertions about the framework’s application programming interface (API) and usually contain nontrivial, unexpected information (e.g., “setArguments” can only be called before the Fragment is attached to its Activity) [9]. We focused on directives because these statements present general framework problems, instead of application specific issues. We collected directives for these frameworks and then created debugging tasks based on directive violations (code that contravenes a directive). We then had participants perform these debugging tasks and recorded their debugging process.

We used a mixed-methods approach to guide our study and analysis, borrowing techniques from case studies [39], constructivist grounded theory [4], and qualitative content analysis [34]. We used this approach to produce a theory explaining which framework aspects help and hinder developers in debugging framework misuses. We also investigated how the presentation of directive violations to developers can affect the debugging process.

We found that certain aspects of frameworks benefit developers by reducing the number of mental steps developers need to achieve a goal, while other aspects of frameworks present challenges (e.g., inversion of control causes participants to misdiagnose possible method states). Our key contributions are:
Results from two studies of humans debugging various directive violations taken from the Android Fragment class, and the Robotic Operating System (ROS).

- An enumeration of the benefits and challenges in debugging misuses of framework APIs.
- A theory that explains the benefits and challenges in framework debugging.

The rest of this paper is organized as follows. We discuss the methodology behind our human studies and theory creation in Section 2. We present the results of our study in Section 3. Section 4 presents the theory we produced from the study. Section 5 discusses the study’s threats to validity. Section 7 discusses related work. Section 8 concludes.

2 METHODOLOGY

We focused on investigating the unique aspects of debugging framework API misuse as compared to debugging sequential programs, and used that knowledge to create a theory of framework debugging. We describe the philosophical basis of our study in Section 2.1. Our source of data was human trials, conducted with a case study procedure, a methodical investigation into a phenomenon where there may be more variables of interest than data points [39]. We chose this method of data collection to observe and analyze the process participants took when addressing framework debugging problems. To perform human trials, we created debugging tasks. We describe the methodology we used to select frameworks and create these tasks in Section 2.2. This resulted in seven Android tasks and three ROS tasks. Once we created the tasks, we collected study participants and conducted human trials, described in Section 2.4. We coded the tasks using an iterative process for each framework. First, we coded the interesting actions of the first few participants. Then, we defined coding frames of the interesting actions using qualitative content analysis, a technique that condenses verbal or visual data into important topics [34]. After coding both case studies, we performed theoretical sorting to condense the coded data and other sources into a cohesive theory [4].

2.1 Philosophical Basis

We created our framework debugging theory via a mixed-method methodology consisting of constructivist grounded theory [4], qualitative content analysis [34], and case studies [39]. Our first guiding principle for our study approach is based in grounded theory: the theory created by the investigation is grounded in the data, but further investigations may be needed to verify the resulting theory [15]. The study also has a philosophical basis in constructivist grounded theory: the researcher influences the results and there may be multiple correct theories for the same phenomenon due to different perspectives [4]. We chose these philosophical bases for two reasons: (1) while an exploratory study can provide enough insight for theory formation, further controlled studies need to be conducted to verify any theory created from an exploratory investigation and (2) while researchers should try to remove as many biases as possible from an investigation, it is currently impossible for a researcher to remove all unconscious biases, which may influence the study results. We also took precautions to minimize the biases that could arise from an in-depth literature review, such as trying to make the study results match a similar study’s results, as recommended by grounded theory [35]. Thus, we conducted a minimal, initial literature review and later conducted a more in-depth literature review after finishing the trials.

2.2 Frameworks in the Study

Definitions. Frameworks provide a set of interfaces and classes that reduce the cost to achieve a general goal [25]. Developers create applications to achieve specific goals by extending frameworks, often by extending abstract framework methods. The framework typically calls application code through inversion of control, a design in which the core framework code, not the application-specific code, controls the data and execution flow of an application [5]. Frameworks usually achieve inversion of control through extending abstract methods. Frameworks commonly require applications to conform to a specified application structure. Frameworks also commonly use object protocols, ordering constraints on calls to an object’s methods [2], and declarative artifacts, non-source code files that contain configuration information [5].

Framework Selection Process. We conducted our study using debugging tasks for two frameworks: Android (version 5.0 Lollipop - API 21, specifically the Fragment class), and the Robotic Operating System (ROS) (Kinetic Kame).

Google’s Android [11] provides a Java framework for developing mobile applications. Android is a widely-used, mature framework and has been released for over seven years. The Android Fragment class represents a reusable component of an Android application’s user interface. A picture of an Android Fragment in an example Android application is shown in Figure 1, to illustrate its usage. We began with the Android framework for three reasons: (1) it is widely-used and well-established, (2) it makes heavy use of inversion of control and object protocols, key features that differentiate frameworks from libraries, and (3) multiple developers express difficulties with the framework, as demonstrated by searching for Stack-Overflow1 questions. In particular, we found that a large portion

Figure 1: An example of the Fragment class taken from the Android development documentation. This diagram demonstrates how the Fragment class is used in an Activity.
of StackOverflow questions focused on the Android `Fragment` class, informing our focus on that class in our study.

To improve the generalizability of our claims, we selected ROS as a second framework for study. Robot Operating System [32] (ROS) is a framework for creating robotics applications, with a focus on the communication between various robotic components. ROS applications are built as a collection of nodes that communicate in an event driven model. ROS is also a mature framework and has been released for over eight years. ROS is written in both C++ and Python. The ROS framework is both more domain specific and has a significantly smaller developer base than Android.

Our criteria for the second framework was that it should focus on a different domain than Android, and have a different framework architecture. We decided on the ROS framework for four reasons: (1) ROS is designed for robotic applications instead of mobile applications, (2) ROS uses an event based architecture instead of the tiered architecture of Android, (3) ROS is written in C++ instead of Java, and (4) ROS has a smaller user base, but still sufficient users that we could find experienced participants for the study.

