A Framework for Assessing Decompiler Inference Accuracy of Source-Level Program Constructs

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Abstract

Decompilation is the process of reverse engineering a binary program into an equivalent source code representation with the objective to recover high-level program constructs such as functions, variables, data types, and control flow mechanisms. Decompilation is applicable in many contexts, particularly for security analysts attempting to decipher the construction and behavior of malware samples. However, due to the loss of information during compilation, this process is naturally speculative and thus is prone to inaccuracy. This inherent speculation motivates the idea of an evaluation framework for decompilers.

In this work, we present a novel framework to quantitatively evaluate the inference accuracy of decompilers, regarding functions, variables, and data types. Within our framework, we develop a domain-specific language (DSL) for representing such program information from any "ground truth" or decompiler source. Using our DSL, we implement a strategy for comparing ground truth and decompiler representations of the same program. Subsequently, we extract and present insightful metrics illustrating the accuracy of decompiler inference regarding functions, variables, and data types, over a given set of benchmark programs. We leverage our framework to assess the correctness of the Ghidra decompiler when compared to ground truth information scraped from DWARF debugging information. We perform this assessment over a subset of the GNU Core Utilities (Coreutils) programs and discuss our findings.

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Chapter 1

Introduction

1.1 Context and Background

In an increasingly digital world, cybersecurity has emerged as a crucial consideration for individuals, companies, and governments trying to protect their information, financial assets, and intellectual property. Of the many digital threats, various forms of malware continue to pervade the digital landscape and thus remain a key concern for security analysts. One approach to combating malware is to deconstruct and reason about the malware itself. Understanding the functionality and behavior of malware samples may aid a security analyst in identifying methods to thwart or disable the malware's effects on a target system and similar systems.

Although simple in concept, the act of reverse engineering and reasoning about malware proves to be a steep challenge. The primary issue is that access to high-level malware source code is almost never available and, thus, any reasoning about the malware must be derived from the malware binary. Another issue is that malware authors often leverage obfuscation techniques to mask the intention and behavior of malware samples. To evade antivirus tools using signature-based detection, malware authors may employ techniques such as dead-code insertion, register reassignment, subroutine reordering, instruction substitution, code transposition, and code integration [3]. To complicate semantic binary code analysis of malware samples, malware authors may leverage compile-time strategies such as stripping and compiler optimizations [4]. Along with the employment of these obfuscation strategies in the context of malware, these techniques may be also leveraged by developers or companies to dissuade binary code analysis of proprietary software.

Despite the challenge of binary code analysis, there exist many tools that attempt to glean high-level semantic information from binary code samples. A *disassembler* takes binary code as input and produces assembly code as output. Many challenges and considerations exist in the disassembly process, particularly for stripped binary code, such as discerning code from data and locating function boundaries [5]. One invariant in the disassembly process, however, is that the mapping from assembly instructions to binary instructions and vice-versa is always one-to-one. A *decompiler* takes this reverse mapping process one step further by translating binary code into an equivalent high-level source code representation. The decompilation process is inherently speculative since high-level information such as function boundaries, variables, data types, and high-level control flow mechanisms are lost when a program is compiled. With this, the decompiler must infer enough high-level structure for useful analysis without being overly aggressive and consequently blurring the program's intent. Many decompiler tools are currently in use by the reverse engineering community. Commercial decompiler tools include IDA Pro [6] and JEB3 [7]. Popular open-source decompiler frameworks include Ghidra [8] and RetDec [9].

1.2 Research Problem

Due to the proposed utility of decompiler tools as well as the imprecise nature of decompilation, a generalized and extensible quantitative evaluation framework for decompilers is critical. Existing work by Liu et. al [10] proposes an evaluation technique to determine whether recompiled decompiled programs are consistent in behavior to their original binaries. Work by Naeem et. al [11] proposes a set of metrics for assessing the clarity of decompiled Java programs with respect to program size, conditional complexity, identifier complexity, number of local variables, and expression complexity. These works, although insightful for assessing decompiler quality, do not measure the recovery accuracy of high-level program constructs such as functions, variables, and data types. The recovery and inference of the these high-level constructs, in conjunction with clarity and behavioral correctness, is important for analysts to gain an understanding of decompiled binary programs.

1.3 Research Objectives

Targeting the current gap in the literature outlined in the previous section, this paper presents a novel framework for quantifying and assessing the accuracy of decompiler tools with respect to high-level program constructs, including functions, variables, and data types. To prove our concept, we apply our framework to the Ghidra decompiler and discuss our findings. The primary objectives achieved by this work are as follows:

1. We define a domain-specific language (DSL), written in Python, for expressing high-level program information including functions, variables, and data types. This serves as a medium whereby we can translate program information extracted from a decompiler or a ground-truth source.

2. We extend our DSL to compare program information representations from different sources. The primary use case is to compare ground-truth program information to decompiler-inferred program information.

3. Leveraging the comparison logic in (2), we define a set of quantitative metrics to measure the accuracy of function, variable, and data type inference.

4. We develop a translation module in Python that uses DWARF debugging information from a binary program to generate a ground-truth program information representation in our DSL.

5. We utilize the Ghidra Python API to implement a translation module. This module takes Ghidra decompilation of a binary program as input and outputs a program information representation in our DSL.

6. Using our developed language, metrics, and translation modules, we quantitatively assess the accuracy of the Ghidra decompiler when compared to ground truth program information obtained from DWARF debugging information. We peform this analysis using the set of GNU Coreutils programs as benchmarks. We present the evaluation results and discuss additional findings and takeaways.

1.4 Evaluation Summary

We use our evaluation framework to perform an assessment of the Ghidra decompiler (version 10.2) over 105 GNU Core Utilities (version 9.1) benchmark programs compiled with GCC (version 11.1.0). We evaluate Ghidra with no optimizations under three compilation cases of the benchmark programs - (1) stripped, (2) standard (not stripped, no DWARF symbols added), and (3) debug (DWARF symbols included) - to determine how the type and quantity of information provided in the binaries affects recovery and inference performance of functions, variables, and data types by Ghidra.

Our function recovery analysis reveals that Ghidra successfully recovers 100% of the 18139 functions under the stripped and standard compilation conditions across all benchmarks. In the debug compilation case, Ghidra successfully identifies all functions but fails to decompile four functions in the *factor* program due to a type resolution error. Upon further analysis, we conclude this is a bug in the Ghidra decompiler.

Analysis of high-level variable recovery shows that the recovery accuracy of variables of primitive data types (char, int, float, pointer) is significantly higher than the recovery accuracy of complex (aggregate) types (array, struct, union), particularly in the stripped and standard compilation cases when no debugging information is present. Overall, we see a partial high-level variable recoveries percentages of 97.1%, 99.2%, and 99.9% for the three compilation cases, respectively. The percentages of exact high-level variable matches for each of the compilation cases are 36.1%, 38.6%, and 99.6%, respectively.

Related to our high-level variable recovery analysis, we perform a "decomposed" variable recovery analysis. For the decomposition, we recursively decompose each variable into a set of primitive variables as they appear in memory. We then perform the comparison and evaluation similar to in the high-level analysis. We show that the partial recovery percentages for each of the stripped, standard, and debug compilation cases are 73.8%, 92.4%, and 98.0%, respectively. The exact match percentages over the decomposed variables are 24.6%, 25.0%, and 98.0% for each of the compilation cases, respectively. The lower recovery accuracy results in this decomposed analysis are explained by the decomposition of the variables with complex types, namely arrays, that are partially or fully missed in the high-level analysis. These variables, when decomposed, result in an increase in the number of total missed variables. Analysis of decomposed variable recovery by data type shows that int (and char) variables are most accurately inferred, followed by pointer variables, with floating-point (float, double) variables showing the lowest recovery accuracy.

We perform a data bytes recovery analysis to determine the total percentage of data bytes that are found and missed across all ground truth variables by the decompiler. We discover that the bytes recovery percentages are 61.3%, 80.6%, and 99.5% for each the stripped, standard, and debug compilation cases, respectively.

Lastly, we perform an evaluation of the Ghidra decompiler's array recovery accuracy. We find that, for each the stripped, standard, and debug compilation cases, 36.2%, 71.6%, and 99.5% of ground truth array varnodes overlap with at least one associated decompiler-inferred array varnode, respectively. We find the average size (in bytes) discrepancies between compared ground truth and the decompiler variables to be 458.6, 239.0, and 9.42 for each of the compilation cases, respectively. When scaled with respect to the sizes of the ground truth arrays, the average array size error percentages for the array comparisons in each compilation case are 91.2%, 47.5%, and 11.0%, respectively.

Across our analyses, we observe that there is a clear relationship between the compilation configuration of the benchmark programs and the recovery accuracy of program constructs by the Ghidra decompiler. We find that, with respect to recovery of program constructs, the debug compilation case far outperforms the standard case, which moderately outperforms the stripped case. However, despite the relatively high recovery accuracy of the Ghidra decompiler in the debug case, we futher explore the causes of misses and partial misses in the debug case and find that Ghidra possesses a major limitation in expressing local variables declared in lexical scopes below the top level of a function. A compiler such as GCC may reuse stack address space for variables associated with disjoint (non-overlapping and non-nested) lexical scopes. This is a problem for the Ghidra decompiler as we observe that all variable declarations are placed at the top level of the function, ultimately preventing these scope-specific variables from being precisely captured. From our manual analysis of the decompiled benchmark programs, we find that this is the cause of the majority of partially missed variables and data bytes in the debug compilation case. This limitation affects the stripped and standard compilation cases as well.

1.5 Contributions

The three key contributions of this work are as follows:

1. We develop a novel framework for evaluating decompiler tools based on the recovery accuracy of high-level program constructs, including functions, variables, and data types. This framework includes a domain-specific language (DSL), developed in Python, to represent and compare sources of high-level program information and their association with binary-level information. In addition, we devise quantitative metrics for expressing the recovery accuracy of high-level program constructs.

2. We leverage our framework to perform an in-depth evaluation of the Ghidra decompiler with respect to high-level function, variable, and data type recovery. This evaluation is performed over the GNU Core Utilities programs under three compilation conditions.

3. From our evalution of Ghidra, we discover and discuss the implications of two key issues present in the Ghidra decompiler.

1.6 Outline

The remainder of this paper is outlined as follows: In Chapter 2, we discuss related research and background concepts useful for the understanding of this work. Next, in Chapter 3, we detail our methodology for developing our evaluation framework. In Chapter 4, we present and discuss the results of applying our evaluation framework to the Ghidra decompiler. We conclude in Chapter 5 with a summary of our results, implications of our work, limitations, and future research directions.

Chapter 2

Background and Related Work

2.1 Software Reverse Engineering, Dissassembly, and Decompilation

Software reverse engineering (SRE) is the process of analyzing a software system with the intention to extract design and implementation information, particularly in situations where high-level source code is unavailable [12]. One common use case for this practice is to understand and deconstruct legacy code present in a software system where the source code has been lost. In this scenario, analysts could use SRE to understand this legacy code, determine its behavior, and ultimately decide how to reuse, patch, or replace the code. Another context for the use of SRE is computer security. Malware, or malicious programs, are nearly always encountered in binary form without their associated high-level source code. An analyst may use SRE to deconstruct the malware's logic, determine its behavior, and identify approaches to neutralize the malware and harden the host system for prevention of future attacks.

To perform SRE on a binary program, a critical first step is *disassembly*. This process takes binary code as input and produces assembly code as output. A key to this process is that binary and assembly instructions are always mapped one-to-one, and thus the main challenges lie in determining function boundaries and differentiating code, data, and metadata. Factors that contribute to these challenges include the following [5]:

- Data embedded in code regions
- Variable instruction size (on some architectures)
- Indirect branch instructions (the target of a branch instruction is not statically known)

- Functions without explicit ‘CALL‘ references
- Position independent code sequences
- Manually crafted assembly code

The conversion of binary code to assembly code through disassembly is a desirable starting point in the process of SRE. However, program semantics are still often difficult to interpret and reason about at the assembly code level. This difficulty necessitates an even more speculative process, *decompilation*, that takes a binary program as input and produces a high-level source code representation of the input program’s semantics, usually in C. Decompilation, therefore, involves the speculative inference of high-level constructs such as control flow mechanisms, variables, and data types. Decompiler tools rely heavily on the disassembly process as a first step in their analysis, and therefore the challenges affecting disassembly also naturally affect decompilation. Additional factors that obfuscate the accuracy of decompilation are the following:

- Compiler optimizations
- Stripped debugging information and metadata

With these compounding challenges affecting the decompilation process, it is clear that decompiler tools operate under a great degree of uncertainty and speculation. This fact highlights the need for a common evaluation framework for decompiler tools.

2.2 DWARF Debugging Standard

DWARF [13] is a debugging file format used by many compilers and debuggers to support source-level debugging for compiled binary programs. When specified flags (usually ’-g’) are present at compilation, DWARF-supporting compilers such as GCC and Clang will augment the outputted binary program or object file with DWARF debugging information. A resulting binary executable can then be loaded into a DWARF-supporting debugger such as GDB to debug the target binary program with references to line numbers, functions, variables, and types in the source-level program. The DWARF standard is source language agnostic, but generally supports equivalent representations for constructs present in common procedural languages such as C, C++, and Fortran. In addition, DWARF is decoupled from any architecture or operating system. The generalizability of DWARF debugging information makes it a prime candidate for extracting "ground truth" information about a particular binary program, regardless of the specifics of the source language, architecture, or operating system. DWARF is leveraged in this work to scrape ground-truth information about target binary programs. This information is subsequently used to evaluate the accuracy of the output produced by a target decompiler.

2.3 Ghidra Reverse Engineering Framework

Ghidra [8], created and maintained by the National Security Agency (NSA) Research Directorate, is an extensible software reverse engineering framework that features a disassembler, decompiler, and an integrated scripting environment in both Python and Java. We use the Ghidra decompiler in this work to demonstrate our decompiler evaluation framework.

2.4 Related Work

In the 2020 paper *How Far We Have Come: Testing Decompilation Correctness of C Decompilers* by Liu et. al [10], the authors present an approach to determine the correctness of decompilers outputting C source code. They aim to find decompilation errors, recompilation errors, and behavior discrepancies exhibited by decompilers. To evaluate behavioral correctness, they attempt to recompile decompiled binaries (after potential syntax modifications) and use existing dynamic analysis techniques such as fuzzing to find differences in behavior between the recompiled and original programs. The objective of our work differs as we aim to evaluate decompiler inference of high-level structures such as functions, variables, and data types. Accurate inference of high-level structures enables easier understanding of decompiled programs by analysts; however, accurate behavior is also necessary to ensure that the decompiled representation is consistent with the original program. Hence, both of these works evaluate important aspects of decompiler correctness.

The review *Type Inference on Executables* by Caballero and Lin [2] provides a comprehensive summary of recent literature on techniques used for variable discovery and type inference. In addition, the authors present various software reverse engineering (SRE) tools and frameworks in terms of their inputs, analysis types, output formats, and use cases. In essence, this work surveys the a set of decompiler tools and characterizes them based on their purported capabilities. The purpose of our work, on the contrary, is to objectively determine the correctness of decompiler tools based on their inference accuracy of high-level program constructs.

The 2006 technical report by Naeem et. al [11] proposes a set of metrics for assessing the "cognitive expressibility" (clarity) of decompiled Java code. This is achieved through metrics that capture program size, conditional complexity, identifier complexity, number of local variables, and expression complexity. Despite the importance of these aspects in assessing the quality of a decompiler, this approach does not consider the "correctness" - either behavioral or structural - of the decompiled code. In addition, this work only targets decompiled Java programs.

Several existing works propose methodologies and frameworks targeting high-level variable and type inference from binary programs [14, 15, 1, 16, 17, 18]. Many of these works contain an evaluation of their inference accuracy; however, none of these works demonstrate evaluation metrics that express a unified assessment of function, variable, and data type recovery. Our work aims to fill this gap by providing a common and reusable framework for the recovery assessment of these high-level constructs, decoupled from the source of the extracted program information.

Chapter 3

Methodology

In this section, we discuss the design, construction, and evolution of our decompiler evaluation framework. To achieve this, we identify key objectives that we subsequently address in more detail in the following sections. These objectives are as follows:

1. Express program information such as functions, variables, data types, and addresses in a common language.
2. Programmatically capture a "ground truth" representation of program information for a given binary program.
3. Programmatically scrape program information from decompiler tools, namely Ghidra.
4. Compare two program representations of the same program expressed in our common language.
5. Formulate quantitative metrics for evaluating the accuracy of a decompiler.

3.1 Domain-Specific Language (DSL) for Program Information

In order to make our framework general and reusable, we devise a common domain-specific language (DSL) to represent program information such as functions, variables, data types, and addresses, as well as the relationships between them. This DSL must act as a bridge linking binary-level address information with the source-level structures such as functions, variables, and data types. Combining the information from these two layers of abstraction is, in essence, a mapping

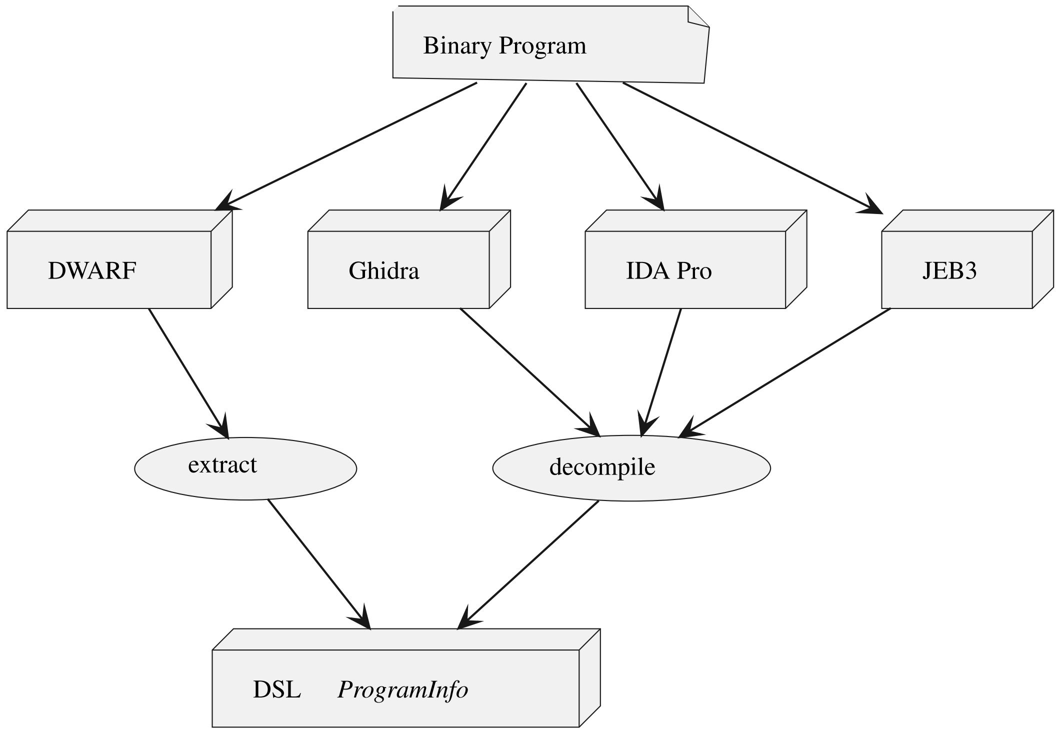


Figure 3.1: DSL *ProgramInfo* extraction from multiple sources

between binary-level and source-level structures. The accuracy of this mapping for a given decompiler is precisely the objective of our analysis.

The DSL we devised is entirely decoupled from the source of the program information. This allows any ground truth or decompiler source of program information to be translated into this common language and subsequently analyzed or compared with another source of program information. The core of our language is defined in Python and is compatible with Python (Jython or CPython) versions >= 2.7. We chose Python because the Ghidra framework supports custom Python scripts for querying and manipulating program information obtained from the disassembler and decompiler. In addition, the Python ’pyelftools’ open-source library [19] allows scraping DWARF debugging information directly from binary programs. This DWARF information can then be utilized to construct a "ground truth" representation of program information. We discuss this further in the next subsection.

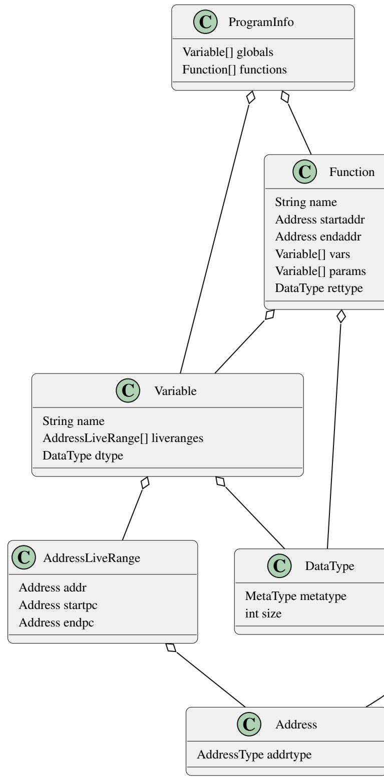


Figure 3.2: Simplified DSL class relationships

3.1.1 DSL Definitions

In this section, we briefly describe the structure and relationships of the major constructs that comprise our DSL.

At the root of our DSL is the *ProgramInfo* type. The fields of this type include a list of global variables (*Variable* objects) and a list of functions (*Function* objects).

The *Function* type holds information about a function such as the name, the start PC address (*Address* object), the end PC address (*Address* object), a list of parameters (*Variable* objects), a list of local non-parameter variables (*Variable* objects), and the return type (*DataType* object).

The *Variable* type contains information about a source-level global variable, local variable, or parameter. A variable has a name, a data type (*DataType* object), and a list of address "live ranges". We consider an address live range (*AddressLiveRange* type) to be the association of a variable's storage address with the PC address range where the storage location is valid for the variable. This "live range" concept allows for the expression of source-level variables that map to multiple underlying storage locations throughout their lifetime. Multiple live ranges may be associated with a single variable when compiler optimizations are present.

The *Address* type represents any absolute or relative location referenced in a binary program. This could include a PC location, variable storage location, or a register. From an implementation perspective, *Address* is the base class with subclasses representing the different types of address constructions based on context. These *Address* subclasses include *AbsoluteAddress*, *RegisterAddress*, *RegisterOffsetAddress*, and *StackAddress*. Each address is associated with an *AddressRegion*. This type is used to manage ordering and comparison logic for addresses that fall within the same region.

The last main construct in our core DSL is *DataType*. This type is represents a source-level data type and is typically associated with a variable or a function return type. *DataType* is the base of a class hierarchy with subclasses representing particular data types. The subclasses include *DataTypeFunctionPrototype*, *DataTypeInt*, *DataTypeFloat*, *DataTypeUndefined*, *DataTypeVoid*, *DataTypePointer*, *DataTypeArray*, *DataTypeStruct*, *DataTypeUnion*. Although these defined types correspond to C-like data types, this language can easily be extended to support other data types present in other high-level programming languages. All data type objects contain a "size" field representing the number of bytes the given data type occupies in memory.

3.2 Capturing Ground Truth Program Information

With our DSL defined, we need a reliable method to extract "ground truth" information from a program and translate this information into our DSL. This "ground truth" information is intended to be used in a comparison with the program information obtained from a decompiler. Our framework is meant for evaluation and therefore we assume that we have access to the source code of benchmark programs to be used for the evaluation. With this assumption, we consider two options for extracting program information from a given source program.

The first option for extracting ground truth information is to parse the source code's abstract syntax tree (AST) and then use this AST to manually extract functions, variables, and data types.

There are two major issues with this approach. First, parsing source code to an AST assumes a particular source programming language which greatly reduces generality. Second, obtaining the AST alone does not offer any binary-level information that allows us to link binary-level addresses with the source-level structures.

The second, more favorable, approach to extracting ground truth program information involves leveraging debugging information optionally included in the binary by the compiler. The primary purpose of debugging information is to link binary-level instructions and addresses with source-level structures. This binary-level to source-level association is precisely what is needed to translate program information into our DSL. We choose the DWARF debugging standard as the assumed debugging format for our framework. However, defining a translation module from another debugging format into our DSL is certainly possible and is an idea for future work. The DWARF debugging standard is supported by nearly all major Linux compilers and may be extended to support any source-level programming language. These properties of the DWARF standard allow it to be used as a "ground truth" source of program information, decoupled from the source language or the compiler.

3.2.1 Translating DWARF to the DSL

Starting with a source-level program, we must perform the following steps to extract program information represented in our DSL. First, we compile the source program with the option to include debugging symbols. In our particular analysis we use the GCC compiler specifying the "-g" flag. Many other compilers also offer the option for compilation with the inclusion of DWARF debugging symbols. After we compile the program, we then extract the DWARF debugging information from the resulting binary. We utilize the 'pyelftools' Python library [19] to perform this extraction. The extraction results in, among other information, a set of debugging information entries (DIEs). Together, these DIE records provide a description of source-level entities such as functions, variables, and data types in relation to low-level binary information such as PC addresses and storage locations. Each DIE contains the following important features:

- An *offset* uniquely identifying the DIE within its compilation unit. These offsets are how DIEs reference other DIEs.

- A *tag* representing the "class" of the DIE. Example tags include "DW_TAG_subprogram", "DW_TAG_variable", and "DW_TAG_base_type".

- A set of *attributes* specifying tag-specific properties of the DIE. Examples include "DW_AT_name", "DW_AT_size", and "DW_AT_type".

The translation process from the DIE graph into our DSL is, at its core, a process of forming a nested data structure (our DSL's *ProgramInfo* type) from a flattened one (a collection of DWARF DIEs). To tackle this translation, we first define an intermediate representation (IR) language that acts as a "flattened" analog to the constructs present in our DSL. Instead of each IR construct directly containing the fields of other constructs, they instead contain fields that reference the IDs of other constructs through a shared database. The responsibility of the database is to map unique IDs to the flattened constructs. When all the IR constructs have been inserted into the database, we use the database to recursively resolve the flattened IR structures into their associated DSL structures, starting from the root *ProgramInfoStub* object, the IR analog to the *ProgramInfo* DSL type. This process is complicated by the fact that some data types, particularly *struct* types, may be recursive or mutually recursive, ultimately creating a cycle in the reference resolver. To address this, we implement a mechanism whereby each IR node is marked when it is visited. Future attempts to resolve the same IR construct return with the existing object being resolved instead of attempting to resolve the same reference again. With the IR defined and the resolution logic in place, we map the DWARF DIE objects into our "flattened" IR and construct the IR object database. When all the DIEs are processed and translated, we specify the *ProgramInfoStub* node as the root reference and then execute our resolver algorithm to recursively generate the *ProgramInfo* object and subobjects defined in our DSL.

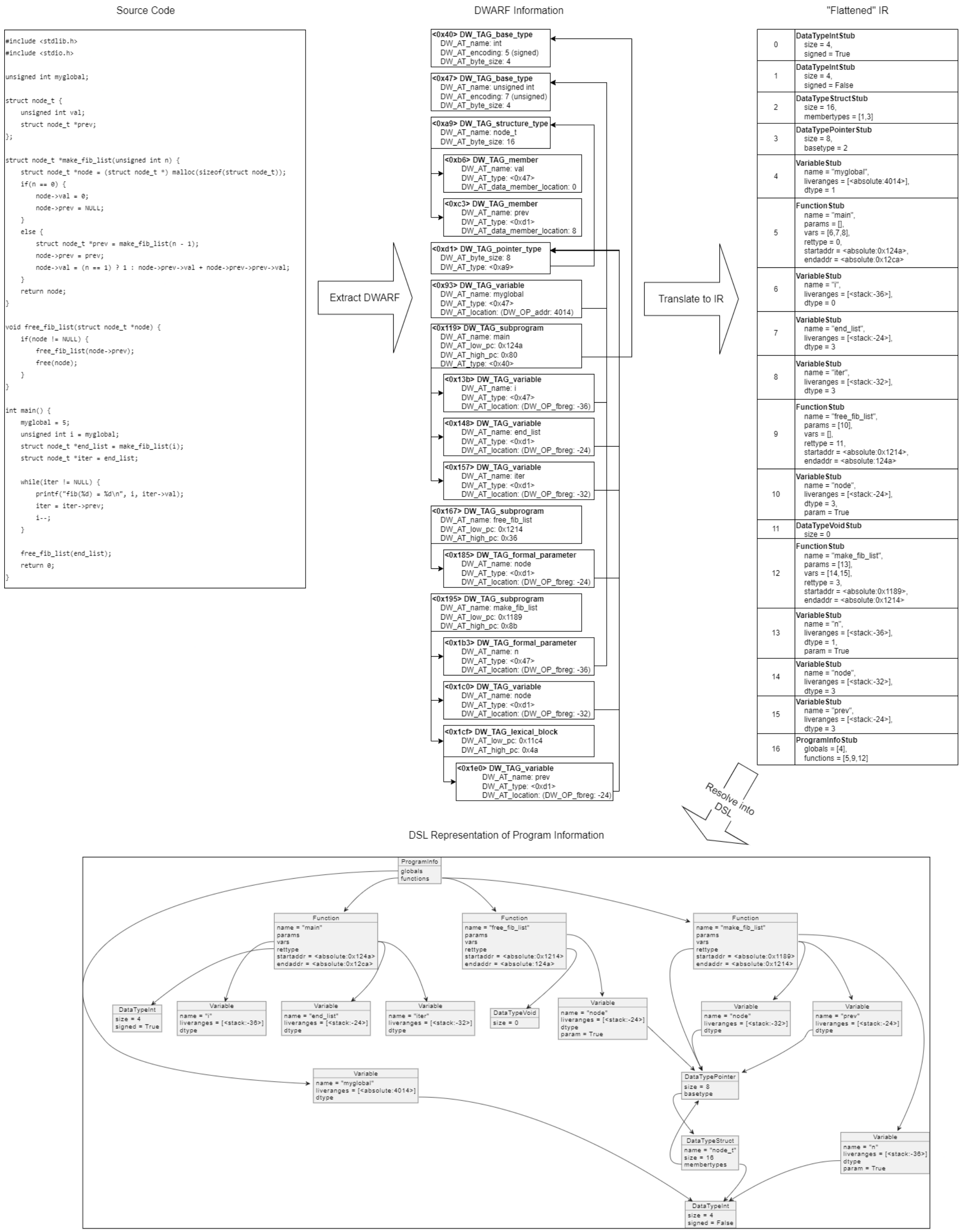


Figure 3.3: An example of translating DWARF information into the DSL

3.3 Capturing Decompiler Program Information

In addition to capturing a ground-truth program representation in our DSL, we must construct a DSL representation of the program information obtained from a decompiler we wish to evaluate. Depending on the decompiler and the structure of its output, this process may take many forms, often involving querying APIs exposed by the decompiler framework. In all cases however, this shall involve defining a translation module from the decompiler output to the structures defined in the DSL. Hence, our framework can be employed on any decompiler assuming a translation module implementation.

3.3.1 Translating Ghidra Decompiler Output to the DSL

For our analysis of the Ghidra decompiler, we utilize the Ghidra scripting API to programmatically scrape and process information about the decompilation of target binary programs. The Ghidra scripting environment exposes its own collection of data structures and functions from which we obtain our information. Since the Ghidra scripting environment supports Python, we directly import and leverage our "flattened" IR (described in the previous section) and our DSL constructs to carry out the translation.

The strategy employed for the Ghidra translation is similar to that of our DWARF translation algorithm described in the previous section. We utilize the Ghidra API to obtain particular information about functions, variables, data types, and associated addresses gathered during the decompilation. Of particular use to our translation logic is the *DecompInterface* object exposed by the Ghidra API. This interface supports decompiling functions one at a time. Information inferred by each function's decompilation is used to update Ghidra's internal representation of the program information. By decompiling each of the functions extracted from Ghidra's disassembly analysis, we attempt to form a complete decompiled interpretation of the entire input program.

We use the same IR defined for the DWARF translation to accumulate flattened records corresponding to these program constructs in a database. From here, we run the same resolution algorithm on the IR constructs database to generate the root *ProgramInfo* object in our DSL.

3.4 Comparison of "Ground Truth" and Decompiler Program Information

After converting both the ground-truth and decompiler program information into our DSL representation, we next formulate and implement a strategy to compare the two resulting *ProgramInfo* objects. To achieve this, we create an extension of our DSL that defines data structures and functions for capturing comparison information at different layers.

3.4.1 Data Type Comparison

Given two *DataType* objects and an offset between their start locations, we devise a method to capture nuanced information about the comparison of the data types.

3.4.1.1 Definitions

We define the *metatype* of a data type to be general "class" of the given data type. These metatypes include *INT*, *FLOAT*, *POINTER*, *ARRAY*, *STRUCT*, *UNION*, *UNDEFINED*, *VOID*, and *FUNCTION_PROTOTYPE*. We consider *INT*, *FLOAT*, *POINTER*, *UNDEFINED*, and *VOID* to be *primitive metatypes* since they cannot be decomposed further. *ARRAY*, *STRUCT*, and *UNION* are considered *complex metatypes* since these types are formed via the composition or aggregation of different members or subtypes. We consider the 'char' data type to be of the *INT* metatype with size equal to one byte.

A *primitive type lattice* [2] is used to hierarchically relate primitive data types based on their metatype, size, and signedness (if applicable). More general types are located higher in the lattice while more specific types are located closer to the leaves. A type lattice may be used to determine whether two primitive data types are equivalent or share a common parent type. Our framework leverages the ARTISTE primitive type lattice defined in Caballero et. al [1] and shown in Figure 3.4.

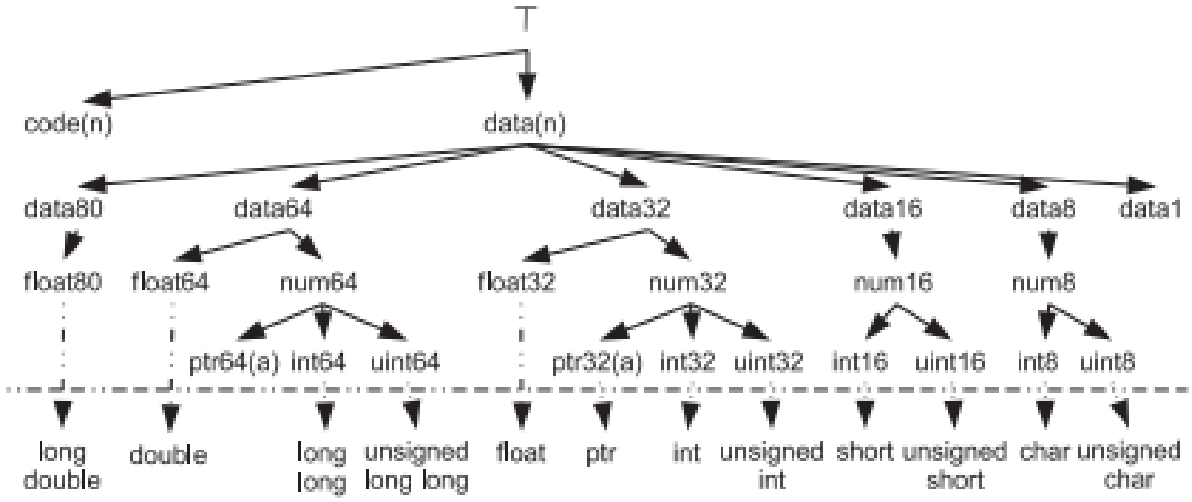


Figure 3.4: ARTISTE type lattice [1, 2]

We next define a *subset* relationship between two data types. For a given complex data type X and another data type Y with a given offset (possibly 0) between the location of X and Y in memory, Y is considered a *subset* type of X if Y is equivalent to a "portion" of X, consistent with the offset between X and Y. For example, if X is an array, any sub-array or element of X such that elements are aligned and the element types are equivalent to X is considered a subset of X. If X is a struct or union, any sub-struct or member with proper alignment and equal constituent elements is considered a subset of X.

3.4.1.2 Comparison Logic

Suppose we have two *DataType* objects X (ground truth) and Y (decompiler) with offset k from the start of X to the start of Y. The goal is to compute the *data type comparison level* for the given comparison. The possible values for the comparison level are as follows, from lowest equality to highest equality:

- *NO_MATCH*: No relationship could be found between X and Y.
- *SUBSET*: Y is a subset type of the complex type X.
- *PRIMITIVE_COMMON_ANCESTOR*: In the primitive type lattice, Y is an ancestor of X.

This indicates that the inferred type Y is a conservative (more general) form of the ground truth type X.

- *MATCH*: All properties of X and Y match including metatype, size, and possibly subtypes (applicable to pointers, arrays, structs, and unions).

We first check the equality of X and Y. If X and Y are equal, we assign the *MATCH* comparison code. In the case that X and Y are both primitive types, we attempt to compute their shared ancestor in the primitive type lattice. If Y is an ancestor (more general form) of X, we assign *PRIMITIVE_COMMON_ANCESTOR*. If X is a complex type, we employ an algorithm to determine whether Y is a subset of X at offset k by recursively descending into constituent portions of X starting at offset k (sub-structs, sub-arrays, elements, members) and checking for equality with Y. If a subset relationship is found, we assign the *SUBSET* compare level. In all other cases, we assign the *NO_MATCH* compare level.

3.4.2 Variable Comparison

There are two main contexts where variable comparison occurs. The first context is at the top level, where the set of ground-truth global variables is compared to the set of decompiler global variables. The second context for variable comparison is within the context of a function when we compare local variables between the ground-truth and the decompiler. In either case, comparing sets of variables starts with the decomposition of each *Variable* object from the DSL into a set of *Varnode* objects in our extended DSL.

A *Varnode* ties a *Variable* to a specific storage location and the range of PC addresses indicating when variable lives at that location. The varnodes for a given variable are directly computed from the variable's live ranges discussed previously. In unoptimized binaries, it is the case that a single *Variable* shall decompose into a single *Varnode*.

With each variable decomposed into its associated varnodes, we next partition the varnodes from each the ground-truth and the decompiler based on the "address space" in which they reside.

These address spaces include the *absolute* address space, the *stack* address space, and the *register offset* address space (for a given register). The *stack* address space is a special case of the *register offset* address space where the offset register is the base pointer which points to the base of the current stack frame.

For the set of varnodes in each address space, we first order them based on their offset within the address space. Next, we attempt to find overlaps between varnodes from the two sources based on their location and size. If an overlap occurs between two varnodes, we compute a data type comparison taking into account the offset between the start locations of the two varnodes. The data type comparison approach is described in the previous section.

Based on the overlap status and data type comparison of a ground-truth varnode X, one of the following *varnode comparison levels* will be assigned:

- *NO_MATCH*: X is not overlapped with any varnodes from the other source.
- *OVERLAP*: X overlaps with one or more varnodes from the other space, but the data type comparisons are level *NO_MATCH*.
- *SUBSET*: X overlaps with one or more varnodes and each of its compared varnodes has data type comparison level equal to *SUBSET*. In other words, the compared varnode(s) make up a portion of X.
- *ALIGNED*: For some varnode Y from the other source, X and Y share the same location and size in memory; however, the data types of X and Y do not match. The data types comparison could have any comparison level less than *MATCH*.
- *MATCH*: For some varnode Y from the other source, X and Y share the same location and size in memory, and their data types match exactly.

