Using a universal intermediate representation to perform static analysis

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Abstract

Bug finding using static analysis is a complex process that usually targets a single programming language. The task of generalizing such static analyzer tool to other programming languages is nontrivial and expensive in industrial settings. Therefore, static analysis companies typically minimize this effort by targeting multiple programming languages in one single intermediate representation. However, the main technical problem is to support and approximate different language features and paradigms in the same representation.

In this thesis, we study *SLang*, an intermediate representation defined by SonarSource, used as the input of a static analyzer for Kotlin, Scala, Ruby, and Apex. The key ideas are the representation of unknown expressions by natives elements in *SLang*, and the notion of unreliable basic block for dataflow analysis. Our experiments compare the results of an implementation of a *null* pointer dereference checker over *SLang* and an implementation on the original language. The results show that we are able to find real issues with a very low false positive rate, and also reach the same precision as the implementation on the original language.

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1 Introduction

SonarSource is a company that develops tools for continuous code quality for more than ten years, with the time, the team has developed good expertise in the domain. Static code analysis is the action of automatically analyzing the behavior of a program without actually executing it. This kind of analysis is particularly useful to identify potential issues as early as possible in the development cycle, reducing the effort needed to fix them. A year ago, SonarSource was supporting more than twenty languages, but realized that they were not targeting the most used and asked by the community. In 2018, SonarSource decided to respond to this demand and add the support for five new languages not supported: *Go*, *Kotlin*, *Ruby*, *Scala* and *Apex*.

1.1 Supporting 5 new languages

Supporting 5 new languages was a challenging objective since adding a new language to the list used to take months of work, the team had to question their whole process to tackle this challenge. Historically, the usual SonarSource's process to develop a new static analysis tool was to build a front-end, specifically a lexer and a parser, then to implement different checks, metrics, copy-paste detection, and syntax highlighting. At this stage, the main part of the work is done, but still needs to be regularly maintained to stay up to date. Since every language produces a different tree, every check has to be implemented individually for each language. The complexity of the current situation is, therefore, a multiplication between the number of languages and the number of checks. As the objective is to increase the number of languages, the current situation does not scale. The first observation they made is that implementing the front-end for a language is a hard task, which often takes most of the production time. Hopefully, open-source's projects already providing complete and maintained parsing, exists. This is the first important choice: SonarSource is not going to develop its own front end anymore, but is going to re-use existing one. A second observation is that many rules are implemented in the same way and some of them are common, they make sense for every programming language.

Table 1 shows a sample of typical checks considered as common [1], applying to any programming language. At this point, the high-level idea is to use an existing front-end to perform the parsing, to translate it to a

Unused local variables should be removed
Class names should comply with a naming convention
Credentials should not be hard-coded
Functions should not have too many parameters

Table 1: Common rule examples

universal intermediate representation and to implement checks and metrics on it. This was the main motivation: avoid redoing the same work again and again, by implementing checks on top of common representation, reducing the complexity to a single implementation of each check. This idea is promising, it would enable SonarSource to support new languages faster, avoiding duplication, and to reduce the maintainability cost, allowing them to reach their objective. After a few trial and error, the team came up with SonarLanguage, or *SLang*, an incomplete universal intermediate representation.

1.2 Incomplete Universal Intermediate Representation

In order to implement checks only once, SonarSource introduced an incomplete universal intermediate representation, a domain specific language for static analysis: ***SLang***. The goal was to have a unified representation of common programming language, for easy, scalable and maintainable code smell and bug detection. The language is designed to implement the common rules introduced before, it is therefore not designed for mainstream programming, and in fact, the current goal is not even to be able to compile it. It contains all the metadata and abstract syntax tree nodes needed to support these rules, and only the ones needed. It is therefore a balance between complexity (number of different features supported) and accuracy to be able to report interesting issues.

The current grammar [2] and interface [3] of *SLang* is not fixed, it is meant to change and to adapt to suit arising needs. We can see that it contains all the typical nodes of any programming language. The different nodes approximate the different programming concepts. To be able to support multiple input languages, but we do not need the translation to be faithful, as a transformation of source code requires[4]. For example, the loops are all mapped to one single node, with one child representing the condition, and another for the body. Even if we keep the original type of

the loop, this procedure can still mutilate the input, reducing the three part of a *for* loop header into one condition. The transformation is therefore incomplete, we are going to make abstraction of some concepts, but it is not a problem as long as the results of the checks are not affected. One interesting note is that there are important nodes not present, for example, there is no function invocation. The reason is that none of the rules use them, we eventually need to know the list of the arguments to report unused variable, but we do not need the concept of function invocation in itself. The specificity of this language is the **native nodes**. During the translation, we are going to map all original nodes to their equivalent in *SLang*, if one has no equivalent, it is going to be mapped to a native node.

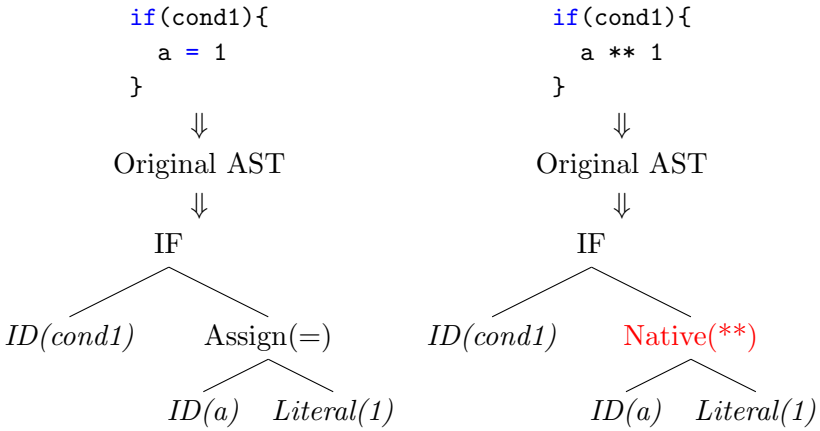


Figure 1: One native node in *SLang*

Figure 1 shows an example of native node in a *SLang* tree. In the left tree, we understand that the equal is part of an assignment, but in the second case, we have an unknown expression. We will keep, but as a native node. Native nodes therefore represent unknown nodes, but we will still be able to compare them since we will keep the original type, list of their children and tokens inside the native node. Since we can compare two native nodes, we are able to find when two branches of a switch are the same, for example, without knowing exactly what is inside. The other interesting point is that we now control the shape of the tree, we know what and where to expect a tree. For example, if we want to detect when two functions body are similar, we can compare the child corresponding to the body, making abstraction of all its content. This is the key to ensure that the rule will work on any new language. For example, for the function body comparison, we are going to add all elements who can differentiate two implementations inside the body,

even if the node was not directly inside in the original language. The native nodes also enable to process to the implementation incrementally: we can implement the translation only for a few nodes, letting others as native, and already be able to run some of the checks and see the first results.

If the *Why?* is now clear, we will discuss the *How?* in this work. To better understand the challenge of implementing a new language, we will start by describing the process of adding a new language to the ecosystem (Section 2), with the challenges and choices needed to be done (Subsection 2.2.2). We will then try to push *SLang*, and verify whether the results of a control-flow base check on *SLang* are comparable in quality (based on number of true positives, false positives, etc.) with the same checker over the original tree (Section 3, 4, 5 and 6). We will finish comparing our checker with other related work (Section 7), to see what is the current state of the art, how we could improve our current version, and try to anticipate the potential problem that can arise in the future of *SLang*.

2 Adding a new language to SLang

In this part, we are going to discuss the challenge to add a new language to *SLang*, with a general process and a concrete example with *Scala*.

2.1 General Process

The addition of a new language follows a general process that can be described in a high-level way. The first step is to choose a front-end to perform the parsing of the language.

2.1.1 Front-end

To choose a front-end, we have to take into consideration multiple points:

1. ***License***
   The tool developed will be open source, we have to use an existing front end with a compatible license.
2. ***Features***
   Static analysis requires specific needs, that is not necessarily provided by any front-end. For example, we need a precise location of tokens to be able to report the issues to the user as precisely as possible. Another example is the comments, required for some of the common rule 1, but typically removed early in a compiler front-end.
3. ***Maintenance***
   The last criteria are completeness and maintenance. We want a tool regularly maintained and supporting the potential new feature of the language.

2.1.2 Incrementally add new mapping and enable checks

With the front-end, we now have access to the intermediate representation of the original language. We can start to work on running more and more checks. The work starts by looking at which rule we want to implement. Depending on the rule, we have to add the translation of more nodes from

the original language to *SLang*. If the prerequisites for the front-end are respected, the initial effort of adding the mapping for a new node is an easy task. We have to identify which nodes in the original language correspond to the node in *SLang*, and understand its structure to adapt it. Once we have added the nodes needed by the rule, and enabled it, we can then look at the results. This is a critical step, we must be sure that the rule makes sense on this new language, and that the reported issues are relevant.

In many cases, this is where unexpected problems arise, they are usually due to an unknown language feature, a wrong approximation, and so on... Hopefully, there are multiple ways to improve the results. The first one is to set up a parameter for the rule. It will adapt the behavior of the rule depending on the original language, and even depending on the user input. For example, all the rules of naming conventions have to be set up with the convention of the language and can be changed by the user thanks to a custom setup. Sometimes, the rule simply does not apply for the language. For example, if a language does not have a *switch* statement, all the rules related to *switch* will obviously not apply to this language. The most challenging situation arises when the problem is not clear, where the approximation of the translation leads to issues that the tool could report, but the language specific features change the behavior of the check. These situations must be addressed case by case.

The problem of reporting relevant issues without too much noise is common in static analysis, it is often referred to as the precision and recall trade-off.

2.1.3 Precision and Recall trade-off

In static analysis, a common challenge is to deal with the precision and recall trade-off. When reporting an issue, we can be in two situations:

1. ***False Positive***
   The tool is reporting a non-existing bug.
2. ***True Positive***
   The tool is reporting a real bug.

Similarly, we can have false and true negatives, for real issue not reported

and non-existing bug not reported, respectively.

Precision is the number of true positives, over the total number of issues reported by the tool (*true positives* + *false positives*). *Recall* is the number of true positive over the number of issues present in the code. Finding a good balance is a challenging task, in the first case, the programmer does not want to be surrounded with issues considered as irrelevant, this would hide the real issues and discredit the tool. In the other extreme, a checker never reporting any issue will never report false positive, and will not be useful,because containing a lot of false negatives. Since there is no concrete solution to this trade-off, we are going to target a rate of less than **5%** of false positive for our work. This is an arbitrary choice, other tools like FindBugs [5] initially targeted a rate of less than 50% of false positives for example. It mainly depends on the context in which the tool is used, an analysis of the software of an aircraft might want to have a high recall while a user working on a small project would like a precise tool. Targeting as little false positives as possible, accepting therefore more false negatives, but still report real issues is an important choice since it will greatly influence our design and implementation choices.