### 2.3 Task Creation Methodology

We used violations of framework directives to create the debugging tasks. Framework directives are testable, non-obvious statements in a documentation source about how to use the framework (e.g., “`setHasOptionsMenu(true)` must be called to execute an overridden `onCreateOptionsMenu` method”). A directive violation is a section of code or application that does not conform to the testable statement. We focused on directive violations to improve the chances that our results will generalize, because framework API misuse errors are not application specific. Framework directives are also likely to provide situations where participants have difficulty with a framework, due to the surprising nature of directives. The process of extracting directives for both frameworks consisted of one author extracting directives from the documentation and another author double-checking the extracted directives, similar to the coding process in prior work [35].

We first collected 45 Android `Fragment` directives from three official documentation sources: (1) the `Fragment` page in the developer’s guide, (2) the `Fragment` API page, and (3) the `Fragment` class’s source code. 11 directives were from the fragment guide, 19 directives were from the `Fragment` API page, and 15 were from the official `Fragment` code. We extracted directives from documentation statements and error messages in the code, but only if the directives were testable and described a non-obvious requirement of the framework.

To inform our task selection, we investigated the consequences of violating Android `Fragment` directives and how those violations were presented to developers. We created violation scenarios through a multi-step process: (1) we manually inspected the directives, (2) we created scenarios that violated the directives, and (3) we manually confirmed the directive violation, either with the scenario’s output or through print statements. We then categorized the directives by the directive violation consequence — The effect on the application that the developer would see when that directive was violated.

To select tasks, we searched for StackOverflow questions that cover Android `Fragment` directives from a wide range of violation consequence categories. We found seven StackOverflow questions and used the questions to create seven tasks. The seven tasks were created by taking an Android Lollipop sample application [4] that demonstrated the various notifications available in Android Lollipop and changing the application to encompass the scenarios mentioned in the StackOverflow questions.

For the ROS framework, we extracted 28 directives from two sources: (1) the official ROS C++ documentation [5] and (2) ROS C++ source code [6]. 9 directives were from the documentation and 19 were from the source code. Due to the relatively low number of online questions about ROS, we were unable to collect ROS directive scenarios from StackOverflow. Instead, we choose three directives that represented materially different cases, and manually created tasks for each. We created the first and third task by modifying the TurtleSim scenario [7], a two node configuration where a virtual turtle in one window moves and publishes the movements so the virtual turtle in the other window mimics the movements. The second task involved a simple, custom-built directory reading application.

In the rest of the paper, the Android tasks and participants will be prefixed with a “TA” and “PA” respectively. The ROS tasks and participants will be prefixed with a “TR” and “PR” respectively. Table 1 lists the number of participants per task and briefly explains the Android and ROS tasks.

### 2.4 Human Trials Methodology

After obtaining IRB approval, our human trial process started with a pre-survey to document participants’ framework experience. We provided participants a Surface Pro 3 tablet containing the tasks, and we instructed them to perform think-aloud debugging, vocalizing what they thought as they went through the debugging process [31]. We assigned a task to each participant, and asked them to fix the bug. We did not inform participants of the directive violation in the task because we were interested in also studying the fault localization process. If participants finished a task and could stay for another 20 minutes, we asked them to attempt another task. We initially assigned tasks randomly but later selected tasks that the fewest participants had attempted, to provide a relatively even task coverage. For each task, we gave participants the maximum time allowed, but they were able to quit at any time. We allowed participants to search online for anything, including the inspiration for the tasks, but we did not allow them to post questions. While searching online, no participant found the inspiration for any of the study’s tasks. In addition to asking them to vocalize aloud their thoughts and strategies during the tasks, we asked participants about their approach in greater detail at the end of the study.

For the Android study, we collected a convenience sample of 15 participants. 11 of the participants had over 2 years of industrial Java or Android experience, and 14 of the participants had more

---

1. developer.android.com/guide/components/fragments.html
2. developer.android.com/reference/android/app/Fragment.html
3. docs.ros.org
4. github.com/googlesamples/android-LNotifications
5. wiki.ros.org
6. http://wiki.ros.org/ROS/Tutorials/UsingRxconsoleRoslaunch
### Table 1: Android and ROS tasks in the human trials. TA tasks indicate Android tasks; TR, ROS tasks. “Count” shows number of participants per task. “Goal” indicates task success conditions. “Violated Directive” is a simplified explanation of the violated directive motivating the task. “Result of Directive Violation” explains how the application presented errors to participants.

| Task | Count | Goal | Violated Directive | Result of Directive Violation |
|------|-------|------|--------------------|-------------------------------|
| TA1  | 5     | The participant must connect user inputs to the output message when input components initially share the same ID. | Application components must have a unique ID to be referenced individually. | Any attempt to access one of the components with the same ID returned the last component added. |
| TA2  | 6     | The participant must display the application start time on a tab without a warning. | The application should not pass time data through the constructor. | AndroidStudio displayed a warning and recommend a fix. |
| TA3  | 4     | The participant must make the framework check for an updated `OptionsMenu`. | The framework only checks for a `OptionsMenu` if the application calls `setHasOptionsMenu(true)`. | The `OptionsMenu` does not appear, although a `OptionsMenu` is defined. |
| TA4  | 5     | The participant must display the application’s `Activity` (the entry point for an Android application) title in a pop-up message on a specific tab. | The `Fragment` could only access the `Activity` if the `Activity` was attached to the `Fragment`, and the `Activity` was not attached. | The application crashed with a notification that the `Activity` was not set. |
| TA5  | 4     | The participant must fix a problem that occurs when the application tries to change the color of a button on a tab when the tab had been previously accessed. | A tab’s arguments can only be set before the tab is accessed. | The application crashed, stating that arguments can only be set before the tab has started. |
| TA6  | 3     | The participant must change a specified `ContextMenu` to an `OptionsMenu`. | Items should be added to the `OptionsMenu` in the `onCreateOptionsMenu` method. | The `OptionsMenu` would not appear. |
| TA7  | 5     | The participant must fix an incorrect `inflate` method call. | In the application’s current state, the last parameter of the `inflate` call must be `false`. | The application crashed with a stack trace that pointed towards core framework code. |
| TR1  | 8     | The participant must fix an incorrect `spinOnce()` call. | `spinOnce()` cannot be used when the framework should perform the callback more than once. | A node in the application would quit unexpectedly without an error message. |
| TR2  | 8     | The participant must fix an application node’s parameter access. | Local namespaces are not checked if a global namespace is used in a parameter search. | The parameter search returned that the parameter does not exist. |
| TR3  | 6     | The participant must fix an obsolete message type. | An incorrect message type was used for this version of ROS. | The application crashed with an incorrect type declaration error. |

---

than a year of industrial Java or Android experience. 2 participants were current developers and 13 were graduate students. For the ROS study, we collected a convenience sample of 12 participants. 9 of the 12 participants preferred the C++ version of ROS over the Python version. 2 of the participants had more than 2 years of ROS experience and 5 of the participants had over a year of experience. 3 of the participants were research staff, 8 of the participants were graduate students, and 1 was an undergraduate student.