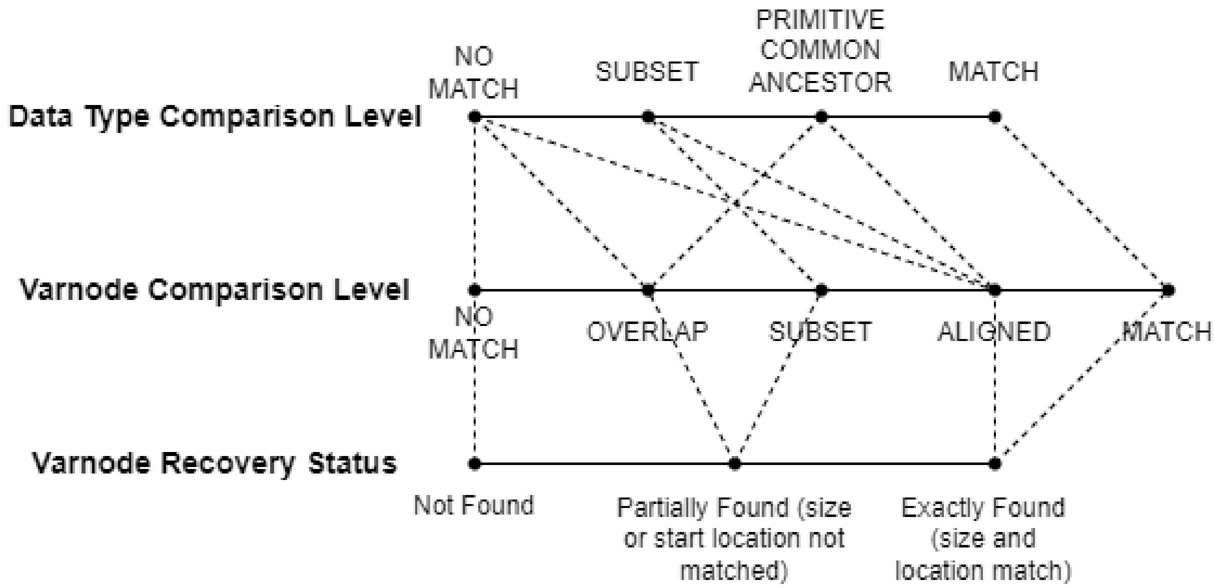


Figure 3.5: Derivation of varnode comparison level from varnode recovery status and data type comparison

3.4.2.1 Decomposed Variable Comparison

The inference of variables with complex data types including structs, arrays, and unions proves to be a major challenge for decompilers. Recognizing this, we develop an approach to compare the sets of ground truth and decompiler variables (varnodes) in their most "decomposed" forms. An analysis of this sort helps to recognize how well a decompiler infers the primitive constituent components of complex variables. Furthermore, this allows us to recognize the aggressiveness and accuracy of complex variable synthesis from more primitive components.

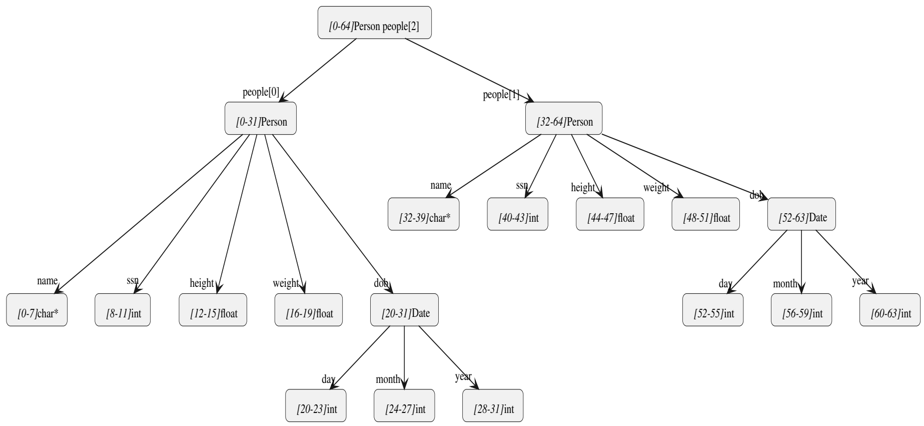
We first implement an approach to recursively strip away the "complex layers" of a varnode to its most primitive decomposition. This primitive decomposition produces a set of one or more primitive varnodes as they would appear in memory. For example, an array of elements is broken down into a set of its elements (decomposed recursively). A struct is broken down into a set of varnodes associated with each of its members (decomposed recursively). Unions present a special case since the members share a common, overlapping region of memory. Hence, to decompose a union, we transform it into an *UNDEFINED* primitive type with the same size as the union.

We apply this primitive decomposition to each varnode in the sets of ground truth and de-

```
typedef struct {
    int day;
    int month;
    int year;
} Date;

typedef struct {
    char* name;
    int ssn;
    float height;
    float weight;
    Date dob;
} Person;

Person people[2];
```



(b) Decomposition of a high-level varnode into primitive components

(a) Definition of a high-level variable

Figure 3.6: Example of high-level varnode decomposition

compiler varnodes. With the two sets of decomposed varnodes, we leverage the same variable comparison approach described previously to compare the varnodes in these sets. The resulting comparison information is treated as a separate analysis from the unaltered varnode sets.

3.4.3 Function Comparison

The first step in function comparison is to determine whether each ground-truth function is found by the decompiler. We first order the functions from each source by the start PC address of the function. Next, we attempt to match the functions from the two sources based on start address. Any functions from the ground-truth that are not matched by a decompiler function are considered "missed". For any missed functions, we consider its associated parameters, local variables, and data types to also be "missed".

For each "matched" function based on start PC address, we compute and store information including the return type comparison, parameter comparisons, and local variable comparisons. These sub-comparisons leverage the data type and variable comparison techniques described previously.

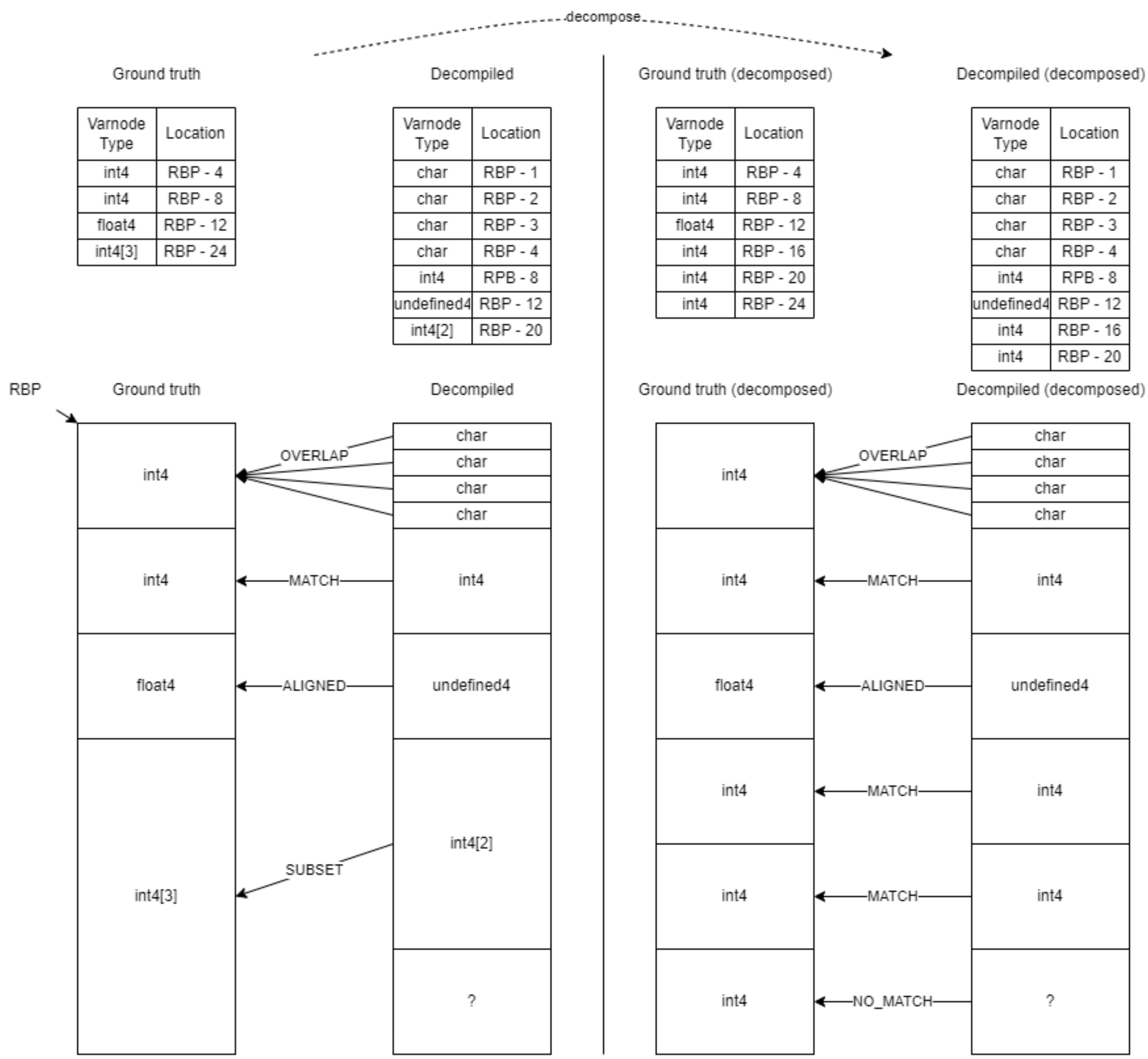


Figure 3.7: An example of varnode comparisons between ground truth and decompiler varnodes for a given stack frame

3.5 Quantitative Evaluation Metrics

In this section, we define quantitative metrics for evaluating the accuracy of the a given decompiler when compared to a ground-truth source. We rely on the function, variable, and data type comparison information discussed previously to extract these metrics. In the following sub-sections, we define sets of metrics that associated with tables seen in Chapter 4.

3.5.1 Functions

This set of metrics outlines the function identification performance of the decompiler.

- *Ground truth functions*: The number of functions present in the ground truth program representation.
- *Functions found*: The number of functions from the ground truth set that are identified by the decompiler.
- *Functions missed*: The number of functions from the ground truth set that are not identified by the decompiler.
- *Functions recovery fraction*: The fraction of ground truth functions found by the decompiler divided by the number of ground truth functions.

3.5.2 Varnodes

Recall that a *Varnode* is defined to be a source-level *Variable* tied to a single storage location for a range of PC addresses. In analyses of unoptimized binaries, the mapping of variables to varnodes is one to one. This set of metrics illustrates the decompiler's accuracy in recovering varnodes.

- *Ground truth varnodes*: The total number of varnodes present in the ground truth source. This includes varnodes associated with global and local variables from all functions.

- *Varnodes matched @ level LEVEL*: Each ground truth varnode is associated with a *varnode comparison level* (*NO_MATCH*, *OVERLAP*, *SUBSET*, *ALIGNED*, *MATCH*) during the comparison with the set of decompiler varnodes. This metric specifies the number of ground truth varnodes that are matched at the specified level.

- *Varnodes average comparison score*: For each *varnode comparison level*, we first linearly assign an integer representing the strength of the varnode comparison (*NO_MATCH* = 0, *OVERLAP* = 1, *SUBSET* = 2, *ALIGNED* = 3, *MATCH* = 4). We then normalize these scores to fall within the range zero to one. Then, for each ground truth varnode, we compute this normalized score. We take the average score over all ground truth varnodes to obtain the resulting metric. This metric approximates how well, on average, the decompiler infers the ground truth varnodes.

- *Varnodes fraction partially recovered*: The fraction of ground truth varnodes with a match level greater than *NO_MATCH*.

- *Varnodes fraction exactly recovered*: The fraction of ground truth varnodes with a match level equal to *MATCH*.

We repeat this varnode analysis for the decomposed (primitive) set of varnodes resulting from recursively decomposing each of the high-level varnodes into its most primitive set of varnodes. We also repeat our analysis of the original set of varnodes filtered by metatype. The metatypes considered are *INT*, *FLOAT*, *POINTER*, *ARRAY*, *STRUCT*, and *UNION*. Lastly, we repeat the analysis of the decomposed varnodes when filtered by metatype. For this metatype analysis over the decomposed varnodes, we only consider the primitive metatypes *INT*, *FLOAT*, and *POINTER* since the varnodes are guaranteed to be primitive.

3.5.3 Data Bytes

These metrics look at the total number of data bytes from all variables recovered by the decompiler when compared to the ground truth source.

- *Ground truth data bytes*: The total number of data bytes captured from the ground truth source, derived from all global and local variables.

- *Bytes found*: The total number of data bytes recovered by the decompiler that overlap with data bytes found in the ground truth.

- *Bytes missed*: The number of data bytes present in the ground truth that were not recovered by the decompiler.

- *Bytes recovery fraction*: The fraction of ground truth data bytes found by the decompiler divided by the total number of ground truth bytes.

3.5.4 Array Comparisons

In this set of metrics, we aim to evaluate the accuracy of the array inference performed by the decompiler. We examine each array comparison made during the comparison of the ground truth with the decompiler and observe the discrepancies in length, size (bytes), dimensions, and element type. The following metrics are presented:

- *Ground truth varnodes (metatype=ARRAY)*: The number of ground truth varnodes with metatype of ARRAY.

- *Array comparisons*: The number of array comparisons made when comparing the ground truth with the decompiler. The decompiler may infer 0 or more array varnodes for each given ground truth array varnode.

- *Array varnodes inferred as array*: This measures how many ground truth array varnodes are compared to at least one decompiler-inferred array varnode.

- *Array varnodes inferred as array fraction*: Equivalent to *Array varnodes inferred as array* divided by *Ground truth varnodes (metatype=ARRAY)*. This expresses the fraction of ground truth array varnodes that are associated with at least one decompiler array inference.

- *Array length (elements) average error*: For each array comparison, we find the absolute difference in the number of elements inferred by the decompiler as compared to the ground truth. We then average these differences over all array comparisons to arrive at this metric.

- *Array length (elements) average error ratio*: For each array comparison, we first find the absolute difference in the number of elements inferred by the decompiler as compared to the ground truth. We then divide this error by the length of the ground truth array to get the error as a ratio of the array size. The average of these ratios over all array comparisons produces this metric.

- *Array size (bytes) average error*: This metric is similar to *Array length (elements) average error* but measures the error in bytes instead of number of elements.

- *Array size (bytes) average error ratio*: This metric is similar to *Array length (elements) average error ratio* but computes the error in bytes instead of array elements.

- *Array dimension match score*: This metric is the number of array comparisons where the decompiler inferred the correct number of dimensions divided by the total number of array comparisons.

- *Array average element type comparison score*: Each *data type comparison level* is first mapped to an integer as follows: *NO_MATCH* = 0, *SUBSET* = 1, *PRIMITIVE_COMMON_ANCESTOR* = 2, *MATCH* = 3. We then normalize these values such that the range is scaled from 0 to 1. We refer to this as the *data type comparison score*. Then, for each array comparison, we compute the *data type comparison score* and subsequently average the scores across all array comparisons to generate this metric.

Chapter 4

Evaluation

To demonstrate our evaluation framework, we target the Ghidra decompiler (version 10.2). We use the GNU Core Utilities programs (version 9.1) as our set of benchmarks. For each of the benchmark programs, we evaluate the accuracy of Ghidra decompilation with the program compiled in three ways: (1) stripped, (2) standard (not stripped, no debugging symbols), and (3) DWARF debug symbols included. We use the results from each of these cases to discern how the amount of information included in the binary affects the Ghidra decompiler's inference accuracy. To limit the scope of our analysis, we only consider unoptimized binaries. We use the GCC compiler (version 11.1.0) to compile the benchmark programs. The architecture and operating system of the testing machine are x86-64 and Ubuntu Linux (version 20.04), respectively.

4.1 Setup

Prior to evaluation, we compile the 105 Coreutils benchmark programs with three compilation configurations: (1) stripped, (2) standard (not stripped, no debugging symbols), and (3) DWARF debug symbols included. For each program, we first extract the ground truth information from the binary with DWARF symbols included via our DWARF translation module. We then use our Ghidra translation module to extract the Ghidra decompilation information from the binaries compiled under each of the compilation configurations. At this point, all program information from the DWARF and Ghidra sources are represented as *ProgramInfo* objects in our DSL.

Next, for each program, we perform a comparison of the program information scraped from DWARF (from the "debug" binary including DWARF symbols) with the information obtained

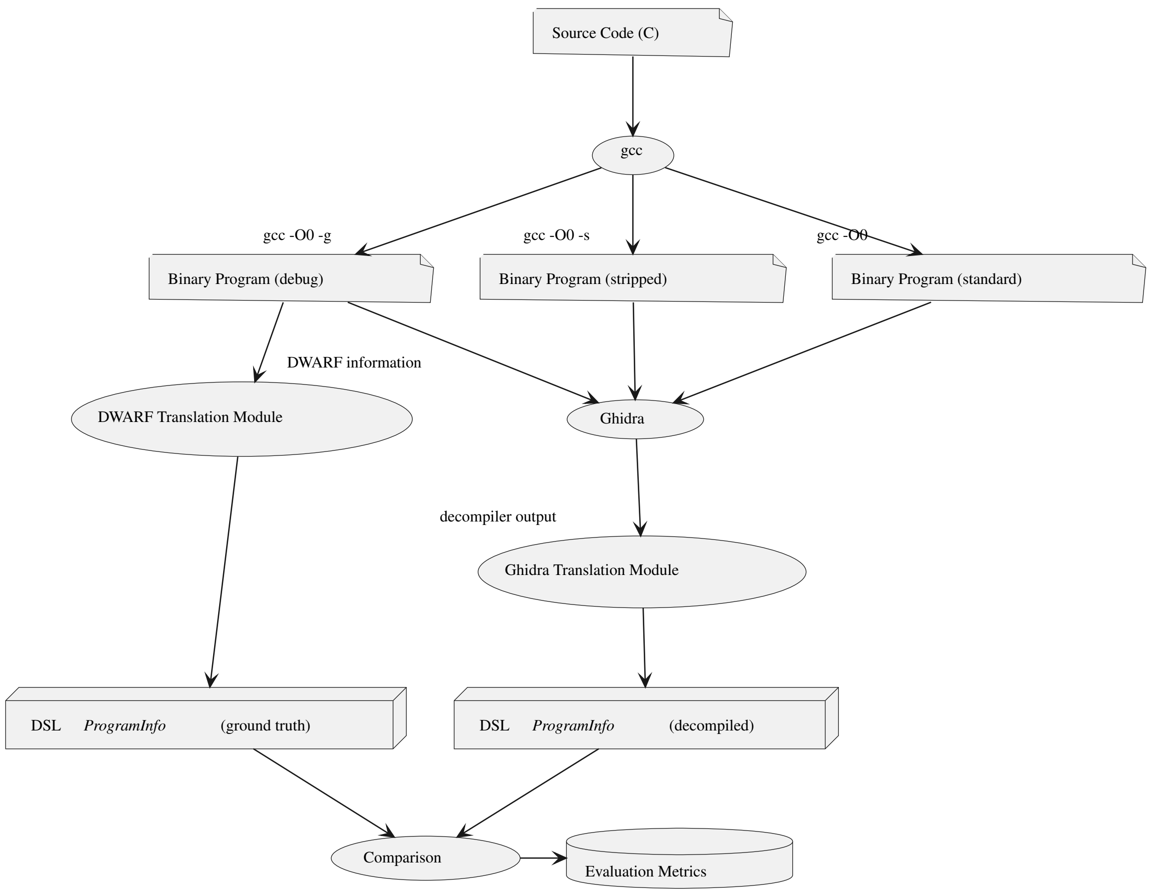


Figure 4.1: Evaluation workflow

Table 4.1: Summary of function recovery by compilation case

	Ground truth functions	Functions found	Functions missed	Functions recovery fraction
strip	18139	18139	0	1.0000
standard	18139	18139	0	1.0000
debug	18139	18135	4	0.9998

from the Ghidra decompilation of the programs under each of the compilation configurations. The information from these comparisons are expressed in the form of objects which contain comparison information about functions, variables, and data types compared between the DWARF and Ghidra sources.

With the comparisons computed for each program and compilation configuration, we use these comparisons to compute high-level metrics that summarize the performance of the Ghidra decompiler with respect to the given benchmarks and compilation configurations (stripped, standard, and debug).

4.2 Function Recovery

Tables 1, 2, and 3 in the appendix present function recovery metrics of each benchmark program under the three compilation configurations. Table 4.1 shows the summarization of the recovery statistics accumulated over all benchmark programs. We find that over the 18139 functions present in the ground truth, the stripped and standard compilation cases produce 100% function recovery while the debug case fails to recover four functions, resulting in a 99.9% recovery rate. Upon examination of Table 3, we find that all four functions missed are from the *factor* program.

To determine the cause of the missed functions, we further investigate the Ghidra decompilation of *factor* and find that each of the missed functions results in a decompilation error, "Low-level Error: Unsupported data-type for ResolveUnion". This indicates that an error occurred when attempting to resolve a union data type within the decompilation of these functions. Since this error only occurs in the debug compilation case, it is clear that Ghidra's parsing and interpretation

Table 4.2: Summary of high-level varnode recovery by compilation case

	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode comparison score	Varnode fraction partially recovered	Varnode fraction exactly recovered
strip	1000	1662	1001	18570	12550	0.788	0.971	0.361
standard	249	1450	613	19029	13442	0.816	0.993	0.386
debug	23	52	24	7	34677	0.998	0.999	0.997

of DWARF information contributes to this error. This same union data type causing the error is successfully captured and represented in our ground truth program information and, thus, this is likely a bug within Ghidra's resolution logic.

In summary, we see that Ghidra successfully finds all functions for all compilation configurations. However, in the debug case, Ghidra's attempt to interpret and utilize DWARF information to resolve a union data type in the *factor* program results in a decompiler error for four functions. This error indicates a bug in Ghidra's DWARF parsing or union resolution logic.

4.3 High-Level Variable (Varnode) Recovery

To evaluate the variable (varnode) recovery accuracy of the Ghidra decompiler, we first measure the inference performance of high-level varnodes, including varnodes with complex and aggregate types such as arrays, structs, and unions. We further measure the varnode inference accuracy by metatype to decipher which of the metatypes are most and least accurately inferred by the decompiler. This analysis is performed under each compilation configuration (stripped, standard, and debug).

Tables 4, 11, and 18 in the appendix show the inference of high-level varnodes for each benchmark compiled with each of the compilation configurations. This data is summarized in Table 4.2. We find that Ghidra at least partially infers 97.2%, 99.3%, and 99.6% and precisely infers

Table 4.3: Summary of high-level varnode recovery by compilation case and metatype

		Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode comparison score	Varnode fraction partially recovered	Varnode fraction exactly recovered
strip	INT	66	48	0	12204	8681	0.850	0.997	0.413
	FLOAT	0	56	0	113	22	0.632	1.000	0.115
	POINTER	53	4	0	5834	3513	0.839	0.994	0.374
	ARRAY	729	597	565	19	228	0.315	0.659	0.107
	STRUCT	152	955	432	390	106	0.419	0.925	0.052
	UNION	0	2	4	10	0	0.625	1.000	0.000
standard	INT	23	48	0	12248	8680	0.851	0.999	0.413
	FLOAT	0	56	0	113	22	0.632	1.000	0.115
	POINTER	44	4	0	5836	3520	0.840	0.995	0.374
	ARRAY	181	578	352	45	982	0.625	0.915	0.459
	STRUCT	1	762	257	777	238	0.560	1.000	0.117
	UNION	0	2	4	10	0	0.625	1.000	0.000
debug	INT	13	27	0	4	20955	0.998	0.999	0.998
	FLOAT	0	0	0	0	191	1.000	1.000	1.000
	POINTER	3	0	0	1	9400	1.000	1.000	1.000
	ARRAY	5	17	24	0	2092	0.986	0.998	0.978
	STRUCT	2	8	0	0	2025	0.996	0.999	0.995
	UNION	0	0	0	2	14	0.969	1.000	0.875

36.1%, 38.6%, and 99.7% of high-level varnodes for each for the stripped, standard, and debug compilation cases, respectively. In addition, the varnode comparison scores for each compilation case are 0.788, 0.816, and 0.998, respectively. These metrics indicate that the standard compilation case slightly outperforms the stripped case in varnode inference while the debug compilation case results in significant improvements over both the stripped and standard cases, particularly in exact varnode recovery.

In Tables 5-10, 12-17, and 19-24, we show the inference performance of high-level varnodes for each benchmark, broken down by the metatype of the ground truth varnodes, and for all compilation configurations. We summarize this information in Table 4.3. From the stripped and standard compilation cases, we observe that varnodes with metatype *INT* are most accurately recovered when considering varnode comparison score, fraction partially recovered, and fraction exactly recovered. In the stripped case, the inference of *ARRAY* varnodes shows the worst performance with a varnode comparison score of 0.315. In the standard case, varnodes with metatype *STRUCT* are least accurately recovered with a varnode comparison score of 0.560, followed closely by *ARRAY* and *UNION*. We see that, for both the stripped and standard compilation cases, the complex (aggregate) metatypes, *ARRAY*, *STRUCT*, and *UNION*, show the lowest recovery accuracy with respect to varnode comparison score. Among the primitive metatypes, *FLOAT* shows the worst recovery metrics for these two compilation cases.

The debug compilation case demonstrates high relative recovery accuracy across varnodes of all metatypes when compared to the stripped and standard cases. Of the primitive metatypes, varnodes of the *FLOAT* metatype are perfectly recovered while varnodes of the *INT* and *POINTER* metatypes show exact recovery percentages of 99.8% and 99.9%, respectively. The complex (aggregate) metatypes, on average, display slightly lower recovery metrics than the primitive metatypes in the debug compilation case. The *ARRAY* metatype reveals the worst varnode comparison score at 0.986. The *UNION* metatype demonstrates the lowest exact match percentage at 87.5%.

4.4 Decomposed Variable (Varnode) Recovery

In this section, we repeat a similar varnode recovery analysis over all varnodes; however, we first recursively decompose each varnode into a set of primitive varnodes (see Section 3). We perform this analysis over all benchmarks for each of the three compilation cases.

Similar to the high-level varnode analysis, we show the inference of the decomposed varnodes for each benchmark and for each compilation configuration in Tables 25, 29, and 33. Table 4.4 summarizes this information. Naturally, we expect to see lower recovery metrics compared to the high-level varnode analysis since each complex varnode is now analyzed as a set of its constituent parts. Hence, a single "missed" high-level varnode is translated into a set of primitive varnodes, each "missed" in this analysis. We find this hypothesis to hold true across all compilation cases as

Table 4.4: Summary of decomposed varnode recovery by compilation case

	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode comparison score	Varnode fraction partially recovered	Varnode fraction exactly recovered
strip	139776	31280	0	231267	131593	0.586	0.738	0.246
standard	40187	56605	0	303527	133597	0.703	0.925	0.250
debug	10547	128	0	5	523236	0.980	0.980	0.980

each the varnode comparison score, varnodes fraction partially recovered, and varnodes fraction exactly recovered show lower values than in the high-level analysis. We see that the decomposed varnode comparison scores for the strip, standard, and debug compilation cases are 0.586, 0.703, and 0.980, respectively. The varnodes fraction partially recovered are 73.8%, 92.5%, and 98.0% while the varnodes fraction exactly recovered are 24.7%, 25.0%, and 98.0% across the compilation cases, respectively. Interestingly, in the stripped compilation case, we find that the number of "missed" decomposed varnodes (139937) exceeds the number of "exactly matched" decomposed varnodes (131719). This is largely due to the quantity of high-level *ARRAY* and *STRUCT* varnodes that are missed in the stripped case.

We split the decomposed varnodes by metatype and show these results in Tables 26-28, 30-32, and 34-36. We present the summary of these results over each compilation case in Table 4.5. The table shows that the stripped and standard compilation cases demostrate the poorest inference performance in terms of varnode comparison score for varnodes of metatype *FLOAT*. However, we find that the percentage of "missed" *INT* varnodes is worse than that of *FLOAT* in the standard and debug compilation cases, and is nearly the same in the stripped case. This may be explained by the prevalence of integer (or character) arrays in the Coreutils benchmark programs when compared to other array types. Recovery accuracy of the *POINTER* metatype is comparable to the *INT* metatype across the three compilation cases.

Table 4.5: Summary of decomposed varnode recovery by compilation case and primitive metatype

		Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode comparison score	Varnode fraction partially recovered	Varnode fraction exactly recovered
strip	INT	132910	28812	0	217923	125159	0.586	0.737	0.248
	FLOAT	72	73	0	103	22	0.435	0.733	0.081
	POINTER	6725	2057	0	13208	6332	0.591	0.763	0.224
standard	INT	40017	46846	0	290436	127505	0.707	0.921	0.253
	FLOAT	0	145	0	103	22	0.502	1.000	0.081
	POINTER	132	9245	0	12955	5990	0.636	0.995	0.211
debug	INT	10533	124	0	4	494143	0.979	0.979	0.979
	FLOAT	0	0	0	0	270	1.000	1.000	1.000
	POINTER	14	2	0	1	28305	0.999	1.000	0.999

Table 4.6: Summary of data bytes recovery by compilation case

	Ground truth data bytes	Bytes found	Bytes missed	Bytes recovery fraction
strip	1183691	725144	458547	0.613
standard	1183691	954105	229586	0.806
debug	1183691	1177221	6470	0.995

4.5 Data Bytes Recovery

Following from our varnode inference analysis, we next assess the accuracy of the Ghidra decompiler with regards to the total number of data bytes recovered across all varnodes. This analysis provides an important perspective on data recovery as the size of an improperly inferred varnode may result in a wide range in the number of misinferred bytes. For example, a large array and a single character are each represented by a varnode, but the quantity of data present in the array is much greater than that of a character. Hence, it is important to capture this nuanced view of data recovery.

In Tables 37, 38, and 39, we show the data bytes recovery metrics for each of the benchmark

Table 4.7: Summary of array recovery by compilation case

	Ground truth array varnodes	Array comparisons	Array varnodes inferred as array	Array varnodes inferred as array fraction	Array length (elements) average error	Array length (elements) average error ratio	Array size (bytes) average error	Array size (bytes) average error ratio	Array dimension match score	Array average element type comparison score
strip	2138	823	774	0.362	134.695	2.845	458.575	0.912	0.979	0.781
standard	2138	1579	1530	0.716	151.156	5.442	239.023	0.475	0.975	0.670
debug	2138	2226	2128	0.995	9.416	0.110	9.416	0.110	1.000	1.000

programs under each compilation case. We summarize the data bytes recovery for each of the compilation cases in Table 4.6. We see that Ghidra recovers 61.3%, 80.6%, and 99.5% of data bytes in the stripped, standard, and debug compilation cases, respectively.

4.6 Array Inference Accuracy

The last major analysis we perform targets the array inference accuracy of the Ghidra decompiler. We aim to measure metrics regarding the total number of arrays inferred, the length and size discrepancies of compared arrays, and the similarity of element types of compared arrays. We perform this analysis across the Coreutils benchmarks and for each compilation configuration, resuling in Tables 40, 41, and 42 located in the appendix. This information is summarized in Table 4.7, broken down by compilation configuration.

Across all benchmarks, there are 2138 ground truth arrays present. For each the stripped, standard, and debug compilation cases, the number of ground truth arrays recognized as arrays by the decompiler are 774 (36.2%), 1530 (71.6%), and 2128 (99.5%), respectively. We see that the numbers of array comparisons for each compilation case are greater than these metrics indicating that Ghidra infers some ground truth arrays to be more than one array.

From the array comparisons, we observe that the average absolute differential in array length (number of elements) for the stripped, standard, and debug compilation cases are 134.7, 151.2, and 9.4, respectively. When scaling these errors with respect to the length of the ground truth arrays in the comparisons, the error ratios are 2.84, 5.44, and 0.11 for the compilation cases, respectively. This reveals that, in the debug case for example, the lengths of decompiler-inferred arrays are off by an average of 9.4 elements and roughly 11% (greater or less than) of the size of the ground truth arrays they are compared to. These metrics, however, fail to capture whether the decompiler-inferred array has element types of the correct length. Thus, a similar analysis on the size (number of bytes) errors yields errors and error ratios of 458.6 (0.91), 239 (0.47), and 9.41 (0.11) for each compilation case, respectively. This, for example, shows that arrays inferred in the standard compilation case have an average absolute byte differential of 239 and a relative error of 47% compared to the size of the ground truth array they are compared to.

In this analysis, we also capture a measure of the array dimension match score for each compilation case. This metric measures the fraction of array comparisons where the decompiler-inferred array has the same dimensionality (one-dimensional, two-dimensional, etc.) as the ground truth array. The stripped and standard compilation cases display dimensionality match ratios of greater than 97.4%, while the debug case shows 100% dimensionality inference accuracy.

The last portion of our array recovery analysis focuses on the element type inference accuracy of the decompiler-inferred arrays when compared to the element types of the ground truth arrays. We compute a data type comparison score between the element types from each array comparison and average these across all array comparisons derived from our benchmark programs. This data type comparison score is similar in concept to the varnode comparison score and is described in Chapter 3. We find that decompiler-inferred arrays in the stripped, standard, and debug compilation cases show 0.781, 0.670, and 0.999 average element type comparison scores, respectively. The better performance demonstrated in the stripped case compared to the standard case appears to be a data artifact resulting from fewer array comparisons present in the stripped analysis.

4.7 Debug Compilation Case Discussion

Upon examination of our results thus far, the reader may wonder why the debug compilation case does not produce 100% recovery for varnodes and data bytes across all benchmarks. The same DWARF debugging information used to generate the ground truth program information is also provided to the Ghidra decompiler in this case and therefore, theoretically, Ghidra should be able to precisely capture the same program information.

We manually investigate this phenomenon over our benchmark programs and find that the cause of these recovery inaccuracies stems from the Ghidra decompiler's inflexibility in expressing local variables tied to lexical scopes. We find that the Ghidra decompiler output only lists variable declarations at the top level of the function and does not support declarations of local variables within lexical scopes. Instead, Ghidra attempts to move the declaration of these scope-specific variables to the top level of the function. Often, this behavior does not negatively influence the variable recovery of the given function. However, there are cases where multiple exclusive (not overlapping or nested) lexical scopes contain variable declarations. In many of these cases, the compiler recognizes the exclusivity of the lexical scopes and assigns the scope-specific variables to shared space on the stack since the variables shall never be instantiated simultaneously. The size of the shared region allocated by the decompiler is equivalent to the size of the largest variable in the set of scope-specific variables that share the region. In essence, this is equivalent to an implicit union formed by the compiler. The DWARF debugging standard and our DSL both possess the ability to express these overlapping scope-specific variables, but the Ghidra decompiler does not. From our observations, we find that Ghidra greedily captures and declares scope-specific variables at the top level of the function based on the order in which it recovers the variables. In the debug compilation case (utilizing DWARF information), Ghidra appears to only consider the first scope-specific variable mapped to a given address on the stack based on the order of the variables in the list of debugging information entries (DIEs) parsed from DWARF. The subsequent scope-specific variables associated with the given address are simply ignored, causing Ghidra to potentially miss several varnodes and data bytes. We consider this to be a shortcoming and an area of future improvement for the Ghidra decompiler.

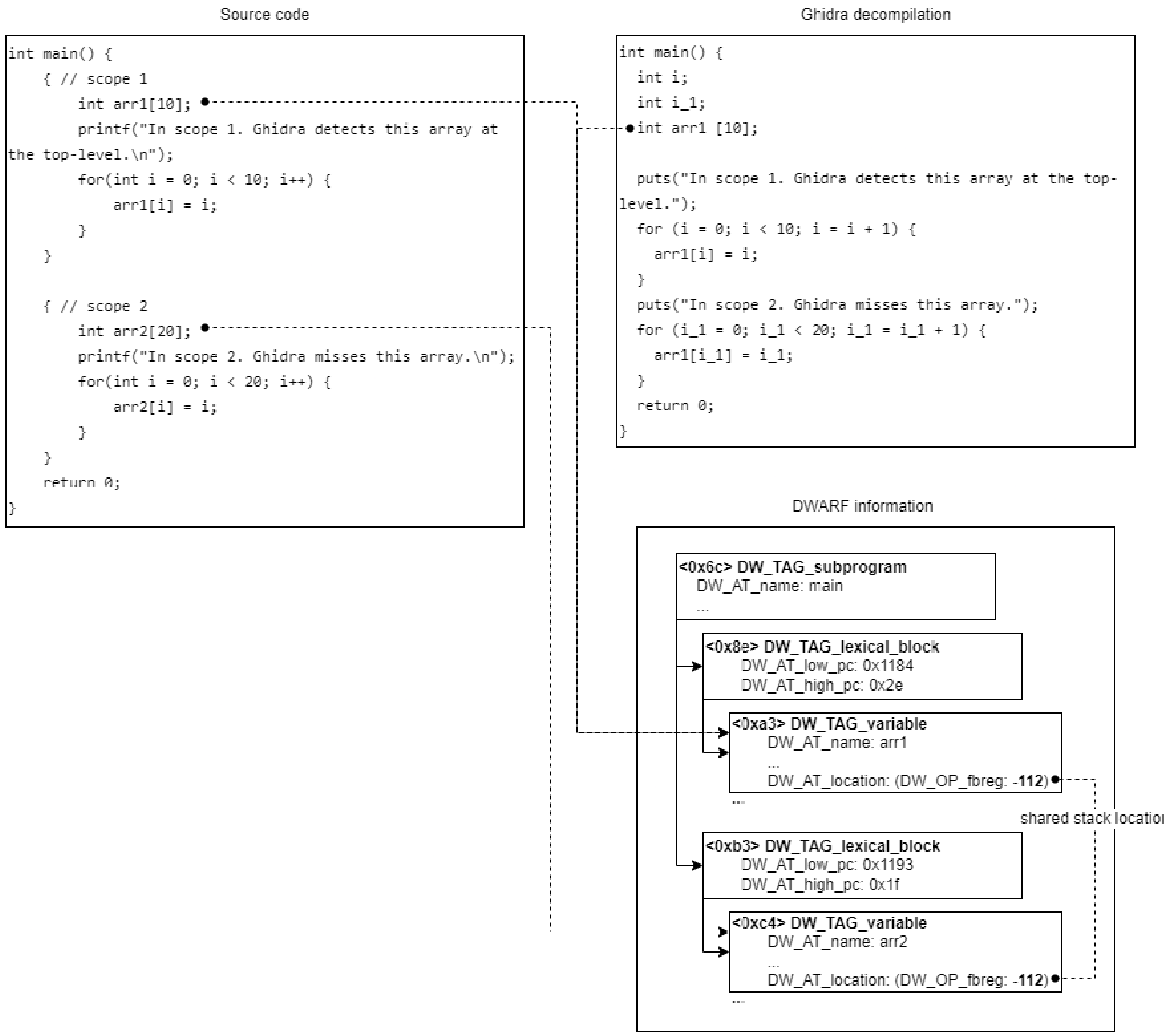


Figure 4.2: An example of the Ghidra decompiler missing the second of two scope-specific variables that share stack space

Chapter 5

Conclusion

5.1 Summary of Methodology

To develop our decompiler evaluation framework, we outline and execute the following objectives:

1. Express program information such as functions, variables, data types, and addresses in a common representation.
2. Programmatically capture a "ground truth" representation for a given program.
3. Programmatically scrape program information from decompiler tools, namely Ghidra.
4. Compare two program representations of the same program.
5. Formulate quantitative metrics for evaluating the accuracy of a decompiler.

We devise and implement a common domain-specific language (DSL) for expressing the association of high-level program information such as functions, variables, and data types, with binary-level constructs such as addresses and storage locations. With our DSL, we develop a parser for extracting DWARF debugging information from binary programs and representing this information in our DSL. This information is to be used as a ground truth source of program information in comparisons with decompiler representations. Next, we leverage the Ghidra Python API to develop a translator module, taking Ghidra decompilation output as our input and translating the information into our DSL. With our parsing modules constructed for both our ground truth and decompiler soures, we extend our DSL to support the comparison of two sources of program information parsed from a ground truth source and a decompiler source. We subsequently develop quantitative metrics for assessing and summarizing comparisons of program information sources.

5.2 Summary of Results

We utilize our developed framework to assess the recovery performance of the Ghidra decompiler (version 10.2) over the 105 GNU Core Utilities (version 9.1) benchmark programs. Using the GCC compiler (version 11.1.0), we compile the benchmarks with no optimizations under three separate compilation configurations: (1) stripped, (2) standard (not stripped, no DWARF symbols added), (3) debug (DWARF symbols included).

Our function recovery analysis reveals that Ghidra recovers 100% of the 18139 functions across all benchmarks in the stripped and standard compilation cases. In the debug case, we find four missed functions in total, all present in the *factor* benchmark program. We discover that the missed functions are all caused by a decompiler error resulting from a failure in resolving a union data type. We conclude that this is a bug in the Ghidra decompiler.

In our high-level varnode analysis, we find that the recovery accuracy of primitive (*INT*, *FLOAT*, *POINTER*) metatypes is greater than that of the complex (aggregate) metatypes (*ARRAY*, *STRUCT*, *UNION*) across all compilation cases. This finding follows from the fact that inferring complex varnodes involves an extra layer of speculation and inference involving the synthesis of low-level varnodes. In all compilation cases, the *ARRAY* metatype displays the greatest number of "missed" varnodes.