An important note is that we are not in the context of proving the absence of bugs, to provide a sound checker, but we want to reduce the best way possible their occurrences by reporting real problems, to be as complete as possible.

2.2 A concrete example: Scala

Scala is particularly interesting as it is the first functional language that is going to be added to *SLang*, it is going to help to understand how it supports different paradigms. The first step is to find a good front-end. Scalameta [6] provides all the features needed, is widely used by the community and is intended to be used by static analysis tools. It seems to suit perfectly to the requirements for a good front-end.

2.2.1 Incrementally mapping Scala to SLang

The front-end have been chosen, we can use it to obtain a Scala abstract syntax tree from a Scala file. At this point, we have enough information to

activate a first rule: file should parse. If Scalameta is not able to parse the file, we report an issue. The first step from this tree is to extract comments, and translate the tokens from Scalameta to *SLang*. With this simple step, we are already able to enable new checks related to comments; the tracking of comments with *TODO* and reporting commented code for example. The second step is to start the translation. As in any compiler phase performing translation, the skeleton of the code will be a pattern matching on the current node. We will traverse the tree using a top-down approach. The initial step is to map all nodes to **native trees**, they represent nodes we do not know anything about. We still have access to the token of the native nodes; we can therefore activate the copy paste detection and the different metrics. In addition, all the rules related to the structure of a file can be enabled: length of line, tabulations, length of file. With only little effort, we manage to enable 8 checks and provide a copy/paste detection and metrics. We will continue the effort by adding more and more nodes translations and activating more and more rules.

Most of the nodes from *SLang* have a direct equivalent in the Scalameta tree. The translation effort is to make sure that the meaning of a node in the original language is the one intended in *SLang*, adapt it if not, and that the metadata is correctly handled. Package declaration, literal and block are examples of nodes having a direct equivalent in *SLang* but surprisingly, more complex nodes such as if tree, and pattern match also fall into this category. The Scalameta nodes without equivalent in *SLang* will be translated to native tree.

The overall mapping stays pretty simple, we sometimes have to regroup multiple children of the original node into one single native node, but it does not contains any complex trick.

2.2.2 Reducing the false positives

SLang is driven by checks, when we add a new node and enable a new one, we have to make sure that everything makes sense. For *Scala*, some feature of the language greatly reduce the quality of the checks. One quick but naive solution when facing false positive is to map the problematic node to a native node, to remove the problematic case.

Listing 1: Pattern matching which can cause false positives

```
something match {
  case "a" if(variable) => println("a")
  case "a" => println("a")
  case "b" if(variable) => println("b")
}
```

For example, listing 1 shows a correct pattern matching, but with the current mapping, we only add the pattern "a" to the condition of the *match* case, and not the guard (*if(variable)*). This will incorrectly trigger the rule reporting identical branch body in a conditional structure. If we map the match case to native, this solves the problem but introduces false negative for other rules related to match tree.

Identifying which node can lead to false positives can be done during the mapping, but it is sometimes hard to feel where the problems will arise. To identify the potentially problematic cases, we can store in all nodes, the original node type from which it was created. After the translation, we can compute a mapping, from every original node to the node(s) in *SLang*. This gives a considerable list with all nodes present in Scalameta, which is not yet useful to identify potential problems. The first observation is that the majority of the nodes are mapped completely to native nodes. This is not a problem, we know we do not need all the nodes from the original language to perform our checks. The more interesting cases are the original nodes mapped to a *SLang* node and a native node. All the rules using the nodes are conditionally translated are subject to false negatives.

DefnDef (1)	FunctionDeclaration(90%); Native(10%)
TermMatch (2)	Matchl(70%); BlockTree (21%); Native(9%)
TermParam (3 & 4)	Native(61%); Parameter(39%);

Table 2: Mapping from a node in Scalameta to the translated node in *SLang*

Table 2 shows the resulting table for Scala if we filter further to only keep the nodes where more than 10% is mapped conditionally. This information can lead our research and lead to identify 4 potentials problematic situations.

1. ***Function with many parameter clauses***

Listing 2: Scala function with many parameters clauses

```
def add(i1: Int)(implicit i2: Int): Int = {
```

```
2     i1 + i2
3 }
```

Listing 2 shows an example of a Scala function with multiple parameters, common in Scala, but not necessarily in other languages. Mapping the whole function to a native node is a big loss, we are not going to be able to run all the checks we could run inside functions. Adding the support for multiple lists to *SLang* is the first solution, but we have to make sure that the benefit for this addition is worth the added complexity. In our situation, multiple list support do not add any value to the checks. Indeed, none of them would use this information, we should not add it to the language. A second solution is to merge all the parameters into one single list. This solution works fine, we recover the possibility to run all checks applying to functions. However, the check limiting the number of parameters raise some unexpected issues. If we limit the number to one single argument, the code from listing 2 will raise an issue. The problem is the implicit keyword, it is here to avoid giving this argument when calling this function, one can argue that implicit parameters should not be accounted for. Despite this concern, we chose this solution, a user can always configure the limit if he thinks that the checks raise unexpected issues.

This case describes the challenge when implementing static analyzer. There are often multiple solutions, not really complex in themselves, but it requires a good understanding of the whole ecosystem, from the original language keyword *implicit* to the final implementation on *SLang*, to be able to produce results of good quality.

2. ***Match statement with at least one conditional case***
   The case of listing 1 seen previously, also appear in the list. In the current situation, the whole match statement is converted to a native tree if at least one conditional case is present. The granularity of this solution is not fine enough. Indeed, we still want to be able to run the different checks related to match tree, even if one branch has an unknown structure. The solution chosen is to wrap the case tree inside a native node in the case where a guard is present. This fine granularity is far better. We are now able to compare the body of the different cases, to report duplicate ones, and to compare the pattern.

3. ***Function parameters with default value***

Listing 3: Scala function with default value

```
def f1(i: String = "Default") = ...
```

In listing 3, we can see function parameters with default value. Once again, the first question is to know if adding support for such construction is worth it. As *Ruby*, *Scala* and *Kotlin* have default value, it makes sense to add the support to *SLang*. This new structure adds new issues on bad naming convention, hard-coded IP addresses inside default values, unused parameters, and few others, comforting our choice that it was worth to support it.

4. ***Function parameters with modifier***

Listing 4: Scala function with implicit modifier

```
def f(implicit param: Int) = {
  g
}

def g(implicit param: Int) = {
  print(param)
}
```

Listing 4 shows a problematic situation with the rule checking for unused parameters in Scala. In this case, the parameter *param* seems to be unused in *f* while it is implicitly passed to *g*. This is the reason why we mapped parameter to native in the first place. At first glance, we might think that *Scala* is the only language having an *implicit* modifier, but if we generalize the idea, we can expect other modifier and even annotation at this place. Annotation is more popular and could be useful in the future, as we will discuss in subsection 7.2.3. The solution we chose is to add the support for modifiers in *SLang*, to map both modifiers and annotation to this node. We are currently supporting only a fraction of the modifier possible, the majority of them, including *implicit*, are going to be native nodes. We are now able to adapt the check for unused variable, but not reporting issues on variable with a modifier. We might miss some real issues since the modifier is a native node unrelated to the problem. However, the approximation performed already provides good results, avoiding obvious false positives.

3 Improving SLang: Null pointer consistency

SLang has already demonstrated his power to support four new languages, some of them in less than a month, and to implement more than forty common checks. However, the language is still young, and the current checks involve mainly syntactic elements. In this section, we are going to attend to push *SLang* further, by implementing more complex checks. To estimate the quality of the results of a checker implemented on *SLang*, we will use a variation *null* pointer consistency check. The check has been chosen because it is a well-known and well-studied bug in static analysis, a lot of different implementations exist with different complexity.

3.1 What is null pointer consistency

Null pointer consistency is the verification that a pointer who is dereferenced is valid and not equal to *null*. Dereferencing a *null* pointer will result at best to abrupt program termination, and at worst could be used by an attacker, by revealing debugging information or bypassing security logic for example.

3.2 Belief style Null Pointer Checker

The goal is to build a checker implementing a variation of the current check *null pointers should not be dereferenced* [7], implemented on SonarJava [8], the tool developed at SonarSource to perform static analysis on Java code. The current implementation uses a complex symbolic execution engine to report potential *null* pointer exception. Symbolic execution tries to estimate all possible execution paths, to track the value of variables, and to report when a pointer is dereferenced while it can be *null* on one path. One important limitation is that it uses a lot of assumptions to deal with the fact that the possible execution paths quickly explode. If it is possible to come up with good assumptions to report interesting bugs, the complexity of the implementation also increases, preventing improvement and therefore the ability to find more bugs. [9]. Our initial goal is not to find all the issues reported by the implementation on SonarJava, but to see if it is possible to still find interesting issues with a less complex implementation which is based on a common intermediate representation.

The idea of this first checker is to use facts implied by the code, called

beliefs [10]. It assumes that the programmer's goal is not to make his code crashes, if two contradicting believes are detected, we report an issue. Concretely, we want to detect the use of a pointer P, followed by a check for *null*. The check for *null* can be equal or not equal to *null*, both statements implying that the programmer believes that the pointer P can be *null*.

Listing 5: Typical example reported by the checker

```
1 p.toString();
2 //The programmer believes that p is not null, otherwise it will
      crash.
3 //... More code
4 if(p == null){//p is checked for null, we have a contradiction!
5 //...
6 }
```

Listing 5 demonstrates a typical example reported by the checker. From line #1, p is dereferenced without having been checked for *null*. We can therefore assume that the programmer believes, at this point, that the pointer is not *null*, otherwise the program will crash. If later, at line #4, p is checked for *null*, it implies that the programmer thinks that p can be *null*, contradicting the previous belief: we report an issue from this contradiction. To implement this check, we need to have a representation of the control flow of the program, which is represented by a control flow graph.

3.2.1 Control Flow Graph

A control flow graph is a directed graph representing the execution flow of a program, the nodes of the graph are individual instructions, and the edges represent the control flow. More precisely, there is an edge from a node *N1* to a node *N2*, if and only if the instruction of the node *N2* can be directly executed after the node *N1*.

