Detecting Oxbow Code in Erlang Codebases with the Highest Degree of Certainty

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Abstract
The presence of source code that is no longer needed is a handicap to project maintainability. The larger and longer-lived the project, the higher the chances of accumulating dead code in its different forms.

Manually detecting unused code is time-consuming, tedious, error-prone, and requires a great level of deep knowledge about the codebase. In this paper, we examine the kinds of dead code (specifically, oxbow code) that can appear in Erlang projects, and formulate rules to identify them with high accuracy.

We also present an open-source static analyzer that implements these rules, allowing for the automatic detection and confident removal of oxbow code in Erlang codebases, actively contributing to increasing their quality and maintainability.

CCS Concepts: • Social and professional topics → Quality assurance; Software maintenance.

Keywords: oxbow code, maintainability, quality, Erlang

1 Introduction
Large codebases tend to become even larger and harder to maintain over time. Systems rarely remain stable, and neither do the teams that manage them. As systems grow, what also grows is the complexity of implementing every desired change, reducing at the same time the developers’ confidence when applying such changes [21, 30]. In most teams, in most systems, there comes a time when developers have to make a change and, giving the high uncertainty they have on the code they are working with, they force themselves to do the smallest change possible.

Particularly when removing some functionality, developers might be tempted to just remove the particular function or the particular expression that implements the functionality, leaving behind other pieces of code (like extra arguments, macros, environment variables, constants, etc.) that are not used anymore. These elements that remain in the code but are not used in production are what we call oxbow code.

Oxbow code is source code that is not used, generally not tested, sometimes not even compiled, but it stays in the codebase, increasing the complexity and slowly but surely taking a toll on the system’s maintainability. Detecting the presence of oxbow code, in general, is not a trivial task. In the particular case of Erlang, some examples of oxbow code instances are:

- macros that are no longer used
- environment variables that are no longer consumed
- header files that are no longer used or that are used by a single module (i.e. they do not need to be shared)
- record fields that are no longer necessary
- function arguments that can be removed since they are ignored in all the function clauses

However, listing all possible oxbow code situations is not enough to solve the problem. Consider an application with the following configuration:

```erlang
{ application ,
  lapp ,
  [{ description , "A large application"},
   {vsn , "10.3.142"},
   {env , [{sample_rate , 0.5}]}
  ]}
```

And consider that we also have a module `lapp` like:

```
-module(lapp).
-include_lib("eunit/include/eunit.hrl").
define(DEFAULT_SAMPLE_RATE , 0.25).
-export([run/1]).
run(Param) ->
  SampleRate = application:get_env(
```
When someone uses the exported function `lapp:run/1`, which in turn invokes private function `maybe_evaluate/2`, this implementation will sometimes run `evaluate/1` (see line 26) and sometimes it will not (see line 24), based on a sampling limited by the configuration parameter `sample_rate` (see line 20). These behaviors are exercised by test functions `ignore_test/0` and `evaluate_test/0` respectively.

If a given developer is now tasked with removing that sampling, that is to say, if the call to `evaluate/1` became mandatory and the need for sampling eliminated, how would they proceed?

To modify the smallest amount of code possible, and following a test-driven development approach (TDD), the first step would be to remove `ignore_test/0` (lines 32–35) and the setting of the `sample_rate` variable in `evaluate_test/0` (lines 38–39). That will result in `evaluate_test/0` failing and, to fix it, the developer would have to remove the first clause of `maybe_evaluate/3` (lines 22–24). That is enough to fix the failing test and complete the task, but it leaves many lines of code that serve no purpose at all anymore.

First, `maybe_evaluate/3` does no longer need to receive three arguments, since it is ignoring the first two. As a matter of fact, the function itself is not needed either, for its only purpose is now to call `evaluate/1` with the same parameter it receives. The developer can just call `evaluate/1` in `maybe_evaluate/2`:

```erlang
maybe_evaluate(_, Param) ->
evaluate(Param).
```

This leads to the same situation repeating: function `maybe_evaluate/2` is also superfluous now. The developer can call `evaluate/1` directly from `run/1`:

```erlang
run(Param) ->
  Result = evaluate(Param),
  logger:info(#{
    param => Param,
    result => Result
  }),
  Result.
```

At this stage, `SampleRate` is no longer needed and the compiler emits a warning about that, which the developer gets rid of by rewriting `run/1` once more:

```erlang
run(Param) ->
  Result = evaluate(Param),
  logger:info(#{
    param => Param,
    result => Result
  }),
  Result.
```

Finally, the developer can safely remove both the macro `?DEFAULT_SAMPLE_RATE` from `lapp.erl` and the environment parameter `sample_rate` from `lapp.app.src`:

```erlang
{ application,
  lapp,
  [{
    description , "A large application"},
    {vsn , "10.3.142"}].
-module ( lapp ).
-include_lib("eunit/include/eunit.hrl").
-export ([run/1]).
run(Param) ->
  Result = evaluate(Param),
  logger:info(#{
    param => Param,
    result => Result
  }),
  Result.
```

The code is now far smaller than the intermediate version, it performs less unnecessary operations (for instance, the random number generation), and it does not contain anything that is no longer needed in production.
In smaller pieces of code like this example, experienced developers aided by good tests can probably detect all the pieces that should be removed by themselves. Advanced IDEs and Language Servers (like erlang-1s [13]) can also help. However, it is not a trivial task and it becomes far less trivial when systems, modules, and functions are larger and more complex, likely spreading a single feature among multiple files in different folders.