We made several procedure changes between the two case studies. For Android, we gave participants time to learn the application before attempting the tasks, while we did not provide a learning period for the ROS tasks. We allowed each Android participant a maximum total study time of three hours; because the ROS tasks required simple fixes, we set the maximum time in the ROS sessions to one hour. In the Android study, we required participants use the recommended Android Integrated Development Environment (IDE), AndroidStudio, because it provides warnings for directive violations. We did not require participants to use any particular IDE for the ROS tasks, because ROS does not have a recommended IDE.

That participants commonly spent the Android learning period exploring sections of the application that were not relevant to the tasks. We allowed each Android participant a maximum total study time of three hours; because the ROS tasks required simple fixes, we set the maximum time in the ROS sessions to one hour. In the Android study, we required participants use the recommended Android Integrated Development Environment (IDE), AndroidStudio, because it provides warnings for directive violations. We did not require participants to use any particular IDE for the ROS tasks, because ROS does not have a recommended IDE.
We first present the challenges that developers faced while debugging the tasks: dynamic challenges (Section 3.1), static challenges (Section 3.2), and historical challenges (Section 3.3). Next, we present the benefits of framework debugging: dynamic benefits (Section 3.4), static benefits (Section 3.5), and historical benefits (Section 3.6). For each category, we begin with a brief example and then elaborate on interesting cases. Because the Android and ROS frameworks serve different purposes (Section 2.2), certain benefits and challenges may have only occurred in one framework.

### 3.1 Dynamic Challenges

Throughout the study, participants struggled to determine the order in which a framework executes application code, which increased the difficulty of the debugging process. Participants seem to prefer a cause and effect ordering. However, framework code does not typically follow a sequential ordering, instead executing application code only when needed. This requires code to be structured as non-sequential event handlers. This can create uncertainty about which parts of project-specific code are called and when, and which framework method will execute “next.” Object protocols exacerbate this issue by requiring participants to understand which states various objects can be in when the framework calls their code.

**Inversion of Control Issues.** In framework programs, application-specific method execution order is not always transparent to the application developer. This sometimes led participants to misunderstand an application’s control flow, increasing the difficulty of the debugging process. For example, in the ROS study, participants (PR18, PR20) assumed the framework did not call a section of code, when instead a problem in that code segment caused the application to terminate earlier than expected. In this instance, the framework’s inversion of control led participants to misunderstand the application’s behavior, causing them to waste time while investigating the application. Inversion of control made it difficult to understand when methods were called and to locate error messages, and prevented intuitive fixes required modification of framework code.

In both Android and ROS, participants had difficulty understanding the application control flow. In Android, two participants (PA10, PA11) tried to use the debugger to understand control flow, but struggled to do so. Both participants stepped past a current method and were unable to figure out how to step back into non-framework code. This led participant PA10 to reach incorrect conclusions about which code executed in task TA7. In ROS, while trying to understand how two nodes communicated, PR22 did not realize that a third node linked two other nodes, because the nodes relied on the framework to handle communication. Participant PR22 read four files before understanding how the framework routed the nodes’ communication. Another participant (PR23) made incorrect control flow deductions due to the way ROS redirects and filters statements printed to standard output. Participant PR26 mentioned uncertainty about how to modify a method because of the states the application could be in when that method was called.

Inversion of control also made localizing errors difficult. In Android, one participant (PA5) searched for an error message thrown by the application, but could not find it in the project. The search failed because the error message was generated from core framework code, not project code.

Some problems stemmed from participants’ uncertainty about the hidden ordering of critical framework activity between events. When participants (PA4, PA12) saw the `getActivity` call returned `NULL`, they questioned whether the framework had incorrectly constructed its own reference to the parent Activity. In fact, `getActivity` was called in an event that occurred before the framework had attached the Activity to the Fragment.

**Object Protocols.** Object protocols are object states that dictate how an object can be used. An example of object protocols in Android are lifecycles: state transitions between starting, active, and stopping for components. Participants experienced challenges with object protocols (e.g., accessing values before they were set). Object protocols are explained and diagrammed explicitly in the documentation, but implemented indirectly in the framework code, and invisible to non-framework code, which likely led to increased difficulty with object protocols. Object protocols were more prevalent in the Android tasks, and thus we observed how object protocols produced framework debugging challenges in the Android study.

Object protocol issues in tasks TA4 and TA5 significantly contributed to the amount of time those tasks took (see Section 4). Most participants assumed the application had performed an invalid action, rather than an invalid action in a given state. Object protocol misunderstandings also led participants to incorrectly conclude that certain values were available for application use. Three participants (PA4, PA6, PA11) wrote code to access variables storing participant-selected times before the participant could have selected those times, and were then confused when the accessed times did not match the time they selected in testing. Participants (PA6, PA10) were confused about the circumstances in which they needed to commit and finalize a Fragment transaction (as opposed to the cases in which transactions were automatically committed).

### 3.2 Static Challenges

While the static structure of frameworks helped developers in the debugging process, further discussed in Section 3.5, the static structure also presented multiple challenges to participants. Participants commonly struggled to understand the separation between static structure and dynamic changes, determine the effects of the application’s static configuration, and use that knowledge to solve problems. This led to uncertainty about whether errors should be addressed by modifying static files, or via a dynamic solution.