Basic Block We initially described the nodes as individual instructions. However, we can see that many instructions are always executed unconditionally in the same sequence. These instructions are regrouped in the same node and called **basic block**, representing the maximum sequence of instructions which are executed unconditionally in sequence. This greatly reduces the number of nodes present in the graph, reducing therefore the

complexity of future computation on top of the graph.

3.3 Formal definition of the checker

More formally, the idea is to check if the use of a pointer p post dominates the check of p for *null*. Intuitively, we report an issue if all path arriving at the check of p go through the use of p, without having been reassigned between the two. To do this, a data-flow analysis using the control flow graph previously described will be used.

3.3.1 Data-flow Analysis

The analysis tracks the pointer use (set of pointers believed to be *non-null*) and flag when the same pointer is checked afterward. The control flow graph will only be built for the current function being analyzed (intraprocedural) and will not have any access to other functions or other files (interprocedural).

Formally:

$$i_n = o_{p1} \cap o_{p2} \cap ... \cap o_{pk} \tag{1}$$

Where $p1, ..., pk$ are all the predecessors, i_n the input set, and o_n the output set of node n.

$$o_n = gen(n) \cup (i_n \setminus kill(n)) \tag{2}$$

Where

$$gen(n) = \text{pointer used in node } n \tag{3}$$
$$kill(n) = \text{assignment of pointer in node } n \tag{4}$$

Intuitively, we can see the analysis as follow:

1. The set of believed to be *non-null* pointer split at branch.

2. On join, we take the intersection of incoming paths, we will remove the ones killed on at least one path. Also called *MUST* analysis.

3.4 Variation of the check

Analysis type	**N° of issues**	**False Positive** [%]
Forward - MUST	32	0
Forward - MAY	2500	> 90
Backward - MUST	65	80

Table 3: Number of issues per type of analysis, with the setup described in section 6.1

The version described before shows one way of doing the analysis, there are small variations can be done on the analysis and will influence the results.

3.4.1 May vs Must analysis

With a MAY analysis, the computation of the input set from equation (1) becomes:

$$i_n = o_{p1} \cup o_{p2} \cup ... \cup o_{pk} \tag{5}$$

If a *MUST* analysis takes the intersection of all incoming path, the *MAY* analysis takes the union of the paths. It means that a pointer will be removed from the set only if all path re-assigns this variable. The choice of *MUST* over *MAY* goes in the sense of the idea to have as little false positives as possible described 2.1.3. Table 3 shows the difference between a *MAY* and a *MUST* analysis of the checker ran on the same sets of sources. We can see that we have more issues, but the rate of false positives is significantly higher, finding interesting issues is too hard with this noise. In addition, understanding which specific path of the execution will raise an exception is hard, making it hard to identify true positives. In practice, to help the user to better understand the issue, we could report multiple locations, the line where the pointer is used, and the one where it is dereferenced, for example.

Intuitively, it is not surprising that the *MAY* analysis performs poorly if we do not take into account the unfeasible paths.

Listing 6: False positive of MAY analysis

```
1 if(p != null){
2   p.toString()
3 }
4 (p == null)
```

Listing 6 shows an example of a false positive reported by the *MAY* analysis. This is obviously an unfeasible path. The pointer p at line #2 is only used if it is not *null*, the check for *null* later at line #4 does not mean that an exception is possible. We will discuss possible amelioration to this situation in subsection 7.2.4.

3.4.2 Used then check, check then used

Listing 7: Pointer used then checked

```
1 p.toString();
2 if(p == null) {}
```

Listing 8: Pointer checked then used

```
1 if(p == null) {}
2 p.toString();
```

Listing 7 and 8 shows the difference between the two versions. The work presented before implements the former. However, the latter makes as much sense, if all paths following the check for *null* uses the pointer p, without re-assigning it, it probably means that an error is possible. In the implementation, this would be implemented using a backward analysis. As the name suggests, a backward analysis means that we take the intersection of all successor's input set to determine the output set of the current node.

For a backward analysis, equation (1) becomes:

$$o_n = i_{s1} \cap i_{s2} \cap ... \cap i_{sk} \tag{6}$$

Where $s1, ..., sk$ are all the successors of n.

And the computation (2) from the forward analysis becomes:

$$i_n = gen(n) \cup (o_n \setminus kill(n)) \tag{7}$$

Surprisingly, the rate of FP is greatly increased, the number of false positives is greater than our goal of $< 5\%$. However, the issues are more interesting than the *MAY* analysis, real issues can still be found since identifying true positive is as easy as false positives.

Listing 9: User define function changing the control flow

```
1 if(p == null) {
2   customThrow();
3 }
4 p.size();
5
6 customThrow() {
7   throw new MyException();
8 }
```

Listing 9 shows a typical example generating false positives, the function *customThrow* is called when p is *null*, and will throw an exception and changing the execution order.

Custom functions changing the control flow is a weak point for flow-based checker not performing interprocedural analysis, and we will probably face this problem both in an original language and in *SLang*. From now, we are only going to work with the first version (used then checked).

4 Implementation on SonarJava

We are first going to implement the check described in section 3 on SonarJava ecosystem. It already provides us symbols resolutions and a control flow graph. The implementation is a classical forward data-flow analysis: the first step is to generate for each basic block the gen and kill set as described before. We are going to store the symbols of the variable in the two sets. We fill the set starting from the last element of the basic block to the first. When a pointer is killed, we also remove it if it was present in the *gen* set. A pointer which is used and assigned in the same basic block will be in the *gen* set only if the use of the pointer follows the assignment, as expected.

Listing 10: Problematic situation with naive basic block creation

```
1 p.toString();
2 b = (p == nul);
3 p = get();
```

Listing 10 shows a potential problem of this method, all the different parts of the code will be added to the same basic block. We will therefore have a structure we would want to report, which is not detected since the pointer is not in the *gen* set of this block. One naive solution would be no to aggregate statements in a basic block, but we will have to compute the input and output set for every statement!
The alternative used in this work is done during the control flow graph creation: we break the basic block when we have a binary expression with an equal (or not equal). In order to support the backward and forward analysis, we should break before and after the check for *null*. We can now safely consider that when a pointer checked, it will never be in the same basic block as where it is used or killed.

Figure 2 shows the old and new control flow graph for the code of listing 10. By doing this, we will be able to support the example showed in listing 10, the check for *null* breaks the block in three, the use and check will therefore not be in the same basic block.

Once the *gen* (equation (3)) and *kill* (equation (4)) set has been generated for every basic block, we can start to run the analysis with a work list approach. The idea is to add all basic blocks in a queue and compute the new *out* set of the current head. Since we are performing a forward analysis, if the new *out* set have changed, this means that all the successors

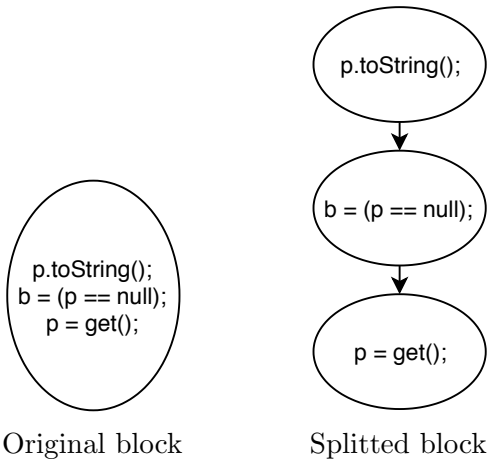


Figure 2: New way to split basic block

might potentially change as well. We add the current basic block and all of its successor at the end of the work-list, if the processed block sets have changed. We continue this process until the list is empty, meaning that we have reached a fixed point.

At the end of this process, we have a set of pointers believed to be not *null* in each basic block. We can therefore perform a second pass through the elements of the basic blocks, if we see a check for *null* in a block where the pointer is in the set of believed to be not *null*, we have a contradiction and we can report an issue.

4.1 Other way to add belief

Null pointer exception does not occur only when a *null* pointer is dereferenced, but can also appear in the following cases for Java, as defined in the documentation [11]:

1. Calling the instance method of a *null* object;
2. Accessing or modifying the field of a *null* object;
3. Taking the length of *null* as if it were an array;
4. Accessing or modifying the slots of *null* as if it were an array;
5. Throwing *null* as if it were a *Throwable* value.

Currently, our checker is only using the first case, but we can use this information to improve our implementation: when we see one of these construction, we will add the pointer to the set of believed to be *non-null* (*gen* set) the same way as we would for a pointer used.

5 Implementation on SLang

In the implementation on SonarJava, we had access to the front end of the checker, with a complete tree, a control flow graph and the symbol resolution available. The first step to implement it on *SLang* is to identify what nodes and structures we need in order to implement everything required for this check.

5.1 Required Nodes

The particularity of *SLang* is that it is incomplete. The intermediate representation does not need to include all node types in order to work, only the one needed for the checks are mapped. We therefore have to make sure that we have all the nodes needed in *SLang* for the implementation of the checker.

Checker specific	**Needed for CFG**	**Others**
Binary operation	If/else	Variable declaration
Identifier	Switch	Function invocation
Assignment	Exception handling, throw	Function declaration
Litteral : Null	Loops	Class declaration
Member select	Jump (break, continue, ...)	

Table 4: Nodes needed for the null pointer dereference check

Table 4 shows the nodes needed in order to implement the different parts of the checker. The first column lists the nodes needed to recognize the different structures used in the checker. The interesting node is the *Member Select*, in fact, to identify when a pointer is used, we will only use this node: we do not need to know anything about the context in which the pointer is used, just that it is dereferenced at some point. When a function is called without a member selection, the tree will be an identifier (name of the function) and a list of argument, but in the case of a pointer use, the tree corresponding to the identifier will be a member selection, that we will use in the checker. By doing this, we can detect not only functions invocations, but also fields selections or anything considered as a member selection in the original language.

The nodes needed for the control flow graph are the ones expected for

identifying the control flow of a program, they are common in all languages and already implemented in *SLang*. The way we handle them will be described in subsection 5.2. The last column describes other nodes needed indirectly by the checker:

1. ***Variable declaration***

Listing 11: Local scope inside a loop who shadows a field

```
1  p.toString();
2  while (cond) {
3    Object p = getP();
4    if(p == null){ } // Compliant
5  }
```

In section 5.3.1, we are going to describe how we perform a naive semantic, assumed inside the check. In this semantic, we are not going to be able to differentiate if two pointers having the same name refer to the same declaration. The idea to better support this limitation is to kill the pointer in the analysis when we see a declaration, the same way as when we see an assignment. In listing 11 the pointer is used at line #1 and check for *null* at line #4, but the two identifier p do not refer to the same symbol. In this case, removing p from the set when it is declared at line #3 will enable us to remove the false positive.