Our decomposed (primitive) varnode analysis demonstrates that Ghidra is least effective at inferring floating-point (metatype *FLOAT*) decomposed varnodes over the benchmark programs in the stripped and standard compilation cases. However, we see that Ghidra completely misses a larger fraction of decomposed varnodes with metatype *INT*. This is explained by the larger incidence of integer arrays in the Coreutils benchmark programs, which are more likely to be missed or only partially recovered as demonstrated in our high-level varnode analysis. We show that decomposed varnodes of metatype *POINTER* are recovered comparably to those of metatype *INT*.

In our analysis of data bytes recovery summarized across all benchmarks, we find that the Ghidra decompiler shows 61.3% recovery in the stripped compilation case, 80.6% recovery in the standard case, and 99.5% recovery in the debug case.

Our array inference analysis illustrates that the compilation configuration of our benchmark programs has a significant impact on both array recovery and the inference accuracy of the arrays that are recovered. We find that, for each the stripped, standard, and debug compilation cases, 36.2%, 71.6%, and 99.5% of ground truth array varnodes overlap with at least one associated decompiler-inferred array varnode, respectively. We find the average size error ratio of the decompiler-inferred arrays with respect to the ground truth arrays to be 0.91, 0.47, and 0.11 for the compilation cases, respectively.

The function, variable, data bytes, and data type recovery analyses show clear recovery accuracy differentials between the three compilation cases. In general, we find that the debug case (DWARF symbols included) performs the best by a large margin, followed by the standard case which slightly outperforms the stripped case. Despite the decent recovery performance in the debug case, we seek an explanation for the decompiler still failing to capture a portion of the ground truth information, particularly varnodes and data bytes. We find that the Ghidra decompiler is limited in its ability to express overlapping stack variables gathered from disjoint (non-overlapping, non-nested) lexical scopes within the same parent function. This scenario arises when the compiler recoginizes the exclusivity of lexical scopes within a function and subsequently assigns scope-specific variables from these lexical scopes to the same address or region on the stack.

5.3 Limitations

The primary limitation of our framework in its current state is the lack of support for comparing and evaluating program information gathered from optimized binary programs. Our DSL supports the expression of program information from optimized binaries, but the comparison logic assumes certain properties about the program information to reduce the complexity of the analysis. Future work shall include the extension of the framework to support the evaluation of optimized binaries.

Another assumption in our analysis is that only non-parameter variables with stack and absolute (global) addresses are considered for comparison. Heap-allocated data must be referenced by a local or global pointer and therefore heap data recovery evaluation is performed indirectly via this pointer. Application of existing static analysis techniques are necessary to peform a more complete evaluation of heap constructs.

Another limitation in this work is our exclusive support for the DWARF debugging standard for extracting ground truth program information. However, as discussed previously, our framework can easily be extended to support the implementation of parsers for other debugging formats.

Regarding decompiler evaluation, our framework excels at assessing the recovery and inference of high-level program constructs. However, our framework lacks the ability to evaluate behavioral correctness and overall clarity of decompiler output. Existing works, including those by Liu et al. [10] and Naeem et al. [11], have proposed strategies for assessing these aspects. A comprehensive decompiler evaluation shall combine our structural recovery analysis with these forms of analyses.

The final noteworthy limitation in our work is that we use our framework to assess only the Ghidra decompiler. We consider our framework to be the primary contribution of this research and therefore leave the analysis and comparison of other decompilers for future work.

5.4 Future Work

As discussed in the previous section, a major future work objective shall be to extend our framework to support optimized binaries. Another area for improvement shall be to include existing static analysis techniques to identify and more accurately assess the recovery of heap-allocated data. Lastly, we shall use our framework to assess and compare the recovery performance of decompilers beyond Ghidra.

In our function recovery analysis, recall that the Ghidra decompiler fails to decompile four functions within the *factor* program only in the case where DWARF debugging symbols are included. We conclude from the error messages returned that the decompilation errors for these functions result from Ghidra's inability to resolve a particular union data type present in the program. Since this error does not occur for the other compilation cases of the *factor* program, we gather that the DWARF information scraped by Ghidra contributes to this error. With this observation, we recognize that a useful obfuscation strategy for binary programs may, instead of stripping all debugging symbols, be to include misleading and contradictory debugging information. Reverse engineering tools and decompilers analyzing a binary program with misleading debugging symbols included may produce incorrect outputs or potentially crash based on this erroneous information. This is certainly an area worthy of future research. In addition, the union resolution issue observed in our analysis shall be patched in the Ghidra framework.

In our assessment of the Ghidra decompiler, we observe that Ghidra does not successfully capture all ground truth variables and data bytes even in the case the DWARF debugging information is present. Upon further investigation, we discover this shortcoming is due to Ghidra's inability to express local variable declarations at lexical scope levels below the top level of a function. In other words, Ghidra forces all local variables to be declared at the top level of a given function. This causes Ghidra to partially miss cases where the same stack address region is used by the compiler to store local variables declared in non-overlapping, non-nested lexical scopes within the same function. An direction for future work shall be to modify the Ghidra decompiler to support the expression of more flexible local variable constructs that are not required to be declared at the top level of a function.

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Appendix

Table 1: Function recovery (compilation = stripped)

	Ground truth functions	Functions found	Functions missed	Functions recovery fraction
[	152	152	0	1.000
b2sum	148	148	0	1.000
base32	128	128	0	1.000
base64	129	129	0	1.000
basename	111	111	0	1.000
basenc	171	171	0	1.000
cat	124	124	0	1.000
chcon	247	247	0	1.000
chgrp	216	216	0	1.000
chmod	214	214	0	1.000
chown	218	218	0	1.000
chroot	125	125	0	1.000
cksum	246	246	0	1.000
comm	126	126	0	1.000
cp	335	335	0	1.000
csplit	339	339	0	1.000
cut	126	126	0	1.000
date	208	208	0	1.000

Continued on next page

Table 1: Function recovery (compilation = stripped)

	Ground truth functions	Functions found	Functions missed	Functions recovery fraction
dd	197	197	0	1.000
df	266	266	0	1.000
dir	484	484	0	1.000
dircolors	125	125	0	1.000
dirname	108	108	0	1.000
du	513	513	0	1.000
echo	105	105	0	1.000
env	126	126	0	1.000
expand	121	121	0	1.000
expr	323	323	0	1.000
factor	174	174	0	1.000
false	104	104	0	1.000
fmt	131	131	0	1.000
fold	116	116	0	1.000
groups	112	112	0	1.000
head	135	135	0	1.000
hostid	106	106	0	1.000
id	142	142	0	1.000
join	152	152	0	1.000
kill	112	112	0	1.000
link	106	106	0	1.000
ln	231	231	0	1.000

Continued on next page

Table 1: Function recovery (compilation = stripped)

	Ground truth functions	Functions found	Functions missed	Functions recovery fraction
logname	106	106	0	1.000
ls	484	484	0	1.000
md5sum	132	132	0	1.000
mkdir	165	165	0	1.000
mkfifo	131	131	0	1.000
mknod	134	134	0	1.000
mktemp	120	120	0	1.000
mv	394	394	0	1.000
nice	110	110	0	1.000
nl	307	307	0	1.000
nohup	115	115	0	1.000
nproc	113	113	0	1.000
numfmt	159	159	0	1.000
od	172	172	0	1.000
paste	114	114	0	1.000
pathchk	110	110	0	1.000
pinky	124	124	0	1.000
pr	208	208	0	1.000
printenv	105	105	0	1.000
printf	138	138	0	1.000
ptx	347	347	0	1.000
pwd	115	115	0	1.000

Continued on next page

Table 1: Function recovery (compilation = stripped)

	Ground truth functions	Functions found	Functions missed	Functions recovery fraction
readlink	168	168	0	1.000
realpath	174	174	0	1.000
rm	234	234	0	1.000
rmdir	124	124	0	1.000
runcon	122	122	0	1.000
seq	129	129	0	1.000
sha1sum	133	133	0	1.000
sha224sum	140	140	0	1.000
sha256sum	140	140	0	1.000
sha384sum	140	140	0	1.000
sha512sum	140	140	0	1.000
shred	181	181	0	1.000
shuf	215	215	0	1.000
sleep	118	118	0	1.000
sort	349	349	0	1.000
split	154	154	0	1.000
stat	240	240	0	1.000
stdbuf	135	135	0	1.000
stty	149	149	0	1.000
sum	142	142	0	1.000
sync	108	108	0	1.000
tac	310	310	0	1.000

Continued on next page

Table 1: Function recovery (compilation = stripped)

	Ground truth functions	Functions found	Functions missed	Functions recovery fraction
tail	234	234	0	1.000
tee	124	124	0	1.000
test	147	147	0	1.000
timeout	130	130	0	1.000
touch	198	198	0	1.000
tr	149	149	0	1.000
true	104	104	0	1.000
truncate	114	114	0	1.000
tsort	125	125	0	1.000
tty	105	105	0	1.000
uname	107	107	0	1.000
unexpand	121	121	0	1.000
uniq	132	132	0	1.000
unlink	106	106	0	1.000
uptime	142	142	0	1.000
users	112	112	0	1.000
vdir	484	484	0	1.000
wc	152	152	0	1.000
who	138	138	0	1.000
whoami	106	106	0	1.000
yes	109	109	0	1.000

Table 2: Function recovery (compilation = standard)

	Ground truth functions	Functions found	Functions missed	Functions recovery fraction
[	152	152	0	1.000
b2sum	148	148	0	1.000
base32	128	128	0	1.000
base64	129	129	0	1.000
basename	111	111	0	1.000
basenc	171	171	0	1.000
cat	124	124	0	1.000
chcon	247	247	0	1.000
chgrp	216	216	0	1.000
chmod	214	214	0	1.000
chown	218	218	0	1.000
chroot	125	125	0	1.000
cksum	246	246	0	1.000
comm	126	126	0	1.000
cp	335	335	0	1.000
csplit	339	339	0	1.000
cut	126	126	0	1.000
date	208	208	0	1.000
dd	197	197	0	1.000
df	266	266	0	1.000
dir	484	484	0	1.000
dircolors	125	125	0	1.000

Continued on next page

Table 2: Function recovery (compilation = standard)

	Ground truth functions	Functions found	Functions missed	Functions recovery fraction
dirname	108	108	0	1.000
du	513	513	0	1.000
echo	105	105	0	1.000
env	126	126	0	1.000
expand	121	121	0	1.000
expr	323	323	0	1.000
factor	174	174	0	1.000
false	104	104	0	1.000
fmt	131	131	0	1.000
fold	116	116	0	1.000
groups	112	112	0	1.000
head	135	135	0	1.000
hostid	106	106	0	1.000
id	142	142	0	1.000
join	152	152	0	1.000
kill	112	112	0	1.000
link	106	106	0	1.000
ln	231	231	0	1.000
logname	106	106	0	1.000
ls	484	484	0	1.000
md5sum	132	132	0	1.000
mkdir	165	165	0	1.000

Continued on next page

Table 2: Function recovery (compilation = standard)

	Ground truth functions	Functions found	Functions missed	Functions recovery fraction
mkfifo	131	131	0	1.000
mknod	134	134	0	1.000
mktemp	120	120	0	1.000
mv	394	394	0	1.000
nice	110	110	0	1.000
nl	307	307	0	1.000
nohup	115	115	0	1.000
nproc	113	113	0	1.000
numfmt	159	159	0	1.000
od	172	172	0	1.000
paste	114	114	0	1.000
pathchk	110	110	0	1.000
pinky	124	124	0	1.000
pr	208	208	0	1.000
printenv	105	105	0	1.000
printf	138	138	0	1.000
ptx	347	347	0	1.000
pwd	115	115	0	1.000
readlink	168	168	0	1.000
realpath	174	174	0	1.000
rm	234	234	0	1.000
rmdir	124	124	0	1.000

Continued on next page

Table 2: Function recovery (compilation = standard)

	Ground truth functions	Functions found	Functions missed	Functions recovery fraction
runcon	122	122	0	1.000
seq	129	129	0	1.000
sha1sum	133	133	0	1.000
sha224sum	140	140	0	1.000
sha256sum	140	140	0	1.000
sha384sum	140	140	0	1.000
sha512sum	140	140	0	1.000
shred	181	181	0	1.000
shuf	215	215	0	1.000
sleep	118	118	0	1.000
sort	349	349	0	1.000
split	154	154	0	1.000
stat	240	240	0	1.000
stdbuf	135	135	0	1.000
stty	149	149	0	1.000
sum	142	142	0	1.000
sync	108	108	0	1.000
tac	310	310	0	1.000
tail	234	234	0	1.000
tee	124	124	0	1.000
test	147	147	0	1.000
timeout	130	130	0	1.000

Continued on next page

Table 2: Function recovery (compilation = standard)

	Ground truth functions	Functions found	Functions missed	Functions recovery fraction
touch	198	198	0	1.000
tr	149	149	0	1.000
true	104	104	0	1.000
truncate	114	114	0	1.000
tsort	125	125	0	1.000
tty	105	105	0	1.000
uname	107	107	0	1.000
unexpand	121	121	0	1.000
uniq	132	132	0	1.000
unlink	106	106	0	1.000
uptime	142	142	0	1.000
users	112	112	0	1.000
vdir	484	484	0	1.000
wc	152	152	0	1.000
who	138	138	0	1.000
whoami	106	106	0	1.000
yes	109	109	0	1.000

Table 3: Function recovery (compilation = debug)

	Ground truth functions	Functions found	Functions missed	Functions recovery fraction
[	152	152	0	1.000
b2sum	148	148	0	1.000
base32	128	128	0	1.000
base64	129	129	0	1.000
basename	111	111	0	1.000
basenc	171	171	0	1.000
cat	124	124	0	1.000
chcon	247	247	0	1.000
chgrp	216	216	0	1.000
chmod	214	214	0	1.000
chown	218	218	0	1.000
chroot	125	125	0	1.000
cksum	246	246	0	1.000
comm	126	126	0	1.000
cp	335	335	0	1.000
csplit	339	339	0	1.000
cut	126	126	0	1.000
date	208	208	0	1.000
dd	197	197	0	1.000
df	266	266	0	1.000
dir	484	484	0	1.000
dircolors	125	125	0	1.000

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Table 3: Function recovery (compilation = debug)

	Ground truth functions	Functions found	Functions missed	Functions recovery fraction
dirname	108	108	0	1.000
du	513	513	0	1.000
echo	105	105	0	1.000
env	126	126	0	1.000
expand	121	121	0	1.000
expr	323	323	0	1.000
factor	174	170	4	0.977
false	104	104	0	1.000
fmt	131	131	0	1.000
fold	116	116	0	1.000
groups	112	112	0	1.000
head	135	135	0	1.000
hostid	106	106	0	1.000
id	142	142	0	1.000
join	152	152	0	1.000
kill	112	112	0	1.000
link	106	106	0	1.000
ln	231	231	0	1.000
logname	106	106	0	1.000
ls	484	484	0	1.000
md5sum	132	132	0	1.000
mkdir	165	165	0	1.000

Continued on next page

Table 3: Function recovery (compilation = debug)

	Ground truth functions	Functions found	Functions missed	Functions recovery fraction
mkfifo	131	131	0	1.000
mknod	134	134	0	1.000
mktemp	120	120	0	1.000
mv	394	394	0	1.000
nice	110	110	0	1.000
nl	307	307	0	1.000
nohup	115	115	0	1.000
nproc	113	113	0	1.000
numfmt	159	159	0	1.000
od	172	172	0	1.000
paste	114	114	0	1.000
pathchk	110	110	0	1.000
pinky	124	124	0	1.000
pr	208	208	0	1.000
printenv	105	105	0	1.000
printf	138	138	0	1.000
ptx	347	347	0	1.000
pwd	115	115	0	1.000
readlink	168	168	0	1.000
realpath	174	174	0	1.000
rm	234	234	0	1.000
rmdir	124	124	0	1.000

Continued on next page

Table 3: Function recovery (compilation = debug)

	Ground truth functions	Functions found	Functions missed	Functions recovery fraction
runcon	122	122	0	1.000
seq	129	129	0	1.000
sha1sum	133	133	0	1.000
sha224sum	140	140	0	1.000
sha256sum	140	140	0	1.000
sha384sum	140	140	0	1.000
sha512sum	140	140	0	1.000
shred	181	181	0	1.000
shuf	215	215	0	1.000
sleep	118	118	0	1.000
sort	349	349	0	1.000
split	154	154	0	1.000
stat	240	240	0	1.000
stdbuf	135	135	0	1.000
stty	149	149	0	1.000
sum	142	142	0	1.000
sync	108	108	0	1.000
tac	310	310	0	1.000
tail	234	234	0	1.000
tee	124	124	0	1.000
test	147	147	0	1.000
timeout	130	130	0	1.000

Continued on next page

Table 3: Function recovery (compilation = debug)

	Ground truth functions	Functions found	Functions missed	Functions recovery fraction
touch	198	198	0	1.000
tr	149	149	0	1.000
true	104	104	0	1.000
truncate	114	114	0	1.000
tsort	125	125	0	1.000
tty	105	105	0	1.000
uname	107	107	0	1.000
unexpand	121	121	0	1.000
uniq	132	132	0	1.000
unlink	106	106	0	1.000
uptime	142	142	0	1.000
users	112	112	0	1.000
vdir	484	484	0	1.000
wc	152	152	0	1.000
who	138	138	0	1.000
whoami	106	106	0	1.000
yes	109	109	0	1.000

Table 4: Varnode recovery (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average comparison score	Varnode fraction partially recovered	Varnode fraction exactly recovered
[	266	5	20	10	125	106	0.789	0.981	0.398
b2sum	237	8	9	9	115	96	0.797	0.966	0.405
base32	160	7	7	4	79	63	0.787	0.956	0.394
base64	160	7	7	4	79	63	0.787	0.956	0.394
basename	129	5	7	4	74	39	0.762	0.961	0.302
basenc	219	14	9	4	103	89	0.779	0.936	0.406
cat	164	5	8	5	92	54	0.777	0.970	0.329
chcon	363	8	16	7	229	103	0.778	0.978	0.284
chgrp	339	8	15	9	200	107	0.782	0.976	0.316
chmod	347	9	16	11	206	105	0.775	0.974	0.303
chown	359	8	16	9	206	120	0.788	0.978	0.334
chroot	198	5	9	4	84	96	0.824	0.975	0.485
cksum	678	31	26	20	392	209	0.766	0.954	0.308
comm	171	5	13	5	99	49	0.754	0.971	0.287
cp	703	17	32	30	351	273	0.796	0.976	0.388
csplit	982	15	43	17	533	374	0.808	0.985	0.381
cut	192	7	8	4	112	61	0.776	0.964	0.318
date	747	29	40	37	383	258	0.768	0.961	0.345

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Table 4: Varnode recovery (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average comparison score	Varnode fraction partially recovered	Varnode fraction exactly recovered
dd	493	18	20	12	243	200	0.798	0.963	0.406
df	640	9	25	15	283	308	0.834	0.986	0.481
dir	1031	30	56	28	544	373	0.785	0.971	0.362
dircolors	190	6	8	6	111	59	0.775	0.968	0.311
dirname	125	6	7	4	70	38	0.754	0.952	0.304
du	1499	30	56	34	824	555	0.803	0.980	0.370
echo	118	4	7	4	68	35	0.761	0.966	0.297
env	201	9	12	5	97	78	0.777	0.955	0.388
expand	152	6	8	5	87	46	0.762	0.961	0.303
expr	911	15	38	27	489	342	0.803	0.984	0.375
factor	511	31	27	24	187	242	0.785	0.939	0.474
false	109	4	7	4	63	31	0.752	0.963	0.284
fmt	186	6	8	4	107	61	0.781	0.968	0.328
fold	143	6	8	4	75	50	0.771	0.958	0.350
groups	142	6	7	4	77	48	0.771	0.958	0.338
head	215	5	15	6	113	76	0.779	0.977	0.353
hostid	118	5	7	6	69	31	0.742	0.958	0.263
id	196	8	8	4	99	77	0.792	0.959	0.393

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Table 4: Varnode recovery (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average comparison score	Varnode fraction partially recovered	Varnode fraction exactly recovered
join	260	9	12	5	145	89	0.782	0.965	0.342
kill	148	7	9	4	76	52	0.765	0.953	0.351
link	117	5	7	6	68	31	0.741	0.957	0.265
ln	433	8	17	16	230	162	0.801	0.982	0.374
logname	118	5	7	6	69	31	0.742	0.958	0.263
ls	1031	30	56	28	544	373	0.785	0.971	0.362
md5sum	217	7	13	4	117	76	0.779	0.968	0.350
mkdir	306	7	15	10	146	128	0.805	0.977	0.418
mkfifo	148	6	9	5	83	45	0.757	0.959	0.304
mknod	165	6	9	5	86	59	0.777	0.964	0.358
mktemp	164	6	8	5	91	54	0.773	0.963	0.329
mv	773	15	37	26	427	268	0.790	0.981	0.347
nice	130	5	7	4	70	44	0.771	0.962	0.338
nl	896	23	39	17	468	349	0.802	0.974	0.390
nohup	162	5	8	6	102	41	0.756	0.969	0.253
nproc	139	5	7	4	74	49	0.779	0.964	0.353
numfmt	291	9	13	9	139	121	0.801	0.969	0.416
od	459	11	27	12	205	204	0.807	0.976	0.444

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Table 4: Varnode recovery (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average comparison score	Varnode fraction partially recovered	Varnode fraction exactly recovered
paste	142	5	7	4	82	44	0.769	0.965	0.310
pathchk	141	6	8	4	84	39	0.752	0.957	0.277
pinky	182	8	12	5	106	51	0.747	0.956	0.280
pr	543	12	18	10	324	179	0.795	0.978	0.330
printenv	119	5	7	4	65	38	0.761	0.958	0.319
printf	283	6	18	8	133	118	0.799	0.979	0.417
ptx	1126	19	56	32	575	444	0.804	0.983	0.394
pwd	143	5	8	9	84	37	0.745	0.965	0.259
readlink	243	6	10	7	134	86	0.792	0.975	0.354
realpath	248	6	10	7	135	90	0.795	0.976	0.363
rm	362	9	15	9	218	111	0.781	0.975	0.307
rmdir	234	6	10	7	112	99	0.808	0.974	0.423
runcon	121	5	7	4	72	33	0.750	0.959	0.273
seq	279	8	21	8	121	121	0.792	0.971	0.434
sha1sum	215	7	10	5	113	80	0.790	0.967	0.372
sha224sum	225	8	13	5	116	83	0.781	0.964	0.369
sha256sum	225	8	13	5	116	83	0.781	0.964	0.369
sha384sum	381	8	8	5	275	85	0.776	0.979	0.223

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Table 4: Varnode recovery (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average comparison score	Varnode fraction partially recovered	Varnode fraction exactly recovered
sha512sum	381	8	8	5	275	85	0.776	0.979	0.223
shred	370	9	21	8	200	132	0.787	0.976	0.357
shuf	374	6	9	6	215	138	0.814	0.984	0.369
sleep	143	5	9	6	77	46	0.762	0.965	0.322
sort	847	22	38	18	460	309	0.794	0.974	0.365
split	297	9	14	5	153	116	0.797	0.970	0.391
stat	608	20	22	20	313	233	0.795	0.967	0.383
stdbuf	267	7	10	9	125	116	0.812	0.974	0.434
stty	301	8	16	10	132	135	0.807	0.973	0.449
sum	278	8	13	7	136	114	0.801	0.971	0.410
sync	133	5	8	4	78	38	0.756	0.962	0.286
tac	920	17	39	18	500	346	0.804	0.982	0.376
tail	423	7	25	11	215	165	0.799	0.983	0.390
tee	154	6	9	5	90	44	0.755	0.961	0.286
test	260	4	19	9	125	103	0.792	0.985	0.396
timeout	175	6	10	4	86	69	0.789	0.966	0.394
touch	602	25	37	36	298	206	0.759	0.958	0.342
tr	241	9	9	6	114	103	0.804	0.963	0.427

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Table 4: Varnode recovery (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average comparison score	Varnode fraction partially recovered	Varnode fraction exactly recovered
true	109	4	7	4	63	31	0.752	0.963	0.284
truncate	145	5	8	5	80	47	0.769	0.966	0.324
tsort	162	5	10	6	93	48	0.761	0.969	0.296
tty	114	5	7	4	66	32	0.748	0.956	0.281
uname	120	6	7	5	68	34	0.744	0.950	0.283
unexpand	158	5	7	5	89	52	0.778	0.968	0.329
uniq	202	7	10	6	112	67	0.775	0.965	0.332
unlink	117	5	7	6	68	31	0.741	0.957	0.265
uptime	353	11	12	12	210	108	0.778	0.969	0.306
users	133	5	7	6	78	37	0.754	0.962	0.278
vdir	1031	30	56	28	544	373	0.785	0.971	0.362
wc	268	8	8	8	148	96	0.795	0.970	0.358
who	282	10	10	8	138	116	0.801	0.965	0.411
whoami	120	5	7	6	71	31	0.742	0.958	0.258
yes	132	5	7	6	77	37	0.754	0.962	0.280

Table 5: Varnode recovery (metatype = INT) (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
[	157	0	0	0	83	74	0.868	1.000	0.471
b2sum	147	0	0	0	80	67	0.864	1.000	0.456
base32	96	0	0	0	51	45	0.867	1.000	0.469
base64	96	0	0	0	51	45	0.867	1.000	0.469
basename	71	0	0	0	47	24	0.835	1.000	0.338
basenc	133	0	1	0	70	62	0.863	1.000	0.466
cat	101	0	0	0	64	37	0.842	1.000	0.366
chcon	185	0	0	0	124	61	0.832	1.000	0.330
chgrp	166	0	0	0	103	63	0.845	1.000	0.380
chmod	176	0	0	0	110	66	0.844	1.000	0.375
chown	176	0	0	0	105	71	0.851	1.000	0.403
chroot	110	0	1	0	53	56	0.873	1.000	0.509
cksum	488	2	0	0	329	157	0.827	0.996	0.322
comm	104	0	0	0	74	30	0.822	1.000	0.288
cp	382	2	1	0	206	173	0.858	0.995	0.453
csplit	619	0	1	0	325	293	0.868	1.000	0.473
cut	124	1	0	0	80	43	0.831	0.992	0.347
date	516	4	10	0	317	185	0.824	0.992	0.359

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Table 5: Varnode recovery (metatype = INT) (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
dd	332	1	0	0	186	145	0.857	0.997	0.437
df	326	0	0	0	158	168	0.879	1.000	0.515
dir	615	4	3	0	364	244	0.842	0.993	0.397
dircolors	90	0	0	0	58	32	0.839	1.000	0.356
dirname	73	1	0	0	46	26	0.829	0.986	0.356
du	931	4	3	0	518	406	0.854	0.996	0.436
echo	69	0	0	0	45	24	0.837	1.000	0.348
env	112	0	0	0	61	51	0.864	1.000	0.455
expand	94	0	0	0	59	35	0.843	1.000	0.372
expr	560	0	1	0	286	273	0.871	1.000	0.487
factor	343	21	2	0	128	192	0.841	0.939	0.560
false	62	0	0	0	40	22	0.839	1.000	0.355
fmt	112	0	0	0	72	40	0.839	1.000	0.357
fold	88	0	0	0	51	37	0.855	1.000	0.420
groups	81	0	0	0	51	30	0.843	1.000	0.370
head	138	0	0	0	82	56	0.851	1.000	0.406
hostid	67	0	0	0	45	22	0.832	1.000	0.328
id	112	0	0	0	69	43	0.846	1.000	0.384

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Table 5: Varnode recovery (metatype = INT) (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
join	162	0	0	0	104	58	0.840	1.000	0.358
kill	88	0	0	0	52	36	0.852	1.000	0.409
link	66	0	0	0	44	22	0.833	1.000	0.333
ln	219	0	0	0	125	94	0.857	1.000	0.429
logname	66	0	0	0	44	22	0.833	1.000	0.333
ls	615	4	3	0	364	244	0.842	0.993	0.397
md5sum	139	0	0	0	81	58	0.854	1.000	0.417
mkdir	196	0	0	0	102	94	0.870	1.000	0.480
mkfifo	88	0	0	0	53	35	0.849	1.000	0.398
mknod	100	0	0	0	54	46	0.865	1.000	0.460
mktemp	96	0	0	0	60	36	0.844	1.000	0.375
mv	428	2	0	0	238	188	0.856	0.995	0.439
nice	77	0	0	0	47	30	0.847	1.000	0.390
nl	558	0	1	0	288	269	0.870	1.000	0.482
nohup	99	0	0	0	71	28	0.821	1.000	0.283
nproc	86	0	0	0	51	35	0.852	1.000	0.407
numfmt	184	0	0	0	98	86	0.867	1.000	0.467
od	294	0	1	0	146	147	0.873	1.000	0.500

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Table 5: Varnode recovery (metatype = INT) (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
paste	85	0	0	0	55	30	0.838	1.000	0.353
pathchk	85	0	0	0	57	28	0.832	1.000	0.329
pinky	96	0	0	0	65	31	0.831	1.000	0.323
pr	399	4	1	0	258	136	0.826	0.990	0.341
printenv	68	0	0	0	42	26	0.846	1.000	0.382
printf	168	0	2	0	85	81	0.865	1.000	0.482
ptx	673	0	1	0	347	325	0.870	1.000	0.483
pwd	75	0	0	0	50	25	0.833	1.000	0.333
readlink	111	0	0	0	69	42	0.845	1.000	0.378
realpath	111	0	0	0	65	46	0.854	1.000	0.414
rm	185	0	0	0	115	70	0.845	1.000	0.378
rmdir	139	0	0	0	73	66	0.869	1.000	0.475
runcon	65	0	0	0	42	23	0.838	1.000	0.354
seq	156	0	0	0	78	78	0.875	1.000	0.500
sha1sum	138	0	0	0	78	60	0.859	1.000	0.435
sha224sum	145	0	0	0	80	65	0.862	1.000	0.448
sha256sum	145	0	0	0	80	65	0.862	1.000	0.448
sha384sum	301	0	0	0	236	65	0.804	1.000	0.216

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Table 5: Varnode recovery (metatype = INT) (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
sha512sum	301	0	0	0	236	65	0.804	1.000	0.216
shred	238	0	0	0	140	98	0.853	1.000	0.412
shuf	210	0	0	0	129	81	0.846	1.000	0.386
sleep	76	0	0	0	49	27	0.839	1.000	0.355
sort	440	0	0	0	260	180	0.852	1.000	0.409
split	195	0	0	0	109	86	0.860	1.000	0.441
stat	392	4	1	0	233	154	0.839	0.990	0.393
stdbuf	156	0	0	0	80	76	0.872	1.000	0.487
stty	189	0	1	0	89	99	0.878	1.000	0.524
sum	183	0	0	0	99	84	0.865	1.000	0.459
sync	83	0	0	0	54	29	0.837	1.000	0.349
tac	584	0	1	0	310	273	0.866	1.000	0.467
tail	239	0	0	0	141	98	0.853	1.000	0.410
tee	95	0	0	0	62	33	0.837	1.000	0.347
test	155	0	0	0	83	72	0.866	1.000	0.465
timeout	95	0	0	0	55	40	0.855	1.000	0.421
touch	396	4	9	0	240	143	0.821	0.990	0.361
tr	153	0	0	0	70	83	0.886	1.000	0.542

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Table 5: Varnode recovery (metatype = INT) (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
true	62	0	0	0	40	22	0.839	1.000	0.355
truncate	91	0	0	0	55	36	0.849	1.000	0.396
tsort	85	0	0	0	55	30	0.838	1.000	0.353
tty	65	0	0	0	43	22	0.835	1.000	0.338
uname	67	0	0	0	43	24	0.840	1.000	0.358
unexpand	101	0	0	0	61	40	0.849	1.000	0.396
uniq	125	0	0	0	79	46	0.842	1.000	0.368
unlink	66	0	0	0	44	22	0.833	1.000	0.333
uptime	261	4	1	0	170	86	0.819	0.985	0.330
users	73	0	0	0	47	26	0.839	1.000	0.356
vdir	615	4	3	0	364	244	0.842	0.993	0.397
wc	148	0	0	0	90	58	0.848	1.000	0.392
who	158	0	0	0	90	68	0.858	1.000	0.430
whoami	68	0	0	0	46	22	0.831	1.000	0.324
yes	76	0	0	0	50	26	0.836	1.000	0.342

Table 6: Varnode recovery (metatype = FLOAT) (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
[	2	0	1	0	1	0	0.500	1.000	0.000
b2sum	0	0	0	0	0	0	-	-	-
base32	0	0	0	0	0	0	-	-	-
base64	0	0	0	0	0	0	-	-	-
basename	0	0	0	0	0	0	-	-	-
basenc	0	0	0	0	0	0	-	-	-
cat	0	0	0	0	0	0	-	-	-
chcon	3	0	0	0	3	0	0.750	1.000	0.000
chgrp	3	0	0	0	3	0	0.750	1.000	0.000
chmod	3	0	0	0	3	0	0.750	1.000	0.000
chown	3	0	0	0	3	0	0.750	1.000	0.000
chroot	0	0	0	0	0	0	-	-	-
cksum	3	0	2	0	1	0	0.417	1.000	0.000
comm	0	0	0	0	0	0	-	-	-
cp	3	0	0	0	3	0	0.750	1.000	0.000
csplit	0	0	0	0	0	0	-	-	-
cut	0	0	0	0	0	0	-	-	-
date	2	0	1	0	1	0	0.500	1.000	0.000

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Table 6: Varnode recovery (metatype = FLOAT) (compilation = stripped)

	Ground truth varn-odes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVER-LAP	Varnodes matched @ level SUB-SET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode aver-age com-pare score	Varnode frac-tion par-tially recov-ered	Varnode frac-tion ex-actly recov-ered
dd	7	0	3	0	4	0	0.536	1.000	0.000
df	13	0	3	0	5	5	0.731	1.000	0.385
dir	6	0	2	0	4	0	0.583	1.000	0.000
dircolors	0	0	0	0	0	0	-	-	-
dirname	0	0	0	0	0	0	-	-	-
du	6	0	2	0	4	0	0.583	1.000	0.000
echo	0	0	0	0	0	0	-	-	-
env	0	0	0	0	0	0	-	-	-
expand	0	0	0	0	0	0	-	-	-
expr	0	0	0	0	0	0	-	-	-
factor	0	0	0	0	0	0	-	-	-
false	0	0	0	0	0	0	-	-	-
fmt	0	0	0	0	0	0	-	-	-
fold	0	0	0	0	0	0	-	-	-
groups	0	0	0	0	0	0	-	-	-
head	0	0	0	0	0	0	-	-	-
hostid	0	0	0	0	0	0	-	-	-
id	0	0	0	0	0	0	-	-	-

Continued on next page

Table 6: Varnode recovery (metatype = FLOAT) (compilation = stripped)

	Ground truth varn-odes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVER-LAP	Varnodes matched @ level SUB-SET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode aver-age com-pare score	Varnode frac-tion par-tially recov-ered	Varnode frac-tion ex-actly recov-ered
join	0	0	0	0	0	0	-	-	-
kill	0	0	0	0	0	0	-	-	-
link	0	0	0	0	0	0	-	-	-
ln	3	0	0	0	3	0	0.750	1.000	0.000
logname	0	0	0	0	0	0	-	-	-
ls	6	0	2	0	4	0	0.583	1.000	0.000
md5sum	0	0	0	0	0	0	-	-	-
mkdir	2	0	1	0	1	0	0.500	1.000	0.000
mkfifo	0	0	0	0	0	0	-	-	-
mknod	0	0	0	0	0	0	-	-	-
mktemp	0	0	0	0	0	0	-	-	-
mv	3	0	0	0	3	0	0.750	1.000	0.000
nice	0	0	0	0	0	0	-	-	-
nl	0	0	0	0	0	0	-	-	-
nohup	0	0	0	0	0	0	-	-	-
nproc	0	0	0	0	0	0	-	-	-
numfmt	7	0	5	0	2	0	0.393	1.000	0.000
od	11	0	3	0	8	0	0.614	1.000	0.000

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Table 6: Varnode recovery (metatype = FLOAT) (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
paste	0	0	0	0	0	0	-	-	-
pathchk	0	0	0	0	0	0	-	-	-
pinky	0	0	0	0	0	0	-	-	-
pr	0	0	0	0	0	0	-	-	-
printenv	0	0	0	0	0	0	-	-	-
printf	7	0	5	0	2	0	0.393	1.000	0.000
ptx	0	0	0	0	0	0	-	-	-
pwd	0	0	0	0	0	0	-	-	-
readlink	3	0	0	0	3	0	0.750	1.000	0.000
realpath	3	0	0	0	3	0	0.750	1.000	0.000
rm	3	0	0	0	3	0	0.750	1.000	0.000
rmdir	2	0	1	0	1	0	0.500	1.000	0.000
runcon	0	0	0	0	0	0	-	-	-
seq	10	0	9	0	1	0	0.300	1.000	0.000
sha1sum	0	0	0	0	0	0	-	-	-
sha224sum	0	0	0	0	0	0	-	-	-
sha256sum	0	0	0	0	0	0	-	-	-
sha384sum	0	0	0	0	0	0	-	-	-

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Table 6: Varnode recovery (metatype = FLOAT) (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
sha512sum	0	0	0	0	0	0	-	-	-
shred	3	0	2	0	1	0	0.417	1.000	0.000
shuf	3	0	0	0	3	0	0.750	1.000	0.000
sleep	7	0	0	0	2	5	0.929	1.000	0.714
sort	18	0	4	0	12	2	0.667	1.000	0.111
split	0	0	0	0	0	0	-	-	-
stat	2	0	1	0	1	0	0.500	1.000	0.000
stdbuf	2	0	1	0	1	0	0.500	1.000	0.000
stty	2	0	1	0	1	0	0.500	1.000	0.000
sum	3	0	2	0	1	0	0.417	1.000	0.000
sync	0	0	0	0	0	0	-	-	-
tac	0	0	0	0	0	0	-	-	-
tail	11	0	0	0	6	5	0.864	1.000	0.455
tee	0	0	0	0	0	0	-	-	-
test	2	0	1	0	1	0	0.500	1.000	0.000
timeout	8	0	0	0	4	4	0.875	1.000	0.500
touch	2	0	1	0	1	0	0.500	1.000	0.000
tr	0	0	0	0	0	0	-	-	-

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Table 6: Varnode recovery (metatype = FLOAT) (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
true	0	0	0	0	0	0	-	-	-
truncate	0	0	0	0	0	0	-	-	-
tsort	0	0	0	0	0	0	-	-	-
tty	0	0	0	0	0	0	-	-	-
uname	0	0	0	0	0	0	-	-	-
unexpand	0	0	0	0	0	0	-	-	-
uniq	0	0	0	0	0	0	-	-	-
unlink	0	0	0	0	0	0	-	-	-
uptime	2	0	0	0	1	1	0.875	1.000	0.500
users	0	0	0	0	0	0	-	-	-
vdir	6	0	2	0	4	0	0.583	1.000	0.000
wc	4	0	0	0	4	0	0.750	1.000	0.000
who	2	0	1	0	1	0	0.500	1.000	0.000
whoami	0	0	0	0	0	0	-	-	-
yes	0	0	0	0	0	0	-	-	-

Table 7: Varnode recovery (metatype = POINTER) (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
[	68	0	0	0	38	30	0.860	1.000	0.441
b2sum	56	0	0	0	32	24	0.857	1.000	0.429
base32	41	0	0	0	24	17	0.854	1.000	0.415
base64	41	0	0	0	24	17	0.854	1.000	0.415
basename	38	0	0	0	24	14	0.842	1.000	0.368
basenc	55	0	0	0	30	25	0.864	1.000	0.455
cat	41	0	0	0	25	16	0.848	1.000	0.390
chcon	134	1	0	0	93	40	0.819	0.993	0.299
chgrp	133	1	0	0	90	42	0.823	0.992	0.316
chmod	127	1	0	0	89	37	0.817	0.992	0.291
chown	142	1	0	0	94	47	0.827	0.993	0.331
chroot	67	0	0	0	28	39	0.896	1.000	0.582
cksum	99	0	0	0	56	43	0.859	1.000	0.434
comm	35	0	0	0	22	13	0.843	1.000	0.371
cp	231	0	0	0	133	98	0.856	1.000	0.424
csplit	272	6	0	0	202	64	0.792	0.978	0.235
cut	46	0	0	0	29	17	0.842	1.000	0.370
date	125	1	0	0	60	64	0.872	0.992	0.512