Declarative artifacts are non-source code files or the application environment [6], such as the XML layout specifications in Android or the XML launch file in ROS. An example of a problem with declarative artifacts is when participants tried to add a menu using a declarative artifact in a framework that required menus to be added dynamically. Even though there were no errors in the declarative artifacts in the Android tasks, multiple participants investigated declarative artifacts to see if they were the source of an error.
For Android tasks TA3 and TA6, participants created `OptionsMenu` files. Many participants (PA13, PA14, PA15) looked through the Android layout editor for an `OptionsMenu` or tried to add an `OptionsMenu` to a XML file, before realizing that it must be added dynamically. Another participant (PA9) investigated the `strings.xml` file after an online answer suggested that the problem may lie in an undefined icon title. Participant PA10 remembered that a specific theme could cause errors and checked if the theme caused the error.

In ROS, participants had difficulty understanding how source files map to executable components, partially because ROS executables consist of various components (Nodes, Services, and Topics) that do not map directly to source. ROS also does not provide an easy or well-known way to find source code corresponding to a given component. Participant PR16 struggled to understand how the publisher and subscriber methods in the C++ files integrated with the data redirections in the launch file. Other participants (PR17, PR18, PR20, PR22, PR25, PR27) faced similar difficulties understanding how the application remapped data among the components. In one case, Participant PR17 had difficulty finding a source file after diagnosing the problem: “I am looking for source code for [this node]… Unfortunately ROS is trying to isolate me from the file system, which I dislike, because it cannot isolate me fully.” 16 minutes into the task, Participant PR17 exclaimed “This is ridiculous, I can’t even find the code that I am supposed to be debugging!” Participant PR17 eventually used `grep` to find a node, more than half an hour into the task.

### 3.3 Historical Challenges

Framework changes over time can increase the difficulty of debugging framework errors. Participants must both identify gaps in their current understanding and determine if previous solutions still apply. For example, participants may find a possible answer for a problem online but may reject answers that appear out-of-date.

#### Legacy Challenges

Previous versions of both Android and ROS created issues for several participants. In Android, one participant (PA9) questioned whether a feature should be implemented in a backwards-compatible way, later discovering that the application was not configured to work with backwards-compatible components. A few participants (PA8, PA9, PA14) avoided online answers older than two years because they assumed the answers would no longer apply. Other participants (PA1, PA15) mentioned they were familiar with Android a couple years ago, but there had been many changes to the framework since they were proficient with it.

Some ROS participants incorrectly diagnosed the obsolete message type in task TR2 as correct because they had used it previously. Participant PR21 recognized that the message type caused an issue, searched the message type online, and found its official documentation, not realizing that the documentation was for an older ROS version. This was a problem because the documentation indicated that the file was using the message type correctly. The participant investigated four other possible error sources before realizing that a different message type was needed.

#### Past Experience

While past experience was often helpful, one participant in the Android study (PA10) misdiagnosed an error message due to previous experience. This caused the participant to conclude to “not trust your experience.”

### 3.4 Dynamic Benefits

Throughout the study, participants commonly used the framework to perform actions that would have been much more difficult to recreate without the help of the framework. When faced with a task, almost all participants tried to implement the framework method of performing the action (although PA1, PA3, PA5, PA8, PA11, implemented custom solutions for certain tasks, such as implementing a custom message passing solution in TA1). For example, PA6 in TA1 correctly used the `findFragmentById` method to access user input, instead of writing code to pipe the data through the application. This shows that developers notice the benefits that framework methods provide in application development.

### 3.5 Static Benefits

Study participants found the static organization of the framework helpful when trying to gain an overview of the application, which helped them find files of interest more easily than through unstructured search. In ROS, participants used the launch files as a way to start exploring the application. For example, participant PR27 looked through the ROS launch files to understand which nodes are involved in the application. Participant PR26 mentioned that the participant likes to use launch files to get an overview of the application. Multiple participants (PR17, PR18, PR19, PR22, PR26, PR27) used the launch files as a way to start the debugging process. In Android, participants used the structure of Android application to quickly find resource files and test case files. For example, PA8 was able to quickly look up the correct options menu layout file when writing the required options menu code. Multiple participants in the Android study (PA1, PA2, PA3, PA6, PA8, PA9, PA10, PA11, PA13, PA14, PA15) benefited from being able to easily look up application files to answer questions participants were investigating.

### 3.6 Historical Benefits

Participants often found that past experience was helpful, such as when they were able to correctly diagnose a ROS error simply by looking at the failing section of code. Multiple ROS participants (PR17, PR21, PR26, PR27, PR28) were able to diagnose an error and suggest a working alternative based on past experience. While working on task TR2, participant PR28 noticed the error in the code and said, “I think the fact that there’s a beginning slash means that instead of looking under this node’s namespace it’s gonna look under the global namespace [where] this parameter doesn’t exist.” The participant was correct. Detailed knowledge of a framework, built up through experience, can help mitigate barriers frameworks impose. Other participants (PR18, PR22, PR26, PR27) stated that past experience shaped their general ROS debugging strategy. One participant remembered to set framework environment variables, attributing past environment problems. Another participant (PR26) always used `grep` to find calls to a function modified over the course of a debugging system, to guard against unforeseen side effects, a problem they had faced in the past.
4 ERROR PRESENTATION AND DEBUGGING DIFFICULTY

We further investigated the relationships between the way errors are presented to developers and developer debugging success. We performed an initial investigation into the consequences of violating Android Fragment directives, where we grouped the consequences into categories. Due to the limited nature of the investigation, we do not make claims that the categories will generalize. However, the results are useful as an initial investigation into the correlation between debugging challenges and error presentation.

We explain the consequence categories (Section 4.1) and discuss how consequences influenced participant success in the Android and ROS tasks (Section 4.2).

4.1 Directive Categorization By Consequence

The consequences of violating 41 Android Fragment directives are shown in Table 2 and elaborated below.

| Directive Violation Consequence                  | Count |
|------------------------------------------------|-------|
| AndroidStudio Warning                           | 3     |
| Compiler Error                                  | 3     |
| Crash With Reference To Directive               | 19    |
| Crash Without Reference To Directive            | 2     |
| Expected Action Did Not Occur                   | 9     |
| No Obvious Effect                               | 5     |
| Wrong Value Returned                            | 2     |

Table 2: The consequence of violating 41 fragment directives. Count is the number of directives in the category. One directive violation may produce multiple consequences but each consequence is mutually exclusive.