2. ***Function invocation***

Listing 12: Pointer used as a parameter of a function call

```
1  f(p.size())
2  if(p == null) {} // Noncompliant
```

As discussed before, we do not need explicitly function invocation, only member selection. Due to the way we handle nodes not translated, explained in section 5.4, we will add function invocation support. Listing 12 illustrates the situation which we can now report.

3. ***Function and Class declaration***
As our checker is only ran inside functions, we need function declaration to have our starting point. We also use this to improve our semantic, using the fact that the variable used inside a nested function is not checked.

Class declaration is used for the same idea as the function declaration, variables declared in a nested class are assumed to be in another scope.

5.1.1 Other nodes not supported

In section 4.1, we saw multiple ways to add the belief that a *null* pointer can be raised. *SLang* does not have arrays, we could expect not to find all issues coming from them. The length of the array, in *SLang*, is represented as a member select, and can therefore be supported. Accessing or modifying the fields of *null* as if it were an array is however not supported. It will lead to false positives, but the situation seems to be uncommon.

5.2 Control Flow Graph on SLang

SLang already has every control flow statement represented in the language, we can already start to build it the same way we would do it for any other language. In fact, the current implementation is greatly inspired by the one of SonarPHP [12], also developed at SonarSource. To build the control flow graph, we are going to use two main kinds of basic blocks:

1. ***CFG Block***
   This is the foundation of all basic block of the graph, it contains four fields:
   (a) ***Predecessors***
   List of nodes that may be executed **before** the current block.
   (b) ***Successors***
   List of nodes that may be executed **after** the current block.
   (c) ***Elements***
   List of instruction executed one after the other in this basic block.
   (d) ***Syntactic Successor***
   List of node following the current block if no jump is applied. This is not directly needed for our check, but it may be required in the future.

2. ***CFG Branching Block***
   This interface represents blocks including branching instruction, where the flow depends on the result of a Boolean expression. It inherits from CFG Block and has a true and false successor block reference in addition to the simple block.

This is the only two interfaces needed, we can now start to build the graph.

5.2.1 Building the control flow graph

Since we are going to build a graph for the content of a function, our starting point will be the list of the elements of the function. We are going to start from the end of the execution, using a bottom-up approach. It enables us to always know the successor of the node that we are currently building, making easier to build the different instructions containing control flow. We start by creating an *END* node, containing no element and represents the end of the execution. We will then recursively build the graph by matching on the type of the tree.

1. ***Block and other nodes***
   The simplest tree we will face are the blocks, they represent a list of statements. We can therefore directly recursively build the graph for all children, recursion that will add the content of the block inside the current basic block. This behavior can also be applied to other known trees which do not change the flow of execution, as a default case. The only difference is that we are also going to add the current tree to the elements after having built the graph for the children, in order to keep useful information. For example, having a list of identifiers is not useful if we do not know that they are linked together by a binary expression, we will therefore add both the binary expression and the children to the elements of the current block.
2. ***If/Then/Else***
   This is the typical example implementing a branching block. We will first build the sub flow for the false and true branch, if present, and then construct a branching block with these two new blocks as false and true successors, respectively. We can now recursively build the condition of the *If* tree from the branching block created before.

3. ***Loops: For, While, Do-While***

   The bottom-up approach makes the creation of the *If* tree straightforward, since we already have built the successor of the tree we are currently building. However, in the case of loops, the flow is not going to continue at the successor, but return at the condition of the loop, a predecessor's node not built yet. To address this situation, we can introduce a **forwarding block**, a basic block used to store a reference and will not contain any element. We can now start to build the loop flow by creating a forwarding block linking to the condition, and build the body with this new block as the successor. Finally, we can build the condition of the loop as a branching block, with the true successor as the body of the loop, and the false as the block following the loop. There is one detail we have not addressed yet: break and continue. To support these two statements, we are going to use a stack, containing **breakable** objects. These temporary objects are here to store the link to the condition for emphcontinue, and the end of the loop for *break*. Before starting to build the body of the loop, we will push a breakable object to the top of the stack, and pop it once we are done. We use a stack to support nested loop, a break and continue will refer to the first enclosing loop.

   The current implementation of *For* loops is the same as *While* loops, as we do not need the exact behavior of a loop for our check, we can accept this approximation. For *Do/While* loops, we are going to use the same idea but we are going to start to build the condition before the body.

4. ***Match Tree***

   The particularity of a match tree is that it can behave differently depending on the original language. For example, in Scala, only one match case can be executed, while in Java, all cases are executed after a matching pattern, until a *break* statement. The second example is typically known as fallthrough. In *SLang*, both of them are mapped to the same node, however, identifying which one has the right behavior can be done by storing a flag in the node. Non-fallthrough match tree is an easy case, we can build all the cases separately, and create a block having multiples successors.

   Fallthrough switch is trickier, we first have to use the same idea as we used for loops: add an object (similar to breakable) to the stack, to store the reference to the block executed after the switch. We make the same assumption as we did with loops, that a *break* statements

refer only to the closest enclosing match tree.

The next step is to create a forwarding block for the default case of the match tree, and build the different cases in the reverse order, one after the other. We create one branching block per match cases, with the body of the case as true successor and the next pattern as the false successor. At the same time, we can build the sequence of the body of cases, re-starting each time we see a break.

Listing 13: Fallthrough pattern matching

```
1  x = 0;
2  match(cond) {
3   case pat1:
4     a = 1;
5   case pat2:
6     b = 2;
7     break;
8   case pat3:
9     c = 3;
10 }
11 d = 4;
```

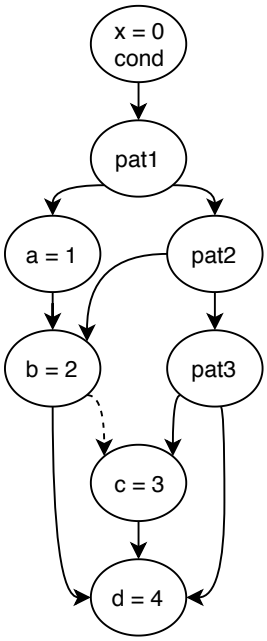


Figure 3: Listing 13's corresponding CFG

Figure 3 shows the resulting control flow graph of the code of listing 13.

We can see that the fallthrough behavior is represented as expected, for example $a = 1$ is executed both when *pat1* and *pat2* is *True*.

5. ***Jump Tree: break and continue***

   Jump trees are not supposed to appear when we do not expect them. If we have an unexpected jump tree, we cannot do anything, and we will directly add it to the current block. We will discuss in section 5.4 a better solution to support this situation. In the usual case, they will appear where we expect them and create an edge from the current block to the head of the stack filled as described in 3 and 4 sections.

6. ***Return***

   Again, starting from the end greatly simplifies the support of return statements: we can store a reference to the *END* block created at the beginning, and use it as successor to the block containing the return expression.

7. ***Exception Handling Tree and Throw Tree***

   In our control flow graph, we are only going to consider exceptions explicitly thrown with a throw statement, and not add an edge to every statement where an exception can occur in reality.
   We are going to start at the end of the exception handling tree. When an exception handling tree is executed, it can result in two possible cases: the exception is caught and the flow can continue, or it is not and the flow goes to the end of the function. To support this behavior, we are going to create a block with two successors: the *END* node and the successor previously created.
   We can then create the *finally* block, if present, and the different catch cases separately, and continue to build the body of the *try* block. At this point we must know where to jump in the case where an exception is thrown. To do this, we will use the same idea as we did with the jump trees: use a stack to push the target of the throw before building the body, and popping it after. If there is no catch block, the target will be the *finally* block, if there is one or more catch block, we will use the first catch case as target. This is an approximation due to the fact that we have no symbol resolution, we cannot know which and where the exception is caught. From now, we can know where to jump in the case of a throw three.
   The last detail to take care of is the case where we have a return inside an exception handling tree. In this case, the *finally* block is executed

after the return. To support this, we will store the exit target on a stack, pushing the reference to the finally block on top of the *END* block previously added.

8. ***Natives Nodes***
   The new challenge comes from the node who is new in *SLang*: the *native node*. The way we deal with native nodes will be described in subsection 5.4.

5.2.2 Normalization

The core of the graph is done, but we still need to perform a few modifications in order to have a proper control flow graph. First, we are going to remove empty blocks. They can be introduced in multiple situations, when we create a temporary forwarding block or when the header of a *For* loop is empty for example. During the creation of the graph, we only knew the successors of the nodes, we still have to compute the predecessor set. Since we have all successors, the task is straightforward. Finally, we can create a *START* node, implementing the same behavior as the *END* node, to indicate the beginning of the flow.

5.3 Data flow analysis

We now have all nodes needed and a control flow graph, we can start the implementation of the checker, which is in fact really similar to the one described in 4. The main difference is the way we deal with nodes having an unreliable execution order and the identification of local variables. The former will be described in 5.4 and the latter in the next section.

5.3.1 Identifying local variable

In SonarJava, we have access to symbols of identifiers, data that we do not have in *SLang*. The current computation of local variables is quite simple: all variable declaration inside the function and all arguments are considered as local variables. This is a naive version will not work for all language but it is used to show that with a proper semantic computation (name definitions and scoping rules) we could expect results as good as the current naive

version.
When we have this set of local variables, we can now check if the variable is in this set before reporting the issues. In practice, we could still report the issues not coming from local variables, but this would add some false positives.

Listing 14: Field can change value during a function call

```
String s = "";

void foo() {
  s.toString();
  changeS(); // An other method can change the value of s!
  if(s == null) { } // Compliant, s changed
}

void changeS() {
  s = null;
}
```

Listing 14 shows an example of a false positive due to a function with side-effect changing the value of a field. Adding the issues coming from non-local variable double the number of issues found, but most of them are false positives. Since a variable can be reassigned between the use and the check of a pointer, these new issues do not exactly respect the original description, we are not going to report them.

5.4 How to deal with native nodes in a CFG based checker?

It is finally time to explain how we are going to deal with the native nodes. For our concern, we will see the native nodes as a node that we do not know anything about, with a list of children.