Thorough code reviews can help detect oxbow code, but that will only work if the reviewers have a deep knowledge of the system that they are reviewing. That is because, most of the time, to determine that some piece of code is actually dead, the reviewers must know for sure that it is not used in the rest of the code, outside the scope of the changes that they are reviewing. In fact, given the complexity of this process, it is generally safer to just let the oxbow code be untouched, although of course not practical and sustainable in the long run. This is what brings up the need for an automatic tool to detect oxbow code.

Such tool should be able to analyze all the modules, headers, and other files in an Erlang system and, based on some rules that characterize the oxbow code instances to look for (like the ones listed on page 1), detect code elements that are not needed anymore and therefore can be (and should be) confidently removed. For the sample code we just used, we could expect to see the following diagnosis:

```
1 % After removing the first clause of maybe_evaluate/3
2 src/lapp.erl:18: maybe_evaluate/3 does not need its #2 argument
3 % After removing the first clause of maybe_evaluate/3
4 src/lapp.erl:18: maybe_evaluate/3 does not need its #1 argument
5 % After removing maybe_evaluate/3 altogether
6 src/lapp.erl:15: maybe_evaluate/2 does not need its #1 argument
7 % After removing maybe_evaluate/2 altogether
8 src/lapp.erl:5: DEFAULT_SAMPLE_RATE is unused
9 src/lapp.app.src:0: sample_rate is not used anywhere in the code
```

In this paper, we present a taxonomy of types of unused code in Sect. 2, and contribute with a set of precise rules that can be used to detect well-defined examples of each of them in Erlang. Then, in Sect. 3, we analyze how those rules can be automated as part of a code analysis tool both in theory and in practice (i.e. with the existing syntactic tools provided by Erlang/OTP). Finally, we present Hank [1], an automatic oxbow code detector that currently supports a subset of those rules, in Sect. 4, and shows concrete examples that demonstrate its features and capabilities.

2 Characterisation of Unused Code

The most common and informal term to refer to unused source code is dead code. However, there are several nuances that we might imply or not when referring to this concept. These are captured by the more specific terms:

- **Unreachable Code**: Part of the source code of a program which can never be executed because there exists no control flow path to the code from the rest of the program. In Erlang, these situations may be detected using tools like XRef [35] and Dialyzer [10].
- **Dead Store**: A local variable that is assigned a value but is not read by any subsequent instruction. The Erlang compiler usually emits a warning about these variables.
- **Redundant Code**: Source code or compiled code in a computer program that is unnecessary, such as recompiling a value that has previously been calculated and is still available.
- **Oxbow Code**: Fragments of program code that were once needed but which are now never used.

The main focus of this work is this last category, i.e. oxbow code. Oxbow code is typically the result of program modification, either when an item is superseded with a newer version but the old version is not removed, or when an item is removed or replaced, but the item’s supporting code is not.

While oxbow code cannot be the source of bugs in itself (for it is never executed), it reduces the system’s maintainability by making it harder for developers to apply changes. Especially for junior developers or simply developers unfamiliar with the code, they typically cannot be sure that the dead code is, in fact, unused.

2.1 Oxbow Code in Erlang Projects

There are many variants of oxbow code that can be seen in Erlang source files (as those listed in the previous section), and before our work, there were no tools to spot them accurately. In this subsection, we will present the analysis we did on several relevant Erlang projects and the rules for detecting them that we designed on the basis of the examples of oxbow code that were present on them.

2.1.1 Existing Code Analysis. Mostly due to how oxbow code appears, it is far more prevalent in large and old systems.

We analyzed several large open-source Erlang codebases, namely:

- **Erlang/OTP** [12]: As the oldest Erlang codebase, the own implementation of the language and its standard libraries is the most interesting and relevant project to consider.
- **Kazoo** [15]: A software platform designed to provide carrier-grade VoIP features. As one of the largest open-source Erlang repositories in existence, it is a relevant project to check. Furthermore, it being an umbrella project means it is self-contained.
- **MongooseIM** [20]: Another very large Erlang system, in this case, an instant messaging platform aimed at large installations. The meticulous maintenance that it is subjected to makes it another excellent candidate
to analyze. We do not expect to find a large number of oxbow code instances here.

Table 1 summarizes our findings in terms of oxbow code presence in these projects. With numbers like these in mind, and even if just a fraction of them were actually caused by oxbow code, the need for a tool that can confidently detect these elements with high accuracy becomes evident.