Crash Without Reference To Directive. When these directives were violated, the application crashed with an exception that did not notify the developer that a directive was violated, usually with an error pointing to where the application crashed instead of the location where the application needed to be fixed. Violations in this category occur when a more general exception message is thrown, or violating the directive puts the application into an invalid state and the invalid state is caught in a later line. One example in this category is when the result of the inflate method is used as the return value for onCreateView, the last parameter to the inflate method call must be false. If this directive was violated, the application would crash with a stack trace that pointed to internal framework code and not the inflate line.

Expected Action Did Not Occur. When these directives were violated, the framework did not execute the intended effect of the relevant section of code. The effect did not occur either because violating the directive caused the control flow to change or the semantics were changed. For example, one directive states that an application will only execute the Fragment's onCreateOptionsMenu method if the Fragment calls hasOptionsMenu(true) in the oncreate Method. If the hasOptionsMenu(true) call is removed, the OptionsMenu will not appear, even if the Fragment overrides onCreateOptionsMenu.

No Obvious Effect. When these directives were violated, the framework correctly performed the intended action of the associated code segment without crashing the application. One example of this category is a directive that states that if a Fragment does not have a user interface (UI), then the Fragment should be accessed by findFragmentByTag(), but the Fragment without a UI could be accessed by findFragmentByTag() without noticeable consequences.

Wrong Value Returned. When these directives were violated, the application did not crash, but a reference to a part of the application had been lost or was used incorrectly. Any attempt to use the lost or incorrect reference returned a wrong value. For example, when a developer dynamically added a UI element, the developer must assign a unique tag to the added UI element. If the added UI element does not use a unique tag, the new tag overrides the matching tag of a previous UI element. The previous UI element is now unreachable through framework supported methods.

Violating certain directives can produce multiple consequences (e.g., a violation can produce an AndroidStudio warning and crash with reference to the directive), but each consequence is mutually exclusive (the same consequence could not be categorized in multiple categories - an application crash cannot be both classified as crash with reference to the directive and crash without reference to the directive). We found that one directive could be violated in two different ways and produced three possible consequences. Two other directives could be violated in two ways, each with different consequences.

4.2 Difficulty By Consequence

We analyzed participant results from both the Android and ROS tasks using the consequence categories. Table 3 shows the categorization of each task and the time spent and participant success rate for each category. Figure 2 shows a box-and-whisker plot of the participant’s time spent on the tasks in the study, providing further
Table 3: The mean time on task and completion rate of tasks with a given consequence. Time on task includes failed attempts.

| Violation Consequence | Time (Mean) | Sessions Completed | Sessions Attempted | Success Rate (%) | Tasks |
|------------------------|-------------|-------------------|-------------------|-----------------|-------|
| 1. Android: Wrong Value Returned | 51 min | 4 | 5 | 80 | TA1 |
| 2. Android: Crash With Reference To Directive | 47 min | 3 | 9 | 33 | TA4, TA5 |
| 3. Android: Expected Action Did Not Occur | 28 min | 4 | 8 | 50 | TA3, TA6 |
| 4. Android: AndroidStudio Warning | 23 min | 6 | 6 | 100 | TA2 |
| 5. Android: Crash Without Reference To Directive | 19 min | 4 | 5 | 80 | TA7 |
| 6. ROS: Expected Action Did Not Occur | 49 min | 5 | 8 | 63 | TR1 |
| 7. ROS: Wrong Value Returned | 36 min | 5 | 8 | 63 | TR2 |
| 8. ROS: Compiler Error | 25 min | 6 | 6 | 100 | TR3 |

Figure 2: A box-and-whisker plot of the time participants spent on tasks. Time results include failed attempts.

We found that there was a significant difference in the mean time to complete tasks (ranging from 19 to 51 minutes) and the success rate on tasks (ranging from 33% to 100%) of difference consequences.

We found that participants struggled to address directive violations that resulted in a "wrong value returned" consequence (tasks TA1 and TR2). Although four out of five attempts were successful in the Android task, the attempts took longer than all other directive violations (with the exception of the "wrong value returned" consequence). One reason for this difficulty is that all directives (excluding directives taken from the Fragment source code) that crashed with a reference to the directive involved object protocols. Although participants were able to find answers on the object protocol in online questions, these answers did not directly apply to the task situation. Instead, participants had to gain a basic understanding of the object protocols used in the application before participant knew when and how to perform the recommended actions.

While participants in the Android study were much quicker when an expected action did not occur (TA3 and TA6), the ROS participants found this violation consequence to be the most difficult (TR1). Likely due to the lack of object protocol issues, the Android participants spent a mean of 28 minutes on these tasks and had a higher success rate on them (six out of seven attempts successful). The ROS participants spent the most time on this task (45 minutes) and tied for the lowest success rate. While the fix for TR1 only involved changing one method call, the participants likely had a more difficult time because participants had difficulty deducing the fault location from the way the error manifested. In TR1, the main functionally of the application behaved incorrectly, while only a single feature of the Android application behaved incorrectly in the Android tasks. Participants in the Android study focused on the section of the application that handled the missing feature, while participants in the ROS study had to consider the many possible reasons for failure.

The third-fastest (25 minutes) violation consequence was the compiler error task (task TR3). Participants in this task were the fastest (25 minutes) and were the most successful (100% completion) for the ROS tasks. The second-fastest set of attempts (23 minutes) addressed directive violations that displayed a warning that provided a possible solution (task TA2). Participants were able to quickly solve the problem that caused the warning but still had to spend time implementing the solution correctly. All 6 attempts at the task were successful, tied for the highest completion rate of directive violation consequences. Participants completed task TA7, in which the application crashed without reference to the directive (task TA7), more quickly than any other task.
was largely inscrutable, most participants searched online for the error after only a brief period investigating the code. An online search yielded a quick solution: the task required adding a new parameter to the inflate method, an easy-to-implement fix based on the online answer. This directive violation consequence was fixed the fastest, on average (19 minutes), and 4 of 5 attempts were successful.