Listing 15: Simple ternary expression

```
true ? b : p.toString();
p == null; // Compliant
```

Figure 4 shows the result of the *SLang* tree created from the code from listing 15. In this example, we assume that we do not have ternary expression in *SLang*, and that they are not mapped to *If/Then/Else* statement. We will

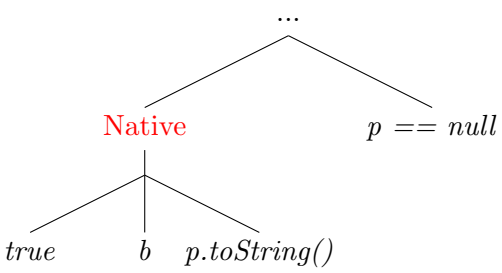


Figure 4: *SLang* AST from the code of listing 15

use ternary expression of Java to represent the problem, but the construction can be any native nodes coming from any original language.
The problem is that we must represent the control flow of an unknown node. We cannot trust the evaluation order of the children of the native nodes, as it can be arbitrary. The first question arising is why do we have to keep the content of a node we do not know anything about? In fact, this is the root of the idea of the native nodes, we are not interested in the node itself, but only in the content.

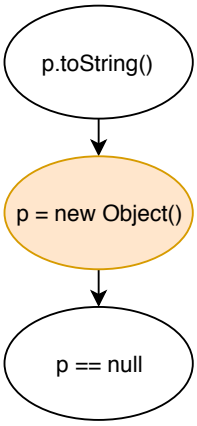


Figure 5: CFG with an assignment in a native node

Figure 5 shows a typical example: in this case, we do not care what exactly happens in this native node (orange node), we just need to know that, at one point, p is assigned, even if it is possible that the assignment is never executed. If it is the case, this will add false negatives, but intuitively, dead code is not common, and will not happen very often.

At this point, we need to keep the content of the native nodes. The next step is to define what to do with them. A naive solution would be to add the

content of the graph in the elements of the basic block, assuming that the evaluation order is not important. This is in fact correct for a native node with only one child, where the evaluation order can obviously not change. If there are multiple children, we have to add the assumption that all the statements who change the flow of a program are represented in *SLang*. This is a reasonable assumption since programming language hardly ever provide an exceptional statement who breaks the control flow, and if it does, we can add it to *SLang* grammar.

Listing 16: Pseudo code with a ternary expression

```
1 K = 1;
2 A ? B : C;
3 P == null;
```

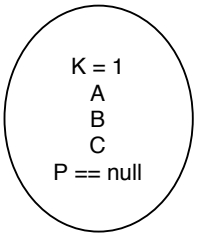
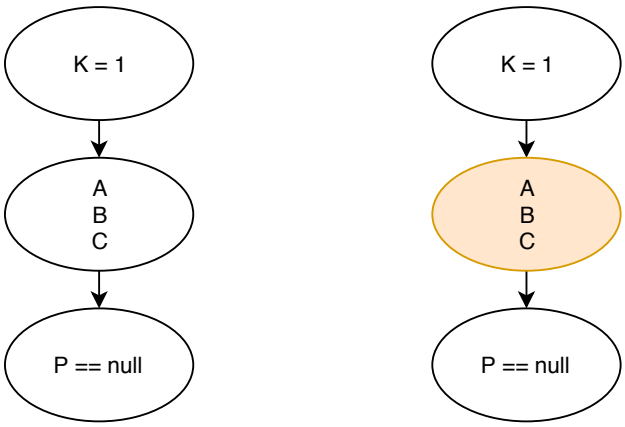


Figure 6: Basic block content of the code in listing 16

Listing 16 some Java pseudo code with the corresponding control flow graph with the naive implementation in figure 6. Since the ternary expression will be mapped to a native node in *SLang*, if we take the children of the native node in order, we will obtain the execution order of the nodes in figure 6. It is obviously not correct, as the pointer will be seen as used then checked in this order, but it is not in the real execution.

We can therefore not ignore these nodes, and not naively add them to the blocks. The idea to solve the problem shown before is to put all elements coming from a native node in a separate basic block (figure 7, left), and mark the block as **unreliable** (figure 7, right), shown in orange. All control flow statement nested inside the native nodes will also lead to an unreliable basic block.
Additionally, we will also mark the whole graph as unreliable.

This information can now be used by any checker using a control flow graph, not only for the *null* pointer dereference checker.



Split CFG Split block with unreliable node

Figure 7: CFG with elements coming from natives nodes

How to use this information? This information can be used in different ways to help to define the multiple level of granularity of the implementation of a new checker:

1. ***Ignore this information***
   In some case, it may make sense to ignore this information, and to treat unreliable nodes as others. In our case, we have shown previously that this solution is not suitable, as it produces too many false positives.

2. ***Don't run the checker on unreliable CFG***
   This is the opposite of the previous point: in the case where the checker needs to really trust the control flow graph, it can make sense to stop the checker if the graph cannot be trusted.

Language	**%**	**% of completely native**	**N° of files**
Scala	41	6.25	6126
Kotlin	47	6.5	26758
Ruby	39	5.2	7811

Table 5: Percentage of native and completely native nodes in the different languages

Table 5 shows the percentage of native nodes in *SLang* after translating open-source projects [13] to *SLang*. The percentage of completely

native nodes refers to the nodes having all their children as native. If more than 40% of nodes are not translated, this does not mean that our language lacks nodes, but that we do not map some kind of nodes on purpose. This table shows us that native nodes are not rare, using the above approach will greatly reduce our chance to find any relevant issue as we will, in most of the case, be in the presence of native nodes in the body of a function.

The two approaches described before seems not well-suited for our checker, we may want something between the two extremes.

3. ***Fine grain***
   We can use the fact that we know if an element comes from a native node or not to define a finer grain implementation of our checker. It consists mainly in one modification of the data flow analysis described in section 3.3.1: we do not add a pointer used in an unreliable block to the believed to be *non-null* set, the equation (3) therefore becomes:

$$newGen(n) = \begin{array}{l}\text{pointer used in the node n} \\ \text{exept if marked as unreliable}\end{array} \tag{8}$$

Listing 17: First example of finer grain behavior

```
1 true ? B : p.toString();
2 p == null; // Compliant
```

Listing 18: Second example of finer grain behavior

```
1 b ? p.toString() : (p == null); // Compliant
```

With this idea, we are now avoiding to report any issue for the two correct pseudo code from listing 17 and 18. Since ternary expressions are unreliable, we will not consider p as used, even though it may look like in the control flow graph.

Listing 19: Third example of finer grain behavior

```
1 p.isEmpty() ? "" : (p == null); // Compliant
```

In listing 19, the real evaluation order use p and then check it for *null*. This code is not reported by our tool despite the fact that it should be. This is a false negative.

Listing 20: Fourth example of finer grain behavior

```
p.toString;
(p == null) ? "" : "null"; // Noncompliant
```

In addition, the implementation will still report issues inside native nodes. For example, in listing 20, we can see that the pointer p is used, and then checked for *null* later in a un-trusted node. We do not know what happens in this node, but we can expect that a check for *null* still means that p can be *null*. In this example, we report an issue, who is a true positive.

5.5 Problematic situations

We have already presented the main problematic situations, coming from native nodes, but there are still a few cases raising false positives that we have to take care of.

1. ***Boolean short-circuit***
   Our current implementation of the control flow graph does not encode the possible path due to Boolean short-circuit. This will lead to a wrong evaluation order, even if the nodes are known. Since the evaluation order is not correct, it makes sense to treat them the same way we do with native nodes. We will hence keep all the content of these nodes, to be able to use them in the checkers, but mark them as unreliable.

   Listing 21: Problematic situations due to Boolean short circuit

   ```
   if(p == null || p.isEmpty())
   p = a.get(1) == null || p.toString()
   ```

   With this addition, we are now able to avoid the false negative reported in the two examples of listing 21.

2. ***Order of evaluation of known nodes***
   In section 5.4, we saw that the order of evaluation of the nodes are critical for our checker. When coming from different languages, even known nodes can have different evaluation order, as we have seen an example in section 4. The same situation can arise for any statement. Hopefully, the solution is often to add the support for the new behavior

in *SLang*. This trick should be used with caution, the initial goal is to be language agnostic, we should ideally not have to modify *SLang* for every new language we add. The good news is that there is only a limited number of variations possible, since the number of known nodes is fixed (and only a fraction of it in practice). This kind of problems are difficulties hard to anticipate and will arise during the implementation of a new checker, but it is not in itself a strong limitation.

3. ***Lost Jump Statements***
   We have seen in section 5 that we directly add jump statements to a basic block in the case where we do not expect it, without doing anything special. In fact, we face similar uncertainties happening with native nodes, we do not know exactly what is happening, but we can expect that something will go wrong. The same arises with jump tree with labels, the way different language deals with label can be arbitrary. We cannot assume anything related to them. We just know that the statement will change the execution flow in an unreliable way, we will therefore mark the flow generated by this statement as *unreliable*.

6 Experimental evaluation: Running the checker on open source Java projects

In this section, we are going to compare the implementation of the checker on SonarJava (section 4) with the implementation on *SLang* (section 5), on a set of open source Java projects. It is a good source of data since it enables us to test the result on real production code.

6.1 Experimental Setup

To test the checker, we are going to create a SonarQube instance [14], with the version of the checker we want to test. We are going to run the analysis with the plugin containing the implementation of our checker on more than 100 open source projects and publish the results on the SonarQube instance. Table 8 shows a sample of the projects used for this experiment and appendix A shows the complete list.

6.2 Early results

The checker has been run on more than one hundred projects of various size and complexity. The idea is to run the two implementations and compare the results.

SonarJava issues	**Slang issues**	%
37	29	78

Table 6: Number of issues reported by the two implementations, before improvement

Table 6 shows the number of issues reported by the two implementations, with the sources and setup described in section 6.1. Despite all our efforts to prevent problematic situations done in the previous sections, the implementation has more than 20% of false negatives compared to the implementation on SonarJava. This is already a good start, but it is not enough for our objective set in section 2.1.3. We will have a look at the issues reported by SonarJava but not by *SLang* in the following part, to see if this comes from misbehavior of the implementation or a real limitation.

6.2.1 Reducing the false negatives from SonarJava

The difference between the two implementations is mainly due to the way ternary expression and loop header are currently handled in *SLang*.

1. ***Ternary expression***
   Ternary expression has been used as example previously, and they actually appear to be causing false positives in real project.

   Listing 22: Typical code structure with ternary expression

```
1 s = p.isEmpty()  ? "Empty" : p.length;
2 // More code ...
3 (p == null);
```

   The situation is not as obvious as the one presented before, listing 22 shows a possible situation where no issue will be reported. To solve this problem, one solution is to map ternary expression to if/else tree. This solution is already used for other checks and seems to solve our problem nicely.

2. ***Loop Header***
   Currently, no check uses the details of the for-loop header, the three distinct part are therefore mapped to a single native tree.