2.1.2 Oxbow Code Classification. Oxbow code, particularly in Erlang, can present itself in multiple ways. Therefore, one of our first tasks was to identify as many of them as possible. Using the projects listed above and our personal experience, we generated the following non-exhaustive list of oxbow code classes:

- **Unused Macros**: These are macros that are defined using a `define` attribute but not used anywhere in the code. They are usually the result of the removal of some code where they were originally used.

- **Unused Record Fields**: These are record fields that are declared using a `record` attribute and then never set nor accessed anywhere in the code. This situation may arise when the last place where a particular record field is used is removed, but the corresponding field definition is left in place.

- **Unused Header Files**: These are files (usually with `.hrl` extension within an `include` folder) that are supposed to be used in one or more Erlang modules, but that is not the case. The existence of such files is usually the result of removing the modules where they were included or just the `include` attributes in them, without removing the associated files.

- **Unused Configuration Options**: These are application configuration parameters (i.e., the ones that are retrieved using `application:get_env/2,3`) that have a value but are never consumed throughout the code. Like the previous examples, they may have been consumed once, but the code that consumed them was removed, and they remained in `app.src` or `sys.config` files.

- **Unused Function Arguments**: These are positional arguments that are consistently ignored in all the clauses of a function. Except when the functions are called dynamically and are expected to have a fixed arity (e.g., if they are callbacks for a particular behavior), these functions can serve their purpose without such arguments.

3 Tool Design

Our goal was to build a tool that could detect all the classes of oxbow code listed in the previous section, as well as new ones that can be defined in the future, automatically and accurately. These were its desired features:

- **Ease of use**.
- **Detailed configuration**.

- **Dialyzer-style levels of certainty**.
- **With room for extensibility**.

3.1 Ease of Use

For developers to be able to, and more importantly, willing to use a brand-new tool, this tool should not require complex configuration or set up [23]. At least, not to get the basic stuff running. It is also essential that the results the tool produces are clear and actionable.

In this regard, the Erlang ecosystem already has an extensible plugin `framework` for tools to run: `rebar3` [26]. There are also other existing tools with similar interfaces (like `rebar3_lint` [28] or `rebar3_format` [27]) that we can use for inspiration and be consistent with behavior that is already intuitive to the Erlang developers around the world.

It is also important to consider that a tool like **Hank** is helpful to be run on the developer’s computer, but it is far more useful if it is set up to run as a continuous integration task that validates code automatically. That is why it was very important for this tool to be easy to integrate into any CI pipeline and `rebar3` helps enormously with that.

Effectively, running **Hank** on a `rebar3`-maintained project is as simple as adding an entry to the `project_plugins` list in `rebar.config` and executing `rebar3 hank` in the shell. That will analyze all source files in the project with all the default rules that **Hank** provides to find different kinds of oxbow code. Then it will produce a list of warnings with filenames and line numbers that the developers can follow to investigate and eventually remove or refactor.

3.2 Detailed Configuration

For tools to be run as checks in CI pipelines, they need to be **certain** (i.e., they need to produce an exit code other than 0 if and only if they find errors) and thus they should allow developers to specify the errors they want to ignore or the files they do not want to analyze.

That is why we made **Hank** extensible and configurable. Its default configuration should analyze all files and report all warnings, but it provides several different ways to ignore particular warnings, particular files, or even entire checks.

3.3 Full Certainty

One of the foundational goals of **Hank** is to allow developers to remove code without fear. That can only be achieved if the tool produces no **false positives**. Otherwise, the developers will always doubt if what the tool reports as a removable piece of code can actually be removed, and they will keep it just in case. We would be back to square one.

Nevertheless, as we will explain in the next section, most rules cannot be implemented with full accuracy. Even for rules that are fully defined in theory, implementing an algorithm that would detect all instances of that kind of oxbow code and nothing else can be extremely complex, hard on performance, etc. There is a trade-off to make:
Table 1. Oxbow code presence in several Erlang projects

|                        | Erlang/OTP | Kazoo  | MongooseIM |
|------------------------|------------|--------|------------|
| Size of project (in SLOC) | > 2M       | > 400K | > 180K     |
| Number of active maintainers | 10        | 6      | 5          |
| Project age (in years)    | > 20       | 11     | 8          |
| Unused macros            | > 1000     | > 150  | 90         |
| Unused record fields     | > 200      | > 20   | 7          |
| Unused header files      | > 15       | 3      |            |
| Unused configuration options | 1        | 3      |            |
| Unused function arguments| > 1000     | > 500  | > 200      |

- the algorithm may report all the instances of certain kind of dead code and some other things that are not actual instances of it (i.e. false positives) or,
- the algorithm may report only instances of that kind of oxbow code, but maybe not all of them.

The latter is how Dialyzer [29] works: it may not report all discrepancies in your code, but it is never wrong. In other words, if Dialyzer produces a warning, then developers can be completely sure that there is a discrepancy in their code.