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Table 7: Varnode recovery (metatype = POINTER) (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
dd	98	0	0	0	50	48	0.872	1.000	0.490
df	239	0	0	0	110	129	0.885	1.000	0.540
dir	293	1	0	0	171	121	0.851	0.997	0.413
dircolors	76	0	0	0	50	26	0.836	1.000	0.342
dirname	32	0	0	0	21	11	0.836	1.000	0.344
du	438	8	0	0	295	135	0.813	0.982	0.308
echo	30	0	0	0	20	10	0.833	1.000	0.333
env	54	0	0	0	32	22	0.852	1.000	0.407
expand	35	0	0	0	25	10	0.821	1.000	0.286
expr	259	6	0	0	197	56	0.787	0.977	0.216
factor	98	1	0	0	57	40	0.844	0.990	0.408
false	28	0	0	0	20	8	0.821	1.000	0.286
fmt	52	0	0	0	32	20	0.846	1.000	0.385
fold	33	0	0	0	21	12	0.841	1.000	0.364
groups	40	0	0	0	23	17	0.856	1.000	0.425
head	47	0	0	0	28	19	0.851	1.000	0.404
hostid	29	0	0	0	21	8	0.819	1.000	0.276
id	60	0	0	0	27	33	0.887	1.000	0.550

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Table 7: Varnode recovery (metatype = POINTER) (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
join	66	0	0	0	38	28	0.856	1.000	0.424
kill	36	0	0	0	21	15	0.854	1.000	0.417
link	29	0	0	0	21	8	0.819	1.000	0.276
ln	161	0	0	0	95	66	0.852	1.000	0.410
logname	30	0	0	0	22	8	0.817	1.000	0.267
ls	293	1	0	0	171	121	0.851	0.997	0.413
md5sum	50	0	0	0	33	17	0.835	1.000	0.340
mkdir	71	0	0	0	39	32	0.863	1.000	0.451
mkfifo	36	0	0	0	27	9	0.812	1.000	0.250
mknod	41	0	0	0	29	12	0.823	1.000	0.293
mktemp	44	0	0	0	28	16	0.841	1.000	0.364
mv	254	1	0	0	176	77	0.823	0.996	0.303
nice	33	0	0	0	20	13	0.848	1.000	0.394
nl	247	6	0	0	174	67	0.800	0.976	0.271
nohup	40	0	0	0	28	12	0.825	1.000	0.300
nproc	32	0	0	0	20	12	0.844	1.000	0.375
numfmt	70	0	0	0	36	34	0.871	1.000	0.486
od	93	0	0	0	40	53	0.892	1.000	0.570

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Table 7: Varnode recovery (metatype = POINTER) (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
paste	37	0	0	0	24	13	0.838	1.000	0.351
pathchk	33	0	0	0	23	10	0.826	1.000	0.303
pinky	57	0	0	0	38	19	0.833	1.000	0.333
pr	102	1	0	0	62	39	0.838	0.990	0.382
printenv	31	0	0	0	20	11	0.839	1.000	0.355
printf	76	0	2	0	40	34	0.849	1.000	0.447
ptx	331	6	0	0	219	106	0.816	0.982	0.320
pwd	41	0	0	0	30	11	0.817	1.000	0.268
readlink	100	0	0	0	57	43	0.858	1.000	0.430
realpath	105	0	0	0	62	43	0.852	1.000	0.410
rm	136	1	0	0	96	39	0.816	0.993	0.287
rmdir	66	0	0	0	35	31	0.867	1.000	0.470
runcon	36	0	0	0	27	9	0.812	1.000	0.250
seq	81	0	1	0	39	41	0.870	1.000	0.506
sha1sum	49	0	0	0	32	17	0.837	1.000	0.347
sha224sum	50	0	0	0	33	17	0.835	1.000	0.340
sha256sum	50	0	0	0	33	17	0.835	1.000	0.340
sha384sum	50	0	0	0	33	17	0.835	1.000	0.340

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Table 7: Varnode recovery (metatype = POINTER) (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
sha512sum	50	0	0	0	33	17	0.835	1.000	0.340
shred	87	0	0	0	56	31	0.839	1.000	0.356
shuf	134	0	0	0	79	55	0.853	1.000	0.410
sleep	35	0	0	0	23	12	0.836	1.000	0.343
sort	299	0	0	0	182	117	0.848	1.000	0.391
split	69	0	0	0	41	28	0.851	1.000	0.406
stat	150	1	0	0	73	76	0.872	0.993	0.507
stdbuf	79	0	0	0	41	38	0.870	1.000	0.481
stty	73	0	0	0	39	34	0.866	1.000	0.466
sum	60	0	0	0	33	27	0.863	1.000	0.450
sync	29	0	0	0	21	8	0.819	1.000	0.276
tac	250	6	0	0	184	60	0.792	0.976	0.240
tail	124	0	1	0	65	58	0.863	1.000	0.468
tee	35	0	0	0	25	10	0.821	1.000	0.286
test	67	0	0	0	38	29	0.858	1.000	0.433
timeout	41	0	0	0	23	18	0.860	1.000	0.439
touch	110	1	0	0	53	56	0.870	0.991	0.509
tr	58	0	0	0	39	19	0.832	1.000	0.328

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Table 7: Varnode recovery (metatype = POINTER) (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
true	28	0	0	0	20	8	0.821	1.000	0.286
truncate	32	0	0	0	22	10	0.828	1.000	0.312
tsort	52	0	0	0	35	17	0.832	1.000	0.327
tty	29	0	0	0	20	9	0.828	1.000	0.310
uname	30	0	0	0	22	8	0.817	1.000	0.267
unexpand	36	0	0	0	25	11	0.826	1.000	0.306
uniq	50	0	0	0	30	20	0.850	1.000	0.400
unlink	29	0	0	0	21	8	0.819	1.000	0.276
uptime	57	1	0	0	36	20	0.825	0.982	0.351
users	38	0	0	0	28	10	0.816	1.000	0.263
vdir	293	1	0	0	171	121	0.851	0.997	0.413
wc	84	0	0	0	52	32	0.845	1.000	0.381
who	83	0	0	0	44	39	0.867	1.000	0.470
whoami	30	0	0	0	22	8	0.817	1.000	0.267
yes	34	0	0	0	24	10	0.824	1.000	0.294

Table 8: Varnode recovery (metatype = ARRAY) (compilation = stripped)

	Ground truth varn-odes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVER-LAP	Varnodes matched @ level SUB-SET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode aver-age com-pare score	Varnode frac-tion par-tially recov-ered	Varnode frac-tion ex-actly recov-ered
[	15	4	5	4	0	2	0.350	0.733	0.133
b2sum	24	7	4	8	0	5	0.417	0.708	0.208
base32	12	6	2	3	0	1	0.250	0.500	0.083
base64	12	6	2	3	0	1	0.250	0.500	0.083
basename	10	4	2	3	0	1	0.300	0.600	0.100
basenc	20	13	2	3	0	2	0.200	0.350	0.100
cat	11	4	3	3	0	1	0.295	0.636	0.091
chcon	18	4	10	3	0	1	0.278	0.778	0.056
chgrp	15	4	7	3	0	1	0.283	0.733	0.067
chmod	19	5	8	5	0	1	0.289	0.737	0.053
chown	16	4	8	3	0	1	0.281	0.750	0.062
chroot	11	4	3	3	0	1	0.295	0.636	0.091
cksum	66	28	10	19	0	9	0.318	0.576	0.136
comm	22	4	8	4	0	6	0.455	0.818	0.273
cp	40	12	13	11	3	1	0.300	0.700	0.025
csplit	35	8	13	6	0	8	0.407	0.771	0.229
cut	12	5	3	3	0	1	0.271	0.583	0.083
date	63	23	14	20	0	6	0.310	0.635	0.095

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Table 8: Varnode recovery (metatype = ARRAY) (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
dd	34	16	7	8	0	3	0.257	0.529	0.088
df	25	7	9	6	1	2	0.320	0.720	0.080
dir	71	21	27	19	1	3	0.282	0.704	0.042
dircolors	13	5	2	5	0	1	0.308	0.615	0.077
dirname	10	4	2	3	0	1	0.300	0.600	0.100
du	51	15	16	12	0	8	0.353	0.706	0.157
echo	9	3	2	3	0	1	0.333	0.667	0.111
env	18	6	7	3	1	1	0.278	0.667	0.056
expand	13	5	3	4	0	1	0.288	0.615	0.077
expr	33	8	9	8	0	8	0.432	0.758	0.242
factor	37	8	10	10	0	9	0.446	0.784	0.243
false	9	3	2	3	0	1	0.333	0.667	0.111
fmt	12	5	3	3	0	1	0.271	0.583	0.083
fold	12	5	3	3	0	1	0.271	0.583	0.083
groups	11	5	2	3	0	1	0.273	0.545	0.091
head	18	4	9	4	0	1	0.292	0.778	0.056
hostid	12	4	2	5	0	1	0.333	0.667	0.083
id	14	7	3	3	0	1	0.232	0.500	0.071

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Table 8: Varnode recovery (metatype = ARRAY) (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
join	18	7	5	3	0	3	0.319	0.611	0.167
kill	14	6	4	3	0	1	0.250	0.571	0.071
link	12	4	2	5	0	1	0.333	0.667	0.083
ln	22	6	7	5	3	1	0.341	0.727	0.045
logname	12	4	2	5	0	1	0.333	0.667	0.083
ls	71	21	27	19	1	3	0.282	0.704	0.042
md5sum	16	6	6	3	0	1	0.250	0.625	0.062
mkdir	19	6	7	4	0	2	0.303	0.684	0.105
mkfifo	12	5	3	3	0	1	0.271	0.583	0.083
mknod	12	5	3	3	0	1	0.271	0.583	0.083
mktemp	12	5	2	4	0	1	0.292	0.583	0.083
mv	34	9	14	7	3	1	0.301	0.735	0.029
nice	10	4	2	3	0	1	0.300	0.600	0.100
nl	36	13	9	6	0	8	0.368	0.639	0.222
nohup	13	4	3	5	0	1	0.327	0.692	0.077
nproc	10	4	2	3	0	1	0.300	0.600	0.100
numfmt	20	8	3	8	0	1	0.287	0.600	0.050
od	40	10	18	8	0	4	0.312	0.750	0.100

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Table 8: Varnode recovery (metatype = ARRAY) (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
paste	10	4	2	3	0	1	0.300	0.600	0.100
pathchk	10	4	2	3	0	1	0.300	0.600	0.100
pinky	17	6	7	3	0	1	0.250	0.647	0.059
pr	20	6	6	6	0	2	0.325	0.700	0.100
printenv	10	4	2	3	0	1	0.300	0.600	0.100
printf	17	5	4	5	0	3	0.382	0.706	0.176
ptx	39	12	9	7	3	8	0.410	0.692	0.205
pwd	10	4	2	3	0	1	0.300	0.600	0.100
readlink	12	4	3	3	1	1	0.333	0.667	0.083
realpath	11	4	2	3	1	1	0.341	0.636	0.091
rm	15	5	5	4	0	1	0.283	0.667	0.067
rmdir	14	5	3	4	0	2	0.339	0.643	0.143
runcon	10	4	2	3	0	1	0.300	0.600	0.100
seq	15	7	2	4	0	2	0.300	0.533	0.133
sha1sum	16	6	3	4	0	3	0.359	0.625	0.188
sha224sum	17	7	5	4	0	1	0.250	0.588	0.059
sha256sum	17	7	5	4	0	1	0.250	0.588	0.059
sha384sum	17	7	3	4	0	3	0.338	0.588	0.176

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Table 8: Varnode recovery (metatype = ARRAY) (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
sha512sum	17	7	3	4	0	3	0.338	0.588	0.176
shred	27	8	11	5	0	3	0.306	0.704	0.111
shuf	12	4	3	3	0	2	0.354	0.667	0.167
sleep	12	4	2	5	0	1	0.333	0.667	0.083
sort	46	19	17	8	0	2	0.223	0.587	0.043
split	18	6	7	4	0	1	0.264	0.667	0.056
stat	32	14	7	9	0	2	0.258	0.562	0.062
stdbuf	16	6	3	5	0	2	0.328	0.625	0.125
stty	19	5	5	7	0	2	0.355	0.737	0.105
sum	22	7	6	6	0	3	0.341	0.682	0.136
sync	11	4	3	3	0	1	0.295	0.636	0.091
tac	33	9	9	7	0	8	0.417	0.727	0.242
tail	20	5	9	5	0	1	0.287	0.750	0.050
tee	14	5	4	4	0	1	0.286	0.643	0.071
test	12	3	4	3	0	2	0.375	0.750	0.167
timeout	13	5	4	3	0	1	0.269	0.615	0.077
touch	56	19	14	17	0	6	0.321	0.661	0.107
tr	17	8	3	5	0	1	0.250	0.529	0.059

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Table 8: Varnode recovery (metatype = ARRAY) (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
true	9	3	2	3	0	1	0.333	0.667	0.111
truncate	10	4	2	3	0	1	0.300	0.600	0.100
tsort	13	4	3	5	0	1	0.327	0.692	0.077
tty	10	4	2	3	0	1	0.300	0.600	0.100
uname	12	5	2	4	0	1	0.292	0.583	0.083
unexpand	11	4	2	4	0	1	0.318	0.636	0.091
uniq	15	6	3	5	0	1	0.283	0.600	0.067
unlink	12	4	2	5	0	1	0.333	0.667	0.083
uptime	18	5	4	8	0	1	0.333	0.722	0.056
users	12	4	2	5	0	1	0.333	0.667	0.083
vdir	71	21	27	19	1	3	0.282	0.704	0.042
wc	16	7	3	5	0	1	0.266	0.562	0.062
who	25	8	4	4	0	9	0.480	0.680	0.360
whoami	12	4	2	5	0	1	0.333	0.667	0.083
yes	12	4	2	5	0	1	0.333	0.667	0.083

Table 9: Varnode recovery (metatype = STRUCT) (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
[	24	1	14	6	3	0	0.365	0.958	0.000
b2sum	10	1	5	1	3	0	0.400	0.900	0.000
base32	11	1	5	1	4	0	0.432	0.909	0.000
base64	11	1	5	1	4	0	0.432	0.909	0.000
basename	10	1	5	1	3	0	0.400	0.900	0.000
basenc	11	1	6	1	3	0	0.386	0.909	0.000
cat	11	1	5	2	3	0	0.409	0.909	0.000
chcon	23	3	6	4	9	1	0.489	0.870	0.043
chgrp	22	3	8	6	4	1	0.409	0.864	0.045
chmod	22	3	8	6	4	1	0.409	0.864	0.045
chown	22	3	8	6	4	1	0.409	0.864	0.045
chroot	10	1	5	1	3	0	0.400	0.900	0.000
cksum	22	1	14	1	6	0	0.386	0.955	0.000
comm	10	1	5	1	3	0	0.400	0.900	0.000
cp	46	3	18	19	5	1	0.408	0.935	0.022
csplit	56	1	29	11	6	9	0.469	0.982	0.161
cut	10	1	5	1	3	0	0.400	0.900	0.000
date	39	1	15	15	5	3	0.462	0.974	0.077

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Table 9: Varnode recovery (metatype = STRUCT) (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
dd	22	1	10	4	3	4	0.489	0.955	0.182
df	37	2	13	9	9	4	0.500	0.946	0.108
dir	46	4	24	9	4	5	0.402	0.913	0.109
dircolors	11	1	6	1	3	0	0.386	0.909	0.000
dirname	10	1	5	1	3	0	0.400	0.900	0.000
du	73	3	35	22	7	6	0.425	0.959	0.082
echo	10	1	5	1	3	0	0.400	0.900	0.000
env	17	3	5	2	3	4	0.500	0.824	0.235
expand	10	1	5	1	3	0	0.400	0.900	0.000
expr	59	1	28	19	6	5	0.441	0.983	0.085
factor	32	1	14	14	2	1	0.406	0.969	0.031
false	10	1	5	1	3	0	0.400	0.900	0.000
fmt	10	1	5	1	3	0	0.400	0.900	0.000
fold	10	1	5	1	3	0	0.400	0.900	0.000
groups	10	1	5	1	3	0	0.400	0.900	0.000
head	12	1	6	2	3	0	0.396	0.917	0.000
hostid	10	1	5	1	3	0	0.400	0.900	0.000
id	10	1	5	1	3	0	0.400	0.900	0.000

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Table 9: Varnode recovery (metatype = STRUCT) (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
join	14	2	7	2	3	0	0.357	0.857	0.000
kill	10	1	5	1	3	0	0.400	0.900	0.000
link	10	1	5	1	3	0	0.400	0.900	0.000
ln	28	2	10	11	4	1	0.429	0.929	0.036
logname	10	1	5	1	3	0	0.400	0.900	0.000
ls	46	4	24	9	4	5	0.402	0.913	0.109
md5sum	12	1	7	1	3	0	0.375	0.917	0.000
mkdir	18	1	7	6	4	0	0.431	0.944	0.000
mkfifo	12	1	6	2	3	0	0.396	0.917	0.000
mknod	12	1	6	2	3	0	0.396	0.917	0.000
mktemp	12	1	6	1	3	1	0.438	0.917	0.083
mv	53	3	23	19	6	2	0.410	0.943	0.038
nice	10	1	5	1	3	0	0.400	0.900	0.000
nl	55	4	29	11	6	5	0.405	0.927	0.091
nohup	10	1	5	1	3	0	0.400	0.900	0.000
nproc	11	1	5	1	3	1	0.455	0.909	0.091
numfmt	10	1	5	1	3	0	0.400	0.900	0.000
od	13	1	5	4	3	0	0.423	0.923	0.000

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Table 9: Varnode recovery (metatype = STRUCT) (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
paste	10	1	5	1	3	0	0.400	0.900	0.000
pathchk	13	2	6	1	4	0	0.385	0.846	0.000
pinky	12	2	5	2	3	0	0.375	0.833	0.000
pr	22	1	11	4	4	2	0.443	0.955	0.091
printenv	10	1	5	1	3	0	0.400	0.900	0.000
printf	15	1	5	3	6	0	0.483	0.933	0.000
ptx	82	1	45	25	6	5	0.405	0.988	0.061
pwd	17	1	6	6	4	0	0.441	0.941	0.000
readlink	17	2	7	4	4	0	0.397	0.882	0.000
realpath	18	2	8	4	4	0	0.389	0.889	0.000
rm	23	3	10	5	4	1	0.391	0.870	0.043
rmdir	13	1	6	3	3	0	0.404	0.923	0.000
runcon	10	1	5	1	3	0	0.400	0.900	0.000
seq	17	1	9	4	3	0	0.382	0.941	0.000
sha1sum	12	1	7	1	3	0	0.375	0.917	0.000
sha224sum	13	1	8	1	3	0	0.365	0.923	0.000
sha256sum	13	1	8	1	3	0	0.365	0.923	0.000
sha384sum	13	1	5	1	6	0	0.481	0.923	0.000

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Table 9: Varnode recovery (metatype = STRUCT) (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
sha512sum	13	1	5	1	6	0	0.481	0.923	0.000
shred	15	1	8	3	3	0	0.383	0.933	0.000
shuf	15	2	6	3	4	0	0.400	0.867	0.000
sleep	13	1	7	1	3	1	0.423	0.923	0.077
sort	44	3	17	10	6	8	0.494	0.932	0.182
split	15	3	7	1	3	1	0.367	0.800	0.067
stat	32	1	13	11	6	1	0.445	0.969	0.031
stdbuf	14	1	6	4	3	0	0.411	0.929	0.000
stty	18	3	9	3	3	0	0.333	0.833	0.000
sum	10	1	5	1	3	0	0.400	0.900	0.000
sync	10	1	5	1	3	0	0.400	0.900	0.000
tac	53	2	29	11	6	5	0.420	0.962	0.094
tail	29	2	15	6	3	3	0.414	0.931	0.103
tee	10	1	5	1	3	0	0.400	0.900	0.000
test	24	1	14	6	3	0	0.365	0.958	0.000
timeout	18	1	6	1	4	6	0.611	0.944	0.333
touch	36	1	13	17	4	1	0.438	0.972	0.028
tr	13	1	6	1	5	0	0.442	0.923	0.000

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Table 9: Varnode recovery (metatype = STRUCT) (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
true	10	1	5	1	3	0	0.400	0.900	0.000
truncate	12	1	6	2	3	0	0.396	0.917	0.000
tsort	12	1	7	1	3	0	0.375	0.917	0.000
tty	10	1	5	1	3	0	0.400	0.900	0.000
uname	11	1	5	1	3	1	0.455	0.909	0.091
unexpand	10	1	5	1	3	0	0.400	0.900	0.000
uniq	12	1	7	1	3	0	0.375	0.917	0.000
unlink	10	1	5	1	3	0	0.400	0.900	0.000
uptime	15	1	7	4	3	0	0.400	0.933	0.000
users	10	1	5	1	3	0	0.400	0.900	0.000
vdir	46	4	24	9	4	5	0.402	0.913	0.109
wc	16	1	5	3	2	5	0.578	0.938	0.312
who	14	2	5	4	3	0	0.393	0.857	0.000
whoami	10	1	5	1	3	0	0.400	0.900	0.000
yes	10	1	5	1	3	0	0.400	0.900	0.000

Table 10: Varnode recovery (metatype = UNION) (compilation = stripped)

	Ground truth varn-odes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVER-LAP	Varnodes matched @ level SUB-SET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode aver-age com-pare score	Varnode frac-tion par-tially recov-ered	Varnode frac-tion ex-actly recov-ered
[	0	0	0	0	0	0	-	-	-
b2sum	0	0	0	0	0	0	-	-	-
base32	0	0	0	0	0	0	-	-	-
base64	0	0	0	0	0	0	-	-	-
basename	0	0	0	0	0	0	-	-	-
basenc	0	0	0	0	0	0	-	-	-
cat	0	0	0	0	0	0	-	-	-
chcon	0	0	0	0	0	0	-	-	-
chgrp	0	0	0	0	0	0	-	-	-
chmod	0	0	0	0	0	0	-	-	-
chown	0	0	0	0	0	0	-	-	-
chroot	0	0	0	0	0	0	-	-	-
cksum	0	0	0	0	0	0	-	-	-
comm	0	0	0	0	0	0	-	-	-
cp	1	0	0	0	1	0	0.750	1.000	0.000
csplit	0	0	0	0	0	0	-	-	-
cut	0	0	0	0	0	0	-	-	-
date	2	0	0	2	0	0	0.500	1.000	0.000

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Table 10: Varnode recovery (metatype = UNION) (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
dd	0	0	0	0	0	0	-	-	-
df	0	0	0	0	0	0	-	-	-
dir	0	0	0	0	0	0	-	-	-
dircolors	0	0	0	0	0	0	-	-	-
dirname	0	0	0	0	0	0	-	-	-
du	0	0	0	0	0	0	-	-	-
echo	0	0	0	0	0	0	-	-	-
env	0	0	0	0	0	0	-	-	-
expand	0	0	0	0	0	0	-	-	-
expr	0	0	0	0	0	0	-	-	-
factor	1	0	1	0	0	0	0.250	1.000	0.000
false	0	0	0	0	0	0	-	-	-
fmt	0	0	0	0	0	0	-	-	-
fold	0	0	0	0	0	0	-	-	-
groups	0	0	0	0	0	0	-	-	-
head	0	0	0	0	0	0	-	-	-
hostid	0	0	0	0	0	0	-	-	-
id	0	0	0	0	0	0	-	-	-

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Table 10: Varnode recovery (metatype = UNION) (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
join	0	0	0	0	0	0	-	-	-
kill	0	0	0	0	0	0	-	-	-
link	0	0	0	0	0	0	-	-	-
ln	0	0	0	0	0	0	-	-	-
logname	0	0	0	0	0	0	-	-	-
ls	0	0	0	0	0	0	-	-	-
md5sum	0	0	0	0	0	0	-	-	-
mkdir	0	0	0	0	0	0	-	-	-
mkfifo	0	0	0	0	0	0	-	-	-
mknod	0	0	0	0	0	0	-	-	-
mktemp	0	0	0	0	0	0	-	-	-
mv	1	0	0	0	1	0	0.750	1.000	0.000
nice	0	0	0	0	0	0	-	-	-
nl	0	0	0	0	0	0	-	-	-
nohup	0	0	0	0	0	0	-	-	-
nproc	0	0	0	0	0	0	-	-	-
numfmt	0	0	0	0	0	0	-	-	-
od	8	0	0	0	8	0	0.750	1.000	0.000

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Table 10: Varnode recovery (metatype = UNION) (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
paste	0	0	0	0	0	0	-	-	-
pathchk	0	0	0	0	0	0	-	-	-
pinky	0	0	0	0	0	0	-	-	-
pr	0	0	0	0	0	0	-	-	-
printenv	0	0	0	0	0	0	-	-	-
printf	0	0	0	0	0	0	-	-	-
ptx	1	0	1	0	0	0	0.250	1.000	0.000
pwd	0	0	0	0	0	0	-	-	-
readlink	0	0	0	0	0	0	-	-	-
realpath	0	0	0	0	0	0	-	-	-
rm	0	0	0	0	0	0	-	-	-
rmdir	0	0	0	0	0	0	-	-	-
runcon	0	0	0	0	0	0	-	-	-
seq	0	0	0	0	0	0	-	-	-
sha1sum	0	0	0	0	0	0	-	-	-
sha224sum	0	0	0	0	0	0	-	-	-
sha256sum	0	0	0	0	0	0	-	-	-
sha384sum	0	0	0	0	0	0	-	-	-

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Table 10: Varnode recovery (metatype = UNION) (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
sha512sum	0	0	0	0	0	0	-	-	-
shred	0	0	0	0	0	0	-	-	-
shuf	0	0	0	0	0	0	-	-	-
sleep	0	0	0	0	0	0	-	-	-
sort	0	0	0	0	0	0	-	-	-
split	0	0	0	0	0	0	-	-	-
stat	0	0	0	0	0	0	-	-	-
stdbuf	0	0	0	0	0	0	-	-	-
stty	0	0	0	0	0	0	-	-	-
sum	0	0	0	0	0	0	-	-	-
sync	0	0	0	0	0	0	-	-	-
tac	0	0	0	0	0	0	-	-	-
tail	0	0	0	0	0	0	-	-	-
tee	0	0	0	0	0	0	-	-	-
test	0	0	0	0	0	0	-	-	-
timeout	0	0	0	0	0	0	-	-	-
touch	2	0	0	2	0	0	0.500	1.000	0.000
tr	0	0	0	0	0	0	-	-	-

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Table 10: Varnode recovery (metatype = UNION) (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
true	0	0	0	0	0	0	-	-	-
truncate	0	0	0	0	0	0	-	-	-
tsort	0	0	0	0	0	0	-	-	-
tty	0	0	0	0	0	0	-	-	-
uname	0	0	0	0	0	0	-	-	-
unexpand	0	0	0	0	0	0	-	-	-
uniq	0	0	0	0	0	0	-	-	-
unlink	0	0	0	0	0	0	-	-	-
uptime	0	0	0	0	0	0	-	-	-
users	0	0	0	0	0	0	-	-	-
vdir	0	0	0	0	0	0	-	-	-
wc	0	0	0	0	0	0	-	-	-
who	0	0	0	0	0	0	-	-	-
whoami	0	0	0	0	0	0	-	-	-
yes	0	0	0	0	0	0	-	-	-

Table 11: Varnode recovery (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average comparison score	Varnode fraction partially recovered	Varnode fraction exactly recovered
[	266	1	18	5	128	114	0.816	0.996	0.429
b2sum	237	1	8	7	118	103	0.831	0.996	0.435
base32	160	2	6	2	82	68	0.825	0.988	0.425
base64	160	1	6	2	82	69	0.831	0.994	0.431
basename	129	1	6	2	77	43	0.800	0.992	0.333
basenc	219	5	8	2	106	98	0.824	0.977	0.447
cat	164	1	6	2	98	57	0.811	0.994	0.348
chcon	363	2	14	4	234	109	0.799	0.994	0.300
chgrp	339	2	11	5	204	117	0.812	0.994	0.345
chmod	347	3	12	7	211	114	0.803	0.991	0.329
chown	359	2	12	5	209	131	0.817	0.994	0.365
chroot	198	1	8	2	87	100	0.850	0.995	0.505
cksum	678	13	24	13	396	232	0.799	0.981	0.342
comm	171	1	11	3	103	53	0.787	0.994	0.310
cp	703	3	28	12	357	303	0.830	0.996	0.431
csplit	982	8	41	15	537	381	0.816	0.992	0.388
cut	192	1	7	2	117	65	0.810	0.995	0.339
date	747	4	38	26	387	292	0.810	0.995	0.391

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Table 11: Varnode recovery (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average comparison score	Varnode fraction partially recovered	Varnode fraction exactly recovered
dd	493	4	18	9	250	212	0.829	0.992	0.430
df	640	1	20	11	287	321	0.854	0.998	0.502
dir	1031	3	52	13	560	403	0.817	0.997	0.391
dircolors	190	2	6	2	115	65	0.809	0.989	0.342
dirname	125	1	6	2	74	42	0.800	0.992	0.336
du	1499	10	54	28	835	572	0.818	0.993	0.382
echo	118	1	6	2	71	38	0.794	0.992	0.322
env	201	2	11	3	102	83	0.815	0.990	0.413
expand	152	1	7	2	90	52	0.804	0.993	0.342
expr	911	8	37	25	492	349	0.812	0.991	0.383
factor	511	23	24	22	191	251	0.805	0.955	0.491
false	109	1	6	2	66	34	0.789	0.991	0.312
fmt	186	1	6	2	110	67	0.817	0.995	0.360
fold	143	1	7	2	78	55	0.813	0.993	0.385
groups	142	1	6	2	80	53	0.813	0.993	0.373
head	215	1	13	2	116	83	0.810	0.995	0.386
hostid	118	1	6	4	72	35	0.784	0.992	0.297
id	196	1	7	2	102	84	0.833	0.995	0.429

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Table 11: Varnode recovery (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average comparison score	Varnode fraction partially recovered	Varnode fraction exactly recovered
join	260	1	8	3	151	97	0.822	0.996	0.373
kill	148	3	8	2	79	56	0.799	0.980	0.378
link	117	1	6	4	71	35	0.784	0.991	0.299
ln	433	2	12	7	233	179	0.832	0.995	0.413
logname	118	1	6	4	72	35	0.784	0.992	0.297
ls	1031	3	52	13	560	403	0.817	0.997	0.391
md5sum	217	2	12	2	120	81	0.806	0.991	0.373
mkdir	306	2	12	6	149	137	0.833	0.993	0.448
mkfifo	148	2	7	2	86	51	0.799	0.986	0.345
mknod	165	2	7	2	89	65	0.815	0.988	0.394
mktemp	164	2	6	2	94	60	0.811	0.988	0.366
mv	773	4	30	12	433	294	0.818	0.995	0.380
nice	130	1	6	2	73	48	0.810	0.992	0.369
nl	896	11	36	15	476	358	0.816	0.988	0.400
nohup	162	1	7	4	105	45	0.787	0.994	0.278
nproc	139	1	6	2	77	53	0.815	0.993	0.381
numfmt	291	1	12	3	142	133	0.838	0.997	0.457
od	459	2	20	7	209	221	0.842	0.996	0.481

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Table 11: Varnode recovery (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average comparison score	Varnode fraction partially recovered	Varnode fraction exactly recovered
paste	142	1	6	2	85	48	0.805	0.993	0.338
pathchk	141	1	6	2	88	44	0.798	0.993	0.312
pinky	182	1	11	2	110	58	0.793	0.995	0.319
pr	543	2	16	8	332	185	0.814	0.996	0.341
printenv	119	1	6	2	68	42	0.803	0.992	0.353
printf	283	1	17	7	136	122	0.819	0.996	0.431
ptx	1126	8	44	28	590	456	0.820	0.993	0.405
pwd	143	1	6	3	87	46	0.799	0.993	0.322
readlink	243	1	9	5	137	91	0.817	0.996	0.374
realpath	248	1	8	5	138	96	0.823	0.996	0.387
rm	362	2	10	5	222	123	0.814	0.994	0.340
rmdir	234	1	8	5	115	105	0.837	0.996	0.449
runcon	121	1	6	2	75	37	0.791	0.992	0.306
seq	279	1	20	6	128	124	0.817	0.996	0.444
sha1sum	215	2	9	3	116	85	0.817	0.991	0.395
sha224sum	225	2	12	3	119	89	0.812	0.991	0.396
sha256sum	225	2	12	3	119	89	0.812	0.991	0.396
sha384sum	381	3	7	3	278	90	0.792	0.992	0.236

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Table 11: Varnode recovery (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average comparison score	Varnode fraction partially recovered	Varnode fraction exactly recovered
sha512sum	381	3	7	3	278	90	0.792	0.992	0.236
shred	370	2	18	2	203	145	0.818	0.995	0.392
shuf	374	1	7	3	218	145	0.834	0.997	0.388
sleep	143	1	8	4	80	50	0.797	0.993	0.350
sort	847	7	34	12	467	327	0.817	0.992	0.386
split	297	2	12	2	159	122	0.826	0.993	0.411
stat	608	5	21	14	321	247	0.822	0.992	0.406
stdbuf	267	1	8	6	128	124	0.843	0.996	0.464
stty	301	1	13	5	138	144	0.841	0.997	0.478
sum	278	2	12	2	140	122	0.831	0.993	0.439
sync	133	1	7	2	81	42	0.793	0.992	0.316
tac	920	8	37	15	505	355	0.816	0.991	0.386
tail	423	1	18	5	220	179	0.830	0.998	0.423
tee	154	1	8	2	93	50	0.797	0.994	0.325
test	260	0	17	4	128	111	0.820	1.000	0.427
timeout	175	2	9	2	89	73	0.817	0.989	0.417
touch	602	3	33	25	305	236	0.806	0.995	0.392
tr	241	1	8	3	117	112	0.843	0.996	0.465

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Table 11: Varnode recovery (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average comparison score	Varnode fraction partially recovered	Varnode fraction exactly recovered
true	109	1	6	2	66	34	0.789	0.991	0.312
truncate	145	1	6	2	83	53	0.812	0.993	0.366
tsort	162	1	9	4	96	52	0.792	0.994	0.321
tty	114	1	6	2	69	36	0.792	0.991	0.316
uname	120	2	6	2	71	39	0.790	0.983	0.325
unexpand	158	1	6	2	92	57	0.813	0.994	0.361
uniq	202	1	9	2	115	75	0.814	0.995	0.371
unlink	117	1	6	4	71	35	0.784	0.991	0.299
uptime	353	1	11	10	218	113	0.805	0.997	0.320
users	133	1	6	4	81	41	0.791	0.992	0.308
vdir	1031	3	52	13	560	403	0.817	0.997	0.391
wc	268	1	7	5	153	102	0.825	0.996	0.381
who	282	1	9	5	144	123	0.836	0.996	0.436
whoami	120	1	6	4	74	35	0.783	0.992	0.292
yes	132	1	6	4	80	41	0.792	0.992	0.311

Table 12: Varnode recovery (metatype = INT) (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
[	157	0	0	0	83	74	0.868	1.000	0.471
b2sum	147	0	0	0	80	67	0.864	1.000	0.456
base32	96	0	0	0	51	45	0.867	1.000	0.469
base64	96	0	0	0	51	45	0.867	1.000	0.469
basename	71	0	0	0	47	24	0.835	1.000	0.338
basenc	133	0	1	0	70	62	0.863	1.000	0.466
cat	101	0	0	0	64	37	0.842	1.000	0.366
chcon	185	0	0	0	124	61	0.832	1.000	0.330
chgrp	166	0	0	0	102	64	0.846	1.000	0.386
chmod	176	0	0	0	110	66	0.844	1.000	0.375
chown	176	0	0	0	103	73	0.854	1.000	0.415
chroot	110	0	1	0	53	56	0.873	1.000	0.509
cksum	488	2	0	0	329	157	0.827	0.996	0.322
comm	104	0	0	0	74	30	0.822	1.000	0.288
cp	382	0	1	0	208	173	0.862	1.000	0.453
csplit	619	0	1	0	325	293	0.868	1.000	0.473
cut	124	0	0	0	81	43	0.837	1.000	0.347
date	516	0	10	0	321	185	0.830	1.000	0.359

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Table 12: Varnode recovery (metatype = INT) (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
dd	332	0	0	0	187	145	0.859	1.000	0.437
df	326	0	0	0	158	168	0.879	1.000	0.515
dir	615	0	3	0	368	244	0.847	1.000	0.397
dircolors	90	0	0	0	58	32	0.839	1.000	0.356
dirname	73	0	0	0	47	26	0.839	1.000	0.356
du	931	0	3	0	522	406	0.857	1.000	0.436
echo	69	0	0	0	45	24	0.837	1.000	0.348
env	112	0	0	0	61	51	0.864	1.000	0.455
expand	94	0	0	0	59	35	0.843	1.000	0.372
expr	560	0	1	0	286	273	0.871	1.000	0.487
factor	343	21	2	0	128	192	0.841	0.939	0.560
false	62	0	0	0	40	22	0.839	1.000	0.355
fmt	112	0	0	0	72	40	0.839	1.000	0.357
fold	88	0	0	0	51	37	0.855	1.000	0.420
groups	81	0	0	0	51	30	0.843	1.000	0.370
head	138	0	0	0	82	56	0.851	1.000	0.406
hostid	67	0	0	0	45	22	0.832	1.000	0.328
id	112	0	0	0	69	43	0.846	1.000	0.384

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Table 12: Varnode recovery (metatype = INT) (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
join	162	0	0	0	104	58	0.840	1.000	0.358
kill	88	0	0	0	52	36	0.852	1.000	0.409
link	66	0	0	0	44	22	0.833	1.000	0.333
ln	219	0	0	0	125	94	0.857	1.000	0.429
logname	66	0	0	0	44	22	0.833	1.000	0.333
ls	615	0	3	0	368	244	0.847	1.000	0.397
md5sum	139	0	0	0	81	58	0.854	1.000	0.417
mkdir	196	0	0	0	102	94	0.870	1.000	0.480
mkfifo	88	0	0	0	53	35	0.849	1.000	0.398
mknod	100	0	0	0	54	46	0.865	1.000	0.460
mktemp	96	0	0	0	60	36	0.844	1.000	0.375
mv	428	0	0	0	241	187	0.859	1.000	0.437
nice	77	0	0	0	47	30	0.847	1.000	0.390
nl	558	0	1	0	288	269	0.870	1.000	0.482
nohup	99	0	0	0	71	28	0.821	1.000	0.283
nproc	86	0	0	0	51	35	0.852	1.000	0.407
numfmt	184	0	0	0	98	86	0.867	1.000	0.467
od	294	0	1	0	146	147	0.873	1.000	0.500

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Table 12: Varnode recovery (metatype = INT) (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
paste	85	0	0	0	55	30	0.838	1.000	0.353
pathchk	85	0	0	0	57	28	0.832	1.000	0.329
pinky	96	0	0	0	65	31	0.831	1.000	0.323
pr	399	0	1	0	262	136	0.834	1.000	0.341
printenv	68	0	0	0	42	26	0.846	1.000	0.382
printf	168	0	2	0	85	81	0.865	1.000	0.482
ptx	673	0	1	0	347	325	0.870	1.000	0.483
pwd	75	0	0	0	50	25	0.833	1.000	0.333
readlink	111	0	0	0	69	42	0.845	1.000	0.378
realpath	111	0	0	0	65	46	0.854	1.000	0.414
rm	185	0	0	0	115	70	0.845	1.000	0.378
rmdir	139	0	0	0	73	66	0.869	1.000	0.475
runcon	65	0	0	0	42	23	0.838	1.000	0.354
seq	156	0	0	0	81	75	0.870	1.000	0.481
sha1sum	138	0	0	0	78	60	0.859	1.000	0.435
sha224sum	145	0	0	0	80	65	0.862	1.000	0.448
sha256sum	145	0	0	0	80	65	0.862	1.000	0.448
sha384sum	301	0	0	0	236	65	0.804	1.000	0.216