   Listing 23: Pointer used inside loop header

```
1 for (int i = 0; i < p.size(); i ++) {
2 // ...
3 }
4 if(p == null) { }
```

   Listing 23 shows the problematic situation. The pointer p is used, not re-assigned, and check for *null* later. It is exactly the kind of situation we would like to report. However, the different parts of the header are in a native node, as described before It will therefore not be added to the set of pointers used. This makes sense, from a language agnostic point of view, we cannot know anything from the execution order of the different blocks of the loop header, as it can depend on the original language. This is the kind of behavior we want to achieve, the language specific features do not produce false positives, but we accept false negatives. One way to solve this problem is to adapt the loop node in *SLang* to better support this situations. Adding a new

node to *SLang* is a solution we should not use in all situation, it is not well-suited when the feature is specific to a single language. In this case, the correct handling of loop's header can be useful in other checks, it makes sense to support it correctly.

6.3 Improved results

SonarJava issues	Slang issues	%
37	37	100

Table 7: Final issues found by the two implementations for Java

With the two modification done on *SLang*, on the same source and setup described in section 6.1, we managed to report exactly the same issues reported by the implementation on SonarJava!

Project	N° of issues
OpenJDK 9	12
ElasticSearch	7
Apache Abdera	5
Apache Tika	4
Ops4j Pax Logging	3
Apache Jackrabbit	2
RestComm Sip Servlets	1
Wildfly Application Server	1
Apache pluto	1
Fabric8 Maven Plugin	1
Total	37

Table 8: Final issues found by the two implementations for Java, with the setup described in section 6.1

Table 8 shows the projects containing one or more issues and the number of true positives reported, for both forward and backward analysis.

6.3.1 Other languages

The check is implemented on top of *SLang* we can therefore run the checker on other languages for free if we make sure that all nodes described in

subsection 5.1 exists. Currently, the mapping has been completed for Scala and Kotlin. Recently, SonarSource has prepared a setup to run an analyzer on more than 170'000 projects, coming from open-source project on Github with more than 50 stars [15]. This is a huge database, with billions of lines of code, containing many languages, and of overall good quality. This setup is nice to test our tool.

Language	**N° of issues**	**N° of projects**	**True positive rate [%]**
Java	6572	88'871	>99 ?
Scala	99	2'561	89.9
Kotlin	10	1'134	0

Table 9: Number of issues found on more than 170K projects

Table 9 shows the number of issues per language found during the analysis of the 170K projects, with the number of projects containing the language, and the true positives rate. The first observation is that we have issues for all three languages!

1. ***Java***
   The number of issues reported on Java code is exiting, there are a lot of interesting bugs, and not generating a lot of noise since the number of issues per project is hardly ever above thirty. The true positives rate is hard to estimate with this number of issues, but by looking randomly in the list, we did not manage to find any false positive, and most of them are still on the master branch of their Github repository. If we cannot guarantee that the true positive rate is at 100%, our goal to have less than 5% of false positive set in subsection 2.1.3 seems to be reached for Java!

2. ***Scala***
   Finding issues on Scala is good news to consolidate our confidence on the strength of the checker, it is confirmed to be working on at least two languages with two different paradigms! The number of issues is lower than Java, it is partly due to the fact that there is way less Scala than Java projects. A second reason is that Scala language provides the statement *Option*, which can be used to avoid *null* pointer. The experiment also shows that this statement is not consistently used by the community.

Listing 24: False positive due to high-order function

```
1 p.map(p => (p == null))
```

The true positives rate is slightly lower for Scala, this can be explained by a situation similar to the one in listing 24. In this case, our naive semantic described in 5.3.1 considers that both pointer p refers to the same pointer, but it is not the case as the second one is the element of the list p, and not the list itself. The pointer will appear as used and then checked for *null* in the control flow, we will therefore have a false positive. This is an expected problem, the same can happen for variables shadowed in a pattern matching, but it is not a limitation since the computation of proper pointer semantic would solve this problem.

3. ***Kotlin*** The checker only reports 10 issues on Kotlin, and all of them are false positives.

Listing 25: False positive in Kotlin

```
1  fun f() {
2      val a: Any? = null;
3      a.isBooleanOrInt();
4      if(a == null) { }
5  }
6
7  fun Any?.isBooleanOrInt(): Boolean = when(this) {
8      is Boolean, is Int-> true
9      else -> false
10 }
```

Listing 25 shows Kotlin code with an interesting situation reflecting the reason for the false positives. At line #3, we can see that the function *isBooleanOrInt* from the pointer *a* is called without a safe call with *.?*, it is exactly what we want to detect and might look like a true positive at first glance. However, this code will not throw a *null* pointer exception since the function *isBooleanOrInt* is called, without dereferencing the pointer *a*. This called an extension functions [16] in Kotlin, it will extend a class with new functionality. When used, it will not dereference the pointer. Our checker is only looking at the content of one function, from his point of view this code can raise an exception. In fact, in Kotlin, we do not expect to detect any situations where an exception is possible due to the fact that the type system is

built to prevent this kind of issue. As this check does not make sense for Kotlin, we might want to remove it from the list of checks ran on the language, to avoid reporting false positives.

6.4 Are the issues found really relevant?

Table 8 shows the number of issues found per project. This includes all the true positives of the forward and backward analysis. A first observation is that the issues found are coming from various projects and in various situations, it is not one anti-pattern repeated multiple times in the same project. Additionally, all the issues seem to be relevant from a high-level view and without any specific knowledge of the project, you cannot easily justify the correctness of any of the issues reported. To estimate more reliably this interest, we can also look at the fix-rate of the issues.

6.4.1 Fix-rate

Fix-rate is the rate of issues reported by a tool and really fixed by the user. As discussed in section 2.1.3, static analysis tools have to deal with the fact reporting too many issues increase the risk of reporting irrelevant ones and preventing the user to pay attention to them. This is where fix-rate may be useful, it shows that the user did really care about the issues and took some time to fix them.
We cannot define at a given instant this rate, we can only retroactively look at this number. It will therefore depend on the time we give to the user to fix the issues. Our goal is not to reach a precise number, but to find examples of issues fixed, to improve our confidence in the quality of the results.
The first way we will use to estimate the fix-rate is by using some of our test projects not updated for every version. In practice, there are only a few in the infrastructure of SonarSource, the main one we will use is the OpenJDK. The issues reported come from version 9, which will be compared with version 11.

OpenJDK V.9 issues	**Issues fixed in V.11**	**%**
12	3	25

Table 10: OpenJDK 9 issues fixed in version 11

Table 10 shows that 25% of the issues found on OpenJDK 9 have been

fixed in version 11. This may seem like a low number, but it seems to be the kind of results we can expect from this kind of estimation. For example, research from Jetbrains [17] reports that 32% of the issues reported by their tool were considered as useful (rated with a high value) by the person confronted to the issue. We can explain this by the fact developers have priorities, especially in such big open-source projects, fixing a bug already here and is apparently not causing any trouble for many years has low priority, even if this is a legitimate issue. SonarSource often refers to this idea as the **Fix the leak** approach: it does not make sense to spend considerable effort to fix every bug already present in the code if you keep introducing new one in new code, the same way you would not start to mop the floor during a flooding without having fixed the origin of the leak.

A nice story related to the fix-rate is during the run on thousands of projects described in section 6.3.1, the checker reported an issue on an old fork of the code of the Scala compiler. The issue has already been fixed, and the commit fixing the issue state:

Move null check case higher to avoid NPE

It is a nice result. This is exactly the kind of issue we want to report, meaning that the issues reported really matters for the programmer and he is willing to fix it.

One other way to estimate the fix-rate is to look into the issues reported by the tool, understand them, eventually write a unit test raising an exception and report this issue to let the owner of the project decide if this issue is worth the attention. One of the problems is that sometimes, a function can throw a *null* pointer exception, but it will never happen in a real execution. These kinds of issues should however not directly be classified as false positive, as it can also report dead code.

Listing 26: Contradicting code leading to dead code

```
1 if (p != null) {
2   p.toString();
3   if (p == null) { }
4 }
```

Potential Null Pointer Exception or Dead code ?

Despite the fact that we try to find *null* pointer exception, some of the issues found can be considered as dead code, as they can never raise an exception in practice. It comes from the fact that beliefs are implied from the code the programmer writes, if he writes himself contradicting statements, we will still report an issue. Listing 26 shows an example of such situation, the checker does not take in consideration the check for *null* as a path-sensitive tool would do.

One similar situation is that sometimes, it is possible to write a unit test targeting a specific function and throw an exception. However, it will never happen in real execution due to the fact that the programmer has an implicit knowledge about his code. For example, if a user only calls a function if he finds a specific element in a list, he will assume that the list will never be *null* in this function, and therefore the check for *null* is dead code. This will however not deteriorate the quality of the results, this is still raising poor practice and poor code quality since this will be dead code that can confuse the user.

6.5 In-depth comparison with SpotBugs

In addition to comparing the results between two implementations of the same check, we can also compare the issues with the one reported by other tools. SpotBugs [18] is the successor of Findbugs [19], an open-source static analysis tool, it implements multiple checks related to *null* dereference, it is therefore a good candidate to have a comparison with, on the previously tested sources.

SLang	**SLang ∩ SpotBugs**	**SpotBugs: annotations**
21	21	263
SpotBugs: others	**SpotBugs: correctness**	
161	424	

Table 11: *SLang* and Spotbugs comparison on open-source projects

Table 11 shows the number of issues reported by the two tools, with the setup described in section 6.1. For SpotBugs, we used the default configuration, namely confidence level and effort set to default, and took only the issues related to real potential bug.

Table 12 shows a subset of more than 30 checks related to *null* pointer

Rule	Category
Nullcheck of value previously dereferenced	Correctness
Possible null pointer dereference	Correctness
Load of known null value	Dodgy code
Method with Boolean return type should not return null	Bad practice

Table 12: Sample of issues kinds reported by SpotBugs

dereference reported by SpotBugs. For our purpose, we are only interested by the checks labeled as correctness, as they represent bugs we try to identify.

Note that the number is different from the previous experiments because SpotBugs was crashing during the analysis of some of the project (OpenJDK, elastic search). This leads to our first observation: our tool can be run with no configuration on thousands of projects, and during the experiment presented in section 6.3.1, our plugin did not experience a single crash on a huge amount of file! This is particularly good: if we want to introduce our tool on top of a huge project like OpenJDK, it is extremely complex to debug if it does not work out of the box. The second observation is all issues reported by *SLang*, are also reported by SpotBugs. This result may seem discouraging, we are not finding anything new, but it also shows that the issues reported by our check do matter for other tools as well. These issues are reported by SpotBugs as "NullCheck of value previously dereferenced", who is corresponding to the issues reported when we use the forward version of the analysis. In addition, *SLang* implementation is reporting all issues reported under this category, showing that we are not missing any obvious issues.