The consequence of violating a directive appears to influence how long it takes to debug the error as well as how likely a developer is to succeed in doing so over a short debugging session. Overall, we observe that it appears important not only to notify developers of directive violations but also to help them explicitly. Often participants knew that certain directives were violated, such as in the crash with reference to the directive tasks, but they did not know how to fix the error. Participants found this frustrating, with one participant stating “Why don’t they tell me the right thing to use? They tell me it is going to cause a problem but they don’t tell me what the alternative is.”

5 THEORY

After analyzing the benefits and challenges of frameworks in our study, we condensed those aspects into a theory that provides insight into the framework debugging process. This theory presents the benefits and challenges of framework debugging in terms of cognitive steps, the number of mental tasks that a participant must use to achieve a goal. In this section, we first present the theory created from the human trial results (Section 5.1). We then discuss our evaluation of the theory (Section 5.2).

5.1 Theory Description

When compared to debugging sequential programs, aspects of the framework application debugging process reduce the number of cognitive steps required to achieve certain goals, and increase the cognitive steps required to achieve others. When developers need to find a resource, such as an XML configuration file, the structure of frameworks keeps the number of steps required to find the resource to a minimum. Frameworks can increase the cognitive steps required to debug and fix an error when participants must understand how to fix an error that has dependencies on object protocols. A developer’s cognitive load also increases when inversion of control increases the difficulty in determining the relevant control flows, and when participants have misconceptions about what the framework is doing outside application-specific code.

This theory leads to two predictions. The first is that when debugging framework problems, developers will require fewer steps to do tasks that involve navigating to files placed in standard framework locations. Developers will have more difficulty with inversion of control or object protocol issues. The second prediction from this theory is that, when debugging, it will normally be more costly to investigate framework code to understand the details of how the code works than library code. This is due to the fact that frameworks are generally larger than libraries and commonly involve interactions between more components. This complexity increases the time required to understand portions of a framework, and increases the chance that participants will investigate an aspect of the framework that does not apply to the current problem.

5.2 Theory Evaluation

Constructivist grounded theory studies can be evaluated along four criteria [4]. The first criterion is credibility, which addresses whether the study has collected enough data to merit its claims. This criterion was addressed through our selection of frameworks and tasks, which cover two diverse frameworks with diverse debugging scenarios. Having multiple participants perform each task reduced the risk that our analysis focuses on anomalous behavior. We attempted to improve the realism of our scenarios by recreating scenarios from StackOverflow for the Android tasks. The second criterion is originality, which addresses whether a theory offers new insights. While previous studies have investigated what differentiates framework programming from other types of programming [18] and the learning issues associated with frameworks [22], no previous study has investigated how framework aspects affect the debugging process. The third criterion is resonance, or whether the theory makes sense to people in the associated circumstances. To evaluate this criterion, we contacted six participants after finalizing the theory and asked them if the theory reflected their experiences and if the theory provided deeper insights. All six of the participants said that the theory reflected their experiences, although one participant mentioned that the object protocol issues are likely more task dependent, and not necessarily framework dependent. Two of the six participants said that the theory provided deeper insights into the application debugging process for framework API errors than they had initially. The fourth criterion is usefulness, which concerns whether the theory provides interpretations that people can use or build upon. This theory could be useful to framework debugging tool designers because the theory can help designers focus on the challenging aspects of framework debugging. The theory could also be used to guide novices who are debugging frameworks by focusing them on questions that can be more easily answered than questions that are more difficult to answer.

6 THREATS TO VALIDITY

Threats to external validity. We attempt to mitigate the risk that our theory will fail to generalize to other frameworks or languages by investigating two very different frameworks and a wide range of framework debugging problems. As stated earlier, our categorization of framework directives by violation consequence may not generalize (e.g., other frameworks may not issue formal warnings), and it may be incomplete; in particular, we did not consider potential non-functional violation effects, such as degraded performance.

Our constructed tasks may not represent real-world debugging tasks. This concern was reduced by basing the Android tasks on StackOverflow questions. Additionally, participants were new to the code in each task, possibly leading to unrealistic problems with code familiarity. We sought to reduce this threat by providing Android participants with a learning period, but we note that, for example, one participant mentioned that if the task was encountered in everyday development, it would be preferable to spend a day reading documentation before tackling it. As such, time limitations may have influenced our results. Finally, the participants in the study may not represent the population of framework users.
We attempted to address this limitation by recruiting participants with experience with the framework: 14 of the Android study participants had over a year of industrial Android or Java experience and 7 of the ROS participants had over a year of experience with the framework.

**Threats to internal validity.** Since this study was exploratory and qualitative, the focus was not on internal validity. Exploratory studies allow for the investigation of a wide array of problems but do not support definitive cause-effect conclusions. Participants could freely decide, in a low-risk situation, when to quit a task. Participants were also asked to think-aloud, and prompted to do so by the researcher. These prompts may have altered the route a participant would have taken absent the prompt. Additionally, the think-aloud aspect of the study may affect how long participants took to solve the tasks. We believe that this affected tasks roughly equally, such that tasks which took significantly longer than the others are likely to have taken longer in a non-think-aloud context. Finally, some participants mentioned they would have been more comfortable if the researcher were not watching, and if they were able to use their preferred IDE, operating system, or laptop. These irritants may have caused participants to take different routes than they would have in their preferred environment.

7 **RELATED WORK**

In this section, we discuss related work in framework investigations, directive studies, debugging papers, theories of debugging, and grounded theory projects in software engineering.

**Frameworks.** One of the closest studies to ours investigated the learning barriers participants face in framework scenarios [22], finding some similar challenges to those we identified, such as coordination barriers, or difficulties related to using the correct parts of a framework to achieve framework programming goals. However, this study focused on general learning barriers and the relationships among the barriers, instead of focusing on framework problems. Our work also covers the benefits of framework debugging and focuses on framework directive scenarios. Other prior work has created formal specifications for framework plugins [16] and investigated the use of declarative artifacts with static analysis [17]. Another study found that survey respondents believed they needed to understand the design intent of a framework to use it effectively [33]. Researchers have used StackOverflow, a popular question-and-answer website, to investigate framework problems [37]. Other works have investigated patterns that appear in framework development [10, 18]. To the best of our knowledge, none of this prior work specifically addresses debugging.