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Table 12: Varnode recovery (metatype = INT) (compilation = standard)

	Ground truth varn-odes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVER-LAP	Varnodes matched @ level SUB-SET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode aver-age com-pare score	Varnode frac-tion par-tially recov-ered	Varnode frac-tion ex-actly recov-ered
sha512sum	301	0	0	0	236	65	0.804	1.000	0.216
shred	238	0	0	0	140	98	0.853	1.000	0.412
shuf	210	0	0	0	129	81	0.846	1.000	0.386
sleep	76	0	0	0	49	27	0.839	1.000	0.355
sort	440	0	0	0	260	180	0.852	1.000	0.409
split	195	0	0	0	109	86	0.860	1.000	0.441
stat	392	0	1	0	237	154	0.847	1.000	0.393
stdbuf	156	0	0	0	80	76	0.872	1.000	0.487
stty	189	0	1	0	89	99	0.878	1.000	0.524
sum	183	0	0	0	99	84	0.865	1.000	0.459
sync	83	0	0	0	54	29	0.837	1.000	0.349
tac	584	0	1	0	310	273	0.866	1.000	0.467
tail	239	0	0	0	141	98	0.853	1.000	0.410
tee	95	0	0	0	62	33	0.837	1.000	0.347
test	155	0	0	0	83	72	0.866	1.000	0.465
timeout	95	0	0	0	55	40	0.855	1.000	0.421
touch	396	0	9	0	244	143	0.829	1.000	0.361
tr	153	0	0	0	70	83	0.886	1.000	0.542

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Table 12: Varnode recovery (metatype = INT) (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
true	62	0	0	0	40	22	0.839	1.000	0.355
truncate	91	0	0	0	55	36	0.849	1.000	0.396
tsort	85	0	0	0	55	30	0.838	1.000	0.353
tty	65	0	0	0	43	22	0.835	1.000	0.338
uname	67	0	0	0	43	24	0.840	1.000	0.358
unexpand	101	0	0	0	61	40	0.849	1.000	0.396
uniq	125	0	0	0	79	46	0.842	1.000	0.368
unlink	66	0	0	0	44	22	0.833	1.000	0.333
uptime	261	0	1	0	174	86	0.830	1.000	0.330
users	73	0	0	0	47	26	0.839	1.000	0.356
vdir	615	0	3	0	368	244	0.847	1.000	0.397
wc	148	0	0	0	90	58	0.848	1.000	0.392
who	158	0	0	0	90	68	0.858	1.000	0.430
whoami	68	0	0	0	46	22	0.831	1.000	0.324
yes	76	0	0	0	50	26	0.836	1.000	0.342

Table 13: Varnode recovery (metatype = FLOAT) (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
[	2	0	1	0	1	0	0.500	1.000	0.000
b2sum	0	0	0	0	0	0	-	-	-
base32	0	0	0	0	0	0	-	-	-
base64	0	0	0	0	0	0	-	-	-
basename	0	0	0	0	0	0	-	-	-
basenc	0	0	0	0	0	0	-	-	-
cat	0	0	0	0	0	0	-	-	-
chcon	3	0	0	0	3	0	0.750	1.000	0.000
chgrp	3	0	0	0	3	0	0.750	1.000	0.000
chmod	3	0	0	0	3	0	0.750	1.000	0.000
chown	3	0	0	0	3	0	0.750	1.000	0.000
chroot	0	0	0	0	0	0	-	-	-
cksum	3	0	2	0	1	0	0.417	1.000	0.000
comm	0	0	0	0	0	0	-	-	-
cp	3	0	0	0	3	0	0.750	1.000	0.000
csplit	0	0	0	0	0	0	-	-	-
cut	0	0	0	0	0	0	-	-	-
date	2	0	1	0	1	0	0.500	1.000	0.000

Continued on next page

Table 13: Varnode recovery (metatype = FLOAT) (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
dd	7	0	3	0	4	0	0.536	1.000	0.000
df	13	0	3	0	5	5	0.731	1.000	0.385
dir	6	0	2	0	4	0	0.583	1.000	0.000
dircolors	0	0	0	0	0	0	-	-	-
dirname	0	0	0	0	0	0	-	-	-
du	6	0	2	0	4	0	0.583	1.000	0.000
echo	0	0	0	0	0	0	-	-	-
env	0	0	0	0	0	0	-	-	-
expand	0	0	0	0	0	0	-	-	-
expr	0	0	0	0	0	0	-	-	-
factor	0	0	0	0	0	0	-	-	-
false	0	0	0	0	0	0	-	-	-
fmt	0	0	0	0	0	0	-	-	-
fold	0	0	0	0	0	0	-	-	-
groups	0	0	0	0	0	0	-	-	-
head	0	0	0	0	0	0	-	-	-
hostid	0	0	0	0	0	0	-	-	-
id	0	0	0	0	0	0	-	-	-

Continued on next page

Table 13: Varnode recovery (metatype = FLOAT) (compilation = standard)

	Ground truth varn-odes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVER-LAP	Varnodes matched @ level SUB-SET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode aver-age com-pare score	Varnode frac-tion par-tially recov-ered	Varnode frac-tion ex-actly recov-ered
join	0	0	0	0	0	0	-	-	-
kill	0	0	0	0	0	0	-	-	-
link	0	0	0	0	0	0	-	-	-
ln	3	0	0	0	3	0	0.750	1.000	0.000
logname	0	0	0	0	0	0	-	-	-
ls	6	0	2	0	4	0	0.583	1.000	0.000
md5sum	0	0	0	0	0	0	-	-	-
mkdir	2	0	1	0	1	0	0.500	1.000	0.000
mkfifo	0	0	0	0	0	0	-	-	-
mknod	0	0	0	0	0	0	-	-	-
mktemp	0	0	0	0	0	0	-	-	-
mv	3	0	0	0	3	0	0.750	1.000	0.000
nice	0	0	0	0	0	0	-	-	-
nl	0	0	0	0	0	0	-	-	-
nohup	0	0	0	0	0	0	-	-	-
nproc	0	0	0	0	0	0	-	-	-
numfmt	7	0	5	0	2	0	0.393	1.000	0.000
od	11	0	3	0	8	0	0.614	1.000	0.000

Continued on next page

Table 13: Varnode recovery (metatype = FLOAT) (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
paste	0	0	0	0	0	0	-	-	-
pathchk	0	0	0	0	0	0	-	-	-
pinky	0	0	0	0	0	0	-	-	-
pr	0	0	0	0	0	0	-	-	-
printenv	0	0	0	0	0	0	-	-	-
printf	7	0	5	0	2	0	0.393	1.000	0.000
ptx	0	0	0	0	0	0	-	-	-
pwd	0	0	0	0	0	0	-	-	-
readlink	3	0	0	0	3	0	0.750	1.000	0.000
realpath	3	0	0	0	3	0	0.750	1.000	0.000
rm	3	0	0	0	3	0	0.750	1.000	0.000
rmdir	2	0	1	0	1	0	0.500	1.000	0.000
runcon	0	0	0	0	0	0	-	-	-
seq	10	0	9	0	1	0	0.300	1.000	0.000
sha1sum	0	0	0	0	0	0	-	-	-
sha224sum	0	0	0	0	0	0	-	-	-
sha256sum	0	0	0	0	0	0	-	-	-
sha384sum	0	0	0	0	0	0	-	-	-

Continued on next page

Table 13: Varnode recovery (metatype = FLOAT) (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
sha512sum	0	0	0	0	0	0	-	-	-
shred	3	0	2	0	1	0	0.417	1.000	0.000
shuf	3	0	0	0	3	0	0.750	1.000	0.000
sleep	7	0	0	0	2	5	0.929	1.000	0.714
sort	18	0	4	0	12	2	0.667	1.000	0.111
split	0	0	0	0	0	0	-	-	-
stat	2	0	1	0	1	0	0.500	1.000	0.000
stdbuf	2	0	1	0	1	0	0.500	1.000	0.000
stty	2	0	1	0	1	0	0.500	1.000	0.000
sum	3	0	2	0	1	0	0.417	1.000	0.000
sync	0	0	0	0	0	0	-	-	-
tac	0	0	0	0	0	0	-	-	-
tail	11	0	0	0	6	5	0.864	1.000	0.455
tee	0	0	0	0	0	0	-	-	-
test	2	0	1	0	1	0	0.500	1.000	0.000
timeout	8	0	0	0	4	4	0.875	1.000	0.500
touch	2	0	1	0	1	0	0.500	1.000	0.000
tr	0	0	0	0	0	0	-	-	-

Continued on next page

Table 13: Varnode recovery (metatype = FLOAT) (compilation = standard)

	Ground truth varn-odes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVER-LAP	Varnodes matched @ level SUB-SET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode aver-age com-pare score	Varnode frac-tion par-tially recov-ered	Varnode frac-tion ex-actly recov-ered
true	0	0	0	0	0	0	-	-	-
truncate	0	0	0	0	0	0	-	-	-
tsort	0	0	0	0	0	0	-	-	-
tty	0	0	0	0	0	0	-	-	-
uname	0	0	0	0	0	0	-	-	-
unexpand	0	0	0	0	0	0	-	-	-
uniq	0	0	0	0	0	0	-	-	-
unlink	0	0	0	0	0	0	-	-	-
uptime	2	0	0	0	1	1	0.875	1.000	0.500
users	0	0	0	0	0	0	-	-	-
vdir	6	0	2	0	4	0	0.583	1.000	0.000
wc	4	0	0	0	4	0	0.750	1.000	0.000
who	2	0	1	0	1	0	0.500	1.000	0.000
whoami	0	0	0	0	0	0	-	-	-
yes	0	0	0	0	0	0	-	-	-

Table 14: Varnode recovery (metatype = POINTER) (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
[	68	0	0	0	38	30	0.860	1.000	0.441
b2sum	56	0	0	0	32	24	0.857	1.000	0.429
base32	41	0	0	0	24	17	0.854	1.000	0.415
base64	41	0	0	0	24	17	0.854	1.000	0.415
basename	38	0	0	0	24	14	0.842	1.000	0.368
basenc	55	0	0	0	30	25	0.864	1.000	0.455
cat	41	0	0	0	28	13	0.829	1.000	0.317
chcon	134	1	0	0	93	40	0.819	0.993	0.299
chgrp	133	1	0	0	90	42	0.823	0.992	0.316
chmod	127	1	0	0	89	37	0.817	0.992	0.291
chown	142	1	0	0	94	47	0.827	0.993	0.331
chroot	67	0	0	0	28	39	0.896	1.000	0.582
cksum	99	0	0	0	56	43	0.859	1.000	0.434
comm	35	0	0	0	22	13	0.843	1.000	0.371
cp	231	0	0	0	132	99	0.857	1.000	0.429
csplit	272	6	0	0	202	64	0.792	0.978	0.235
cut	46	0	0	0	29	17	0.842	1.000	0.370
date	125	0	0	0	57	68	0.886	1.000	0.544

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Table 14: Varnode recovery (metatype = POINTER) (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
dd	98	0	0	0	50	48	0.872	1.000	0.490
df	239	0	0	0	110	129	0.885	1.000	0.540
dir	293	0	0	0	173	120	0.852	1.000	0.410
dircolors	76	0	0	0	50	26	0.836	1.000	0.342
dirname	32	0	0	0	21	11	0.836	1.000	0.344
du	438	7	0	0	296	135	0.815	0.984	0.308
echo	30	0	0	0	20	10	0.833	1.000	0.333
env	54	0	0	0	32	22	0.852	1.000	0.407
expand	35	0	0	0	25	10	0.821	1.000	0.286
expr	259	6	0	0	197	56	0.787	0.977	0.216
factor	98	1	0	0	57	40	0.844	0.990	0.408
false	28	0	0	0	20	8	0.821	1.000	0.286
fmt	52	0	0	0	32	20	0.846	1.000	0.385
fold	33	0	0	0	21	12	0.841	1.000	0.364
groups	40	0	0	0	23	17	0.856	1.000	0.425
head	47	0	0	0	28	19	0.851	1.000	0.404
hostid	29	0	0	0	21	8	0.819	1.000	0.276
id	60	0	0	0	27	33	0.887	1.000	0.550

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Table 14: Varnode recovery (metatype = POINTER) (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
join	66	0	0	0	38	28	0.856	1.000	0.424
kill	36	0	0	0	21	15	0.854	1.000	0.417
link	29	0	0	0	21	8	0.819	1.000	0.276
ln	161	0	0	0	95	66	0.852	1.000	0.410
logname	30	0	0	0	22	8	0.817	1.000	0.267
ls	293	0	0	0	173	120	0.852	1.000	0.410
md5sum	50	0	0	0	33	17	0.835	1.000	0.340
mkdir	71	0	0	0	39	32	0.863	1.000	0.451
mkfifo	36	0	0	0	27	9	0.812	1.000	0.250
mknod	41	0	0	0	29	12	0.823	1.000	0.293
mktemp	44	0	0	0	28	16	0.841	1.000	0.364
mv	254	1	0	0	174	79	0.825	0.996	0.311
nice	33	0	0	0	20	13	0.848	1.000	0.394
nl	247	6	0	0	174	67	0.800	0.976	0.271
nohup	40	0	0	0	28	12	0.825	1.000	0.300
nproc	32	0	0	0	20	12	0.844	1.000	0.375
numfmt	70	0	0	0	36	34	0.871	1.000	0.486
od	93	0	0	0	40	53	0.892	1.000	0.570

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Table 14: Varnode recovery (metatype = POINTER) (compilation = standard)

	Ground truth varn-odes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVER-LAP	Varnodes matched @ level SUB-SET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode aver-age com-pare score	Varnode frac-tion par-tially recov-ered	Varnode frac-tion ex-actly recov-ered
paste	37	0	0	0	24	13	0.838	1.000	0.351
pathchk	33	0	0	0	23	10	0.826	1.000	0.303
pinky	57	0	0	0	38	19	0.833	1.000	0.333
pr	102	0	0	0	63	39	0.846	1.000	0.382
printenv	31	0	0	0	20	11	0.839	1.000	0.355
printf	76	0	2	0	40	34	0.849	1.000	0.447
ptx	331	6	0	0	219	106	0.816	0.982	0.320
pwd	41	0	0	0	30	11	0.817	1.000	0.268
readlink	100	0	0	0	57	43	0.858	1.000	0.430
realpath	105	0	0	0	62	43	0.852	1.000	0.410
rm	136	1	0	0	95	40	0.818	0.993	0.294
rmdir	66	0	0	0	35	31	0.867	1.000	0.470
runcon	36	0	0	0	27	9	0.812	1.000	0.250
seq	81	0	1	0	39	41	0.870	1.000	0.506
sha1sum	49	0	0	0	32	17	0.837	1.000	0.347
sha224sum	50	0	0	0	33	17	0.835	1.000	0.340
sha256sum	50	0	0	0	33	17	0.835	1.000	0.340
sha384sum	50	0	0	0	33	17	0.835	1.000	0.340

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Table 14: Varnode recovery (metatype = POINTER) (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
sha512sum	50	0	0	0	33	17	0.835	1.000	0.340
shred	87	0	0	0	55	32	0.842	1.000	0.368
shuf	134	0	0	0	78	56	0.854	1.000	0.418
sleep	35	0	0	0	23	12	0.836	1.000	0.343
sort	299	0	0	0	181	118	0.849	1.000	0.395
split	69	0	0	0	41	28	0.851	1.000	0.406
stat	150	0	0	0	74	76	0.877	1.000	0.507
stdbuf	79	0	0	0	40	39	0.873	1.000	0.494
stty	73	0	0	0	39	34	0.866	1.000	0.466
sum	60	0	0	0	33	27	0.863	1.000	0.450
sync	29	0	0	0	21	8	0.819	1.000	0.276
tac	250	6	0	0	184	60	0.792	0.976	0.240
tail	124	0	1	0	65	58	0.863	1.000	0.468
tee	35	0	0	0	25	10	0.821	1.000	0.286
test	67	0	0	0	38	29	0.858	1.000	0.433
timeout	41	0	0	0	23	18	0.860	1.000	0.439
touch	110	0	0	0	53	57	0.880	1.000	0.518
tr	58	0	0	0	39	19	0.832	1.000	0.328

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Table 14: Varnode recovery (metatype = POINTER) (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
true	28	0	0	0	20	8	0.821	1.000	0.286
truncate	32	0	0	0	22	10	0.828	1.000	0.312
tsort	52	0	0	0	35	17	0.832	1.000	0.327
tty	29	0	0	0	20	9	0.828	1.000	0.310
uname	30	0	0	0	22	8	0.817	1.000	0.267
unexpand	36	0	0	0	25	11	0.826	1.000	0.306
uniq	50	0	0	0	30	20	0.850	1.000	0.400
unlink	29	0	0	0	21	8	0.819	1.000	0.276
uptime	57	0	0	0	37	20	0.838	1.000	0.351
users	38	0	0	0	28	10	0.816	1.000	0.263
vdir	293	0	0	0	173	120	0.852	1.000	0.410
wc	84	0	0	0	52	32	0.845	1.000	0.381
who	83	0	0	0	44	39	0.867	1.000	0.470
whoami	30	0	0	0	22	8	0.817	1.000	0.267
yes	34	0	0	0	24	10	0.824	1.000	0.294

Table 15: Varnode recovery (metatype = ARRAY) (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
[	15	1	5	3	0	6	0.583	0.933	0.400
b2sum	24	1	4	7	0	12	0.688	0.958	0.500
base32	12	2	2	2	0	6	0.625	0.833	0.500
base64	12	1	2	2	0	7	0.708	0.917	0.583
basename	10	1	2	2	0	5	0.650	0.900	0.500
basenc	20	5	2	2	0	11	0.625	0.750	0.550
cat	11	1	2	2	0	6	0.682	0.909	0.545
chcon	18	1	10	2	0	5	0.472	0.944	0.278
chgrp	15	1	7	2	0	5	0.517	0.933	0.333
chmod	19	2	8	4	0	5	0.474	0.895	0.263
chown	16	1	8	2	0	5	0.500	0.938	0.312
chroot	11	1	3	2	0	5	0.614	0.909	0.455
cksum	66	11	9	13	1	32	0.629	0.833	0.485
comm	22	1	7	3	1	10	0.636	0.955	0.455
cp	40	3	13	4	3	17	0.613	0.925	0.425
csplit	35	2	13	5	0	15	0.593	0.943	0.429
cut	12	1	3	2	1	5	0.625	0.917	0.417
date	63	4	14	10	0	35	0.690	0.937	0.556

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Table 15: Varnode recovery (metatype = ARRAY) (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
dd	34	4	7	6	2	15	0.625	0.882	0.441
df	25	1	9	3	2	10	0.610	0.960	0.400
dir	71	3	27	6	3	32	0.620	0.958	0.451
dircolors	13	2	2	2	0	7	0.654	0.846	0.538
dirname	10	1	2	2	0	5	0.650	0.900	0.500
du	51	3	16	8	1	23	0.623	0.941	0.451
echo	9	1	2	2	0	4	0.611	0.889	0.444
env	18	2	7	2	1	6	0.528	0.889	0.333
expand	13	1	3	2	0	7	0.673	0.923	0.538
expr	33	2	9	7	0	15	0.629	0.939	0.455
factor	37	1	9	9	0	18	0.669	0.973	0.486
false	9	1	2	2	0	4	0.611	0.889	0.444
fmt	12	1	2	2	0	7	0.708	0.917	0.583
fold	12	1	3	2	0	6	0.646	0.917	0.500
groups	11	1	2	2	0	6	0.682	0.909	0.545
head	18	1	9	2	0	6	0.514	0.944	0.333
hostid	12	1	2	4	0	5	0.625	0.917	0.417
id	14	1	3	2	0	8	0.696	0.929	0.571

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Table 15: Varnode recovery (metatype = ARRAY) (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
join	18	1	3	2	1	11	0.750	0.944	0.611
kill	14	3	4	2	0	5	0.500	0.786	0.357
link	12	1	2	4	0	5	0.625	0.917	0.417
ln	22	2	6	2	3	9	0.625	0.909	0.409
logname	12	1	2	4	0	5	0.625	0.917	0.417
ls	71	3	27	6	3	32	0.620	0.958	0.451
md5sum	16	2	6	2	0	6	0.531	0.875	0.375
mkdir	19	2	7	3	0	7	0.539	0.895	0.368
mkfifo	12	2	3	2	0	5	0.562	0.833	0.417
mknod	12	2	3	2	0	5	0.562	0.833	0.417
mktemp	12	2	2	2	0	6	0.625	0.833	0.500
mv	34	3	13	4	3	11	0.544	0.912	0.324
nice	10	1	2	2	0	5	0.650	0.900	0.500
nl	36	5	8	5	1	17	0.618	0.861	0.472
nohup	13	1	3	4	0	5	0.596	0.923	0.385
nproc	10	1	2	2	0	5	0.650	0.900	0.500
numfmt	20	1	3	3	0	13	0.762	0.950	0.650
od	40	2	12	5	1	20	0.656	0.950	0.500

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Table 15: Varnode recovery (metatype = ARRAY) (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
paste	10	1	2	2	0	5	0.650	0.900	0.500
pathchk	10	1	2	2	0	5	0.650	0.900	0.500
pinky	17	1	7	2	0	7	0.574	0.941	0.412
pr	20	2	6	5	0	7	0.550	0.900	0.350
printenv	10	1	2	2	0	5	0.650	0.900	0.500
printf	17	1	4	5	0	7	0.618	0.941	0.412
ptx	39	2	9	5	4	19	0.686	0.949	0.487
pwd	10	1	2	2	0	5	0.650	0.900	0.500
readlink	12	1	3	2	1	5	0.625	0.917	0.417
realpath	11	1	2	2	1	5	0.659	0.909	0.455
rm	15	1	5	2	0	7	0.617	0.933	0.467
rmdir	14	1	3	3	0	7	0.661	0.929	0.500
runcon	10	1	2	2	0	5	0.650	0.900	0.500
seq	15	1	2	3	1	8	0.717	0.933	0.533
sha1sum	16	2	3	3	0	8	0.641	0.875	0.500
sha224sum	17	2	5	3	0	7	0.574	0.882	0.412
sha256sum	17	2	5	3	0	7	0.574	0.882	0.412
sha384sum	17	3	3	3	0	8	0.603	0.824	0.471

Continued on next page

Table 15: Varnode recovery (metatype = ARRAY) (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
sha512sum	17	3	3	3	0	8	0.603	0.824	0.471
shred	27	2	10	2	1	12	0.602	0.926	0.444
shuf	12	1	3	2	0	6	0.646	0.917	0.500
sleep	12	1	2	4	0	5	0.625	0.917	0.417
sort	46	6	17	5	1	17	0.533	0.870	0.370
split	18	2	7	2	0	7	0.542	0.889	0.389
stat	32	5	7	6	0	14	0.586	0.844	0.438
stdbuf	16	1	3	4	0	8	0.672	0.938	0.500
stty	19	1	4	3	0	11	0.711	0.947	0.579
sum	22	2	6	2	1	11	0.648	0.909	0.500
sync	11	1	3	2	0	5	0.614	0.909	0.455
tac	33	2	9	5	0	17	0.659	0.939	0.515
tail	20	1	9	3	1	6	0.525	0.950	0.300
tee	14	1	4	2	0	7	0.643	0.929	0.500
test	12	0	4	2	0	6	0.667	1.000	0.500
timeout	13	2	4	2	0	5	0.538	0.846	0.385
touch	56	3	13	7	0	33	0.710	0.946	0.589
tr	17	1	3	3	0	10	0.721	0.941	0.588

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Table 15: Varnode recovery (metatype = ARRAY) (compilation = standard)

	Ground truth varn-odes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVER-LAP	Varnodes matched @ level SUB-SET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode aver-age com-pare score	Varnode frac-tion par-tially recov-ered	Varnode frac-tion ex-actly recov-ered
true	9	1	2	2	0	4	0.611	0.889	0.444
truncate	10	1	2	2	0	5	0.650	0.900	0.500
tsort	13	1	3	4	0	5	0.596	0.923	0.385
tty	10	1	2	2	0	5	0.650	0.900	0.500
uname	12	2	2	2	0	6	0.625	0.833	0.500
unexpand	11	1	2	2	0	6	0.682	0.909	0.545
uniq	15	1	3	2	0	9	0.717	0.933	0.600
unlink	12	1	2	4	0	5	0.625	0.917	0.417
uptime	18	1	4	7	0	6	0.583	0.944	0.333
users	12	1	2	4	0	5	0.625	0.917	0.417
vdir	71	3	27	6	3	32	0.620	0.958	0.451
wc	16	1	3	4	2	6	0.641	0.938	0.375
who	25	1	4	3	2	15	0.760	0.960	0.600
whoami	12	1	2	4	0	5	0.625	0.917	0.417
yes	12	1	2	4	0	5	0.625	0.917	0.417

Table 16: Varnode recovery (metatype = STRUCT) (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
[	24	0	12	2	6	4	0.521	1.000	0.167
b2sum	10	0	4	0	6	0	0.550	1.000	0.000
base32	11	0	4	0	7	0	0.568	1.000	0.000
base64	11	0	4	0	7	0	0.568	1.000	0.000
basename	10	0	4	0	6	0	0.550	1.000	0.000
basenc	11	0	5	0	6	0	0.523	1.000	0.000
cat	11	0	4	0	6	1	0.591	1.000	0.091
chcon	23	0	4	2	14	3	0.674	1.000	0.130
chgrp	22	0	4	3	9	6	0.693	1.000	0.273
chmod	22	0	4	3	9	6	0.693	1.000	0.273
chown	22	0	4	3	9	6	0.693	1.000	0.273
chroot	10	0	4	0	6	0	0.550	1.000	0.000
cksum	22	0	13	0	9	0	0.455	1.000	0.000
comm	10	0	4	0	6	0	0.550	1.000	0.000
cp	46	0	14	8	10	14	0.630	1.000	0.304
csplit	56	0	27	10	10	9	0.504	1.000	0.161
cut	10	0	4	0	6	0	0.550	1.000	0.000
date	39	0	13	14	8	4	0.519	1.000	0.103

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Table 16: Varnode recovery (metatype = STRUCT) (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
dd	22	0	8	3	7	4	0.580	1.000	0.182
df	37	0	8	8	12	9	0.649	1.000	0.243
dir	46	0	20	7	12	7	0.533	1.000	0.152
dircolors	11	0	4	0	7	0	0.568	1.000	0.000
dirname	10	0	4	0	6	0	0.550	1.000	0.000
du	73	0	33	20	12	8	0.483	1.000	0.110
echo	10	0	4	0	6	0	0.550	1.000	0.000
env	17	0	4	1	8	4	0.676	1.000	0.235
expand	10	0	4	0	6	0	0.550	1.000	0.000
expr	59	0	27	18	9	5	0.466	1.000	0.085
factor	32	0	12	13	6	1	0.469	1.000	0.031
false	10	0	4	0	6	0	0.550	1.000	0.000
fmt	10	0	4	0	6	0	0.550	1.000	0.000
fold	10	0	4	0	6	0	0.550	1.000	0.000
groups	10	0	4	0	6	0	0.550	1.000	0.000
head	12	0	4	0	6	2	0.625	1.000	0.167
hostid	10	0	4	0	6	0	0.550	1.000	0.000
id	10	0	4	0	6	0	0.550	1.000	0.000

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Table 16: Varnode recovery (metatype = STRUCT) (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
join	14	0	5	1	8	0	0.554	1.000	0.000
kill	10	0	4	0	6	0	0.550	1.000	0.000
link	10	0	4	0	6	0	0.550	1.000	0.000
ln	28	0	6	5	7	10	0.688	1.000	0.357
logname	10	0	4	0	6	0	0.550	1.000	0.000
ls	46	0	20	7	12	7	0.533	1.000	0.152
md5sum	12	0	6	0	6	0	0.500	1.000	0.000
mkdir	18	0	4	3	7	4	0.653	1.000	0.222
mkfifo	12	0	4	0	6	2	0.625	1.000	0.167
mknod	12	0	4	0	6	2	0.625	1.000	0.167
mktemp	12	0	4	0	6	2	0.625	1.000	0.167
mv	53	0	17	8	11	17	0.632	1.000	0.321
nice	10	0	4	0	6	0	0.550	1.000	0.000
nl	55	0	27	10	13	5	0.482	1.000	0.091
nohup	10	0	4	0	6	0	0.550	1.000	0.000
nproc	11	0	4	0	6	1	0.591	1.000	0.091
numfmt	10	0	4	0	6	0	0.550	1.000	0.000
od	13	0	4	2	6	1	0.577	1.000	0.077

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Table 16: Varnode recovery (metatype = STRUCT) (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
paste	10	0	4	0	6	0	0.550	1.000	0.000
pathchk	13	0	4	0	8	1	0.615	1.000	0.077
pinky	12	0	4	0	7	1	0.604	1.000	0.083
pr	22	0	9	3	7	3	0.545	1.000	0.136
printenv	10	0	4	0	6	0	0.550	1.000	0.000
printf	15	0	4	2	9	0	0.583	1.000	0.000
ptx	82	0	33	23	20	6	0.497	1.000	0.073
pwd	17	0	4	1	7	5	0.691	1.000	0.294
readlink	17	0	6	3	7	1	0.544	1.000	0.059
realpath	18	0	6	3	7	2	0.569	1.000	0.111
rm	23	0	5	3	9	6	0.674	1.000	0.261
rmdir	13	0	4	2	6	1	0.577	1.000	0.077
runcon	10	0	4	0	6	0	0.550	1.000	0.000
seq	17	0	8	3	6	0	0.471	1.000	0.000
sha1sum	12	0	6	0	6	0	0.500	1.000	0.000
sha224sum	13	0	7	0	6	0	0.481	1.000	0.000
sha256sum	13	0	7	0	6	0	0.481	1.000	0.000
sha384sum	13	0	4	0	9	0	0.596	1.000	0.000

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Table 16: Varnode recovery (metatype = STRUCT) (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
sha512sum	13	0	4	0	9	0	0.596	1.000	0.000
shred	15	0	6	0	6	3	0.600	1.000	0.200
shuf	15	0	4	1	8	2	0.633	1.000	0.133
sleep	13	0	6	0	6	1	0.538	1.000	0.077
sort	44	1	13	7	13	10	0.602	0.977	0.227
split	15	0	5	0	9	1	0.600	1.000	0.067
stat	32	0	12	8	9	3	0.523	1.000	0.094
stdbuf	14	0	4	2	7	1	0.589	1.000	0.071
stty	18	0	7	2	9	0	0.528	1.000	0.000
sum	10	0	4	0	6	0	0.550	1.000	0.000
sync	10	0	4	0	6	0	0.550	1.000	0.000
tac	53	0	27	10	11	5	0.472	1.000	0.094
tail	29	0	8	2	7	12	0.698	1.000	0.414
tee	10	0	4	0	6	0	0.550	1.000	0.000
test	24	0	12	2	6	4	0.521	1.000	0.167
timeout	18	0	5	0	7	6	0.694	1.000	0.333
touch	36	0	10	16	7	3	0.521	1.000	0.083
tr	13	0	5	0	8	0	0.558	1.000	0.000

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Table 16: Varnode recovery (metatype = STRUCT) (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
true	10	0	4	0	6	0	0.550	1.000	0.000
truncate	12	0	4	0	6	2	0.625	1.000	0.167
tsort	12	0	6	0	6	0	0.500	1.000	0.000
tty	10	0	4	0	6	0	0.550	1.000	0.000
uname	11	0	4	0	6	1	0.591	1.000	0.091
unexpand	10	0	4	0	6	0	0.550	1.000	0.000
uniq	12	0	6	0	6	0	0.500	1.000	0.000
unlink	10	0	4	0	6	0	0.550	1.000	0.000
uptime	15	0	6	3	6	0	0.500	1.000	0.000
users	10	0	4	0	6	0	0.550	1.000	0.000
vdir	46	0	20	7	12	7	0.533	1.000	0.152
wc	16	0	4	1	5	6	0.703	1.000	0.375
who	14	0	4	2	7	1	0.589	1.000	0.071
whoami	10	0	4	0	6	0	0.550	1.000	0.000
yes	10	0	4	0	6	0	0.550	1.000	0.000

Table 17: Varnode recovery (metatype = UNION) (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
[	0	0	0	0	0	0	-	-	-
b2sum	0	0	0	0	0	0	-	-	-
base32	0	0	0	0	0	0	-	-	-
base64	0	0	0	0	0	0	-	-	-
basename	0	0	0	0	0	0	-	-	-
basenc	0	0	0	0	0	0	-	-	-
cat	0	0	0	0	0	0	-	-	-
chcon	0	0	0	0	0	0	-	-	-
chgrp	0	0	0	0	0	0	-	-	-
chmod	0	0	0	0	0	0	-	-	-
chown	0	0	0	0	0	0	-	-	-
chroot	0	0	0	0	0	0	-	-	-
cksum	0	0	0	0	0	0	-	-	-
comm	0	0	0	0	0	0	-	-	-
cp	1	0	0	0	1	0	0.750	1.000	0.000
csplit	0	0	0	0	0	0	-	-	-
cut	0	0	0	0	0	0	-	-	-
date	2	0	0	2	0	0	0.500	1.000	0.000

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Table 17: Varnode recovery (metatype = UNION) (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
dd	0	0	0	0	0	0	-	-	-
df	0	0	0	0	0	0	-	-	-
dir	0	0	0	0	0	0	-	-	-
dircolors	0	0	0	0	0	0	-	-	-
dirname	0	0	0	0	0	0	-	-	-
du	0	0	0	0	0	0	-	-	-
echo	0	0	0	0	0	0	-	-	-
env	0	0	0	0	0	0	-	-	-
expand	0	0	0	0	0	0	-	-	-
expr	0	0	0	0	0	0	-	-	-
factor	1	0	1	0	0	0	0.250	1.000	0.000
false	0	0	0	0	0	0	-	-	-
fmt	0	0	0	0	0	0	-	-	-
fold	0	0	0	0	0	0	-	-	-
groups	0	0	0	0	0	0	-	-	-
head	0	0	0	0	0	0	-	-	-
hostid	0	0	0	0	0	0	-	-	-
id	0	0	0	0	0	0	-	-	-

Continued on next page

Table 17: Varnode recovery (metatype = UNION) (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
join	0	0	0	0	0	0	-	-	-
kill	0	0	0	0	0	0	-	-	-
link	0	0	0	0	0	0	-	-	-
ln	0	0	0	0	0	0	-	-	-
logname	0	0	0	0	0	0	-	-	-
ls	0	0	0	0	0	0	-	-	-
md5sum	0	0	0	0	0	0	-	-	-
mkdir	0	0	0	0	0	0	-	-	-
mkfifo	0	0	0	0	0	0	-	-	-
mknod	0	0	0	0	0	0	-	-	-
mktemp	0	0	0	0	0	0	-	-	-
mv	1	0	0	0	1	0	0.750	1.000	0.000
nice	0	0	0	0	0	0	-	-	-
nl	0	0	0	0	0	0	-	-	-
nohup	0	0	0	0	0	0	-	-	-
nproc	0	0	0	0	0	0	-	-	-
numfmt	0	0	0	0	0	0	-	-	-
od	8	0	0	0	8	0	0.750	1.000	0.000

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Table 17: Varnode recovery (metatype = UNION) (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
paste	0	0	0	0	0	0	-	-	-
pathchk	0	0	0	0	0	0	-	-	-
pinky	0	0	0	0	0	0	-	-	-
pr	0	0	0	0	0	0	-	-	-
printenv	0	0	0	0	0	0	-	-	-
printf	0	0	0	0	0	0	-	-	-
ptx	1	0	1	0	0	0	0.250	1.000	0.000
pwd	0	0	0	0	0	0	-	-	-
readlink	0	0	0	0	0	0	-	-	-
realpath	0	0	0	0	0	0	-	-	-
rm	0	0	0	0	0	0	-	-	-
rmdir	0	0	0	0	0	0	-	-	-
runcon	0	0	0	0	0	0	-	-	-
seq	0	0	0	0	0	0	-	-	-
sha1sum	0	0	0	0	0	0	-	-	-
sha224sum	0	0	0	0	0	0	-	-	-
sha256sum	0	0	0	0	0	0	-	-	-
sha384sum	0	0	0	0	0	0	-	-	-

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Table 17: Varnode recovery (metatype = UNION) (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
sha512sum	0	0	0	0	0	0	-	-	-
shred	0	0	0	0	0	0	-	-	-
shuf	0	0	0	0	0	0	-	-	-
sleep	0	0	0	0	0	0	-	-	-
sort	0	0	0	0	0	0	-	-	-
split	0	0	0	0	0	0	-	-	-
stat	0	0	0	0	0	0	-	-	-
stdbuf	0	0	0	0	0	0	-	-	-
stty	0	0	0	0	0	0	-	-	-
sum	0	0	0	0	0	0	-	-	-
sync	0	0	0	0	0	0	-	-	-
tac	0	0	0	0	0	0	-	-	-
tail	0	0	0	0	0	0	-	-	-
tee	0	0	0	0	0	0	-	-	-
test	0	0	0	0	0	0	-	-	-
timeout	0	0	0	0	0	0	-	-	-
touch	2	0	0	2	0	0	0.500	1.000	0.000
tr	0	0	0	0	0	0	-	-	-

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Table 17: Varnode recovery (metatype = UNION) (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
true	0	0	0	0	0	0	-	-	-
truncate	0	0	0	0	0	0	-	-	-
tsort	0	0	0	0	0	0	-	-	-
tty	0	0	0	0	0	0	-	-	-
uname	0	0	0	0	0	0	-	-	-
unexpand	0	0	0	0	0	0	-	-	-
uniq	0	0	0	0	0	0	-	-	-
unlink	0	0	0	0	0	0	-	-	-
uptime	0	0	0	0	0	0	-	-	-
users	0	0	0	0	0	0	-	-	-
vdir	0	0	0	0	0	0	-	-	-
wc	0	0	0	0	0	0	-	-	-
who	0	0	0	0	0	0	-	-	-
whoami	0	0	0	0	0	0	-	-	-
yes	0	0	0	0	0	0	-	-	-

Table 18: Varnode recovery (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average comparison score	Varnode fraction partially recovered	Varnode fraction exactly recovered
[	266	0	0	0	0	266	1.000	1.000	1.000
b2sum	237	0	0	0	0	237	1.000	1.000	1.000
base32	160	0	0	0	0	160	1.000	1.000	1.000
base64	160	0	0	0	0	160	1.000	1.000	1.000
basename	129	0	0	0	0	129	1.000	1.000	1.000
basenc	219	0	0	0	0	219	1.000	1.000	1.000
cat	164	0	0	0	0	164	1.000	1.000	1.000
chcon	363	0	0	0	0	363	1.000	1.000	1.000
chgrp	339	0	0	0	0	339	1.000	1.000	1.000
chmod	347	0	0	0	0	347	1.000	1.000	1.000
chown	359	0	0	0	0	359	1.000	1.000	1.000
chroot	198	0	1	0	0	197	0.996	1.000	0.995
cksum	678	0	0	0	0	678	1.000	1.000	1.000
comm	171	0	0	0	0	171	1.000	1.000	1.000
cp	703	0	2	0	2	699	0.997	1.000	0.994
csplit	982	0	1	1	0	980	0.999	1.000	0.998
cut	192	0	0	0	0	192	1.000	1.000	1.000
date	747	0	8	2	0	737	0.991	1.000	0.987

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Table 18: Varnode recovery (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average comparison score	Varnode fraction partially recovered	Varnode fraction exactly recovered
dd	493	0	0	0	0	493	1.000	1.000	1.000
df	640	0	2	0	0	638	0.998	1.000	0.997
dir	1031	0	4	3	0	1024	0.996	1.000	0.993
dircolors	190	0	0	0	0	190	1.000	1.000	1.000
dirname	125	0	0	0	0	125	1.000	1.000	1.000
du	1499	0	2	2	0	1495	0.998	1.000	0.997
echo	118	0	0	0	0	118	1.000	1.000	1.000
env	201	0	0	0	0	201	1.000	1.000	1.000
expand	152	0	0	0	0	152	1.000	1.000	1.000
expr	911	0	1	1	0	909	0.999	1.000	0.998
factor	511	23	1	0	0	487	0.954	0.955	0.953
false	109	0	0	0	0	109	1.000	1.000	1.000
fmt	186	0	0	0	0	186	1.000	1.000	1.000
fold	143	0	0	0	0	143	1.000	1.000	1.000
groups	142	0	0	0	0	142	1.000	1.000	1.000
head	215	0	0	0	0	215	1.000	1.000	1.000
hostid	118	0	0	0	0	118	1.000	1.000	1.000
id	196	0	0	0	0	196	1.000	1.000	1.000