While we would want to compute the intersection automatically, this number has to be computed by hand, since fully automatically computing the intersection is not a trivial task [20]. First, due to the fact that SpotBugs works on byte-code, we cannot rely on the positions (even the line) of the reported issues reported by the tool. This problem is even worth since the tool seems to report the issues in an inconsistent way, sometimes in a check for *null*, or at the line where the pointer is used. One solution would be to look at the file level and compare the number of issues. This would be possible if the issues were reported into the same category, but SpotBugs is reporting the issues related to *null* pointer in multiple categories, if we include all of them into the comparison, we greatly increase the chance to have unrelated issues reported in the file.

In addition, table 11 raises one surprising observation: SpotBugs is reporting more than 20 times more issues than our check! We can split this number into two categories: the first one is the issues related to annotation. It is interesting to do the differentiation to understand what can be gained from adding a given feature. The second is the other issues related to *null*, without the help of annotation. It can be interesting for us since it does not require any language-specific knowledge and can serve as a goal that can be reached by our tool.

7 Related work

There is a lot of work about variations of *null* pointer consistency check available in the open-source world. The most relevant and closely related work who is based on a universal representation is the micro-grammar approach [9] who is going to be discussed in subsection 7.1. In subsection 7.2, we will present the different techniques other popular tools are using to perform null pointer dereference check and discuss the differences with other popular tools in subsection 7.3. None of them implement the checks on a universal language, but it is a good way to understand the technologies that they are using to perform the checks, and anticipate the problems that can arise if we want to implement equivalent features on *SLang*.

7.1 Micro-grammar

How to Build Static Checking Systems Using Orders of Magnitude Less Code [9] is raising a concern which is similar of what we tried to solve. The team observed that the current situation makes it hard to target new languages due to the complexity of the current systems. The main idea is similar to *SLang*, they implemented a checker based on an incomplete grammar, called **micro-grammar**. With this approach, they managed to implement a checker an order of magnitude smaller than typical systems. The obtained results are encouraging, they manage to find hundreds of issues with an acceptable false positive rate. The idea is similar to island parsing [21], where the grammar only describes some part of a language, without the requirement to have the whole syntax, enabling the tool to be fast, flexible and robust when confronted to unexpected language features.

Issues	**False positives**	**%**
42	3	7

Table 13: Issues reported by the micro-grammar approach

Issues	**False positives**	**%**
28	0	0

Table 14: Issues reported by *SLang*

Table 13 and 14 are showing the number of issues reported by the micro-grammar approach and *SLang* on OpenJDK 8b132. By reporting no false

positive on Java code, our implementation performs better than the micro-grammar. However, our implementation reports less issues. Unfortunately, the paper does not provide the list of issues reported to help us identify the one we are missing. One probable explanation is that we choose to only report issues coming from local identifiers (subsection 5.3.1). This approach does not report any false positive, at the cost of few false negatives. Both results are similar, and both works reach the conclusion: it is possible to find interesting issues with a universal approach.

7.2 Technology used by other tools

If the initial goal is not to find as many issues as any other tool, looking at the features they provide is a good way to know how to improve the current checker and to anticipate if it is possible to implement them on top of *SLang*.

Tools
SonarJava [8]
FindBugs [5] and SpotBugs [18]
Fbinfer [22]
ErrorProne [23]
IntelliJ IDEA [24]

Table 15: Tools detecting *null* pointer dereference

Table 15 shows the list of tools detecting *null* pointer dereference, we can use to compare and understand the different technologies currently used. The first observation of these tools shows that they are globally using similar technology, with different level of efficiency. However, our tool is implementing only a fraction of these technologies, mainly due to the fact that we did not target them in the first place since we tried not to become too complex. The next parts will discuss the main features used by other tools, for what this technology is good for, and if we can implement it on *SLang*.

7.2.1 Interprocedural

Our current checker is only supporting intraprocedural analysis, going further is obviously a way to find more issues, since it would enable us to learn belief from arguments not only inside one function but also outside it. The

main difficulty is to define which function is called at run time. If it is possible to do it for one language, having a consistent way to do it in a language agnostic way is a real challenge. One of the ways is to compute the summary of every function and to use this information during the analysis of a single function. For example, we can store for every function if it can return *null*, then when the result of this function call is assigned to a variable, we can consider it the same way as if it was *null*. This idea is used by SpotBugs and will be described in subsection 7.3.3. There are multiple other ways to perform interprocedural analysis, representing more precisely the execution flow. However, the ideas are complex and will not be described in this work.

7.2.2 Requires the build

Requiring the build can be perceived as a disadvantage, since compiling code and calling it static analysis seems to be a contradiction. Using the build provides however so much information that the popular tools seem to have opted for it. This can make sense when the checking for error is integrated to the build process, but this is a real disadvantage when we want to have interactive feedback in an IDE or a pull request analysis, and is not possible in a cloud computing scenario when you do not have access to the binaries. The recent trend is, however, to avoid using the build due to the disadvantages stated before.

In the situation of *SLang*, requiring to have access to the binaries of the original language does not make a lot of sense, since it will contradict everything already in place. In addition, the goal of *SLang* is not to be a complete language, it is therefore far from being possible to compile this new code. This adds a new challenge that *SLang* will probably face in the future, but it brings enough benefits to make the effort worth it.

7.2.3 Guided by annotation

We have seen in section 7.2.1 that interprocedural analysis is a difficult operation, to help to reduce the complexity of the analysis, we can use annotation to help the tool report possible problems. f Annotations are typically used to declare that a function can return a *null* value, or that a function should never be called with *null* as an argument.

Listing 27: Annotated code

```
1 @NonNull int f(@Nullable String s1, String s2);
```

In listing 27 for example, the function f is guaranteed never to return *null*, and the callee can directly dereference the result of this function without further checking. For the parameters, it enforces that f can give *null* as a first parameter, but not for the second one.
They are multiple flavors on how to do it, depending on what we want, for example, Error Prone is using a trusting analysis, meaning that method parameters, field, and method return are assumed @*Nullable* only if annotated so. If we see the problem the other way, we could alternatively ask to explicitly mark as *non-null* an argument who should never be *null*.
Nowadays, annotations seems to be the most popular way to detect *null* pointer exception, especially for interactive tools. It enables to detect most of the exceptions with a small effort on the programmer side. It is often worth to make this effort, since it is useful not only for the checker but also helps during the development of the program. The downside of this method is that it requires consistent and coordinate use of annotation in a whole project, a consistency hard to achieve when we want to introduce it in an old project.

Annotation could be added on top of *SLang*. Finding relevant annotations for any language is possible if they share the same concepts. For example, a *non-null* annotation makes sense in any language having the concept of *null*. In other cases, this can be trickier; for example, the annotation *initializer*, used in the context of *null* pointer exception, can not be used in a language agnostic way, since the initialization is not the same in any language.
One solution to this is to provide a way to configure the tool. Using configurable check is always a danger for the user experience. For example, NullAway is providing more than 10 configuration flags, some of them being mandatory, all of them related to *null* dereference. In the context of *SLang*, having so much configuration to do for every check and every language simply does not scale at all.

7.2.4 Path sensitivity

Currently, our tool is using flow-sensitive analysis, meaning that we are only interested in the order in which the statements are executed. In addition, path-sensitivity computes and keeps additional information, based on statements seen along the path and avoid infeasible path. For example, if a pointer is checked for *null*, the tool will know if the pointer is equal to *null* inside the true branch, it will therefore report if the pointer is used or given to a function expecting a *non-null* value. For our purpose, we could also learn the value of a given pointer with an assignment for example.

Listing 28: Simple null pointer exception

```
1 Object p = null;
2 p.toString();
```

Listing 28 shows a simple code obviously raising an exception. Our checker is currently not able to detect it since it does not try to know the current value of a pointer. Path sensitive tools would be able to find this kind of issue. In addition, we could also use the path sensitivity to improve the *MAY* analysis introduce in subsection 3.4.1, to remove the obvious false positives. The main challenge of this kind of analysis is to deal with the fact that the number of paths grows exponentially, making it hard to scale. In the current situation, we do not have path-sensitivity in our checker, but we already have all the features required, implementing it with the same constraints as an implementation over an original language seems to be possible.

7.3 Popular tools

None of the popular tools are based on an incomplete representation, but they face challenges that can be similar to what we can experience, helping us to anticipate the potential problems that can arise in the future.

7.3.1 IntellJ IDEA

IntellJ is a development environment, this is particularly interesting since it requires interactivity, a user wants to see the issues being raised while he

writes code, without having to rebuild the whole project. This tool is also performing a *null* pointer analysis using annotation. It warns when the user uses a pointer who is @*Nullable*, without checking it for *null*. To detect if a pointer is checked for *null*, it uses a definable pattern. This will not work if the user is using custom methods to perform the null-check. In this case, the user can define a contract, it would say that this method fails if the argument is *null*, or more simply configure functions performing *null* check. Having configurable settings for a check in *SLang* is far from being ideal, if the effort to configure one check seems to be minimal, if we have a configuration to do for every rule, this can quickly become a nightmare for the user.

7.3.2 Error prone: Null away

Null away is a tool built on top of Error prone. To perform *null* pointer consistency, the process first checks if the value dereferenced is obviously *non-null* (annotated *@Non-null*). If it is not the case, it performs a data-flow analysis to try to infer that the value should be annotated *non-null*. The data-flow analysis is using existing *null* check into the code, if a field is annotated as @*Nullable* and is dereferenced, an error will be reported if the value is not checked for *null*.
The key idea here is to perform the analysis in multiple steps of increasing complexity, skipping costly parts, as the creation of the control flow graph, if not required. Having multiple steps is a particularly good idea for *SLang*, not only for performance but also for the quality of the results. If we can report an issue, or prevent a complex computation before facing the uncertainties due to *SLang*, it may prevent us to make bad decisions.

7.3.3 SpotBugs

We have seen in subsection 6.5 that SpotBugs is reporting way more issues related to null dereference than our implementation is reporting. The main reason for this huge difference is mainly due to the features described previously in subsection 7.2. In addition, we will look more in-depth into one additional feature implemented in SpotBugs and producing a big difference, and see if it may be implemented on *SLang*.