**Directives.** To the best of our knowledge, prior work on directives has not investigated the challenges developers face when debugging them. Early work investigated how directive knowledge helps developers during coding tasks, and developed a directive classification scheme based on the topic of the directive (such as a protocol directive or a performance directive) [8, 9]. An alternative mechanism for directive classification focuses on the level of code involved (method, subclassing, states, etc.) [29]. Others have mined subclassing directives [3], and fixed directives in documentation after analyzing how methods were used in source code [40].

**Debugging and debugging theories.** Previous work has found that developers incorporate scent finding [28] and ask dataflow questions while debugging generally [27]; The ability to easily answer dataflow questions can significantly reduce the time required in debugging [21]. Others have found that developers encounter design decisions in the bug fix process, such as when to fix incorrect data passed between multiple components [30]. Others have explored the debugging of machine learning programs [24]. Finally, other researchers have investigated the challenges of end-user (non-developer) debugging scenarios, and found that understanding features and testing ideas were important parts of the process [20]. None of this previous work specifically focuses on the problems of debugging framework applications.

Prior debugging theories do not capture the unique problems encountered while debugging frameworks, and thus may only apply to framework debugging at a high level. Debugging has been modeled as a trial-and-error process of hypothesis generation [12]. An alternative theory models debugging as a four-stage troubleshooting process: understanding, testing, locating, and fixing; however this work dealt with programs less than 15 lines long, implying the “understanding” stage involved code many orders of magnitude smaller than a typical modern framework [19].

More recent work has characterized debugging as a cyclical process of gathering and integrating information. One theory describes the process as three sensemaking loops: the bug-fix sensemaking loop, the environment sensemaking loop, and the common sense topics and/or domain sensemaking loop [13]. Another theory models the information gathering process as searching, collecting, and relating information [23]. The information gathering process of debugging has also been portrayed as various fact related actions, such as finding and proposing [26].

**Grounded Theory in Software Engineering.** Multiple papers have covered how to present grounded theory papers in software engineering [1, 6, 14, 36]. There are also various software engineering papers that use grounded theory, such as a theory of the problems developers encounter when moving to a new software project [7], self-organization in an agile development process [15], and how communication in an agile process affects development teams [38]. None of these studies have investigated framework debugging, but they provide support for the use of grounded theory in understanding phenomena in a software engineering context.

8 **CONCLUSIONS**

We have presented the results from human trials on framework directive violation debugging scenarios, and a theory of the benefits and challenges of framework debugging. The theory states that certain aspects of the framework reduce the cognitive steps required by the debugging process, such as the static structure of framework applications, which help developers determine where to find needed files. The theory also states that certain aspects of a framework can increase the number of cognitive steps for developers during debugging, such as the challenges produced by the
inversion of control. In creating this theory, we looked into the difficulty of solving various directive violations by consequence and found that assisting developers with directive violations is more complex than simply notifying them of the directive violation in question. While we believe we have provided sufficient support to justify the creation of a theory, further work will be necessary to verify it. This theory provides the basis for future testable hypotheses, such as investigating framework code often is more time-consuming than investigating library code while debugging. These hypotheses can be explored in future studies.

9 ACKNOWLEDGMENTS

This will be added to a later version of the paper.

REFERENCES

[1] Steve Adolph, Wendy Hall, and Philippe Kruchten. 2008. A Methodological Leg to Stand on: Lessons Learned Using Grounded Theory to Study Software Development. In Center for Advanced Studies on Collaborative Research: Meeting of Minds (CASCON ’08) 166–178.

[2] Nels E. Beckman, Duri Kim, and Jonathan Aldrich. 2011. An Empirical Study of Object Protocols in the Wild. In European Conference on Object-Oriented Programming (ECOOP’11). Berlin Heidelberg, 2–26.

[3] M. Bruch, M. Mezini, and M. Mommers. 2010. Mining subclassing directives to improve framework reuse. In Mining Software Repositories (MSR ’10). 141–150.

[4] Kathy Charmaz. 2014. Constructing Grounded Theory (2nd ed.). Sage Publications, Los Angeles, CA.

[5] Jaspal Ciera. 2011. Proper Plugin Protocols. Ph.D. Dissertation. Carnegie Mellon University.

[6] Gerry Coleman and Rorry O’Connor. 2007. Using Grounded Theory to Understand Software Process Improvement: A Study of Irish Software Product Companies. Information and Software Technology 49, 6 (2007), 654–667.

[7] Barthélémy Dagenais, Harold Ossher, Rachel K. E. Bellamy, Martin P. Robillard, and Jacqueline P. de Vries. 2010. Moving into a New Software Project Landscape. In International Conference on Software Engineering (ICSE ’10) 275–284.

[8] Uri Dekel. 2009. Increasing awareness of delocalized information to facilitate API usage. Ph.D. Dissertation. Carnegie Mellon University.

[9] Uri Dekel and James D. Herbsleb. 2009. Improving API Documentation Usability with Knowledge Pushing. In International Conference on Software Engineering (ICSE ’09) 320–330.

[10] George Fairbanks, David Garlan, and William Scherlis. 2006. Design Fragments Make Using Frameworks Easier. In Object-oriented Programming Systems, Languages, and Applications (OOPSLA ’06) 75–88.

[11] Google. 2017. Android. www.android.com. (2017). Accessed: 2/15/17.

[12] John D. Gould. 1975. Some Psychological Evidence on How People Debug Computer Programs. International Journal of Man-Machine Studies 7, 2 (1975), 151–182.

[13] Valentina Grigoreanu, Margaret Burnett, Susan Wiedenbeck, Jill Cao, Kyle Rec- tor, and Irwin Kwan. 2012. End-User Debugging Strategies: A Sensemaking Perspective. ACM Transactions on Computer-Human Interaction 19, 1 (2012), 1–28.