Considering our goal above, we decided that Hank should be built with a Dialyzer-style of certainty and avoid false positives even if that means failing to detect some instances of oxbow code. This is indeed the only way of guaranteeing that it is always safe to remove the code pointed out by Hank.

3.4 Extensibility

The list of oxbow code classes from Sect. 2.1.2 is by no means complete. Moreover, certain systems can have their own kinds of oxbow code, and we wanted Hank to be able to detect those as well.

That is why we designed Hank to work with a set of rules (one for each class of oxbow code) and made that behavior available to the users, so they can define and run their own rules to detect their particular versions of oxbow code, too.

4 Hank

In this section, we will discuss Hank in detail, from its architectural details to the current set of rules and the mechanism that allows developers to define their own. In following sections we will discuss the caveats of the implementation of each rule and how we dealt with those.

4.1 General Architecture

As we have already mentioned, Hank is a rebar3 plugin, and as such it is built as an OTP application, but without a main supervisor. It provides an entry point for the rebar3 framework in the main module of the app: rebar3_hank. As usual with this kind of plugins, the only responsibility of that module is to implement init/1, a function that receives the current state from rebar3 and calls an internal implementation (rebar3_hank_prv:init/1) with it.

rebar3_hank_prv defines the interface between Hank and rebar3 and abstracts the rest of the system from its details. The actual implementation of our tool begins in the module called hank, which is the facade of the system and is called from rebar3_hank_prv after parsing all the input received from rebar3.

The hank module provides a single point of entry via the analyze/4 function. This function will traverse all the code in the system under analysis, apply all the rules and return a possibly empty list of warnings with all the oxbow code instances found. An illustration of this process we have just described can be visualized in Fig. 1. Specifically, the implementation of analyze/4 can be summarized as follows:

1. Parse all project files and collect their abstract syntax trees (ASTs), which will later be used by the rules to detect instances of oxbow code.
2. Generate a list with all the ignore specifications. This is done at this point since the list of elements to ignore can be defined in rebar.config, but also using the hank attribute in the files themselves (i.e. it will be found in their ASTs).
3. Run each of the rules against all the files and collect all the oxbow code instances they detect.
4. Remove the instances that match the ignore specifications, format the remaining ones as warnings, and output that list.

As can be seen in this general algorithm, each rule is run independently from the others. Each one is defined in its module, implementing a shared behavior called hank_rule, that defines two callbacks:

- analyze/2 that receives a list of ASTs and returns a list of oxbow code instances.
- ignored/2 that allows each rule to define its way to specify ignored oxbow code instances within modules.
This is how Hank provides extensibility: to define a new rule, the only thing a developer needs to do is implement this behavior.

4.2 Default Rules

By far, the most interesting part of the system, and the one that required the most effort, is the implementation of each of the rules defined in Sect. 2.1.2. In this section, we will formalize each of those rules, describing what an ideal implementation of such a rule would involve. However, when such an implementation is not feasible, we will exhibit the problems that we found, analyze possible solutions, and describe the actual implementation.

4.2.1 Unused Macros. This rule aims at detecting all instances of macro definitions that are not used anywhere in the code. More specifically, the goal is to find all define attributes with no corresponding macro nodes anywhere.

As an example, in the following module, the rule should report unused as an unused macro, but it should not emit a warning for used since it is used in my_function/0:

```
1 -module(my_module).
2 -export([my_function/0]).
3 -define(UNUSED, unused).
4 -define(USED, used).
5 my_function() -> ?USED.
```

In AST terms, the algorithm behind this rule can be summarized as:

1. Find all nodes with type == attribute and name == define.
2. For each one of them, extract the corresponding macro name and arity. We need the arity information because in Erlang, it is valid to have two macros with the same name and different number of arguments, same as happens with function definitions.
3. Find all nodes with type == macro.
4. For each of them, extract the corresponding macro name and arity.
5. Return an oxbow code instance for each macro in the first list but not in the second one.

4.2.2 Unused Record Fields. The idea behind this rule is to detect record fields that are defined but not used anywhere in the code. Hank will be looking for record attributes that include fields that appear nowhere else in the code.

Consider the following example:

```
1 -module(my_module).
2 -export([new/0, use/1]).
3 -record(my_record, {used, unused}).
4 new() -> #my_record{}.
5 use(#my_record{used = Value}) -> Value.
```

Upon analyzing this module, the rule should report unused as an unused field, but not used since it is used in use/1.

According to OTP’s erl_syntax module, there are three types of AST nodes that represent usage of field records:

- `record_access` A record field access expression, for instance `Var#record.field`.
- `record_expr` A record expression. It can be either like `#record{field = Value, ...}` or it can include a variable, like `Var#record{field = Value, ...}`.
- `record_index_expr` A record field index expression, for instance `#record.field`.