Summary-based interprocedural analysis Summary-based analysis is a smart and easy first step to perform interprocedural analysis. The idea is to compute a summary of every methods and use this information during the intraprocedural analysis. In our case, we would like to store if a method can return *null*, or if a parameter could be *non-null* to then report if *null* is passed as his argument. We can have this information by looking at annotation. If the annotations are not present, we can still perform intraprocedural analysis to infer them ourselves. For example, if a method ever return *null*, we can annotate the function as @*Nullable*, and if a function always dereference an argument without checking it for *null*, we can infer that the argument is *non-null*. The good part is that we already have the nodes and data required to build the summary. However, we are missing the method references in *SLang* to be able to implement this check. We need to be able to identify which method is called to be able to retrieve the summary of the called function. This is related to the problem of the name reference faced during the previous parts Naive solutions exist, but proper semantics must be computed to obtain interesting results.

```
abstract class A {
 foo(p);
}
```

```
class B extends A {
  foo(p) {
    p.toString();
  }
}
```

```
1 B b = new B();
2 b.foo(null); // True positive
3
4 A a = new B();
5 a.foo(null); // False negative
```

Figure 8: Class extending an abstract class

Method reference can be complex, and happen to be producing false negatives in SpotBugs. In figure 8, we have an example of a true positive and a false negative from SpotBugs. At line #2, the issue is correctly reported, the tool manages to identify statically that the pointer b is called with type B. At line #4 however, the tool is not reporting any issue. This is due to the fact that the type of a is B, the tool is not able to identify the potential run-time type of the variable.
This is clearly a challenge we will also face in the future of *SLang*, but we

have seen that there is no strong push-back to implement it, and it could already greatly increase the number of issues reported by *SLang*, even if we have the same false negative as SpotBugs.

8 Future work

8.1 Rule inference

This work shows the potential of *SLang* to support the implementation of more and more checks. However, the list is limited, finding interesting rules making sense in a language agnostic way is difficult. One promising continuation is to work on rule inference to detect object usage anomalies [25].
Rules inference tries to solve the problem that programmers use a wide range of functions for the same goal, identifying which function does what is typically a cumbersome process needed to be done by hand and even impossible for manual approach if the function is user-defined. If the basic idea is to generate rules specific to a project, it would make sense to adapt it to generate rules specific to a language, everything in an agnostic way on top of *SLang*. The typical example is to look at temporal properties. There is multiples way to do it, looking at the sequence of method call during an execution [20], or to use an idea related to the belief style [10] used in this project. The idea is to learn pattern of sequence of function call from the code and report when this pattern is not respected. For example, if we see that the majority of the time, $< b >$ is used after $< a >$, it might imply the belief that $< b >$ should be called after $< a >$. If, in the minority of the cases, $< b >$ is not called after $< a >$, it contradicts the belief and may therefore imply an error. Concretely, this idea should be able to detect that an unlock is called after a lock, or that a resource is closed. In this example, the way a programmer usually deals with them is dependent on the language and even dependent on the project.
This technique would enable us to find issues without knowing what is correct, everything in a language agnostic way.

8.2 Benchmarks

In section 6, we tested the tools on real-life projects. This step is important to estimate the quality of the results on a set of real-life situations. However, the list of potential issues present in the real-life project is not necessary exhaustive. To complement this work, it makes sense to test it against benchmarks, aiming to test as many language specific features, as callback, high-order and all the features discussed in section 7.2.

8.3 Improving the checker

The work presented under section 7.2 is a good starting point to see what can be done in the future for this check. For example, the comparison with SpotBugs in section 7.3.3 showed us that we can already greatly increase the number of true positive, without any complex features and expected problems.

9 Conclusion

We have described the use of a universal intermediate representation used in SonarSource to perform static analysis. It has enabled the company to reduce the complexity of the ecosystem, the maintenance, and the overall effort to implement more than forty checks on a new language, without any strong push-backs. With this representation, SonarSource managed to provide 5 new languages in less than a year, an effort that would not have been possible without it.

In addition to these forty checks, we pushed *SLang* further and managed to run a null pointer dereference checker on top of this incomplete representation. After some effort to adapt the language, the checker turns out to be as efficient as the implementation on the original intermediate representation. During the implementation, the control flow graph showed some weak spots due to the presence of native nodes, but we managed to introduce the concept of unreliable basic block in order to report a good amount of issues with no obvious false positive. The algorithm contains no complex elements and is still able to find multiple thousands of issues on existing open-source projects, on both Scala and Java.

Finally, we have looked at popular tools also performing null pointer dereference checks, we have identified multiple possible improvements, and pointed language features that can become limitations of the current approach.

SLang seems to have started in a very good way and has already demonstrated his power. However, we have to keep in mind that the language is less than one year's old, if it suits well the situations SonarSource faces today, it still have many challenges to face.

Appendix A Open Source Projects

Open source projects used for experiments in section 6.

Activiti https://github.com/Activiti/Activiti.git
AisLib application framework https://github.com/aispl/net-sf-aislib.git
Ambrose https://github.com/twitter/ambrose.git
Apache Abdera http://svn.apache.org/repos/asf/abdera/java/trunk
Apache Commons BCEL http://svn.apache.org/repos/asf/commons/proper/bcel/trunk
Apache Commons Collections http://git-wip-us.apache.org/repos/asf/commons-collections.git
Apache Commons Configuration http://svn.apache.org/repos/asf/commons/proper/configuration/trunk
Apache Commons Exec http://svn.apache.org/repos/asf/commons/proper/exec/trunk
Apache Commons Logging http://svn.apache.org/repos/asf/commons/proper/logging/trunk
Apache Commons Pool https://github.com/apache/commons-pool.git
Apache Commons VFS http://svn.apache.org/repos/asf/commons/proper/vfs/trunk
Apache Directory LDAP API http://svn.apache.org/repos/asf/directory/shared/trunk
Apache Empire-db http://git-wip-us.apache.org/repos/asf/empire-db.git
Apache Jackrabbit http://svn.apache.org/repos/asf/jackrabbit/trunk
Apache Maven Enforcer http://svn.apache.org/repos/asf/maven/enforcer/trunk
Apache MyFaces CODI http://svn.apache.org/repos/asf/myfaces/extensions/cdi/trunk
Apache OpenNLP Reactor http://svn.apache.org/repos/asf/opennlp/trunk

Apache Pluto http://svn.apache.org/repos/asf/portals/pluto/trunk
Apache Tika https://github.com/apache/tika.git
Apache Tobago http://svn.apache.org/repos/asf/myfaces/tobago/trunk
Apache XBean http://svn.apache.org/repos/asf/geronimo/xbean/trunk
AssertJ - Fluent assertions for java unit testing https://github.com/joel-costigliola/assertj-maven-parent-pom.git
AssertJ fluent assertions for Joda Time https://github.com/joel-costigliola/assertj-joda-time.git
Buck https://github.com/facebook/buck.git
Cayenne https://git-wip-us.apache.org/repos/asf/cayenne.git
Checkstyle https://github.com/checkstyle/checkstyle.git
Code Smells Plugin https://github.com/QualInsight/qualinsight-plugins-sonarqube-smell.git
CodeStory - Fluent-http https://github.com/CodeStory/fluent-http.git
Com squareup okio-okio-parent https://github.com/square/okio.git
Cucumber-reporting https://github.com/damianszczepanik/cucumber-reporting.git
Docker maven plugin https://github.com/fabric8io/docker-maven-plugin.git
Easy Rules https://github.com/EasyRules/easyrules.git
Easybatch https://github.com/easybatch/easybatch-framework.git
EBCDIC to ASCII converter https://github.com/SonarSource/ebcdic-to-ascii-converter.git
Elasticsearch https://github.com/elasticsearch/elasticsearch.git
Fabric8 Maven https://github.com/fabric8io/fabric8-maven-plugin.git
FEST Util https://github.com/alexruiz/fest-util.git
FlatPack https://github.com/appendium/flatpack.git
Flex https://github.com/SonarSource/sonar-flex.git

Grapht Dependency Injector https://github.com/grouplens/grapht
Guava https://github.com/google/guava.git
Guava java9 https://github.com/google/guava.git
HelloJava10 https://github.com/m-g-sonar/HelloJava10.git
HikariCP https://github.com/brettwooldridge/HikariCP.git
Hipster-pom https://github.com/citiususc/hipster.git
Initializr https://github.com/spring-io/initializr.git
JaCoCo https://github.com/jacoco/jacoco.git
JDBDT https://github.com/edrdo/jdbdt.git
Jdk9 - OpenJDK http://hg.openjdk.java.net/jdk9/jdk9
Jhipster https://github.com/jhipster/jhipster.git
Jhipster-sample-app https://github.com/jhipster/jhipster-sample-app.git
JIRA Plugin for SonarQube https://github.com/SonarCommunity/sonar-jira.git
JmxTrans - parent project https://github.com/jmxtrans/jmxtrans.git
Jooq https://github.com/jOOQ/jOOQ.git
JSR 354 (Money and Currency API) https://github.com/JavaMoney/jsr354-api.git
JUnit https://github.com/junit-team/junit4.git
L10n :: French Pack https://github.com/SonarCommunity/sonar-l10n-fr.git
L10n :: Korean Pack https://github.com/SonarCommunity/sonar-l10n-ko.git
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Lightblue-audit-hook https://github.com/lightblue-platform/lightblue-audit-hook.git

Lightblue-core https://github.com/lightblue-platform/lightblue-core.git
Markdown4j http://jdcasey@github.com/jdcasey/markdown4j.git
Maven Release http://svn.apache.org/repos/asf/maven/release/trunk
Moneta (JSR 354 RI) https://github.com/JavaMoney/jsr354-ri.git
Mp3agic https://github.com/mpatric/mp3agic.git
OPS4J Pax Logging (Build POM) https://github.com/ops4j/org.ops4j.pax.logging.git
PageObject library https://github.com/lkwg82/de.lgohlke.selenium-pageobjects.git
PHP https://github.com/SonarSource/sonar-php.git
Pippo Parent https://github.com/decebals/pippo.git
Polyforms Framework https://github.com/Polyforms/Polyforms.git
Python https://github.com/SonarSource/sonar-python.git
QualInsight Cobertura Mojo https://github.com/QualInsight/qualinsight-mojo-cobertura.git
Restcomm Sip Servlets https://github.com/RestComm/sip-servlets.git
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Sonar :: Issues Report https://github.com/SonarCommunity/sonar-issues-report.git
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Sonar JMeter Plugin (parent) https://github.com/SonarCommunity/sonar-jmeter.git
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Spark https://github.com/perwendel/spark.git
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