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Table 18: Varnode recovery (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average comparison score	Varnode fraction partially recovered	Varnode fraction exactly recovered
join	260	0	0	0	0	260	1.000	1.000	1.000
kill	148	0	0	0	0	148	1.000	1.000	1.000
link	117	0	0	0	0	117	1.000	1.000	1.000
ln	433	0	0	0	0	433	1.000	1.000	1.000
logname	118	0	0	0	0	118	1.000	1.000	1.000
ls	1031	0	4	3	0	1024	0.996	1.000	0.993
md5sum	217	0	0	0	0	217	1.000	1.000	1.000
mkdir	306	0	1	0	0	305	0.998	1.000	0.997
mkfifo	148	0	0	0	0	148	1.000	1.000	1.000
mknod	165	0	0	0	0	165	1.000	1.000	1.000
mktemp	164	0	0	0	0	164	1.000	1.000	1.000
mv	773	0	1	0	2	770	0.998	1.000	0.996
nice	130	0	0	0	0	130	1.000	1.000	1.000
nl	896	0	1	1	0	894	0.999	1.000	0.998
nohup	162	0	0	0	0	162	1.000	1.000	1.000
nproc	139	0	0	0	0	139	1.000	1.000	1.000
numfmt	291	0	0	0	0	291	1.000	1.000	1.000
od	459	0	1	0	0	458	0.998	1.000	0.998

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Table 18: Varnode recovery (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average comparison score	Varnode fraction partially recovered	Varnode fraction exactly recovered
paste	142	0	0	0	0	142	1.000	1.000	1.000
pathchk	141	0	0	0	0	141	1.000	1.000	1.000
pinky	182	0	0	1	0	181	0.997	1.000	0.995
pr	543	0	0	1	0	542	0.999	1.000	0.998
printenv	119	0	0	0	0	119	1.000	1.000	1.000
printf	283	0	3	0	0	280	0.992	1.000	0.989
ptx	1126	0	2	1	0	1123	0.998	1.000	0.997
pwd	143	0	0	0	0	143	1.000	1.000	1.000
readlink	243	0	0	0	0	243	1.000	1.000	1.000
realpath	248	0	0	0	0	248	1.000	1.000	1.000
rm	362	0	0	0	0	362	1.000	1.000	1.000
rmdir	234	0	0	0	0	234	1.000	1.000	1.000
runcon	121	0	0	0	0	121	1.000	1.000	1.000
seq	279	0	0	0	0	279	1.000	1.000	1.000
sha1sum	215	0	0	0	0	215	1.000	1.000	1.000
sha224sum	225	0	0	0	0	225	1.000	1.000	1.000
sha256sum	225	0	0	0	0	225	1.000	1.000	1.000
sha384sum	381	0	0	0	0	381	1.000	1.000	1.000

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Table 18: Varnode recovery (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average comparison score	Varnode fraction partially recovered	Varnode fraction exactly recovered
sha512sum	381	0	0	0	0	381	1.000	1.000	1.000
shred	370	0	0	1	0	369	0.999	1.000	0.997
shuf	374	0	0	0	0	374	1.000	1.000	1.000
sleep	143	0	0	0	0	143	1.000	1.000	1.000
sort	847	0	2	0	0	845	0.998	1.000	0.998
split	297	0	1	0	0	296	0.997	1.000	0.997
stat	608	0	0	1	0	607	0.999	1.000	0.998
stdbuf	267	0	0	0	0	267	1.000	1.000	1.000
stty	301	0	0	0	0	301	1.000	1.000	1.000
sum	278	0	0	0	0	278	1.000	1.000	1.000
sync	133	0	0	0	0	133	1.000	1.000	1.000
tac	920	0	1	1	0	918	0.999	1.000	0.998
tail	423	0	1	0	0	422	0.998	1.000	0.998
tee	154	0	0	0	0	154	1.000	1.000	1.000
test	260	0	0	0	0	260	1.000	1.000	1.000
timeout	175	0	0	0	0	175	1.000	1.000	1.000
touch	602	0	8	1	2	591	0.988	1.000	0.982
tr	241	0	0	0	0	241	1.000	1.000	1.000

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Table 18: Varnode recovery (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average comparison score	Varnode fraction partially recovered	Varnode fraction exactly recovered
true	109	0	0	0	0	109	1.000	1.000	1.000
truncate	145	0	0	0	0	145	1.000	1.000	1.000
tsort	162	0	0	0	0	162	1.000	1.000	1.000
tty	114	0	0	0	0	114	1.000	1.000	1.000
uname	120	0	0	0	0	120	1.000	1.000	1.000
unexpand	158	0	0	0	0	158	1.000	1.000	1.000
uniq	202	0	0	0	0	202	1.000	1.000	1.000
unlink	117	0	0	0	0	117	1.000	1.000	1.000
uptime	353	0	0	1	1	351	0.998	1.000	0.994
users	133	0	0	0	0	133	1.000	1.000	1.000
vdir	1031	0	4	3	0	1024	0.996	1.000	0.993
wc	268	0	0	0	0	268	1.000	1.000	1.000
who	282	0	0	0	0	282	1.000	1.000	1.000
whoami	120	0	0	0	0	120	1.000	1.000	1.000
yes	132	0	0	0	0	132	1.000	1.000	1.000

Table 19: Varnode recovery (metatype = INT) (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
[	157	0	0	0	0	157	1.000	1.000	1.000
b2sum	147	0	0	0	0	147	1.000	1.000	1.000
base32	96	0	0	0	0	96	1.000	1.000	1.000
base64	96	0	0	0	0	96	1.000	1.000	1.000
basename	71	0	0	0	0	71	1.000	1.000	1.000
basenc	133	0	0	0	0	133	1.000	1.000	1.000
cat	101	0	0	0	0	101	1.000	1.000	1.000
chcon	185	0	0	0	0	185	1.000	1.000	1.000
chgrp	166	0	0	0	0	166	1.000	1.000	1.000
chmod	176	0	0	0	0	176	1.000	1.000	1.000
chown	176	0	0	0	0	176	1.000	1.000	1.000
chroot	110	0	1	0	0	109	0.993	1.000	0.991
cksum	488	0	0	0	0	488	1.000	1.000	1.000
comm	104	0	0	0	0	104	1.000	1.000	1.000
cp	382	0	1	0	2	379	0.997	1.000	0.992
csplit	619	0	1	0	0	618	0.999	1.000	0.998
cut	124	0	0	0	0	124	1.000	1.000	1.000
date	516	0	5	0	0	511	0.993	1.000	0.990

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Table 19: Varnode recovery (metatype = INT) (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
dd	332	0	0	0	0	332	1.000	1.000	1.000
df	326	0	0	0	0	326	1.000	1.000	1.000
dir	615	0	1	0	0	614	0.999	1.000	0.998
dircolors	90	0	0	0	0	90	1.000	1.000	1.000
dirname	73	0	0	0	0	73	1.000	1.000	1.000
du	931	0	2	0	0	929	0.998	1.000	0.998
echo	69	0	0	0	0	69	1.000	1.000	1.000
env	112	0	0	0	0	112	1.000	1.000	1.000
expand	94	0	0	0	0	94	1.000	1.000	1.000
expr	560	0	1	0	0	559	0.999	1.000	0.998
factor	343	13	0	0	0	330	0.962	0.962	0.962
false	62	0	0	0	0	62	1.000	1.000	1.000
fmt	112	0	0	0	0	112	1.000	1.000	1.000
fold	88	0	0	0	0	88	1.000	1.000	1.000
groups	81	0	0	0	0	81	1.000	1.000	1.000
head	138	0	0	0	0	138	1.000	1.000	1.000
hostid	67	0	0	0	0	67	1.000	1.000	1.000
id	112	0	0	0	0	112	1.000	1.000	1.000

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Table 19: Varnode recovery (metatype = INT) (compilation = debug)

	Ground truth varn-odes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVER-LAP	Varnodes matched @ level SUB-SET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode aver-age com-pare score	Varnode frac-tion par-tially recov-ered	Varnode frac-tion ex-actly recov-ered
join	162	0	0	0	0	162	1.000	1.000	1.000
kill	88	0	0	0	0	88	1.000	1.000	1.000
link	66	0	0	0	0	66	1.000	1.000	1.000
ln	219	0	0	0	0	219	1.000	1.000	1.000
logname	66	0	0	0	0	66	1.000	1.000	1.000
ls	615	0	1	0	0	614	0.999	1.000	0.998
md5sum	139	0	0	0	0	139	1.000	1.000	1.000
mkdir	196	0	0	0	0	196	1.000	1.000	1.000
mkfifo	88	0	0	0	0	88	1.000	1.000	1.000
mknod	100	0	0	0	0	100	1.000	1.000	1.000
mktemp	96	0	0	0	0	96	1.000	1.000	1.000
mv	428	0	0	0	2	426	0.999	1.000	0.995
nice	77	0	0	0	0	77	1.000	1.000	1.000
nl	558	0	1	0	0	557	0.999	1.000	0.998
nohup	99	0	0	0	0	99	1.000	1.000	1.000
nproc	86	0	0	0	0	86	1.000	1.000	1.000
numfmt	184	0	0	0	0	184	1.000	1.000	1.000
od	294	0	1	0	0	293	0.997	1.000	0.997

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Table 19: Varnode recovery (metatype = INT) (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
paste	85	0	0	0	0	85	1.000	1.000	1.000
pathchk	85	0	0	0	0	85	1.000	1.000	1.000
pinky	96	0	0	0	0	96	1.000	1.000	1.000
pr	399	0	0	0	0	399	1.000	1.000	1.000
printenv	68	0	0	0	0	68	1.000	1.000	1.000
printf	168	0	3	0	0	165	0.987	1.000	0.982
ptx	673	0	1	0	0	672	0.999	1.000	0.999
pwd	75	0	0	0	0	75	1.000	1.000	1.000
readlink	111	0	0	0	0	111	1.000	1.000	1.000
realpath	111	0	0	0	0	111	1.000	1.000	1.000
rm	185	0	0	0	0	185	1.000	1.000	1.000
rmdir	139	0	0	0	0	139	1.000	1.000	1.000
runcon	65	0	0	0	0	65	1.000	1.000	1.000
seq	156	0	0	0	0	156	1.000	1.000	1.000
sha1sum	138	0	0	0	0	138	1.000	1.000	1.000
sha224sum	145	0	0	0	0	145	1.000	1.000	1.000
sha256sum	145	0	0	0	0	145	1.000	1.000	1.000
sha384sum	301	0	0	0	0	301	1.000	1.000	1.000

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Table 19: Varnode recovery (metatype = INT) (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
sha512sum	301	0	0	0	0	301	1.000	1.000	1.000
shred	238	0	0	0	0	238	1.000	1.000	1.000
shuf	210	0	0	0	0	210	1.000	1.000	1.000
sleep	76	0	0	0	0	76	1.000	1.000	1.000
sort	440	0	1	0	0	439	0.998	1.000	0.998
split	195	0	0	0	0	195	1.000	1.000	1.000
stat	392	0	0	0	0	392	1.000	1.000	1.000
stdbuf	156	0	0	0	0	156	1.000	1.000	1.000
stty	189	0	0	0	0	189	1.000	1.000	1.000
sum	183	0	0	0	0	183	1.000	1.000	1.000
sync	83	0	0	0	0	83	1.000	1.000	1.000
tac	584	0	1	0	0	583	0.999	1.000	0.998
tail	239	0	0	0	0	239	1.000	1.000	1.000
tee	95	0	0	0	0	95	1.000	1.000	1.000
test	155	0	0	0	0	155	1.000	1.000	1.000
timeout	95	0	0	0	0	95	1.000	1.000	1.000
touch	396	0	5	0	0	391	0.991	1.000	0.987
tr	153	0	0	0	0	153	1.000	1.000	1.000

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Table 19: Varnode recovery (metatype = INT) (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
true	62	0	0	0	0	62	1.000	1.000	1.000
truncate	91	0	0	0	0	91	1.000	1.000	1.000
tsort	85	0	0	0	0	85	1.000	1.000	1.000
tty	65	0	0	0	0	65	1.000	1.000	1.000
uname	67	0	0	0	0	67	1.000	1.000	1.000
unexpand	101	0	0	0	0	101	1.000	1.000	1.000
uniq	125	0	0	0	0	125	1.000	1.000	1.000
unlink	66	0	0	0	0	66	1.000	1.000	1.000
uptime	261	0	0	0	0	261	1.000	1.000	1.000
users	73	0	0	0	0	73	1.000	1.000	1.000
vdir	615	0	1	0	0	614	0.999	1.000	0.998
wc	148	0	0	0	0	148	1.000	1.000	1.000
who	158	0	0	0	0	158	1.000	1.000	1.000
whoami	68	0	0	0	0	68	1.000	1.000	1.000
yes	76	0	0	0	0	76	1.000	1.000	1.000

Table 20: Varnode recovery (metatype = FLOAT) (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
[	2	0	0	0	0	2	1.000	1.000	1.000
b2sum	0	0	0	0	0	0	-	-	-
base32	0	0	0	0	0	0	-	-	-
base64	0	0	0	0	0	0	-	-	-
basename	0	0	0	0	0	0	-	-	-
basenc	0	0	0	0	0	0	-	-	-
cat	0	0	0	0	0	0	-	-	-
chcon	3	0	0	0	0	3	1.000	1.000	1.000
chgrp	3	0	0	0	0	3	1.000	1.000	1.000
chmod	3	0	0	0	0	3	1.000	1.000	1.000
chown	3	0	0	0	0	3	1.000	1.000	1.000
chroot	0	0	0	0	0	0	-	-	-
cksum	3	0	0	0	0	3	1.000	1.000	1.000
comm	0	0	0	0	0	0	-	-	-
cp	3	0	0	0	0	3	1.000	1.000	1.000
csplit	0	0	0	0	0	0	-	-	-
cut	0	0	0	0	0	0	-	-	-
date	2	0	0	0	0	2	1.000	1.000	1.000

Continued on next page

Table 20: Varnode recovery (metatype = FLOAT) (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
dd	7	0	0	0	0	7	1.000	1.000	1.000
df	13	0	0	0	0	13	1.000	1.000	1.000
dir	6	0	0	0	0	6	1.000	1.000	1.000
dircolors	0	0	0	0	0	0	-	-	-
dirname	0	0	0	0	0	0	-	-	-
du	6	0	0	0	0	6	1.000	1.000	1.000
echo	0	0	0	0	0	0	-	-	-
env	0	0	0	0	0	0	-	-	-
expand	0	0	0	0	0	0	-	-	-
expr	0	0	0	0	0	0	-	-	-
factor	0	0	0	0	0	0	-	-	-
false	0	0	0	0	0	0	-	-	-
fmt	0	0	0	0	0	0	-	-	-
fold	0	0	0	0	0	0	-	-	-
groups	0	0	0	0	0	0	-	-	-
head	0	0	0	0	0	0	-	-	-
hostid	0	0	0	0	0	0	-	-	-
id	0	0	0	0	0	0	-	-	-

Continued on next page

Table 20: Varnode recovery (metatype = FLOAT) (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
join	0	0	0	0	0	0	-	-	-
kill	0	0	0	0	0	0	-	-	-
link	0	0	0	0	0	0	-	-	-
ln	3	0	0	0	0	3	1.000	1.000	1.000
logname	0	0	0	0	0	0	-	-	-
ls	6	0	0	0	0	6	1.000	1.000	1.000
md5sum	0	0	0	0	0	0	-	-	-
mkdir	2	0	0	0	0	2	1.000	1.000	1.000
mkfifo	0	0	0	0	0	0	-	-	-
mknod	0	0	0	0	0	0	-	-	-
mktemp	0	0	0	0	0	0	-	-	-
mv	3	0	0	0	0	3	1.000	1.000	1.000
nice	0	0	0	0	0	0	-	-	-
nl	0	0	0	0	0	0	-	-	-
nohup	0	0	0	0	0	0	-	-	-
nproc	0	0	0	0	0	0	-	-	-
numfmt	7	0	0	0	0	7	1.000	1.000	1.000
od	11	0	0	0	0	11	1.000	1.000	1.000

Continued on next page

Table 20: Varnode recovery (metatype = FLOAT) (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
paste	0	0	0	0	0	0	-	-	-
pathchk	0	0	0	0	0	0	-	-	-
pinky	0	0	0	0	0	0	-	-	-
pr	0	0	0	0	0	0	-	-	-
printenv	0	0	0	0	0	0	-	-	-
printf	7	0	0	0	0	7	1.000	1.000	1.000
ptx	0	0	0	0	0	0	-	-	-
pwd	0	0	0	0	0	0	-	-	-
readlink	3	0	0	0	0	3	1.000	1.000	1.000
realpath	3	0	0	0	0	3	1.000	1.000	1.000
rm	3	0	0	0	0	3	1.000	1.000	1.000
rmdir	2	0	0	0	0	2	1.000	1.000	1.000
runcon	0	0	0	0	0	0	-	-	-
seq	10	0	0	0	0	10	1.000	1.000	1.000
sha1sum	0	0	0	0	0	0	-	-	-
sha224sum	0	0	0	0	0	0	-	-	-
sha256sum	0	0	0	0	0	0	-	-	-
sha384sum	0	0	0	0	0	0	-	-	-

Continued on next page

Table 20: Varnode recovery (metatype = FLOAT) (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
sha512sum	0	0	0	0	0	0	-	-	-
shred	3	0	0	0	0	3	1.000	1.000	1.000
shuf	3	0	0	0	0	3	1.000	1.000	1.000
sleep	7	0	0	0	0	7	1.000	1.000	1.000
sort	18	0	0	0	0	18	1.000	1.000	1.000
split	0	0	0	0	0	0	-	-	-
stat	2	0	0	0	0	2	1.000	1.000	1.000
stdbuf	2	0	0	0	0	2	1.000	1.000	1.000
stty	2	0	0	0	0	2	1.000	1.000	1.000
sum	3	0	0	0	0	3	1.000	1.000	1.000
sync	0	0	0	0	0	0	-	-	-
tac	0	0	0	0	0	0	-	-	-
tail	11	0	0	0	0	11	1.000	1.000	1.000
tee	0	0	0	0	0	0	-	-	-
test	2	0	0	0	0	2	1.000	1.000	1.000
timeout	8	0	0	0	0	8	1.000	1.000	1.000
touch	2	0	0	0	0	2	1.000	1.000	1.000
tr	0	0	0	0	0	0	-	-	-

Continued on next page

Table 20: Varnode recovery (metatype = FLOAT) (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
true	0	0	0	0	0	0	-	-	-
truncate	0	0	0	0	0	0	-	-	-
tsort	0	0	0	0	0	0	-	-	-
tty	0	0	0	0	0	0	-	-	-
uname	0	0	0	0	0	0	-	-	-
unexpand	0	0	0	0	0	0	-	-	-
uniq	0	0	0	0	0	0	-	-	-
unlink	0	0	0	0	0	0	-	-	-
uptime	2	0	0	0	0	2	1.000	1.000	1.000
users	0	0	0	0	0	0	-	-	-
vdir	6	0	0	0	0	6	1.000	1.000	1.000
wc	4	0	0	0	0	4	1.000	1.000	1.000
who	2	0	0	0	0	2	1.000	1.000	1.000
whoami	0	0	0	0	0	0	-	-	-
yes	0	0	0	0	0	0	-	-	-

Table 21: Varnode recovery (metatype = POINTER) (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
[	68	0	0	0	0	68	1.000	1.000	1.000
b2sum	56	0	0	0	0	56	1.000	1.000	1.000
base32	41	0	0	0	0	41	1.000	1.000	1.000
base64	41	0	0	0	0	41	1.000	1.000	1.000
basename	38	0	0	0	0	38	1.000	1.000	1.000
basenc	55	0	0	0	0	55	1.000	1.000	1.000
cat	41	0	0	0	0	41	1.000	1.000	1.000
chcon	134	0	0	0	0	134	1.000	1.000	1.000
chgrp	133	0	0	0	0	133	1.000	1.000	1.000
chmod	127	0	0	0	0	127	1.000	1.000	1.000
chown	142	0	0	0	0	142	1.000	1.000	1.000
chroot	67	0	0	0	0	67	1.000	1.000	1.000
cksum	99	0	0	0	0	99	1.000	1.000	1.000
comm	35	0	0	0	0	35	1.000	1.000	1.000
cp	231	0	0	0	0	231	1.000	1.000	1.000
csplit	272	0	0	0	0	272	1.000	1.000	1.000
cut	46	0	0	0	0	46	1.000	1.000	1.000
date	125	0	0	0	0	125	1.000	1.000	1.000

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Table 21: Varnode recovery (metatype = POINTER) (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
dd	98	0	0	0	0	98	1.000	1.000	1.000
df	239	0	0	0	0	239	1.000	1.000	1.000
dir	293	0	0	0	0	293	1.000	1.000	1.000
dircolors	76	0	0	0	0	76	1.000	1.000	1.000
dirname	32	0	0	0	0	32	1.000	1.000	1.000
du	438	0	0	0	0	438	1.000	1.000	1.000
echo	30	0	0	0	0	30	1.000	1.000	1.000
env	54	0	0	0	0	54	1.000	1.000	1.000
expand	35	0	0	0	0	35	1.000	1.000	1.000
expr	259	0	0	0	0	259	1.000	1.000	1.000
factor	98	3	0	0	0	95	0.969	0.969	0.969
false	28	0	0	0	0	28	1.000	1.000	1.000
fmt	52	0	0	0	0	52	1.000	1.000	1.000
fold	33	0	0	0	0	33	1.000	1.000	1.000
groups	40	0	0	0	0	40	1.000	1.000	1.000
head	47	0	0	0	0	47	1.000	1.000	1.000
hostid	29	0	0	0	0	29	1.000	1.000	1.000
id	60	0	0	0	0	60	1.000	1.000	1.000

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Table 21: Varnode recovery (metatype = POINTER) (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
join	66	0	0	0	0	66	1.000	1.000	1.000
kill	36	0	0	0	0	36	1.000	1.000	1.000
link	29	0	0	0	0	29	1.000	1.000	1.000
ln	161	0	0	0	0	161	1.000	1.000	1.000
logname	30	0	0	0	0	30	1.000	1.000	1.000
ls	293	0	0	0	0	293	1.000	1.000	1.000
md5sum	50	0	0	0	0	50	1.000	1.000	1.000
mkdir	71	0	0	0	0	71	1.000	1.000	1.000
mkfifo	36	0	0	0	0	36	1.000	1.000	1.000
mknod	41	0	0	0	0	41	1.000	1.000	1.000
mktemp	44	0	0	0	0	44	1.000	1.000	1.000
mv	254	0	0	0	0	254	1.000	1.000	1.000
nice	33	0	0	0	0	33	1.000	1.000	1.000
nl	247	0	0	0	0	247	1.000	1.000	1.000
nohup	40	0	0	0	0	40	1.000	1.000	1.000
nproc	32	0	0	0	0	32	1.000	1.000	1.000
numfmt	70	0	0	0	0	70	1.000	1.000	1.000
od	93	0	0	0	0	93	1.000	1.000	1.000

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Table 21: Varnode recovery (metatype = POINTER) (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
paste	37	0	0	0	0	37	1.000	1.000	1.000
pathchk	33	0	0	0	0	33	1.000	1.000	1.000
pinky	57	0	0	0	0	57	1.000	1.000	1.000
pr	102	0	0	0	0	102	1.000	1.000	1.000
printenv	31	0	0	0	0	31	1.000	1.000	1.000
printf	76	0	0	0	0	76	1.000	1.000	1.000
ptx	331	0	0	0	0	331	1.000	1.000	1.000
pwd	41	0	0	0	0	41	1.000	1.000	1.000
readlink	100	0	0	0	0	100	1.000	1.000	1.000
realpath	105	0	0	0	0	105	1.000	1.000	1.000
rm	136	0	0	0	0	136	1.000	1.000	1.000
rmdir	66	0	0	0	0	66	1.000	1.000	1.000
runcon	36	0	0	0	0	36	1.000	1.000	1.000
seq	81	0	0	0	0	81	1.000	1.000	1.000
sha1sum	49	0	0	0	0	49	1.000	1.000	1.000
sha224sum	50	0	0	0	0	50	1.000	1.000	1.000
sha256sum	50	0	0	0	0	50	1.000	1.000	1.000
sha384sum	50	0	0	0	0	50	1.000	1.000	1.000

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Table 21: Varnode recovery (metatype = POINTER) (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
sha512sum	50	0	0	0	0	50	1.000	1.000	1.000
shred	87	0	0	0	0	87	1.000	1.000	1.000
shuf	134	0	0	0	0	134	1.000	1.000	1.000
sleep	35	0	0	0	0	35	1.000	1.000	1.000
sort	299	0	0	0	0	299	1.000	1.000	1.000
split	69	0	0	0	0	69	1.000	1.000	1.000
stat	150	0	0	0	0	150	1.000	1.000	1.000
stdbuf	79	0	0	0	0	79	1.000	1.000	1.000
stty	73	0	0	0	0	73	1.000	1.000	1.000
sum	60	0	0	0	0	60	1.000	1.000	1.000
sync	29	0	0	0	0	29	1.000	1.000	1.000
tac	250	0	0	0	0	250	1.000	1.000	1.000
tail	124	0	0	0	0	124	1.000	1.000	1.000
tee	35	0	0	0	0	35	1.000	1.000	1.000
test	67	0	0	0	0	67	1.000	1.000	1.000
timeout	41	0	0	0	0	41	1.000	1.000	1.000
touch	110	0	0	0	0	110	1.000	1.000	1.000
tr	58	0	0	0	0	58	1.000	1.000	1.000

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Table 21: Varnode recovery (metatype = POINTER) (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
true	28	0	0	0	0	28	1.000	1.000	1.000
truncate	32	0	0	0	0	32	1.000	1.000	1.000
tsort	52	0	0	0	0	52	1.000	1.000	1.000
tty	29	0	0	0	0	29	1.000	1.000	1.000
uname	30	0	0	0	0	30	1.000	1.000	1.000
unexpand	36	0	0	0	0	36	1.000	1.000	1.000
uniq	50	0	0	0	0	50	1.000	1.000	1.000
unlink	29	0	0	0	0	29	1.000	1.000	1.000
uptime	57	0	0	0	1	56	0.996	1.000	0.982
users	38	0	0	0	0	38	1.000	1.000	1.000
vdir	293	0	0	0	0	293	1.000	1.000	1.000
wc	84	0	0	0	0	84	1.000	1.000	1.000
who	83	0	0	0	0	83	1.000	1.000	1.000
whoami	30	0	0	0	0	30	1.000	1.000	1.000
yes	34	0	0	0	0	34	1.000	1.000	1.000

Table 22: Varnode recovery (metatype = ARRAY) (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
[	15	0	0	0	0	15	1.000	1.000	1.000
b2sum	24	0	0	0	0	24	1.000	1.000	1.000
base32	12	0	0	0	0	12	1.000	1.000	1.000
base64	12	0	0	0	0	12	1.000	1.000	1.000
basename	10	0	0	0	0	10	1.000	1.000	1.000
basenc	20	0	0	0	0	20	1.000	1.000	1.000
cat	11	0	0	0	0	11	1.000	1.000	1.000
chcon	18	0	0	0	0	18	1.000	1.000	1.000
chgrp	15	0	0	0	0	15	1.000	1.000	1.000
chmod	19	0	0	0	0	19	1.000	1.000	1.000
chown	16	0	0	0	0	16	1.000	1.000	1.000
chroot	11	0	0	0	0	11	1.000	1.000	1.000
cksum	66	0	0	0	0	66	1.000	1.000	1.000
comm	22	0	0	0	0	22	1.000	1.000	1.000
cp	40	0	1	0	0	39	0.981	1.000	0.975
csplit	35	0	0	1	0	34	0.986	1.000	0.971
cut	12	0	0	0	0	12	1.000	1.000	1.000
date	63	0	2	2	0	59	0.960	1.000	0.937

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Table 22: Varnode recovery (metatype = ARRAY) (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
dd	34	0	0	0	0	34	1.000	1.000	1.000
df	25	0	1	0	0	24	0.970	1.000	0.960
dir	71	0	2	3	0	66	0.958	1.000	0.930
dircolors	13	0	0	0	0	13	1.000	1.000	1.000
dirname	10	0	0	0	0	10	1.000	1.000	1.000
du	51	0	0	2	0	49	0.980	1.000	0.961
echo	9	0	0	0	0	9	1.000	1.000	1.000
env	18	0	0	0	0	18	1.000	1.000	1.000
expand	13	0	0	0	0	13	1.000	1.000	1.000
expr	33	0	0	1	0	32	0.985	1.000	0.970
factor	37	5	0	0	0	32	0.865	0.865	0.865
false	9	0	0	0	0	9	1.000	1.000	1.000
fmt	12	0	0	0	0	12	1.000	1.000	1.000
fold	12	0	0	0	0	12	1.000	1.000	1.000
groups	11	0	0	0	0	11	1.000	1.000	1.000
head	18	0	0	0	0	18	1.000	1.000	1.000
hostid	12	0	0	0	0	12	1.000	1.000	1.000
id	14	0	0	0	0	14	1.000	1.000	1.000

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Table 22: Varnode recovery (metatype = ARRAY) (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
join	18	0	0	0	0	18	1.000	1.000	1.000
kill	14	0	0	0	0	14	1.000	1.000	1.000
link	12	0	0	0	0	12	1.000	1.000	1.000
ln	22	0	0	0	0	22	1.000	1.000	1.000
logname	12	0	0	0	0	12	1.000	1.000	1.000
ls	71	0	2	3	0	66	0.958	1.000	0.930
md5sum	16	0	0	0	0	16	1.000	1.000	1.000
mkdir	19	0	1	0	0	18	0.961	1.000	0.947
mkfifo	12	0	0	0	0	12	1.000	1.000	1.000
mknod	12	0	0	0	0	12	1.000	1.000	1.000
mktemp	12	0	0	0	0	12	1.000	1.000	1.000
mv	34	0	1	0	0	33	0.978	1.000	0.971
nice	10	0	0	0	0	10	1.000	1.000	1.000
nl	36	0	0	1	0	35	0.986	1.000	0.972
nohup	13	0	0	0	0	13	1.000	1.000	1.000
nproc	10	0	0	0	0	10	1.000	1.000	1.000
numfmt	20	0	0	0	0	20	1.000	1.000	1.000
od	40	0	0	0	0	40	1.000	1.000	1.000

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Table 22: Varnode recovery (metatype = ARRAY) (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
paste	10	0	0	0	0	10	1.000	1.000	1.000
pathchk	10	0	0	0	0	10	1.000	1.000	1.000
pinky	17	0	0	1	0	16	0.971	1.000	0.941
pr	20	0	0	1	0	19	0.975	1.000	0.950
printenv	10	0	0	0	0	10	1.000	1.000	1.000
printf	17	0	0	0	0	17	1.000	1.000	1.000
ptx	39	0	0	1	0	38	0.987	1.000	0.974
pwd	10	0	0	0	0	10	1.000	1.000	1.000
readlink	12	0	0	0	0	12	1.000	1.000	1.000
realpath	11	0	0	0	0	11	1.000	1.000	1.000
rm	15	0	0	0	0	15	1.000	1.000	1.000
rmdir	14	0	0	0	0	14	1.000	1.000	1.000
runcon	10	0	0	0	0	10	1.000	1.000	1.000
seq	15	0	0	0	0	15	1.000	1.000	1.000
sha1sum	16	0	0	0	0	16	1.000	1.000	1.000
sha224sum	17	0	0	0	0	17	1.000	1.000	1.000
sha256sum	17	0	0	0	0	17	1.000	1.000	1.000
sha384sum	17	0	0	0	0	17	1.000	1.000	1.000

Continued on next page

Table 22: Varnode recovery (metatype = ARRAY) (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
sha512sum	17	0	0	0	0	17	1.000	1.000	1.000
shred	27	0	0	1	0	26	0.981	1.000	0.963
shuf	12	0	0	0	0	12	1.000	1.000	1.000
sleep	12	0	0	0	0	12	1.000	1.000	1.000
sort	46	0	1	0	0	45	0.984	1.000	0.978
split	18	0	1	0	0	17	0.958	1.000	0.944
stat	32	0	0	1	0	31	0.984	1.000	0.969
stdbuf	16	0	0	0	0	16	1.000	1.000	1.000
stty	19	0	0	0	0	19	1.000	1.000	1.000
sum	22	0	0	0	0	22	1.000	1.000	1.000
sync	11	0	0	0	0	11	1.000	1.000	1.000
tac	33	0	0	1	0	32	0.985	1.000	0.970
tail	20	0	1	0	0	19	0.963	1.000	0.950
tee	14	0	0	0	0	14	1.000	1.000	1.000
test	12	0	0	0	0	12	1.000	1.000	1.000
timeout	13	0	0	0	0	13	1.000	1.000	1.000
touch	56	0	2	1	0	53	0.964	1.000	0.946
tr	17	0	0	0	0	17	1.000	1.000	1.000

Continued on next page

Table 22: Varnode recovery (metatype = ARRAY) (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
true	9	0	0	0	0	9	1.000	1.000	1.000
truncate	10	0	0	0	0	10	1.000	1.000	1.000
tsort	13	0	0	0	0	13	1.000	1.000	1.000
tty	10	0	0	0	0	10	1.000	1.000	1.000
uname	12	0	0	0	0	12	1.000	1.000	1.000
unexpand	11	0	0	0	0	11	1.000	1.000	1.000
uniq	15	0	0	0	0	15	1.000	1.000	1.000
unlink	12	0	0	0	0	12	1.000	1.000	1.000
uptime	18	0	0	1	0	17	0.972	1.000	0.944
users	12	0	0	0	0	12	1.000	1.000	1.000
vdir	71	0	2	3	0	66	0.958	1.000	0.930
wc	16	0	0	0	0	16	1.000	1.000	1.000
who	25	0	0	0	0	25	1.000	1.000	1.000
whoami	12	0	0	0	0	12	1.000	1.000	1.000
yes	12	0	0	0	0	12	1.000	1.000	1.000

Table 23: Varnode recovery (metatype = STRUCT) (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
[	24	0	0	0	0	24	1.000	1.000	1.000
b2sum	10	0	0	0	0	10	1.000	1.000	1.000
base32	11	0	0	0	0	11	1.000	1.000	1.000
base64	11	0	0	0	0	11	1.000	1.000	1.000
basename	10	0	0	0	0	10	1.000	1.000	1.000
basenc	11	0	0	0	0	11	1.000	1.000	1.000
cat	11	0	0	0	0	11	1.000	1.000	1.000
chcon	23	0	0	0	0	23	1.000	1.000	1.000
chgrp	22	0	0	0	0	22	1.000	1.000	1.000
chmod	22	0	0	0	0	22	1.000	1.000	1.000
chown	22	0	0	0	0	22	1.000	1.000	1.000
chroot	10	0	0	0	0	10	1.000	1.000	1.000
cksum	22	0	0	0	0	22	1.000	1.000	1.000
comm	10	0	0	0	0	10	1.000	1.000	1.000
cp	46	0	0	0	0	46	1.000	1.000	1.000
csplit	56	0	0	0	0	56	1.000	1.000	1.000
cut	10	0	0	0	0	10	1.000	1.000	1.000
date	39	0	1	0	0	38	0.981	1.000	0.974

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Table 23: Varnode recovery (metatype = STRUCT) (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
dd	22	0	0	0	0	22	1.000	1.000	1.000
df	37	0	1	0	0	36	0.980	1.000	0.973
dir	46	0	1	0	0	45	0.984	1.000	0.978
dircolors	11	0	0	0	0	11	1.000	1.000	1.000
dirname	10	0	0	0	0	10	1.000	1.000	1.000
du	73	0	0	0	0	73	1.000	1.000	1.000
echo	10	0	0	0	0	10	1.000	1.000	1.000
env	17	0	0	0	0	17	1.000	1.000	1.000
expand	10	0	0	0	0	10	1.000	1.000	1.000
expr	59	0	0	0	0	59	1.000	1.000	1.000
factor	32	2	1	0	0	29	0.914	0.938	0.906
false	10	0	0	0	0	10	1.000	1.000	1.000
fmt	10	0	0	0	0	10	1.000	1.000	1.000
fold	10	0	0	0	0	10	1.000	1.000	1.000
groups	10	0	0	0	0	10	1.000	1.000	1.000
head	12	0	0	0	0	12	1.000	1.000	1.000
hostid	10	0	0	0	0	10	1.000	1.000	1.000
id	10	0	0	0	0	10	1.000	1.000	1.000

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Table 23: Varnode recovery (metatype = STRUCT) (compilation = debug)

	Ground truth varn-odes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVER-LAP	Varnodes matched @ level SUB-SET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode aver-age com-pare score	Varnode frac-tion par-tially recov-ered	Varnode frac-tion ex-actly recov-ered
join	14	0	0	0	0	14	1.000	1.000	1.000
kill	10	0	0	0	0	10	1.000	1.000	1.000
link	10	0	0	0	0	10	1.000	1.000	1.000
ln	28	0	0	0	0	28	1.000	1.000	1.000
logname	10	0	0	0	0	10	1.000	1.000	1.000
ls	46	0	1	0	0	45	0.984	1.000	0.978
md5sum	12	0	0	0	0	12	1.000	1.000	1.000
mkdir	18	0	0	0	0	18	1.000	1.000	1.000
mkfifo	12	0	0	0	0	12	1.000	1.000	1.000
mknod	12	0	0	0	0	12	1.000	1.000	1.000
mktemp	12	0	0	0	0	12	1.000	1.000	1.000
mv	53	0	0	0	0	53	1.000	1.000	1.000
nice	10	0	0	0	0	10	1.000	1.000	1.000
nl	55	0	0	0	0	55	1.000	1.000	1.000
nohup	10	0	0	0	0	10	1.000	1.000	1.000
nproc	11	0	0	0	0	11	1.000	1.000	1.000
numfmt	10	0	0	0	0	10	1.000	1.000	1.000
od	13	0	0	0	0	13	1.000	1.000	1.000

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Table 23: Varnode recovery (metatype = STRUCT) (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
paste	10	0	0	0	0	10	1.000	1.000	1.000
pathchk	13	0	0	0	0	13	1.000	1.000	1.000
pinky	12	0	0	0	0	12	1.000	1.000	1.000
pr	22	0	0	0	0	22	1.000	1.000	1.000
printenv	10	0	0	0	0	10	1.000	1.000	1.000
printf	15	0	0	0	0	15	1.000	1.000	1.000
ptx	82	0	1	0	0	81	0.991	1.000	0.988
pwd	17	0	0	0	0	17	1.000	1.000	1.000
readlink	17	0	0	0	0	17	1.000	1.000	1.000
realpath	18	0	0	0	0	18	1.000	1.000	1.000
rm	23	0	0	0	0	23	1.000	1.000	1.000
rmdir	13	0	0	0	0	13	1.000	1.000	1.000
runcon	10	0	0	0	0	10	1.000	1.000	1.000
seq	17	0	0	0	0	17	1.000	1.000	1.000
sha1sum	12	0	0	0	0	12	1.000	1.000	1.000
sha224sum	13	0	0	0	0	13	1.000	1.000	1.000
sha256sum	13	0	0	0	0	13	1.000	1.000	1.000
sha384sum	13	0	0	0	0	13	1.000	1.000	1.000

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Table 23: Varnode recovery (metatype = STRUCT) (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
sha512sum	13	0	0	0	0	13	1.000	1.000	1.000
shred	15	0	0	0	0	15	1.000	1.000	1.000
shuf	15	0	0	0	0	15	1.000	1.000	1.000
sleep	13	0	0	0	0	13	1.000	1.000	1.000
sort	44	0	0	0	0	44	1.000	1.000	1.000
split	15	0	0	0	0	15	1.000	1.000	1.000
stat	32	0	0	0	0	32	1.000	1.000	1.000
stdbuf	14	0	0	0	0	14	1.000	1.000	1.000
stty	18	0	0	0	0	18	1.000	1.000	1.000
sum	10	0	0	0	0	10	1.000	1.000	1.000
sync	10	0	0	0	0	10	1.000	1.000	1.000
tac	53	0	0	0	0	53	1.000	1.000	1.000
tail	29	0	0	0	0	29	1.000	1.000	1.000
tee	10	0	0	0	0	10	1.000	1.000	1.000
test	24	0	0	0	0	24	1.000	1.000	1.000
timeout	18	0	0	0	0	18	1.000	1.000	1.000
touch	36	0	1	0	0	35	0.979	1.000	0.972
tr	13	0	0	0	0	13	1.000	1.000	1.000