Figure 1. General behavior of Hank
Considering the list above, in AST terms, the algorithm for this rule can be summarized as:
1. Find all nodes with type == attribute and name == record.
2. With them, generate a list of all fully-qualified record field names, like {RecordName, FieldName}.
3. Find all nodes with any of the three types listed above.
4. With them, build a list of all pairs of fully-qualified record field names.
5. Return an oxbow code instance for each tuple that is on the first list but not on the second one.

### 4.2.3 Unused Header Files

This rule’s goal is to detect *.hr1 files that are not included in any module. To achieve that goal, this rule’s algorithm is simple:

1. Find all the paths to files with hr1 extension.
2. Find all the nodes with type == attribute and name == include or name == include_lib.
3. Return an oxbow code instance for each file in the first list that does not correspond to any of the paths in the second list.

### 4.2.4 Unused Configuration Parameters

For this rule, the idea is to find all application configuration parameters (the ones that can be retrieved via application:get_env) that are defined either in .app.src or sys.config files but never used within the system.

When set up to write down an algorithm for this rule, we immediately find out that finding all places where a certain parameter is used precisely (i.e. without missing any) is not as simple as it seems. It is not enough to find all usages of application:get_env/1,2,3 with the parameter in the corresponding position. That is because somebody can wrap up that call in a function, like in the following example:

```erlang
-module(my_module).
-export([get_env/1]).

get_env(Param) ->
  application:get_env(Param, unknown).
```

In order to preserve our desired Dialyzer-style level of certainty in our results, we decided to count any appearance of the configuration parameter as a usage. That will generate some false negatives (undetected instances of oxbow code).

For instance, when Hank analyzes the code above, if there is a parameter called unknown in the application configuration that is not used anywhere, the rule will not report it as unused since the atom unknown appears somewhere in the code, even if no one ever calls get_env/1.

With that in mind, the algorithm we implemented is:

1. From rebar3 context, gather the names of all the applications being built (for a single repository can hold more than one OTP application).
2. Find all files containing configuration parameters (that is, files with extensions like config or app.src).
3. From those files, create a list with all the configuration options associated to the applications listed before.
4. Create a list with all the nodes with type == atom in all the modules and header files being analyzed.
5. Return an oxbow code instance for each element in the first list that is not a member of the second one.

### 4.2.5 Unnecessary Function Arguments

The idea behind this rule is to detect all instances of positional arguments that are consistently ignored in all the clauses of a function, and therefore can be unnecessary to that function’s behavior. An example of such a situation follows:

```erlang
-module(my_module).
-export([external/1]).

external(Param) when is_integer(Param) ->
  {is_integer, Param};

internal(Used, _Unused) when is_integer(Used) ->
  {is_integer, Used};

internal(_Used, _Unused) when not_integer() ->
  not_integer.
```

For the module above, the rule should identify internal’s second argument as an unnecessary function argument, but it should not report the first argument since it is indeed used in its first clause. Finding this kind of oxbow code is particularly important since, as in the example, it may effectively lead to the removal of unneeded computations, which may improve the system’s performance of the system as well as making it more maintainable.

It is relevant to mention that the algorithm for this rule does not need to look for unused variables. That is to say, it does not need to figure out if _Unused is actually unused in the function clause. That is because if it had a non underscored name (like Unused), the compiler itself would emit a warning and, for variables with underscore prefixes, there are other tools (like Elvis/rebar3_lint) that will generate a warning if they are, rather incorrectly, used. This means that, to determine that an argument is unused, this rule implementation only needs to check if it is either _ or an underscored variable (like _Unused).

Under this consideration, the resulting algorithm is:

1. Find all nodes with type == function.
2. For each of them, find all their clauses.
3. For each clause, find all the patterns and keep the ones that are just a node with either type == underscore, or type == variable and a name that starts with _.
4. For each function, return an oxbow code instance for each element that is a member of the list of ignored arguments in all its clauses.

### 4.3 Implementation of New Rules

As we mentioned in Sect. 3, we do not want to limit the number of rules that Hank can apply. On the contrary, Hank
is designed to allow developers to build their own rules by implementing the hank_rule behavior. As stated in Sect. 4.1, the behavior only defines two callbacks: analyze/2 and ignored/2. To understand how to implement a new rule, developers can check any of the existing ones as a source of inspiration or copy the template on Lst. 1.

5 Discussion
This section provides further insights into some of the design or implementation decisions that affect Hank.

5.1 Rule Implementation Caveats
When trying to implement most, if not all, of the rules in Sect. 4.2, we found some corner cases where our rules either failed to detect actual oxbow code instances (false negatives) or reported as oxbow code instances some pieces of code that were actually used (false positives). Our intention was always to remove false negatives and false positives completely, but in some cases, that was too hard or even impossible. Whenever a trade-off was needed, we always chose to remove false positives entirely (i.e. Dialyzer-style certainty), even if that increased the number of false negatives. In other words, Hank may not detect all the oxbow code instances, but every instance it reports is an oxbow code instance.