[14] Rashina Hoda, James Noble, and Stuart Marshall. 2011. Grounded Theory for Geeks. In Pattern Languages of Programs (PLoP ’11). 1–17.

[15] Rashina Hoda, James Noble, and Stuart Marshall. 2012. Developing a Grounded Theory to Explain the Practices of Self-organizing Agile Teams. Empirical Software Engineering 17, 6 (2012), 609–639.

[16] Ciera Jaspan and Jonathan Aldrich. 2009. Checking Framework Interactions with Relationships. In Proceedings of the European Conference on Object Oriented Programming (ECOOP ’09). 27–51.

[17] Ciera Jaspan and Jonathan Aldrich. 2009. Retrieving Relationships from Declara- tive Files. In Relationships and Associations in Object-Oriented Languages (RAOOL ’09). 1–4.

[18] Ralph E. Johnson. 1992. Documenting Frameworks Using Patterns. In Object-Oriented Programming Systems, Languages, and Applications (OOPSLA ’92) 63–76.

[19] Irvin R. Katz and John R. Anderson. 1987. Debugging: An Analysis of Bug Location Strategies. Human-Computer Interaction 3, 4 (Dec. 1987), 351–399.

[20] Cory Kissinger, Margaret Burnett, Simone Stumpf, Neeraja Subrahmanian, Laura Beckwith, Sherry Yang, and Mary Beth Rosson. 2006. Supporting End-user Debugging: What Do Users Want to Know? In Advanced Visual Interfaces (AVI ’06). New York, NY, USA, 135–142.

[21] Andrew J. Ko and Brad A. Myers. 2008. Debugging Reinvented: Asking and An- swering Why and Why Not Questions About Program Behavior. In International Conference on Software Engineering (ICSE ’08) 301–310.

[22] Andrew J. Ko, Brad A. Myers, and Htet Htet Aung. 2004. Six Learning Barri- ers in End-User Programming Systems. In Visual Languages - Human Centric Computing (VLHCC ’04) 199–206.

[23] Andrew J. Ko, Brad A. Myers, Michael J. Cohlenz, and Htet Htet Aung. 2006. An Exploratory Study of How Developers Seek, Relate, and Collect Relevant Information During Software Maintenance Tasks. IEEE Transactions of Software Engineering 32, 12 (Dec. 2006), 971–987.

[24] T. Kulesza, S. Stumpf, M. Burnett, W. K. Wong, Y. Rüche, T. Moore, I. Oberst, A. Shinzel, and K. McIntosh. 2010. Explanatory Debugging: Supporting End-User Debugging of Machine-Learned Programs. In 2010 IEEE Symposium on Visual Languages and Human-Centric Computing. 41–48.

[25] Craig Larman. 2004. Applying UML and Patterns: An Introduction to Object-Oriented Analysis and Design and Iterative Development (3rd ed.). Upper Saddle River, New Jersey, USA.

[26] Thomas D. LaToza, David Garlan, James D. Herbsleb, and Brad A. Myers. 2007. Program Comprehension As Fact Finding. In Symposium on The Foundations of Software Engineering (ESEC-FSE ’07). New York, NY, USA, 361–370.
[27] Thomas D. LaToza and Brad A. Myers. 2010. Hard-to-Answer Questions About Code. In Evaluation and Usability of Programming Languages and Tools. 1–6.

[28] Joseph Lawrence, Christopher Bogart, Margaret Burnett, Rachel Bellamy, Kyle Rector, and Scott D. Fleming. 2013. How Programmers Debug, Revisited: An Information Foraging Theory Perspective. IEEE Transactions of Software Engineering 39, 2 (Feb. 2013), 197–215.

[29] Martin Monperrus, Michael Eichberg, Elif Tekes, and Mira Mezini. 2012. What should developers be aware of? An empirical study on the directives of API documentation. Empirical Software Engineering 17, 6 (2012), 703–737.

[30] E. Murphy-Hill, T. Zimmermann, C. Bird, and N. Nagappan. 2015. The Design Space of Bug Fixes and How Developers Navigate It. IEEE Transactions on Software Engineering 41, 1 (Jan 2015), 65–81.

[31] B. A. Myers, A. J. Ko, T. D. LaToza, and Y. Yoon. 2016. Programmers Are Users Too: Human-Centered Methods for Improving Programming Tools. Computer 49, 7 (July 2016), 44–52.

[32] Morgan Quigley, Ken Conley, Brian P. Gerkey, Josh Faust, Tully Foote, Jeremy Leibs, Rob Wheeler, and Andrew Y. Ng. 2009. ROS: an open-source Robot Operating System. In ICRA Workshop on Open Source Software.

[33] Martin P. Robillard. 2009. What Makes APIs Hard to Learn? Answers from Developers. IEEE Software 26, 6 (Nov. 2009), 27–34.

[34] M. Schreier. 2012. Qualitative Content Analysis in Practice. SAGE Publications, Thousand Oaks California, USA.

[35] Klaas-Jan Stol, Paul Ralph, and Brian Fitzgerald. 2016. Grounded Theory in Software Engineering Research: A Critical Review and Guidelines. In International Conference on Software Engineering (ICSE ’16). 120–131.

[36] Klaas-Jan Stol, Paul Ralph, and Brian Fitzgerald. 2016. Grounded Theory in Software Engineering Research: A Critical Review and Guidelines. In International Conference on Software Engineering (ICSE ’16). 120–131.

[37] Wei Wang and Michael W. Godfrey. 2013. Detecting API Usage Obstacles: A Study of iOS and Android Developer Questions. In Mining Software Repositories (MSR ’13). 61–64.

[38] Elizabeth Whitworth and Robert Biddle. 2007. The Social Nature of Agile Teams. In Agile 2007 (AGILE ’07). 26–36.

[39] Robert K. Yin. 2008. Case Study Research: Design and Methods (4th ed.). Sage Publications, Thousand Oaks California, USA.

[40] Yu Zhou, Ruihang Gu, Taolue Chen, Zhiqiu Huang, Sebastiano Panichella, and Harald Gall. 2017. Analyzing APIs Documentation and Code to Detect Directive Defects. In International Conference on Software Engineering (ICSE ’17). 27–37.