Type Flattening Obfuscation

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***Abstract*—Beside data and control flow, high-level types are important in binary code analysis, particularly in decompilation. Some research papers have introduced methods to map machine-dependent objects into types of some C-like type system. For the obfuscation/anti-decompilation purpose, we present a technique which bypasses existing type recovery approaches. We have implemented a prototype obfuscating C compiler to demonstrate the technique, the compiler is given open source.**

***Index Terms*—type recovery, decompilation, obfuscation**

1. Introduction

Binary code *decompilation* [4] is to transform the low-level, machine-dependent code of a program into a high-level form, like code of a high-level language. In almost all academic research papers and commerical products, the target language is C. Similar to compilers, a modern binary code decompiler consists of many phases [4, 8]: disassembly, function boundary detection, immediate representation (IR) lifting, control-flow graph (CFG) recovery, high-level variables detection, type (i.e. variable types and function signatures) recovery, etc. Each phase requires particular but not independent [6] analysis techniques: the results of one can affect another. The analyzed program is transformed gradually into a higher-level, more abstract and more understandable representation.

In the opposite direction, binary code *obfuscation* is a method to protect the low-level code from being decompiled, or from being analyzed in general. Because the code analysis contains of different interdependent phases, the obfuscation [10, 21] can proceed at any of them, e.g. anti-disassembly (binary packer, self-modifying code), binary stripping, control-flow flattening, virtualization (for both data and control obfuscation)... just name a few. Basically, each obfuscation method consists of one or several *semantics-preserving* transformations [7, 10] which hide certain properties of the code.

An optional feature of binary code decompilation is *type reconstruction*, namely to recover high-level types from machine-dependent objects [5, 8]. This is the research objective of some research papers [12, 14, 17, 18], and killing feature of commercial [26, 27] as well as open source [25] binary code analysis tools. Beside decompilation, types and particularly *function signatures* are also essential in numerous applications, e.g. static binary rewriting [11, 13] and raising [23], see for example [15] for a survey. Thus the knowledge about types expand the attack surface since more analysis can be applied on the programs.

Despite of successes in binary type reconstruction and the need of protecting function signatures, to the best of our knowledge there is no explicit effort in hiding type information. This paper presents a method for type obfuscation, the principal idea is based on the fact that the compiler does not need to preserve all information about high-level types (type erasure), then with specific tricks we can exploit the *semantics gap* between the high-level language and machine code to make some information very hard if not impossible to be recovered. We do not claim that all type information can be hidden, the attacker can eventually know some but it would be hard to distinguish the concrete underlying types from one to another, thus the proposed notion of *type flattening*.

We implement the tricks in *uCc*, an open source obfuscating C compiler which obfuscates function signatures. The functions in binaries generated by *uCc* can be perfectly analyzed by classical procedures (boundary detection, disassembling, CFG recovery, etc), only their signatures are obfuscated. That way, we can evaluate the effectiveness of type obfuscation tricks on function signatures while excluding unwanted obfuscation effects that may come from (bad) results of other analysis phases. We find that Mixed Boolean Arithmetic (MBA) expressions [9, 20] are a good match for the goal.

In summary, our contributions are as follows:

- We introduce the notion of *type flattening*, it aims at protecting a high-level property (types) of the program in contrast with classical methods which focus on lower properties as data or control flow.
- We build a prototype compiler *uCc* to realize the ideas of type flattening obfuscation. *uCc* also implements the permutation polynomials of MBA [9] while other open source state-of-the-art obfuscators (e.g. Tigress [28]) give only basic arithmetic encoding expressions. Other deobfuscation tools (e.g. Syntia [19], QSynth [24]) can profit *uCc* to test their capabilities of MBA simplification.
- We evaluate the binaries generated by *uCc* against decent decompilers, the results show that no one can detect correctly the underlying types of arguments on function signatures: the original types are indistinguishable from the highest types in the C's integer conversion rank.

2. Brief history of binary type inference

We review quickly some semantics-based approaches in high-level type recovery from binary codes. Though a broad survey for research up until 2015 has given in [15], it sustained a storage point of view bias: types are attached always with some storage primitives (e.g. registers, memory), there are no essential differences between types and data structures. Actually, types (in statically typed languages) are compile-time constraints, they may or may not have runtime storage imprints. An example is C's *type qualifier* (e.g. `const`, `restrict`), or in general any *refinement type* should not leave storage traces. Also, the survey lacks some important papers which are only published until later [17, 18].

We focus on semantics-based approaches only, recent research using machine learning [22] or statistical language model [16] are out of scope of the paper. From now on, unless otherwise stated, the target language is C which is also the target language of almost all research papers and tools in the domain.