5.1.1 Preconditions. Each rule in Hank assumes certain preconditions on the code that it is going to analyze. These assumptions limit the scope of application of the rule and present some scenarios in which the outcome of applying the rule is undetermined. These limitations are listed in the module’s documentation. For instance, for the Unused Record Fields rule, we have:

This rule assumes that your code will never use the underlying tuple structure of your records directly.

5.1.2 Conditional Compilation. It is also important to notice that Hank works directly on the code as it is written, i.e. without pre-processing. This is by design: on one hand, part of Hank’s job is to detect, for instance, unused macros (which is something that the Erlang pre-processor removes). On top of that, once again to avoid false positives, Hank will look through all the code that can be compiled. In other words, if there is any way of compiling the code (say, defining a particular macro or assigning a particular value to it at compile time) that will include some pieces of code (e.g. a particular record definition), Hank will consider those “used”. Check for instance, the following example:

```
1  -define(SOME_MACRO, a:function(call)).
2  -ifdef(DEBUG).
3  another_function() -> ?SOME_MACRO.
4  -else.
5  another_function() -> ok.
6  -endif.
```

Listing 1. Hank rule template.
?SOME_MACRO will be unused unless the code is compiled with DEBUG defined. But Hank will not report that macro as unused, because there is a way to compile the code in which it is actually needed and therefore it can not be safely removed.

5.1.3 Unused Record Fields. Originally, we did not want to consider record creation (i.e. building a new instance of a record) as record usage, since assigning a value to a record field is not actually using it, but the parser that Hank uses (based on the one provided by OTP) did not allow us to implement this rule that way because it does not differentiate record creation from record pattern-matching. In other words, all the expressions in the following function generate virtually indistinguishable syntax tree nodes in the part where they use the record:

```erlang
1 a_function(#a_record(a_field = AValue)) ->
2 R = #a_record(a_field = AValue),
3 #a_record(a_field = AValue) = R,
4 #a_record(a_field = AValue).
```

Lines 1 and 3 have patterns in them, while lines 2 and 4 create new records, but according to the parser, they are all nodes with type = record_expr. So, to avoid false positives stemming from code like the one in lines 1 and 3, we had to consider all these nodes as record usage.

In addition, Erlang also allows another kind of special syntax for records to allow developers to work on multiple record fields at once:

```erlang
1 %% @doc Returns a record with all 'null's.
2 nullified() -> #a_record(_ = null).
```

This is particularly useful when working with match expressions for ets or mnesia. In these scenarios, we just considered all the fields in the record as used.

5.1.4 Unused Header Files. Attributes include and include_lib both use relative paths that are affected by the list of include folders (provided with the -I argument to the compiler) and the current version of each in a release (folders in releases are called app_name-vsn). When running Hank, we do not have any of that required information, so we cannot know for sure which file is each include and include_lib attribute referring to precisely.

Always intending to remove false positives, we decided to fail on the safer side and follow this algorithm when comparing the path of a header file against the path of one of the attributes:

1. If both paths are the same, then they match (i.e. the header file is used).
2. Remove all relative path information from the include path (i.e. remove ../ and ./).
3. If the largest of both paths ends with an exact match of the shorter one, then they match.
4. Otherwise, they do not match.

That algorithm would determine that a_header.hrl and app/a_header.hrl match, but app/other_header.hrl and app/a_header.hrl will not. Neither will app2/h2.hrl and app/h2.hrl.

The problem, of course, arises when a project has two apps, each one with a header file called h.hrl and only one module has the following code:

```erlang
1 -include("h.hrl").
```

In this scenario, only one of the header files is actually used since no module includes the other one. But Hank cannot tell which of the header files is the one that is being included, and therefore it does not report the other as unused.

5.1.5 Unused Configuration Parameters. The main issue with this rule appeared when we tried to identify the files to analyze in search for configuration parameters. The obvious ones (i.e. *.app.src) were easy, but they did not cover much ground. In most projects, particularly those implementing large applications, some sort of sys.config file is used. That is why we decided to consider all *.config files as well.

This decision brought several side-effects with it. First, the structure of sys.config files is not the same as the structure for *.app.src files. Thus, the rule must be able to parse both, finding the env configuration section in the application files and reading the entire file in the config ones.

Then, there is the problem that sys.config files usually contain configuration parameters for applications that are not in the system (i.e. dependencies). Luckily, rebar3 offers a way to get the list of OTP applications in the system. We used that list to filter the information included in config files.

Finally, not all config files are sys.config ones. Some files may not even be parseable as Erlang terms. The rule just ignores them. Others are parseable but do not work as configuration for the run-time, most notably rebar.config and elvis.config. To deal with this, we included a list of known config files that the rule should ignore.

5.1.6 Unnecessary Function Arguments. There are two main scenarios where a positional argument for a function must be ignored and cannot be removed, and therefore it is not an instance of oxbow code: when the function implements a behavior callback, and when the function is a NIF stub.