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Table 23: Varnode recovery (metatype = STRUCT) (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
true	10	0	0	0	0	10	1.000	1.000	1.000
truncate	12	0	0	0	0	12	1.000	1.000	1.000
tsort	12	0	0	0	0	12	1.000	1.000	1.000
tty	10	0	0	0	0	10	1.000	1.000	1.000
uname	11	0	0	0	0	11	1.000	1.000	1.000
unexpand	10	0	0	0	0	10	1.000	1.000	1.000
uniq	12	0	0	0	0	12	1.000	1.000	1.000
unlink	10	0	0	0	0	10	1.000	1.000	1.000
uptime	15	0	0	0	0	15	1.000	1.000	1.000
users	10	0	0	0	0	10	1.000	1.000	1.000
vdir	46	0	1	0	0	45	0.984	1.000	0.978
wc	16	0	0	0	0	16	1.000	1.000	1.000
who	14	0	0	0	0	14	1.000	1.000	1.000
whoami	10	0	0	0	0	10	1.000	1.000	1.000
yes	10	0	0	0	0	10	1.000	1.000	1.000

Table 24: Varnode recovery (metatype = UNION) (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
[	0	0	0	0	0	0	-	-	-
b2sum	0	0	0	0	0	0	-	-	-
base32	0	0	0	0	0	0	-	-	-
base64	0	0	0	0	0	0	-	-	-
basename	0	0	0	0	0	0	-	-	-
basenc	0	0	0	0	0	0	-	-	-
cat	0	0	0	0	0	0	-	-	-
chcon	0	0	0	0	0	0	-	-	-
chgrp	0	0	0	0	0	0	-	-	-
chmod	0	0	0	0	0	0	-	-	-
chown	0	0	0	0	0	0	-	-	-
chroot	0	0	0	0	0	0	-	-	-
cksum	0	0	0	0	0	0	-	-	-
comm	0	0	0	0	0	0	-	-	-
cp	1	0	0	0	0	1	1.000	1.000	1.000
csplit	0	0	0	0	0	0	-	-	-
cut	0	0	0	0	0	0	-	-	-
date	2	0	0	0	0	2	1.000	1.000	1.000

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Table 24: Varnode recovery (metatype = UNION) (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
dd	0	0	0	0	0	0	-	-	-
df	0	0	0	0	0	0	-	-	-
dir	0	0	0	0	0	0	-	-	-
dircolors	0	0	0	0	0	0	-	-	-
dirname	0	0	0	0	0	0	-	-	-
du	0	0	0	0	0	0	-	-	-
echo	0	0	0	0	0	0	-	-	-
env	0	0	0	0	0	0	-	-	-
expand	0	0	0	0	0	0	-	-	-
expr	0	0	0	0	0	0	-	-	-
factor	1	0	0	0	0	1	1.000	1.000	1.000
false	0	0	0	0	0	0	-	-	-
fmt	0	0	0	0	0	0	-	-	-
fold	0	0	0	0	0	0	-	-	-
groups	0	0	0	0	0	0	-	-	-
head	0	0	0	0	0	0	-	-	-
hostid	0	0	0	0	0	0	-	-	-
id	0	0	0	0	0	0	-	-	-

Continued on next page

Table 24: Varnode recovery (metatype = UNION) (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
join	0	0	0	0	0	0	-	-	-
kill	0	0	0	0	0	0	-	-	-
link	0	0	0	0	0	0	-	-	-
ln	0	0	0	0	0	0	-	-	-
logname	0	0	0	0	0	0	-	-	-
ls	0	0	0	0	0	0	-	-	-
md5sum	0	0	0	0	0	0	-	-	-
mkdir	0	0	0	0	0	0	-	-	-
mkfifo	0	0	0	0	0	0	-	-	-
mknod	0	0	0	0	0	0	-	-	-
mktemp	0	0	0	0	0	0	-	-	-
mv	1	0	0	0	0	1	1.000	1.000	1.000
nice	0	0	0	0	0	0	-	-	-
nl	0	0	0	0	0	0	-	-	-
nohup	0	0	0	0	0	0	-	-	-
nproc	0	0	0	0	0	0	-	-	-
numfmt	0	0	0	0	0	0	-	-	-
od	8	0	0	0	0	8	1.000	1.000	1.000

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Table 24: Varnode recovery (metatype = UNION) (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
paste	0	0	0	0	0	0	-	-	-
pathchk	0	0	0	0	0	0	-	-	-
pinky	0	0	0	0	0	0	-	-	-
pr	0	0	0	0	0	0	-	-	-
printenv	0	0	0	0	0	0	-	-	-
printf	0	0	0	0	0	0	-	-	-
ptx	1	0	0	0	0	1	1.000	1.000	1.000
pwd	0	0	0	0	0	0	-	-	-
readlink	0	0	0	0	0	0	-	-	-
realpath	0	0	0	0	0	0	-	-	-
rm	0	0	0	0	0	0	-	-	-
rmdir	0	0	0	0	0	0	-	-	-
runcon	0	0	0	0	0	0	-	-	-
seq	0	0	0	0	0	0	-	-	-
sha1sum	0	0	0	0	0	0	-	-	-
sha224sum	0	0	0	0	0	0	-	-	-
sha256sum	0	0	0	0	0	0	-	-	-
sha384sum	0	0	0	0	0	0	-	-	-

Continued on next page

Table 24: Varnode recovery (metatype = UNION) (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
sha512sum	0	0	0	0	0	0	-	-	-
shred	0	0	0	0	0	0	-	-	-
shuf	0	0	0	0	0	0	-	-	-
sleep	0	0	0	0	0	0	-	-	-
sort	0	0	0	0	0	0	-	-	-
split	0	0	0	0	0	0	-	-	-
stat	0	0	0	0	0	0	-	-	-
stdbuf	0	0	0	0	0	0	-	-	-
stty	0	0	0	0	0	0	-	-	-
sum	0	0	0	0	0	0	-	-	-
sync	0	0	0	0	0	0	-	-	-
tac	0	0	0	0	0	0	-	-	-
tail	0	0	0	0	0	0	-	-	-
tee	0	0	0	0	0	0	-	-	-
test	0	0	0	0	0	0	-	-	-
timeout	0	0	0	0	0	0	-	-	-
touch	2	0	0	0	2	0	0.750	1.000	0.000
tr	0	0	0	0	0	0	-	-	-

Continued on next page

Table 24: Varnode recovery (metatype = UNION) (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
true	0	0	0	0	0	0	-	-	-
truncate	0	0	0	0	0	0	-	-	-
tsort	0	0	0	0	0	0	-	-	-
tty	0	0	0	0	0	0	-	-	-
uname	0	0	0	0	0	0	-	-	-
unexpand	0	0	0	0	0	0	-	-	-
uniq	0	0	0	0	0	0	-	-	-
unlink	0	0	0	0	0	0	-	-	-
uptime	0	0	0	0	0	0	-	-	-
users	0	0	0	0	0	0	-	-	-
vdir	0	0	0	0	0	0	-	-	-
wc	0	0	0	0	0	0	-	-	-
who	0	0	0	0	0	0	-	-	-
whoami	0	0	0	0	0	0	-	-	-
yes	0	0	0	0	0	0	-	-	-

Table 25: Decomposed varnode recovery (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average comparison score	Varnode fraction partially recovered	Varnode fraction exactly recovered
[	1190	391	129	0	233	437	0.541	0.671	0.367
b2sum	1954	607	174	0	775	398	0.523	0.689	0.204
base32	1169	647	82	0	102	338	0.372	0.447	0.289
base64	1197	679	78	0	102	338	0.363	0.433	0.282
basename	844	359	74	0	98	313	0.480	0.575	0.371
basenc	1847	1276	76	0	128	367	0.261	0.309	0.199
cat	933	394	78	0	129	332	0.480	0.578	0.356
chcon	17348	436	79	0	16395	438	0.735	0.975	0.025
chgrp	1264	463	83	0	291	427	0.527	0.634	0.338
chmod	1305	493	85	0	292	435	0.517	0.622	0.333
chown	1308	466	82	0	320	440	0.536	0.644	0.336
chroot	933	359	75	0	129	370	0.520	0.615	0.397
cksum	31618	11527	17077	0	2434	580	0.211	0.635	0.018
comm	998	367	98	0	202	331	0.508	0.632	0.332
cp	4028	1852	249	0	474	1453	0.464	0.540	0.361
csplit	5511	819	455	0	1885	2352	0.704	0.851	0.427
cut	5022	381	74	0	4232	335	0.702	0.924	0.067
date	8648	2437	238	0	2928	3045	0.613	0.718	0.352

Continued on next page

Table 25: Decomposed varnode recovery (compilation = stripped)

	Ground truth varn-odes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVER-LAP	Varnodes matched @ level SUB-SET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode aver-age com-par-ison score	Varnode frac-tion par-tially recov-ered	Varnode frac-tion ex-actly recov-ered
dd	6329	1987	128	0	2993	1221	0.553	0.686	0.193
df	3575	514	189	0	1764	1108	0.693	0.856	0.310
dir	39259	9090	178	0	16150	13841	0.662	0.768	0.353
dircolors	5810	5258	77	0	140	335	0.079	0.095	0.058
dirname	832	352	74	0	94	312	0.482	0.577	0.375
du	8012	1042	558	0	2843	3569	0.729	0.870	0.445
echo	810	335	74	0	92	309	0.490	0.586	0.381
env	1464	751	74	0	218	421	0.412	0.487	0.288
expand	898	390	74	0	113	321	0.472	0.566	0.357
expr	5706	930	472	0	2017	2287	0.687	0.837	0.401
factor	4701	3420	335	0	263	683	0.205	0.272	0.145
false	801	335	74	0	87	305	0.485	0.582	0.381
fmt	15915	15374	74	0	132	335	0.028	0.034	0.021
fold	893	394	74	0	101	324	0.468	0.559	0.363
groups	865	368	74	0	101	322	0.481	0.575	0.372
head	33790	392	97	0	24757	8544	0.803	0.988	0.253
hostid	827	347	74	0	97	309	0.484	0.580	0.374
id	1007	438	74	0	144	351	0.474	0.565	0.349

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Table 25: Decomposed varnode recovery (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average comparison score	Varnode fraction partially recovered	Varnode fraction exactly recovered
join	1004	381	76	0	178	369	0.519	0.621	0.368
kill	1325	787	74	0	119	345	0.342	0.406	0.260
link	826	347	74	0	96	309	0.484	0.580	0.374
ln	1991	604	142	0	263	982	0.610	0.697	0.493
logname	827	347	74	0	97	309	0.484	0.580	0.374
ls	39259	9090	178	0	16150	13841	0.662	0.768	0.353
md5sum	1170	467	154	0	199	350	0.460	0.601	0.299
mkdir	3260	449	118	0	2208	485	0.666	0.862	0.149
mkfifo	938	404	80	0	108	346	0.477	0.569	0.369
mknod	955	404	80	0	111	360	0.485	0.577	0.377
mktemp	971	432	94	0	115	330	0.453	0.555	0.340
mv	4056	1781	270	0	538	1467	0.478	0.561	0.362
nice	837	351	74	0	94	318	0.486	0.581	0.380
nl	6094	1656	453	0	1721	2264	0.602	0.728	0.372
nohup	874	347	74	0	134	319	0.501	0.603	0.365
nproc	865	355	76	0	96	338	0.496	0.590	0.391
numfmt	1280	447	142	0	163	528	0.536	0.651	0.412
od	11965	698	117	0	10606	544	0.713	0.942	0.045

Continued on next page

Table 25: Decomposed varnode recovery (compilation = stripped)

	Ground truth varn-odes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVER-LAP	Varnodes matched @ level SUB-SET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode aver-age com-par-ison score	Varnode frac-tion par-tially recov-ered	Varnode frac-tion ex-actly recov-ered
paste	857	359	74	0	106	318	0.485	0.581	0.371
pathchk	869	353	96	0	107	313	0.480	0.594	0.360
pinky	3335	425	81	0	2212	617	0.689	0.873	0.185
pr	2854	529	138	0	397	1790	0.744	0.815	0.627
printenv	826	351	74	0	89	312	0.481	0.575	0.378
printf	3369	518	120	0	2194	537	0.657	0.846	0.159
ptx	7315	2390	623	0	1869	2433	0.546	0.673	0.333
pwd	969	445	80	0	109	335	0.451	0.541	0.346
readlink	1146	386	99	0	162	499	0.563	0.663	0.435
realpath	1051	410	102	0	163	376	0.498	0.610	0.358
rm	1276	457	121	0	268	430	0.518	0.642	0.337
rmdir	3076	386	107	0	2161	422	0.673	0.875	0.137
runcon	844	367	74	0	96	307	0.471	0.565	0.364
seq	1136	396	121	0	174	445	0.533	0.651	0.392
sha1sum	1178	467	158	0	185	368	0.464	0.604	0.312
sha224sum	1315	531	205	0	206	373	0.440	0.596	0.284
sha256sum	1323	531	205	0	214	373	0.442	0.599	0.282
sha384sum	1599	611	205	0	410	373	0.458	0.618	0.233

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Table 25: Decomposed varnode recovery (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average comparison score	Varnode fraction partially recovered	Varnode fraction exactly recovered
sha512sum	1631	611	205	0	442	373	0.463	0.625	0.229
shred	3337	562	90	0	1614	1071	0.690	0.832	0.321
shuf	1168	406	90	0	243	429	0.543	0.652	0.367
sleep	855	347	76	0	107	325	0.496	0.594	0.380
sort	11845	2147	336	0	686	8676	0.783	0.819	0.732
split	1533	780	80	0	242	431	0.413	0.491	0.281
stat	3141	741	189	0	416	1795	0.686	0.764	0.571
stdbuf	2142	375	124	0	1200	443	0.641	0.825	0.207
stty	1868	1102	108	0	197	461	0.340	0.410	0.247
sum	2368	382	79	0	1518	389	0.653	0.839	0.164
sync	847	355	74	0	106	312	0.484	0.581	0.368
tac	13723	9252	453	0	1756	2262	0.269	0.326	0.165
tail	34216	566	120	0	33048	482	0.739	0.983	0.014
tee	9070	367	74	0	8310	319	0.724	0.960	0.035
test	1126	344	129	0	221	432	0.560	0.694	0.384
timeout	1334	682	76	0	130	446	0.422	0.489	0.334
touch	7107	2125	214	0	2824	1944	0.579	0.701	0.274
tr	10204	9337	345	0	143	379	0.056	0.085	0.037

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Table 25: Decomposed varnode recovery (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average comparison score	Varnode fraction partially recovered	Varnode fraction exactly recovered
true	801	335	74	0	87	305	0.485	0.582	0.381
truncate	902	384	90	0	104	324	0.471	0.574	0.359
tsort	876	347	83	0	120	326	0.499	0.604	0.372
tty	825	355	76	0	88	306	0.474	0.570	0.371
uname	1274	410	74	0	92	698	0.617	0.678	0.548
unexpand	874	360	74	0	113	327	0.492	0.588	0.374
uniq	962	401	77	0	138	346	0.487	0.583	0.360
unlink	826	347	74	0	96	309	0.484	0.580	0.374
uptime	10379	380	109	0	256	9634	0.949	0.963	0.928
users	842	347	74	0	106	315	0.490	0.588	0.374
vdir	39259	9090	178	0	16150	13841	0.662	0.768	0.353
wc	33888	444	75	0	32916	453	0.742	0.987	0.013
who	1577	472	119	0	221	765	0.609	0.701	0.485
whoami	829	347	74	0	99	309	0.485	0.581	0.373
yes	841	347	74	0	105	315	0.490	0.587	0.375

Table 26: Decomposed varnode recovery (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
[	1010	379	116	0	171	344	0.496	0.625	0.341
b2sum	1813	567	169	0	719	358	0.518	0.687	0.197
base32	1061	623	77	0	56	305	0.345	0.413	0.287
base64	1089	655	73	0	56	305	0.335	0.399	0.280
basename	739	335	69	0	52	283	0.459	0.547	0.383
basenc	1707	1236	70	0	75	326	0.234	0.276	0.191
cat	817	362	73	0	82	300	0.465	0.557	0.367
chcon	17106	390	70	0	16271	375	0.736	0.977	0.022
chgrp	1026	418	78	0	168	362	0.495	0.593	0.353
chmod	1080	453	80	0	172	375	0.485	0.581	0.347
chown	1059	420	77	0	192	370	0.504	0.603	0.349
chroot	799	335	70	0	79	315	0.490	0.581	0.394
cksum	31380	11445	17069	0	2354	512	0.209	0.635	0.016
comm	870	339	85	0	146	300	0.495	0.610	0.345
cp	3616	1744	244	0	304	1324	0.446	0.518	0.366
csplit	4073	774	181	0	857	2261	0.724	0.810	0.555
cut	4899	347	69	0	4181	302	0.705	0.929	0.062
date	8190	2255	202	0	2841	2892	0.619	0.725	0.353

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Table 26: Decomposed varnode recovery (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
dd	6097	1967	112	0	2915	1103	0.544	0.677	0.181
df	3126	437	170	0	1620	899	0.690	0.860	0.288
dir	38591	8808	167	0	15943	13673	0.665	0.772	0.354
dircolors	5577	5150	72	0	64	291	0.064	0.077	0.052
dirname	737	332	69	0	51	285	0.462	0.550	0.387
du	6328	947	277	0	1709	3395	0.750	0.850	0.537
echo	725	323	69	0	50	283	0.466	0.554	0.390
env	1323	713	69	0	162	379	0.391	0.461	0.286
expand	796	367	69	0	66	294	0.453	0.539	0.369
expr	4280	901	192	0	991	2196	0.698	0.789	0.513
factor	4491	3399	305	0	174	613	0.183	0.243	0.136
false	718	323	69	0	45	281	0.462	0.550	0.391
fmt	13788	13343	69	0	77	299	0.027	0.032	0.022
fold	793	370	69	0	58	296	0.450	0.533	0.373
groups	764	350	69	0	56	289	0.456	0.542	0.378
head	33664	359	92	0	24705	8508	0.804	0.989	0.253
hostid	733	329	69	0	54	281	0.462	0.551	0.383
id	872	406	69	0	95	302	0.448	0.534	0.346

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Table 26: Decomposed varnode recovery (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
join	854	347	71	0	113	323	0.498	0.594	0.378
kill	1222	763	69	0	76	314	0.318	0.376	0.257
link	732	329	69	0	53	281	0.462	0.551	0.384
ln	1704	544	135	0	138	887	0.601	0.681	0.521
logname	732	329	69	0	53	281	0.462	0.551	0.384
ls	38591	8808	167	0	15943	13673	0.665	0.772	0.354
md5sum	1037	429	149	0	142	317	0.444	0.586	0.306
mkdir	3057	423	104	0	2140	390	0.661	0.862	0.128
mkfifo	837	382	75	0	59	321	0.459	0.544	0.384
mknod	849	382	75	0	60	332	0.466	0.550	0.391
mktemp	853	402	89	0	65	297	0.431	0.529	0.348
mv	3668	1719	264	0	323	1362	0.455	0.531	0.371
nice	741	331	69	0	52	289	0.466	0.553	0.390
nl	4669	1596	179	0	722	2172	0.591	0.658	0.465
nohup	767	329	69	0	82	287	0.477	0.571	0.374
nproc	768	333	71	0	54	310	0.479	0.566	0.404
numfmt	1088	379	131	0	104	474	0.537	0.652	0.436
od	11712	659	100	0	10534	419	0.712	0.944	0.036

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Table 26: Decomposed varnode recovery (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
paste	753	335	69	0	60	289	0.466	0.555	0.384
pathchk	771	332	90	0	62	287	0.462	0.569	0.372
pinky	3214	404	76	0	2152	582	0.689	0.874	0.181
pr	2634	461	133	0	308	1732	0.758	0.825	0.658
printenv	732	331	69	0	47	285	0.461	0.548	0.389
printf	3173	505	98	0	2131	439	0.650	0.841	0.138
ptx	5741	2318	337	0	803	2283	0.517	0.596	0.398
pwd	863	423	75	0	57	308	0.428	0.510	0.357
readlink	948	346	92	0	79	431	0.541	0.635	0.455
realpath	844	366	95	0	75	308	0.460	0.566	0.365
rm	1032	409	116	0	140	367	0.485	0.604	0.356
rmdir	2886	360	94	0	2103	329	0.669	0.875	0.114
runcon	737	339	69	0	47	282	0.454	0.540	0.383
seq	921	372	96	0	112	341	0.488	0.596	0.370
sha1sum	1046	429	153	0	129	335	0.449	0.590	0.320
sha224sum	1182	493	200	0	149	340	0.424	0.583	0.288
sha256sum	1190	493	200	0	157	340	0.427	0.586	0.286
sha384sum	1466	573	200	0	353	340	0.447	0.609	0.232

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Table 26: Decomposed varnode recovery (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
sha512sum	1498	573	200	0	385	340	0.453	0.617	0.227
shred	3159	523	82	0	1532	1022	0.694	0.834	0.324
shuf	942	370	84	0	137	351	0.504	0.607	0.373
sleep	748	329	71	0	60	288	0.469	0.560	0.385
sort	11317	2020	320	0	452	8525	0.790	0.822	0.753
split	1369	734	74	0	176	385	0.391	0.464	0.281
stat	2845	707	174	0	312	1652	0.678	0.751	0.581
stdbuf	1931	348	111	0	1134	338	0.630	0.820	0.175
stty	1527	937	95	0	133	362	0.318	0.386	0.237
sum	2233	358	71	0	1461	343	0.652	0.840	0.154
sync	751	333	69	0	61	288	0.467	0.557	0.383
tac	12312	9213	179	0	744	2176	0.226	0.252	0.177
tail	33975	516	113	0	32951	395	0.740	0.985	0.012
tee	8961	339	69	0	8261	292	0.726	0.962	0.033
test	959	332	116	0	169	342	0.519	0.654	0.357
timeout	1210	654	71	0	81	404	0.399	0.460	0.334
touch	6684	1960	179	0	2744	1801	0.584	0.707	0.269
tr	10057	9300	332	0	82	343	0.048	0.075	0.034

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Table 26: Decomposed varnode recovery (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
true	718	323	69	0	45	281	0.462	0.550	0.391
truncate	801	358	85	0	60	298	0.455	0.553	0.372
tsort	757	329	77	0	62	289	0.469	0.565	0.382
tty	731	333	71	0	46	281	0.456	0.544	0.384
uname	1155	365	69	0	48	673	0.629	0.684	0.583
unexpand	769	335	69	0	66	299	0.476	0.564	0.389
uniq	818	356	72	0	84	306	0.473	0.565	0.374
unlink	732	329	69	0	53	281	0.462	0.551	0.384
uptime	10247	360	104	0	191	9592	0.953	0.965	0.936
users	739	329	69	0	56	285	0.466	0.555	0.386
vdir	38591	8808	167	0	15943	13673	0.665	0.772	0.354
wc	33696	386	71	0	32838	401	0.743	0.989	0.012
who	1345	421	106	0	154	664	0.599	0.687	0.494
whoami	734	329	69	0	55	281	0.463	0.552	0.383
yes	742	329	69	0	59	285	0.467	0.557	0.384

Table 27: Decomposed varnode recovery (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
[	2	0	1	0	1	0	0.500	1.000	0.000
b2sum	0	0	0	0	0	0	-	-	-
base32	0	0	0	0	0	0	-	-	-
base64	0	0	0	0	0	0	-	-	-
basename	0	0	0	0	0	0	-	-	-
basenc	0	0	0	0	0	0	-	-	-
cat	0	0	0	0	0	0	-	-	-
chcon	7	4	0	0	3	0	0.321	0.429	0.000
chgrp	7	4	0	0	3	0	0.321	0.429	0.000
chmod	7	4	0	0	3	0	0.321	0.429	0.000
chown	7	4	0	0	3	0	0.321	0.429	0.000
chroot	0	0	0	0	0	0	-	-	-
cksum	3	0	3	0	0	0	0.250	1.000	0.000
comm	0	0	0	0	0	0	-	-	-
cp	7	4	0	0	3	0	0.321	0.429	0.000
csplit	0	0	0	0	0	0	-	-	-
cut	0	0	0	0	0	0	-	-	-
date	2	0	1	0	1	0	0.500	1.000	0.000

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Table 27: Decomposed varnode recovery (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
dd	7	0	4	0	3	0	0.464	1.000	0.000
df	17	4	4	0	4	5	0.529	0.765	0.294
dir	10	4	3	0	3	0	0.300	0.600	0.000
dircolors	0	0	0	0	0	0	-	-	-
dirname	0	0	0	0	0	0	-	-	-
du	10	4	3	0	3	0	0.300	0.600	0.000
echo	0	0	0	0	0	0	-	-	-
env	0	0	0	0	0	0	-	-	-
expand	0	0	0	0	0	0	-	-	-
expr	0	0	0	0	0	0	-	-	-
factor	0	0	0	0	0	0	-	-	-
false	0	0	0	0	0	0	-	-	-
fmt	0	0	0	0	0	0	-	-	-
fold	0	0	0	0	0	0	-	-	-
groups	0	0	0	0	0	0	-	-	-
head	0	0	0	0	0	0	-	-	-
hostid	0	0	0	0	0	0	-	-	-
id	0	0	0	0	0	0	-	-	-

Continued on next page

Table 27: Decomposed varnode recovery (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
join	0	0	0	0	0	0	-	-	-
kill	0	0	0	0	0	0	-	-	-
link	0	0	0	0	0	0	-	-	-
ln	7	4	0	0	3	0	0.321	0.429	0.000
logname	0	0	0	0	0	0	-	-	-
ls	10	4	3	0	3	0	0.300	0.600	0.000
md5sum	0	0	0	0	0	0	-	-	-
mkdir	2	0	1	0	1	0	0.500	1.000	0.000
mkfifo	0	0	0	0	0	0	-	-	-
mknod	0	0	0	0	0	0	-	-	-
mktemp	0	0	0	0	0	0	-	-	-
mv	7	4	0	0	3	0	0.321	0.429	0.000
nice	0	0	0	0	0	0	-	-	-
nl	0	0	0	0	0	0	-	-	-
nohup	0	0	0	0	0	0	-	-	-
nproc	0	0	0	0	0	0	-	-	-
numfmt	7	0	6	0	1	0	0.321	1.000	0.000
od	11	0	4	0	7	0	0.568	1.000	0.000

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Table 27: Decomposed varnode recovery (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
paste	0	0	0	0	0	0	-	-	-
pathchk	0	0	0	0	0	0	-	-	-
pinky	0	0	0	0	0	0	-	-	-
pr	0	0	0	0	0	0	-	-	-
printenv	0	0	0	0	0	0	-	-	-
printf	7	0	6	0	1	0	0.321	1.000	0.000
ptx	0	0	0	0	0	0	-	-	-
pwd	0	0	0	0	0	0	-	-	-
readlink	7	4	0	0	3	0	0.321	0.429	0.000
realpath	7	4	0	0	3	0	0.321	0.429	0.000
rm	7	4	0	0	3	0	0.321	0.429	0.000
rmdir	2	0	1	0	1	0	0.500	1.000	0.000
runcon	0	0	0	0	0	0	-	-	-
seq	14	0	13	0	1	0	0.286	1.000	0.000
sha1sum	0	0	0	0	0	0	-	-	-
sha224sum	0	0	0	0	0	0	-	-	-
sha256sum	0	0	0	0	0	0	-	-	-
sha384sum	0	0	0	0	0	0	-	-	-

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Table 27: Decomposed varnode recovery (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
sha512sum	0	0	0	0	0	0	-	-	-
shred	3	0	3	0	0	0	0.250	1.000	0.000
shuf	7	4	0	0	3	0	0.321	0.429	0.000
sleep	7	0	0	0	2	5	0.929	1.000	0.714
sort	22	4	5	0	11	2	0.523	0.818	0.091
split	0	0	0	0	0	0	-	-	-
stat	2	0	1	0	1	0	0.500	1.000	0.000
stdbuf	2	0	1	0	1	0	0.500	1.000	0.000
stty	2	0	1	0	1	0	0.500	1.000	0.000
sum	3	0	3	0	0	0	0.250	1.000	0.000
sync	0	0	0	0	0	0	-	-	-
tac	0	0	0	0	0	0	-	-	-
tail	15	4	0	0	6	5	0.633	0.733	0.333
tee	0	0	0	0	0	0	-	-	-
test	2	0	1	0	1	0	0.500	1.000	0.000
timeout	8	0	0	0	4	4	0.875	1.000	0.500
touch	2	0	1	0	1	0	0.500	1.000	0.000
tr	0	0	0	0	0	0	-	-	-

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Table 27: Decomposed varnode recovery (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
true	0	0	0	0	0	0	-	-	-
truncate	0	0	0	0	0	0	-	-	-
tsort	0	0	0	0	0	0	-	-	-
tty	0	0	0	0	0	0	-	-	-
uname	0	0	0	0	0	0	-	-	-
unexpand	0	0	0	0	0	0	-	-	-
uniq	0	0	0	0	0	0	-	-	-
unlink	0	0	0	0	0	0	-	-	-
uptime	5	0	0	0	4	1	0.800	1.000	0.200
users	0	0	0	0	0	0	-	-	-
vdir	10	4	3	0	3	0	0.300	0.600	0.000
wc	4	0	0	0	4	0	0.750	1.000	0.000
who	2	0	1	0	1	0	0.500	1.000	0.000
whoami	0	0	0	0	0	0	-	-	-
yes	0	0	0	0	0	0	-	-	-

Table 28: Decomposed varnode recovery (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
[	170	12	4	0	61	93	0.822	0.929	0.547
b2sum	140	40	4	0	56	40	0.593	0.714	0.286
base32	107	24	4	0	46	33	0.640	0.776	0.308
base64	107	24	4	0	46	33	0.640	0.776	0.308
basename	104	24	4	0	46	30	0.630	0.769	0.288
basenc	138	40	4	0	53	41	0.592	0.710	0.297
cat	115	32	4	0	47	32	0.593	0.722	0.278
chcon	234	42	8	0	121	63	0.666	0.821	0.269
chgrp	230	41	4	0	120	65	0.678	0.822	0.283
chmod	217	36	4	0	117	60	0.685	0.834	0.276
chown	241	42	4	0	125	70	0.684	0.826	0.290
chroot	133	24	4	0	50	55	0.703	0.820	0.414
cksum	234	82	4	0	80	68	0.551	0.650	0.291
comm	127	28	12	0	56	31	0.598	0.780	0.244
cp	403	104	4	0	167	128	0.631	0.742	0.318
csplit	1416	44	266	0	1023	83	0.647	0.969	0.059
cut	122	34	4	0	51	33	0.592	0.721	0.270
date	426	182	5	0	86	153	0.513	0.573	0.359

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Table 28: Decomposed varnode recovery (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
dd	216	20	4	0	75	117	0.807	0.907	0.542
df	419	71	6	0	140	202	0.736	0.831	0.482
dir	642	267	7	0	204	164	0.496	0.584	0.255
dircolors	229	105	4	0	76	44	0.445	0.541	0.192
dirname	94	20	4	0	43	27	0.641	0.787	0.287
du	1650	90	267	0	1126	167	0.653	0.945	0.101
echo	84	12	4	0	42	26	0.696	0.857	0.310
env	138	38	4	0	56	40	0.601	0.725	0.290
expand	101	23	4	0	47	27	0.626	0.772	0.267
expr	1399	28	266	0	1021	84	0.655	0.980	0.060
factor	196	21	18	0	88	69	0.712	0.893	0.352
false	82	12	4	0	42	24	0.689	0.854	0.293
fmt	2126	2031	4	0	55	36	0.037	0.045	0.017
fold	99	24	4	0	43	28	0.619	0.758	0.283
groups	100	18	4	0	45	33	0.677	0.820	0.330
head	125	33	4	0	52	36	0.608	0.736	0.288
hostid	93	18	4	0	43	28	0.659	0.806	0.301
id	134	32	4	0	49	49	0.647	0.761	0.366

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Table 28: Decomposed varnode recovery (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
join	149	34	4	0	65	46	0.643	0.772	0.309
kill	102	24	4	0	43	31	0.630	0.765	0.304
link	93	18	4	0	43	28	0.659	0.806	0.301
ln	276	54	5	0	122	95	0.680	0.804	0.344
logname	94	18	4	0	44	28	0.660	0.809	0.298
ls	642	267	7	0	204	164	0.496	0.584	0.255
md5sum	132	38	4	0	57	33	0.581	0.712	0.250
mkdir	192	26	4	0	67	95	0.762	0.865	0.495
mkfifo	100	22	4	0	49	25	0.627	0.780	0.250
mknod	105	22	4	0	51	28	0.640	0.790	0.267
mktemp	117	30	4	0	50	33	0.611	0.744	0.282
mv	379	58	5	0	212	104	0.697	0.847	0.274
nice	95	20	4	0	42	29	0.647	0.789	0.305
nl	1404	59	266	0	994	85	0.639	0.958	0.061
nohup	106	18	4	0	52	32	0.679	0.830	0.302
nproc	96	22	4	0	42	28	0.630	0.771	0.292
numfmt	184	68	4	0	58	54	0.535	0.630	0.293
od	226	39	4	0	64	119	0.743	0.827	0.527

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Table 28: Decomposed varnode recovery (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
paste	103	24	4	0	46	29	0.626	0.767	0.282
pathchk	95	20	4	0	45	26	0.639	0.789	0.274
pinky	120	21	4	0	60	35	0.675	0.825	0.292
pr	218	68	5	0	89	56	0.569	0.688	0.257
printenv	93	20	4	0	42	27	0.640	0.785	0.290
printf	178	13	5	0	62	98	0.819	0.927	0.551
ptx	1540	71	266	0	1060	143	0.652	0.954	0.093
pwd	105	22	4	0	52	27	0.638	0.790	0.257
readlink	187	34	5	0	80	68	0.691	0.818	0.364
realpath	196	38	5	0	85	68	0.679	0.806	0.347
rm	236	44	4	0	125	63	0.668	0.814	0.267
rmdir	180	26	4	0	57	93	0.760	0.856	0.517
runcon	106	28	4	0	49	25	0.592	0.736	0.236
seq	193	24	4	0	61	104	0.781	0.876	0.539
sha1sum	131	38	4	0	56	33	0.580	0.710	0.252
sha224sum	132	38	4	0	57	33	0.581	0.712	0.250
sha256sum	132	38	4	0	57	33	0.581	0.712	0.250
sha384sum	132	38	4	0	57	33	0.581	0.712	0.250

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Table 28: Decomposed varnode recovery (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
sha512sum	132	38	4	0	57	33	0.581	0.712	0.250
shred	174	39	4	0	82	49	0.641	0.776	0.282
shuf	218	32	5	0	103	78	0.718	0.853	0.358
sleep	99	18	4	0	45	32	0.674	0.818	0.323
sort	492	114	9	0	223	146	0.641	0.768	0.297
split	162	46	5	0	66	45	0.591	0.716	0.278
stat	286	34	6	0	103	143	0.775	0.881	0.500
stdbuf	201	27	4	0	65	105	0.770	0.866	0.522
stty	331	165	4	0	63	99	0.445	0.502	0.299
sum	131	24	4	0	57	46	0.685	0.817	0.351
sync	95	22	4	0	45	24	0.618	0.768	0.253
tac	1390	38	266	0	1007	79	0.648	0.973	0.057
tail	225	46	6	0	91	82	0.674	0.796	0.364
tee	108	28	4	0	49	27	0.600	0.741	0.250
test	157	12	4	0	51	90	0.823	0.924	0.573
timeout	113	28	4	0	45	36	0.626	0.752	0.319
touch	391	165	4	0	79	143	0.520	0.578	0.366
tr	146	37	12	0	61	36	0.580	0.747	0.247

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Table 28: Decomposed varnode recovery (compilation = stripped)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
true	82	12	4	0	42	24	0.689	0.854	0.293
truncate	100	26	4	0	44	26	0.600	0.740	0.260
tsort	118	18	5	0	58	37	0.693	0.847	0.314
tty	93	22	4	0	42	25	0.618	0.763	0.269
uname	118	45	4	0	44	25	0.500	0.619	0.212
unexpand	104	25	4	0	47	28	0.618	0.760	0.269
uniq	143	45	4	0	54	40	0.570	0.685	0.280
unlink	93	18	4	0	43	28	0.659	0.806	0.301
uptime	126	20	4	0	61	41	0.696	0.841	0.325
users	102	18	4	0	50	30	0.672	0.824	0.294
vdir	642	267	7	0	204	164	0.496	0.584	0.255
wc	176	49	4	0	74	49	0.599	0.722	0.278
who	222	51	4	0	66	101	0.682	0.770	0.455
whoami	94	18	4	0	44	28	0.660	0.809	0.298
yes	98	18	4	0	46	30	0.668	0.816	0.306

Table 29: Decomposed varnode recovery (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average comparison score	Varnode fraction partially recovered	Varnode fraction exactly recovered
[	1190	47	152	0	484	507	0.763	0.961	0.426
b2sum	1954	47	277	0	1234	396	0.712	0.976	0.203
base32	1169	79	145	0	609	336	0.709	0.932	0.287
base64	1197	47	141	0	673	336	0.732	0.961	0.281
basename	844	47	137	0	349	311	0.719	0.944	0.368
basenc	1847	308	171	0	1003	365	0.628	0.833	0.198
cat	933	47	153	0	390	343	0.722	0.950	0.368
chcon	17348	49	180	0	16645	474	0.750	0.997	0.027
chgrp	1264	50	171	0	539	504	0.752	0.960	0.399
chmod	1305	70	163	0	543	529	0.749	0.946	0.405
chown	1308	49	175	0	566	518	0.754	0.963	0.396
chroot	933	47	138	0	380	368	0.737	0.950	0.394
cksum	31618	8266	19512	0	3271	569	0.250	0.739	0.018
comm	998	47	171	0	451	329	0.711	0.953	0.330
cp	4028	205	399	0	1746	1678	0.766	0.949	0.417
csplit	5511	455	584	0	2122	2350	0.742	0.917	0.426
cut	5022	47	157	0	4485	333	0.744	0.991	0.066
date	8648	338	790	0	4470	3050	0.763	0.961	0.353

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Table 29: Decomposed varnode recovery (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average comparison score	Varnode fraction partially recovered	Varnode fraction exactly recovered
dd	6329	625	208	0	4278	1218	0.708	0.901	0.192
df	3575	49	342	0	2002	1182	0.775	0.986	0.331
dir	39259	4924	745	0	19731	13859	0.735	0.875	0.353
dircolors	5810	4855	238	0	386	331	0.117	0.164	0.057
dirname	832	47	129	0	346	310	0.723	0.944	0.373
du	8012	514	789	0	3107	3602	0.765	0.936	0.450
echo	810	47	113	0	343	307	0.731	0.942	0.379
env	1464	362	197	0	486	419	0.569	0.753	0.286
expand	898	47	135	0	398	318	0.724	0.948	0.354
expr	5706	601	552	0	2268	2285	0.723	0.895	0.400
factor	4701	281	1750	0	1989	681	0.555	0.940	0.145
false	801	47	113	0	338	303	0.730	0.941	0.378
fmt	15915	47	10153	0	5382	333	0.434	0.997	0.021
fold	893	47	137	0	387	322	0.724	0.947	0.361
groups	865	47	125	0	373	320	0.729	0.946	0.370
head	33790	47	155	0	25008	8580	0.810	0.999	0.254
hostid	827	47	125	0	348	307	0.725	0.943	0.371
id	1007	47	153	0	458	349	0.726	0.953	0.347

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Table 29: Decomposed varnode recovery (compilation = standard)