2.1. Initial work

Though earlier ideas have been proposed in another context [3], the research in recovering types from low-level languages may begin with the classic paper of Mycroft [5] in his interest of decompilation. The principal idea is similar to which have done by Damas-Hindley-Milner [1, 2] in the ML language: types of variables and functions are checked/referenced automatically from how they are used in the program's source code. For example, given an expression

$$x + y$$

then at least x or y must have numeric type, it is impossible that both of them are pointers since adding two pointers doesn't type check.

The method of Mycroft has several limits, as pointed out by Van Emmerik [8]. One of them comes from the fact that the low-level languages take care mostly on the value of the computation, then (the result of) an expression can be used in several ways and it behaves as different type in each case (low-level polymorphic). Let's consider an assignment

$$p' = p + n$$

where $\vdash p : ptr(S)$ (p is of type pointer to a struct S) and $\vdash n : int$, then Mycroft's rules would derive $\vdash p' : ptr(S)$ since they consider $p+n$ as an offset calculation to access some element of an array of struct S. But $p + n$ can be also an offset calculation to access some field F of S, then $\vdash p' : ptr(F)$.

To overcome these problems, Van Emmerik has proposed a *data-flow based* type analysis approach where type information of an object will be refined gradually, instead of restricting it early to some fixed type. He then introduced the idea of using type lattice¡

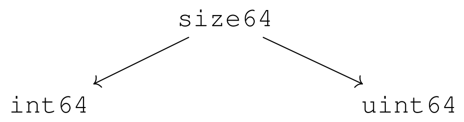

Figure 1. Type lattice

3. Ease of Use

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Number equations consecutively. To make your equations more compact, you may use the solidus (/), the exp function, or appropriate exponents. Italicize Roman symbols for quantities and variables, but not Greek symbols. Use a long dash rather than a hyphen for a minus sign. Punctuate equations with commas or periods when they are part of a sentence, as in:

$$a + b = \gamma \tag{1}$$

Be sure that the symbols in your equation have been defined before or immediately following the equation. Use "(1)", not "Eq. (1)" or "equation (1)", except at the beginning of a sentence: "Equation (1) is . . ."

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- There is no period after the "et" in the Latin abbreviation "et al.".
- The abbreviation "i.e." means "that is", and the abbreviation "e.g." means "for example".

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Component heads identify the different components of your paper and are not topically subordinate to each other. Examples include Acknowledgments and References and, for these, the correct style to use is "Heading 5". Use "figure caption" for your Figure captions, and "table head" for your table title. Run-in heads, such as "Abstract", will require you to apply a style (in this case, italic) in addition to the style provided by the drop down menu to differentiate the head from the text.

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Figure Labels: Use 8 point Times New Roman for Figure labels. Use words rather than symbols or abbreviations when writing Figure axis labels to avoid confusing the reader. As an example, write the quantity "Magnetization",

TABLE 1. TABLE TYPE STYLES

Table Head	**Table Column Head**		
	Table column subhead	***Subhead***	***Subhead***
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[a]Sample of a Table footnote.

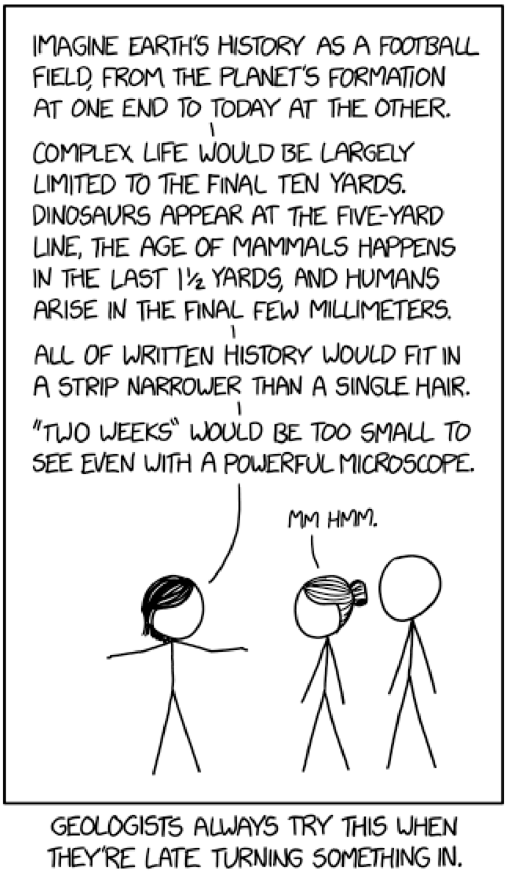

Figure 2. Example of a figure caption.

or "Magnetization, M", not just "M". If including units in the label, present them within parentheses. Do not label axes only with units. In the example, write "Magnetization (A/m)" or "Magnetization {A[m(1)]}", not just "A/m". Do not label axes with a ratio of quantities and units. For example, write "Temperature (K)", not "Temperature/K".

Acknowledgment

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