**Behavior Callbacks.** When a module implements a behavior, it has to implement all non-optional callbacks defined by it, even if it has nothing to do for them. That usually leads to functions like this one:

```erlang
1 handle_cast(_, State) -> {noreply, State}.
```

The function has effectively nothing to do with the first parameter of that function, so it would seem unnecessary. But the behavior demands the implementation of handle_cast/2
not handle_cast/1. Hence, the rule should not report this as an oxbow code instance.

Detecting functions that implement callbacks is not a trivial task. If the module defining the behavior is already compiled at the time of running the rule, Hank can collect the callback definitions by calling module:behavior_info(callbacks). Nevertheless, if the module is not accessible (for instance, if it is part of the code that Hank has yet to analyze), Hank will need to find the callback definitions by itself in the module AST.

Moreover, not all callbacks for a particular behavior may be explicitly listed as callbacks. An example of this is the gen_statem behavior, which defines an arity for each of its state function callbacks, but not a name for those functions: the implementer can choose any name for those functions, as long as they have the proper arity and are exported.

To fail on the safer side, we added a list of known behaviors to the rule (including, among others, gen_server and supervisor). For modules implementing those behaviors, Hank checks all functions except the expected callbacks. For all other modules implementing a behavior, this rule ignores all functions for the time being.

NIF Stubs. When implementing a NIF (Native Implemented Function), developers are required to create an associated Erlang module with the same interface but with all NIF functions being just stubs. This rule assumes that, following OTP recommendations, such stubs will just call.erlang:nif_error/1, 2 and ignore all their arguments. These arguments are not oxbow code instances, and to avoid reporting them as such, the rule ignores all functions that contain a call to erlang:nif_error/1 or erlang:nif_error/2.

5.2 Rule Exceptions

Even after all the decisions we have described that have been taken to achieve the highest degree of certainty when detecting oxbow code instances, there will be instances in which the developers will like to preserve some particular oxbow code instances. It can be for documentation purposes, or because the particular project doesn’t align with the preconditions of a rule, as described in section 5.1.1. To deal with these scenarios, Hank provides multiple ways to determine which warnings to ignore:

1. Specifying particular instances to ignore or even entire files using the ignore option in the hank section of their rebar.config files.
2. Entire modules can be ignored by adding the attribute -hank ignore. to them.
3. Particular rules or particular oxbow instances can be ignored in a module using the hank attribute with appropriate options, as seen below:

```erlang
-hank([{unused_record_fields, [ignored_record, (a_record, field_1), (a_record, field_2)]}]).
```

This code will prevent Hank’s Unused Record Fields rule from emitting warnings about fields field_1 and field_2 in the record a_record, or about any field in the record ignored_record.

5.3 Performance

As we showed in Fig. 1, Hank’s algorithm has two main steps:

1. Parsing all the files, which is mainly impacted by the number of files to parse and their size.
2. Running the rules on the ASTs, with its execution time derived from the number of rules and the complexity of their algorithms.

Before releasing version 0.4.0 of Hank, we run some benchmarks for both of those stages. We compared the execution times of each stage, both running it in a parallelized way (using rpc:pmap/3) and a sequential way (using list comprehensions). The projects we benchmarked were the same included on Table 1, and the results are presented in Table 2.

We found that file parsing was greatly improved by using parallel execution, but rule evaluation was actually faster if performed sequentially. This may seem counter-intuitive, but it can be explained by the fact that there are very few rules, and none of them are bound by I/O or network processing. That is why the time spent by rpc:pmap/3 spawning processes, waiting for results, and collating responses outweighs the time spent actually running the algorithms.

With that consideration in mind, we came up with the Optimal Runtime shown as the last row of Table 2, which is the one currently implemented in Hank: file parsing is run in parallel, but rule evaluation is performed sequentially.

6 Related Work

Code analysis and code quality improvement have long been dynamic research areas within software engineering research. Efforts have targeted from unused variables [33] or dead-code elimination in recursive data [18] to parallel programs [16].

We find the most applied state of the art in this field to be language-specific, thus exploring the ways in which programming paradigm and language features manifest, specifically, as unreachable or dead code [8], precisely as we have done in our work. In many cases research is focused on the formulation, and sometimes formal verification of the detection/removal technique [3], but we find also empirical evaluations [5] and tool implementations [14].

The benchmarks were executed in a Macbook Pro with a 2.6 GHz 6-Core Intel Core i7 processor and 16 GB of RAM and an SSD hard drive.

In order to find a way to deal with this issue in a better way, we opened a ticket for the Erlang/OTP team [25].
As far as functional languages are concerned, most previous research has focused on typed languages [9], with the most recent efforts applying dependent data type for dead-code elimination [34]. Techniques such as program transformation with dynamic rewrite rules attempt to overcome the context-free nature of rules [7]. Last but not least, partial dead code elimination [17], i.e. code that is only dead on some program paths, has also been proposed, but it requires second order effects to be removed, or else a limited scope (using program slicing [4]).

6.1 Related Tools for Erlang

6.1.1 Other rebar3 Plugins. Hank is just one of the many plugins available for rebar3 that can increase maintainability. As stated in Sect. 4.2.5, we actually assumed that developers would run Hank together with some (if not all) other tools, and that is why we did not create rules to generate reports for aspects that are already covered by those publicly available tools. For reference, some of these tools and their relation with Hank are:

- **Elvis** Elvis [11] is a linter: it reviews code style, like function naming, nesting level, line length, variable naming convention, etc. It works on a file-by-file basis, while Hank rules work on all the files of a project at once.
- **XRef** XRef [35] is a cross-reference tool that can be used to find dependencies between functions, modules, applications, and releases. It is a great tool to detect dead code, but it cannot detect oxbow code instances since it works on compiled beam files.
- **Dialyzer** Dialyzer [10] is a static analysis tool that identifies software discrepancies using success typing. Just like XRef, it analyzes compiled (or at least fully-interpreted) code. Macros and records, among other classes of oxbow code, are virtually invisible to Dialyzer.

6.1.2 Other Erlang Tools. Besides the ones that can be used via rebar3, the Erlang Ecosystem provides several other useful tools that are in one way or another related to Hank. For instance, the Erlang Language Sever [13] (erlang-ls). ELS is a language server (based on the Language Server Protocol [19]) that provides language features (like auto-complete or auto-formatting) for the Erlang programming language. In principle, erlang-ls could integrate with Hank to also provide automatic oxbow code detection, but the protocol works on a file-by-file basis so it cannot easily analyze whole systems at once. Nevertheless, the rules that can work per-file (e.g. unused macros) are being ported to erlang-ls, and the language server is already providing its own implementation of some of this functionality.

The Erlang Ecosystem has seen a number of static analysis and refactoring tools. From those still actively developed or maintained, RefactorErl [6, 24] stands out. It is an open-source static source code analyzer and transformer for Erlang, developed by the Department of Programming Languages and Compilers at the Faculty of Informatics, Eötvös Loránd University, Budapest, Hungary. So far, no analysis of possible collaboration between RefactorErl and Hank has been made, but this is certainly a great path for further investigation. An interesting idea would be to use RefactorErl to automatically fix the warnings reported by Hank, or to use RefactorErl semantic analysis framework to extend the scope or overcome the current limitations of some rules.

6.2 Related Tools for Other Languages

Within the Erlang Ecosystem, Hank is the only tool to detect oxbow code. There are no similar tools for other languages, like Elixir, LFE, or Gleam, and projects written in those languages cannot use Hank. A good path for further research would be to analyze such languages and the development of their corresponding oxbow code detectors. In doing so, our work can serve as inspiration on how to design them, and how to implement similar detection rules avoiding potential pitfalls.

Other communities do have similar tools. For instance, for code written in Python, there is vulture [31]. Vulture finds unused code in Python programs. As opposed to Hank, Vulture developers decided to reduce the number of false positives, thereby decreasing the number of potential false alarms.
negatives, so it may emit warnings for code that is actually used. What they provided as a trade-off is a configurable level of confidence for each warning. It is a slightly arbitrary value that determines how confident Vulture is of a particular piece of code being dead, and the developers can filter Vulture output to just emit warnings with a minimum level.

Other tools, like phpdfc for PHP [2] or dead-code-detector [32] for Java, have a somewhat different focus than Hank, and they mainly aim at finding unreachable or redundant code.

7 Conclusions

In this paper, we have addressed the problem of the identification of dead code, focusing mainly on oxbow code, in the context of the Erlang programming language. By analyzing several relevant open-source projects with many years of development, we showed evidence of the preeminence of this issue in large codebases.

As a solution to this problem, we have presented an open-source static analyzer, Hank, that can help to improve the maintainability of Erlang projects by allowing developers to detect and confidently remove unneeded portions of code. It is a rebar 3 plugin that is easy to use, extensible, optimized for performance, and provides a high level of accuracy. We have described in detail how it is built, and discussed the reasons behind its design decisions. We believe Hank is ready for production usage, and that it should be included in the tool-chain of all well-maintained Erlang systems, together with Elvis, XRef, Dialyzer, and others.

Further work in Hank itself will be focused on the improvement of the existing rules, the creation of new ones, and the addition of new options that may facilitate its usage and integration even more, such as the optimization of file parsing and rule evaluation on unchanged files.

At the same time, the knowledge gained during the development of Hank could be put at service in the analysis of other languages in the Erlang ecosystem, to determine how common it is for them to generate oxbow code instances, what kind of specific instances they may present, and how to best detect them. In cases where it is deemed suitable, the next step would be creating tools similar to Hank to detect and remove code that is no longer needed.

On a more abstract level, we intuitively know that reducing the general code surface of a project while not affecting its functionality improves maintainability. However, we do not have solid data on this matter. A future project may use Hank to verify how much faster or easier it is to work in a project once all instances of oxbow code have been removed.

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