	Ground truth varn-odes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVER-LAP	Varnodes matched @ level SUB-SET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode aver-age com-par-ison score	Varnode frac-tion par-tially recov-ered	Varnode frac-tion ex-actly recov-ered
join	1004	47	166	0	424	367	0.724	0.953	0.366
kill	1325	475	137	0	370	343	0.494	0.642	0.259
link	826	47	125	0	347	307	0.725	0.943	0.372
ln	1991	112	210	0	525	1144	0.799	0.944	0.575
logname	827	47	125	0	348	307	0.725	0.943	0.371
ls	39259	4924	745	0	19731	13859	0.735	0.875	0.353
md5sum	1170	63	245	0	514	348	0.679	0.946	0.297
mkdir	3260	64	182	0	2456	558	0.750	0.980	0.171
mkfifo	938	64	133	0	358	383	0.730	0.932	0.408
mknod	955	64	133	0	361	397	0.734	0.933	0.416
mktemp	971	110	148	0	366	347	0.678	0.887	0.357
mv	4056	257	296	0	1795	1708	0.771	0.937	0.421
nice	837	47	129	0	345	316	0.725	0.944	0.378
nl	6094	478	617	0	2737	2262	0.733	0.922	0.371
nohup	874	47	125	0	385	317	0.729	0.946	0.363
nproc	865	47	133	0	349	336	0.729	0.946	0.388
numfmt	1280	47	297	0	414	522	0.708	0.963	0.408
od	11965	103	313	0	10991	558	0.742	0.991	0.047

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Table 29: Decomposed varnode recovery (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average comparison score	Varnode fraction partially recovered	Varnode fraction exactly recovered
paste	857	47	137	0	357	316	0.721	0.945	0.369
pathchk	869	47	133	0	358	331	0.728	0.946	0.381
pinky	3335	47	137	0	2518	633	0.766	0.986	0.190
pr	2854	102	293	0	651	1808	0.830	0.964	0.633
printenv	826	47	129	0	340	310	0.723	0.943	0.375
printf	3369	222	164	0	2447	536	0.716	0.934	0.159
ptx	7315	663	821	0	3383	2448	0.710	0.909	0.335
pwd	969	47	142	0	358	422	0.749	0.951	0.436
readlink	1146	49	166	0	414	517	0.758	0.957	0.451
realpath	1051	49	174	0	415	413	0.730	0.953	0.393
rm	1276	66	183	0	517	510	0.739	0.948	0.400
rmdir	3076	47	178	0	2412	439	0.745	0.985	0.143
runcon	844	47	145	0	347	305	0.713	0.944	0.361
seq	1136	47	191	0	458	440	0.732	0.959	0.387
sha1sum	1178	63	247	0	502	366	0.683	0.947	0.311
sha224sum	1315	63	360	0	521	371	0.648	0.952	0.282
sha256sum	1323	63	360	0	529	371	0.648	0.952	0.280
sha384sum	1599	143	296	0	789	371	0.648	0.911	0.232

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Table 29: Decomposed varnode recovery (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average comparison score	Varnode fraction partially recovered	Varnode fraction exactly recovered
sha512sum	1631	143	296	0	821	371	0.650	0.912	0.227
shred	3337	112	231	0	1871	1123	0.774	0.966	0.337
shuf	1168	47	160	0	496	465	0.751	0.960	0.398
sleep	855	47	127	0	358	323	0.729	0.945	0.378
sort	11845	269	574	0	2293	8709	0.893	0.977	0.735
split	1533	379	237	0	490	427	0.557	0.753	0.279
stat	3141	225	310	0	785	1821	0.792	0.928	0.580
stdbuf	2142	47	187	0	1449	459	0.743	0.978	0.214
stty	1868	53	697	0	662	456	0.603	0.972	0.244
sum	2368	63	143	0	1778	384	0.740	0.973	0.162
sync	847	47	133	0	357	310	0.721	0.945	0.366
tac	13723	455	556	0	10453	2259	0.746	0.967	0.165
tail	34216	68	203	0	33300	645	0.750	0.998	0.019
tee	9070	47	146	0	8561	316	0.747	0.995	0.035
test	1126	0	152	0	472	502	0.794	1.000	0.446
timeout	1334	362	147	0	381	444	0.575	0.729	0.333
touch	7107	313	733	0	4095	1966	0.735	0.956	0.277
tr	10204	50	424	0	9354	376	0.735	0.995	0.037

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Table 29: Decomposed varnode recovery (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average comparison score	Varnode fraction partially recovered	Varnode fraction exactly recovered
true	801	47	113	0	338	303	0.730	0.941	0.378
truncate	902	47	141	0	355	359	0.732	0.948	0.398
tsort	876	47	132	0	373	324	0.727	0.946	0.370
tty	825	47	133	0	341	304	0.719	0.943	0.368
uname	1274	55	181	0	343	695	0.783	0.957	0.546
unexpand	874	47	139	0	364	324	0.723	0.946	0.371
uniq	962	47	184	0	389	342	0.707	0.951	0.356
unlink	826	47	125	0	347	307	0.725	0.943	0.372
uptime	10379	49	184	0	514	9632	0.970	0.995	0.928
users	842	47	125	0	357	313	0.727	0.944	0.372
vdir	39259	4924	745	0	19731	13859	0.735	0.875	0.353
wc	33888	87	164	0	33168	469	0.749	0.997	0.014
who	1577	47	243	0	505	782	0.775	0.970	0.496
whoami	829	47	125	0	350	307	0.725	0.943	0.370
yes	841	47	125	0	356	313	0.727	0.944	0.372

Table 30: Decomposed varnode recovery (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
[	1010	47	123	0	424	416	0.757	0.953	0.412
b2sum	1813	47	228	0	1180	358	0.717	0.974	0.197
base32	1061	79	112	0	565	305	0.713	0.926	0.287
base64	1089	47	108	0	629	305	0.738	0.957	0.280
basename	739	47	104	0	305	283	0.728	0.936	0.383
basenc	1707	308	121	0	952	326	0.627	0.820	0.191
cat	817	47	112	0	342	316	0.735	0.942	0.387
chcon	17106	47	123	0	16523	413	0.750	0.997	0.024
chgrp	1026	47	120	0	418	441	0.765	0.954	0.430
chmod	1080	68	116	0	425	471	0.758	0.937	0.436
chown	1059	47	122	0	440	450	0.765	0.956	0.425
chroot	799	47	105	0	332	315	0.739	0.941	0.394
cksum	31380	8266	19409	0	3193	512	0.247	0.737	0.016
comm	870	47	126	0	397	300	0.723	0.946	0.345
cp	3616	202	280	0	1579	1555	0.777	0.944	0.430
csplit	4073	444	272	0	1096	2261	0.774	0.891	0.555
cut	4899	47	114	0	4436	302	0.747	0.990	0.062
date	8190	333	557	0	4388	2912	0.774	0.959	0.356

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Table 30: Decomposed varnode recovery (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
dd	6097	625	167	0	4202	1103	0.705	0.897	0.181
df	3126	47	242	0	1860	977	0.778	0.985	0.313
dir	38591	4921	431	0	19529	13710	0.738	0.872	0.355
dircolors	5577	4855	115	0	316	291	0.100	0.129	0.052
dirname	737	47	100	0	305	285	0.731	0.936	0.387
du	6328	500	421	0	1974	3433	0.793	0.921	0.543
echo	725	47	92	0	303	283	0.736	0.935	0.390
env	1323	362	150	0	432	379	0.560	0.726	0.286
expand	796	47	102	0	353	294	0.734	0.941	0.369
expr	4280	590	250	0	1244	2196	0.746	0.862	0.513
factor	4491	280	1694	0	1904	613	0.549	0.938	0.136
false	718	47	92	0	298	281	0.735	0.935	0.391
fmt	13788	47	8112	0	5330	299	0.459	0.997	0.022
fold	793	47	104	0	346	296	0.733	0.941	0.373
groups	764	47	98	0	330	289	0.734	0.938	0.378
head	33664	47	112	0	24958	8547	0.811	0.999	0.254
hostid	733	47	98	0	307	281	0.731	0.936	0.383
id	872	47	112	0	411	302	0.732	0.946	0.346

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Table 30: Decomposed varnode recovery (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
join	854	47	120	0	364	323	0.733	0.945	0.378
kill	1222	475	104	0	329	314	0.480	0.611	0.257
link	732	47	98	0	306	281	0.731	0.936	0.384
ln	1704	110	139	0	402	1053	0.815	0.935	0.618
logname	732	47	98	0	306	281	0.731	0.936	0.384
ls	38591	4921	431	0	19529	13710	0.738	0.872	0.355
md5sum	1037	63	198	0	459	317	0.685	0.939	0.306
mkdir	3057	64	138	0	2390	465	0.750	0.979	0.152
mkfifo	837	64	102	0	311	360	0.739	0.924	0.430
mknod	849	64	102	0	312	371	0.743	0.925	0.437
mktemp	853	110	108	0	318	317	0.683	0.871	0.372
mv	3668	252	227	0	1585	1604	0.777	0.931	0.437
nice	741	47	100	0	305	289	0.732	0.937	0.390
nl	4669	467	289	0	1741	2172	0.760	0.900	0.465
nohup	767	47	98	0	335	287	0.734	0.939	0.374
nproc	768	47	102	0	309	310	0.739	0.939	0.404
numfmt	1088	47	210	0	357	474	0.730	0.957	0.436
od	11712	103	251	0	10921	437	0.742	0.991	0.037

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Table 30: Decomposed varnode recovery (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
paste	753	47	104	0	313	289	0.730	0.938	0.384
pathchk	771	47	102	0	315	307	0.738	0.939	0.398
pinky	3214	47	107	0	2460	600	0.769	0.985	0.187
pr	2634	101	218	0	563	1752	0.846	0.962	0.665
printenv	732	47	100	0	300	285	0.731	0.936	0.389
printf	3173	222	126	0	2386	439	0.712	0.930	0.138
ptx	5741	652	454	0	2334	2301	0.725	0.886	0.401
pwd	863	47	111	0	308	397	0.760	0.946	0.460
readlink	948	47	117	0	333	451	0.770	0.950	0.476
realpath	844	47	121	0	329	347	0.739	0.944	0.411
rm	1032	64	127	0	392	449	0.751	0.938	0.435
rmdir	2886	47	135	0	2356	348	0.745	0.984	0.121
runcon	737	47	108	0	300	282	0.725	0.936	0.383
seq	921	47	138	0	398	338	0.729	0.949	0.367
sha1sum	1046	63	200	0	448	335	0.689	0.940	0.320
sha224sum	1182	63	313	0	466	340	0.650	0.947	0.288
sha256sum	1190	63	313	0	474	340	0.650	0.947	0.286
sha384sum	1466	143	249	0	734	340	0.650	0.902	0.232

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Table 30: Decomposed varnode recovery (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
sha512sum	1498	143	249	0	766	340	0.652	0.905	0.227
shred	3159	112	178	0	1792	1077	0.780	0.965	0.341
shuf	942	47	114	0	393	388	0.755	0.950	0.412
sleep	748	47	100	0	313	288	0.732	0.937	0.385
sort	11317	243	450	0	2063	8561	0.903	0.979	0.756
split	1369	379	181	0	426	383	0.546	0.723	0.280
stat	2845	224	257	0	682	1682	0.794	0.921	0.591
stdbuf	1931	47	139	0	1387	358	0.742	0.976	0.185
stty	1527	53	512	0	600	362	0.616	0.965	0.237
sum	2233	63	104	0	1723	343	0.744	0.972	0.154
sync	751	47	102	0	314	288	0.731	0.937	0.383
tac	12312	444	247	0	9445	2176	0.757	0.964	0.177
tail	33975	68	141	0	33205	561	0.751	0.998	0.017
tee	8961	47	108	0	8514	292	0.748	0.995	0.033
test	959	0	123	0	422	414	0.794	1.000	0.432
timeout	1210	362	110	0	334	404	0.564	0.701	0.334
touch	6684	308	519	0	4017	1840	0.745	0.954	0.275
tr	10057	50	369	0	9295	343	0.736	0.995	0.034

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Table 30: Decomposed varnode recovery (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
true	718	47	92	0	298	281	0.735	0.935	0.391
truncate	801	47	106	0	313	335	0.744	0.941	0.418
tsort	757	47	104	0	317	289	0.730	0.938	0.382
tty	731	47	102	0	301	281	0.728	0.936	0.384
uname	1155	55	126	0	301	673	0.805	0.952	0.583
unexpand	769	47	104	0	319	299	0.734	0.939	0.389
uniq	818	47	128	0	337	306	0.722	0.943	0.374
unlink	732	47	98	0	306	281	0.731	0.936	0.384
uptime	10247	48	157	0	450	9592	0.973	0.995	0.936
users	739	47	98	0	309	285	0.732	0.936	0.386
vdir	38591	4921	431	0	19529	13710	0.738	0.872	0.355
wc	33696	62	124	0	33091	419	0.750	0.998	0.012
who	1345	47	175	0	440	683	0.786	0.965	0.508
whoami	734	47	98	0	308	281	0.731	0.936	0.383
yes	742	47	98	0	312	285	0.732	0.937	0.384

Table 31: Decomposed varnode recovery (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
[	2	0	1	0	1	0	0.500	1.000	0.000
b2sum	0	0	0	0	0	0	-	-	-
base32	0	0	0	0	0	0	-	-	-
base64	0	0	0	0	0	0	-	-	-
basename	0	0	0	0	0	0	-	-	-
basenc	0	0	0	0	0	0	-	-	-
cat	0	0	0	0	0	0	-	-	-
chcon	7	0	4	0	3	0	0.464	1.000	0.000
chgrp	7	0	4	0	3	0	0.464	1.000	0.000
chmod	7	0	4	0	3	0	0.464	1.000	0.000
chown	7	0	4	0	3	0	0.464	1.000	0.000
chroot	0	0	0	0	0	0	-	-	-
cksum	3	0	3	0	0	0	0.250	1.000	0.000
comm	0	0	0	0	0	0	-	-	-
cp	7	0	4	0	3	0	0.464	1.000	0.000
csplit	0	0	0	0	0	0	-	-	-
cut	0	0	0	0	0	0	-	-	-
date	2	0	1	0	1	0	0.500	1.000	0.000

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Table 31: Decomposed varnode recovery (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
dd	7	0	4	0	3	0	0.464	1.000	0.000
df	17	0	8	0	4	5	0.588	1.000	0.294
dir	10	0	7	0	3	0	0.400	1.000	0.000
dircolors	0	0	0	0	0	0	-	-	-
dirname	0	0	0	0	0	0	-	-	-
du	10	0	7	0	3	0	0.400	1.000	0.000
echo	0	0	0	0	0	0	-	-	-
env	0	0	0	0	0	0	-	-	-
expand	0	0	0	0	0	0	-	-	-
expr	0	0	0	0	0	0	-	-	-
factor	0	0	0	0	0	0	-	-	-
false	0	0	0	0	0	0	-	-	-
fmt	0	0	0	0	0	0	-	-	-
fold	0	0	0	0	0	0	-	-	-
groups	0	0	0	0	0	0	-	-	-
head	0	0	0	0	0	0	-	-	-
hostid	0	0	0	0	0	0	-	-	-
id	0	0	0	0	0	0	-	-	-

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Table 31: Decomposed varnode recovery (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
join	0	0	0	0	0	0	-	-	-
kill	0	0	0	0	0	0	-	-	-
link	0	0	0	0	0	0	-	-	-
ln	7	0	4	0	3	0	0.464	1.000	0.000
logname	0	0	0	0	0	0	-	-	-
ls	10	0	7	0	3	0	0.400	1.000	0.000
md5sum	0	0	0	0	0	0	-	-	-
mkdir	2	0	1	0	1	0	0.500	1.000	0.000
mkfifo	0	0	0	0	0	0	-	-	-
mknod	0	0	0	0	0	0	-	-	-
mktemp	0	0	0	0	0	0	-	-	-
mv	7	0	4	0	3	0	0.464	1.000	0.000
nice	0	0	0	0	0	0	-	-	-
nl	0	0	0	0	0	0	-	-	-
nohup	0	0	0	0	0	0	-	-	-
nproc	0	0	0	0	0	0	-	-	-
numfmt	7	0	6	0	1	0	0.321	1.000	0.000
od	11	0	4	0	7	0	0.568	1.000	0.000

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Table 31: Decomposed varnode recovery (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
paste	0	0	0	0	0	0	-	-	-
pathchk	0	0	0	0	0	0	-	-	-
pinky	0	0	0	0	0	0	-	-	-
pr	0	0	0	0	0	0	-	-	-
printenv	0	0	0	0	0	0	-	-	-
printf	7	0	6	0	1	0	0.321	1.000	0.000
ptx	0	0	0	0	0	0	-	-	-
pwd	0	0	0	0	0	0	-	-	-
readlink	7	0	4	0	3	0	0.464	1.000	0.000
realpath	7	0	4	0	3	0	0.464	1.000	0.000
rm	7	0	4	0	3	0	0.464	1.000	0.000
rmdir	2	0	1	0	1	0	0.500	1.000	0.000
runcon	0	0	0	0	0	0	-	-	-
seq	14	0	13	0	1	0	0.286	1.000	0.000
sha1sum	0	0	0	0	0	0	-	-	-
sha224sum	0	0	0	0	0	0	-	-	-
sha256sum	0	0	0	0	0	0	-	-	-
sha384sum	0	0	0	0	0	0	-	-	-

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Table 31: Decomposed varnode recovery (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
sha512sum	0	0	0	0	0	0	-	-	-
shred	3	0	3	0	0	0	0.250	1.000	0.000
shuf	7	0	4	0	3	0	0.464	1.000	0.000
sleep	7	0	0	0	2	5	0.929	1.000	0.714
sort	22	0	9	0	11	2	0.568	1.000	0.091
split	0	0	0	0	0	0	-	-	-
stat	2	0	1	0	1	0	0.500	1.000	0.000
stdbuf	2	0	1	0	1	0	0.500	1.000	0.000
stty	2	0	1	0	1	0	0.500	1.000	0.000
sum	3	0	3	0	0	0	0.250	1.000	0.000
sync	0	0	0	0	0	0	-	-	-
tac	0	0	0	0	0	0	-	-	-
tail	15	0	4	0	6	5	0.700	1.000	0.333
tee	0	0	0	0	0	0	-	-	-
test	2	0	1	0	1	0	0.500	1.000	0.000
timeout	8	0	0	0	4	4	0.875	1.000	0.500
touch	2	0	1	0	1	0	0.500	1.000	0.000
tr	0	0	0	0	0	0	-	-	-

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Table 31: Decomposed varnode recovery (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
true	0	0	0	0	0	0	-	-	-
truncate	0	0	0	0	0	0	-	-	-
tsort	0	0	0	0	0	0	-	-	-
tty	0	0	0	0	0	0	-	-	-
uname	0	0	0	0	0	0	-	-	-
unexpand	0	0	0	0	0	0	-	-	-
uniq	0	0	0	0	0	0	-	-	-
unlink	0	0	0	0	0	0	-	-	-
uptime	5	0	0	0	4	1	0.800	1.000	0.200
users	0	0	0	0	0	0	-	-	-
vdir	10	0	7	0	3	0	0.400	1.000	0.000
wc	4	0	0	0	4	0	0.750	1.000	0.000
who	2	0	1	0	1	0	0.500	1.000	0.000
whoami	0	0	0	0	0	0	-	-	-
yes	0	0	0	0	0	0	-	-	-

Table 32: Decomposed varnode recovery (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
[	170	0	20	0	59	91	0.825	1.000	0.535
b2sum	140	0	48	0	54	38	0.646	1.000	0.271
base32	107	0	32	0	44	31	0.673	1.000	0.290
base64	107	0	32	0	44	31	0.673	1.000	0.290
basename	104	0	32	0	44	28	0.663	1.000	0.269
basenc	138	0	48	0	51	39	0.647	1.000	0.283
cat	115	0	40	0	48	27	0.635	1.000	0.235
chcon	234	2	52	0	119	61	0.698	0.991	0.261
chgrp	230	3	46	0	118	63	0.709	0.987	0.274
chmod	217	2	42	0	115	58	0.713	0.991	0.267
chown	241	2	48	0	123	68	0.715	0.992	0.282
chroot	133	0	32	0	48	53	0.729	1.000	0.398
cksum	234	0	99	0	78	57	0.599	1.000	0.244
comm	127	0	44	0	54	29	0.634	1.000	0.228
cp	403	3	114	0	164	122	0.679	0.993	0.303
csplit	1416	10	304	0	1021	81	0.652	0.993	0.057
cut	122	0	42	0	49	31	0.641	1.000	0.254
date	426	5	202	0	81	138	0.585	0.988	0.324

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Table 32: Decomposed varnode recovery (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
dd	216	0	29	0	73	114	0.815	1.000	0.528
df	419	0	83	0	138	198	0.769	1.000	0.473
dir	642	1	297	0	199	145	0.574	0.998	0.226
dircolors	229	0	119	0	70	40	0.534	1.000	0.175
dirname	94	0	28	0	41	25	0.668	1.000	0.266
du	1650	13	350	0	1125	162	0.663	0.992	0.098
echo	84	0	20	0	40	24	0.702	1.000	0.286
env	138	0	46	0	54	38	0.652	1.000	0.275
expand	101	0	32	0	45	24	0.651	1.000	0.238
expr	1399	10	288	0	1019	82	0.656	0.993	0.059
factor	196	1	44	0	84	67	0.719	0.995	0.342
false	82	0	20	0	40	22	0.695	1.000	0.268
fmt	2126	0	2040	0	52	34	0.274	1.000	0.016
fold	99	0	32	0	41	26	0.654	1.000	0.263
groups	100	0	26	0	43	31	0.698	1.000	0.310
head	125	0	42	0	50	33	0.648	1.000	0.264
hostid	93	0	26	0	41	26	0.680	1.000	0.280
id	134	0	40	0	47	47	0.688	1.000	0.351

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Table 32: Decomposed varnode recovery (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
join	149	0	45	0	60	44	0.673	1.000	0.295
kill	102	0	32	0	41	29	0.664	1.000	0.284
link	93	0	26	0	41	26	0.680	1.000	0.280
ln	276	0	65	0	120	91	0.715	1.000	0.330
logname	94	0	26	0	42	26	0.681	1.000	0.277
ls	642	1	297	0	199	145	0.574	0.998	0.226
md5sum	132	0	46	0	55	31	0.634	1.000	0.235
mkdir	192	0	34	0	65	93	0.783	1.000	0.484
mkfifo	100	0	30	0	47	23	0.657	1.000	0.230
mknod	105	0	30	0	49	26	0.669	1.000	0.248
mktemp	117	0	39	0	48	30	0.647	1.000	0.256
mv	379	5	64	0	207	103	0.724	0.987	0.272
nice	95	0	28	0	40	27	0.674	1.000	0.284
nl	1404	10	320	0	991	83	0.645	0.993	0.059
nohup	106	0	26	0	50	30	0.698	1.000	0.283
nproc	96	0	30	0	40	26	0.661	1.000	0.271
numfmt	184	0	80	0	56	48	0.598	1.000	0.261
od	226	0	49	0	62	115	0.769	1.000	0.509

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Table 32: Decomposed varnode recovery (compilation = standard)

	Ground truth varn-odes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVER-LAP	Varnodes matched @ level SUB-SET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode aver-age com-pare score	Varnode frac-tion par-tially recov-ered	Varnode frac-tion ex-actly recov-ered
paste	103	0	32	0	44	27	0.660	1.000	0.262
pathchk	95	0	28	0	43	24	0.666	1.000	0.253
pinky	120	0	29	0	58	33	0.698	1.000	0.275
pr	218	1	75	0	88	54	0.636	0.995	0.248
printenv	93	0	28	0	40	25	0.667	1.000	0.269
printf	178	0	21	0	60	97	0.827	1.000	0.545
ptx	1540	10	347	0	1043	140	0.655	0.994	0.091
pwd	105	0	30	0	50	25	0.667	1.000	0.238
readlink	187	0	43	0	78	66	0.723	1.000	0.353
realpath	196	0	47	0	83	66	0.714	1.000	0.337
rm	236	2	51	0	122	61	0.700	0.992	0.258
rmdir	180	0	34	0	55	91	0.782	1.000	0.506
runcon	106	0	36	0	47	23	0.634	1.000	0.217
seq	193	0	32	0	59	102	0.799	1.000	0.528
sha1sum	131	0	46	0	54	31	0.634	1.000	0.237
sha224sum	132	0	46	0	55	31	0.634	1.000	0.235
sha256sum	132	0	46	0	55	31	0.634	1.000	0.235
sha384sum	132	0	46	0	55	31	0.634	1.000	0.235

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Table 32: Decomposed varnode recovery (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
sha512sum	132	0	46	0	55	31	0.634	1.000	0.235
shred	174	0	49	0	79	46	0.675	1.000	0.264
shuf	218	0	41	0	100	77	0.744	1.000	0.353
sleep	99	0	26	0	43	30	0.694	1.000	0.303
sort	492	17	113	0	219	143	0.682	0.965	0.291
split	162	0	55	0	64	43	0.647	1.000	0.265
stat	286	1	44	0	102	139	0.792	0.997	0.486
stdbuf	201	0	39	0	61	101	0.779	1.000	0.502
stty	331	0	176	0	61	94	0.555	1.000	0.284
sum	131	0	35	0	55	41	0.695	1.000	0.313
sync	95	0	30	0	43	22	0.650	1.000	0.232
tac	1390	10	301	0	1003	76	0.650	0.993	0.055
tail	225	0	57	0	89	79	0.711	1.000	0.351
tee	108	0	37	0	47	24	0.634	1.000	0.222
test	157	0	20	0	49	88	0.826	1.000	0.561
timeout	113	0	36	0	43	34	0.666	1.000	0.301
touch	391	5	183	0	77	126	0.587	0.987	0.322
tr	146	0	54	0	59	33	0.622	1.000	0.226

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Table 32: Decomposed varnode recovery (compilation = standard)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
true	82	0	20	0	40	22	0.695	1.000	0.268
truncate	100	0	34	0	42	24	0.640	1.000	0.240
tsort	118	0	27	0	56	35	0.710	1.000	0.297
tty	93	0	30	0	40	23	0.651	1.000	0.247
uname	118	0	54	0	42	22	0.568	1.000	0.186
unexpand	104	0	34	0	45	25	0.647	1.000	0.240
uniq	143	0	55	0	52	36	0.621	1.000	0.252
unlink	93	0	26	0	41	26	0.680	1.000	0.280
uptime	126	1	26	0	60	39	0.718	0.992	0.310
users	102	0	26	0	48	28	0.691	1.000	0.275
vdir	642	1	297	0	199	145	0.574	0.998	0.226
wc	176	16	40	0	73	47	0.635	0.909	0.267
who	222	0	59	0	64	99	0.729	1.000	0.446
whoami	94	0	26	0	42	26	0.681	1.000	0.277
yes	98	0	26	0	44	28	0.689	1.000	0.286

Table 33: Decomposed varnode recovery (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average comparison score	Varnode fraction partially recovered	Varnode fraction exactly recovered
[	1190	0	0	0	0	1190	1.000	1.000	1.000
b2sum	1954	0	0	0	0	1954	1.000	1.000	1.000
base32	1169	0	0	0	0	1169	1.000	1.000	1.000
base64	1197	0	0	0	0	1197	1.000	1.000	1.000
basename	844	0	0	0	0	844	1.000	1.000	1.000
basenc	1847	0	0	0	0	1847	1.000	1.000	1.000
cat	933	0	0	0	0	933	1.000	1.000	1.000
chcon	17348	0	0	0	0	17348	1.000	1.000	1.000
chgrp	1264	0	0	0	0	1264	1.000	1.000	1.000
chmod	1305	0	0	0	0	1305	1.000	1.000	1.000
chown	1308	0	0	0	0	1308	1.000	1.000	1.000
chroot	933	0	1	0	0	932	0.999	1.000	0.999
cksum	31618	0	0	0	0	31618	1.000	1.000	1.000
comm	998	0	0	0	0	998	1.000	1.000	1.000
cp	4028	0	2	0	2	4024	1.000	1.000	0.999
csplit	5511	295	2	0	0	5214	0.946	0.946	0.946
cut	5022	0	0	0	0	5022	1.000	1.000	1.000
date	8648	9	6	0	0	8633	0.998	0.999	0.998

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Table 33: Decomposed varnode recovery (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average comparison score	Varnode fraction partially recovered	Varnode fraction exactly recovered
dd	6329	0	0	0	0	6329	1.000	1.000	1.000
df	3575	0	7	0	0	3568	0.999	1.000	0.998
dir	39259	1255	21	0	0	37983	0.968	0.968	0.967
dircolors	5810	3	0	0	0	5807	0.999	0.999	0.999
dirname	832	0	0	0	0	832	1.000	1.000	1.000
du	8012	295	3	0	0	7714	0.963	0.963	0.963
echo	810	0	0	0	0	810	1.000	1.000	1.000
env	1464	0	0	0	0	1464	1.000	1.000	1.000
expand	898	0	0	0	0	898	1.000	1.000	1.000
expr	5706	302	2	0	0	5402	0.947	0.947	0.947
factor	4701	53	7	0	0	4641	0.988	0.989	0.987
false	801	0	0	0	0	801	1.000	1.000	1.000
fmt	15915	4000	0	0	0	11915	0.749	0.749	0.749
fold	893	0	0	0	0	893	1.000	1.000	1.000
groups	865	0	0	0	0	865	1.000	1.000	1.000
head	33790	0	0	0	0	33790	1.000	1.000	1.000
hostid	827	0	0	0	0	827	1.000	1.000	1.000
id	1007	0	0	0	0	1007	1.000	1.000	1.000

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Table 33: Decomposed varnode recovery (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average comparison score	Varnode fraction partially recovered	Varnode fraction exactly recovered
join	1004	0	0	0	0	1004	1.000	1.000	1.000
kill	1325	0	0	0	0	1325	1.000	1.000	1.000
link	826	0	0	0	0	826	1.000	1.000	1.000
ln	1991	0	0	0	0	1991	1.000	1.000	1.000
logname	827	0	0	0	0	827	1.000	1.000	1.000
ls	39259	1255	21	0	0	37983	0.968	0.968	0.967
md5sum	1170	0	0	0	0	1170	1.000	1.000	1.000
mkdir	3260	0	2	0	0	3258	1.000	1.000	0.999
mkfifo	938	0	0	0	0	938	1.000	1.000	1.000
mknod	955	0	0	0	0	955	1.000	1.000	1.000
mktemp	971	0	0	0	0	971	1.000	1.000	1.000
mv	4056	0	1	0	2	4053	1.000	1.000	0.999
nice	837	0	0	0	0	837	1.000	1.000	1.000
nl	6094	316	2	0	0	5776	0.948	0.948	0.948
nohup	874	0	0	0	0	874	1.000	1.000	1.000
nproc	865	0	0	0	0	865	1.000	1.000	1.000
numfmt	1280	0	0	0	0	1280	1.000	1.000	1.000
od	11965	0	1	0	0	11964	1.000	1.000	1.000

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Table 33: Decomposed varnode recovery (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average comparison score	Varnode fraction partially recovered	Varnode fraction exactly recovered
paste	857	0	0	0	0	857	1.000	1.000	1.000
pathchk	869	0	0	0	0	869	1.000	1.000	1.000
pinky	3335	224	0	0	0	3111	0.933	0.933	0.933
pr	2854	0	0	0	0	2854	1.000	1.000	1.000
printenv	826	0	0	0	0	826	1.000	1.000	1.000
printf	3369	0	3	0	0	3366	0.999	1.000	0.999
ptx	7315	325	9	0	0	6981	0.955	0.956	0.954
pwd	969	0	0	0	0	969	1.000	1.000	1.000
readlink	1146	0	0	0	0	1146	1.000	1.000	1.000
realpath	1051	0	0	0	0	1051	1.000	1.000	1.000
rm	1276	0	0	0	0	1276	1.000	1.000	1.000
rmdir	3076	0	0	0	0	3076	1.000	1.000	1.000
runcon	844	0	0	0	0	844	1.000	1.000	1.000
seq	1136	0	0	0	0	1136	1.000	1.000	1.000
sha1sum	1178	0	0	0	0	1178	1.000	1.000	1.000
sha224sum	1315	0	0	0	0	1315	1.000	1.000	1.000
sha256sum	1323	0	0	0	0	1323	1.000	1.000	1.000
sha384sum	1599	0	0	0	0	1599	1.000	1.000	1.000

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Table 33: Decomposed varnode recovery (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average comparison score	Varnode fraction partially recovered	Varnode fraction exactly recovered
sha512sum	1631	0	0	0	0	1631	1.000	1.000	1.000
shred	3337	631	0	0	0	2706	0.811	0.811	0.811
shuf	1168	0	0	0	0	1168	1.000	1.000	1.000
sleep	855	0	0	0	0	855	1.000	1.000	1.000
sort	11845	9	1	0	0	11835	0.999	0.999	0.999
split	1533	0	2	0	0	1531	0.999	1.000	0.999
stat	3141	0	0	0	0	3141	1.000	1.000	1.000
stdbuf	2142	0	0	0	0	2142	1.000	1.000	1.000
stty	1868	0	0	0	0	1868	1.000	1.000	1.000
sum	2368	0	0	0	0	2368	1.000	1.000	1.000
sync	847	0	0	0	0	847	1.000	1.000	1.000
tac	13723	302	2	0	0	13419	0.978	0.978	0.978
tail	34216	0	6	0	0	34210	1.000	1.000	1.000
tee	9070	0	0	0	0	9070	1.000	1.000	1.000
test	1126	0	0	0	0	1126	1.000	1.000	1.000
timeout	1334	0	0	0	0	1334	1.000	1.000	1.000
touch	7107	9	6	0	0	7092	0.998	0.999	0.998
tr	10204	0	0	0	0	10204	1.000	1.000	1.000

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Table 33: Decomposed varnode recovery (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average comparison score	Varnode fraction partially recovered	Varnode fraction exactly recovered
true	801	0	0	0	0	801	1.000	1.000	1.000
truncate	902	0	0	0	0	902	1.000	1.000	1.000
tsort	876	0	0	0	0	876	1.000	1.000	1.000
tty	825	0	0	0	0	825	1.000	1.000	1.000
uname	1274	0	0	0	0	1274	1.000	1.000	1.000
unexpand	874	0	0	0	0	874	1.000	1.000	1.000
uniq	962	0	0	0	0	962	1.000	1.000	1.000
unlink	826	0	0	0	0	826	1.000	1.000	1.000
uptime	10379	0	0	0	1	10378	1.000	1.000	1.000
users	842	0	0	0	0	842	1.000	1.000	1.000
vdir	39259	1255	21	0	0	37983	0.968	0.968	0.967
wc	33888	9	0	0	0	33879	1.000	1.000	1.000
who	1577	0	0	0	0	1577	1.000	1.000	1.000
whoami	829	0	0	0	0	829	1.000	1.000	1.000
yes	841	0	0	0	0	841	1.000	1.000	1.000

Table 34: Decomposed varnode recovery (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
[	1010	0	0	0	0	1010	1.000	1.000	1.000
b2sum	1813	0	0	0	0	1813	1.000	1.000	1.000
base32	1061	0	0	0	0	1061	1.000	1.000	1.000
base64	1089	0	0	0	0	1089	1.000	1.000	1.000
basename	739	0	0	0	0	739	1.000	1.000	1.000
basenc	1707	0	0	0	0	1707	1.000	1.000	1.000
cat	817	0	0	0	0	817	1.000	1.000	1.000
chcon	17106	0	0	0	0	17106	1.000	1.000	1.000
chgrp	1026	0	0	0	0	1026	1.000	1.000	1.000
chmod	1080	0	0	0	0	1080	1.000	1.000	1.000
chown	1059	0	0	0	0	1059	1.000	1.000	1.000
chroot	799	0	1	0	0	798	0.999	1.000	0.999
cksum	31380	0	0	0	0	31380	1.000	1.000	1.000
comm	870	0	0	0	0	870	1.000	1.000	1.000
cp	3616	0	2	0	2	3612	0.999	1.000	0.999
csplit	4073	295	2	0	0	3776	0.927	0.928	0.927
cut	4899	0	0	0	0	4899	1.000	1.000	1.000
date	8190	8	6	0	0	8176	0.998	0.999	0.998

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Table 34: Decomposed varnode recovery (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
dd	6097	0	0	0	0	6097	1.000	1.000	1.000
df	3126	0	7	0	0	3119	0.998	1.000	0.998
dir	38591	1255	21	0	0	37315	0.967	0.967	0.967
dircolors	5577	3	0	0	0	5574	0.999	0.999	0.999
dirname	737	0	0	0	0	737	1.000	1.000	1.000
du	6328	295	3	0	0	6030	0.953	0.953	0.953
echo	725	0	0	0	0	725	1.000	1.000	1.000
env	1323	0	0	0	0	1323	1.000	1.000	1.000
expand	796	0	0	0	0	796	1.000	1.000	1.000
expr	4280	302	2	0	0	3976	0.929	0.929	0.929
factor	4491	41	5	0	0	4445	0.990	0.991	0.990
false	718	0	0	0	0	718	1.000	1.000	1.000
fmt	13788	4000	0	0	0	9788	0.710	0.710	0.710
fold	793	0	0	0	0	793	1.000	1.000	1.000
groups	764	0	0	0	0	764	1.000	1.000	1.000
head	33664	0	0	0	0	33664	1.000	1.000	1.000
hostid	733	0	0	0	0	733	1.000	1.000	1.000
id	872	0	0	0	0	872	1.000	1.000	1.000

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Table 34: Decomposed varnode recovery (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
join	854	0	0	0	0	854	1.000	1.000	1.000
kill	1222	0	0	0	0	1222	1.000	1.000	1.000
link	732	0	0	0	0	732	1.000	1.000	1.000
ln	1704	0	0	0	0	1704	1.000	1.000	1.000
logname	732	0	0	0	0	732	1.000	1.000	1.000
ls	38591	1255	21	0	0	37315	0.967	0.967	0.967
md5sum	1037	0	0	0	0	1037	1.000	1.000	1.000
mkdir	3057	0	2	0	0	3055	1.000	1.000	0.999
mkfifo	837	0	0	0	0	837	1.000	1.000	1.000
mknod	849	0	0	0	0	849	1.000	1.000	1.000
mktemp	853	0	0	0	0	853	1.000	1.000	1.000
mv	3668	0	1	0	2	3665	1.000	1.000	0.999
nice	741	0	0	0	0	741	1.000	1.000	1.000
nl	4669	316	2	0	0	4351	0.932	0.932	0.932
nohup	767	0	0	0	0	767	1.000	1.000	1.000
nproc	768	0	0	0	0	768	1.000	1.000	1.000
numfmt	1088	0	0	0	0	1088	1.000	1.000	1.000
od	11712	0	1	0	0	11711	1.000	1.000	1.000

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Table 34: Decomposed varnode recovery (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
paste	753	0	0	0	0	753	1.000	1.000	1.000
pathchk	771	0	0	0	0	771	1.000	1.000	1.000
pinky	3214	224	0	0	0	2990	0.930	0.930	0.930
pr	2634	0	0	0	0	2634	1.000	1.000	1.000
printenv	732	0	0	0	0	732	1.000	1.000	1.000
printf	3173	0	3	0	0	3170	0.999	1.000	0.999
ptx	5741	325	7	0	0	5409	0.942	0.943	0.942
pwd	863	0	0	0	0	863	1.000	1.000	1.000
readlink	948	0	0	0	0	948	1.000	1.000	1.000
realpath	844	0	0	0	0	844	1.000	1.000	1.000
rm	1032	0	0	0	0	1032	1.000	1.000	1.000
rmdir	2886	0	0	0	0	2886	1.000	1.000	1.000
runcon	737	0	0	0	0	737	1.000	1.000	1.000
seq	921	0	0	0	0	921	1.000	1.000	1.000
sha1sum	1046	0	0	0	0	1046	1.000	1.000	1.000
sha224sum	1182	0	0	0	0	1182	1.000	1.000	1.000
sha256sum	1190	0	0	0	0	1190	1.000	1.000	1.000
sha384sum	1466	0	0	0	0	1466	1.000	1.000	1.000

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Table 34: Decomposed varnode recovery (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
sha512sum	1498	0	0	0	0	1498	1.000	1.000	1.000
shred	3159	631	0	0	0	2528	0.800	0.800	0.800
shuf	942	0	0	0	0	942	1.000	1.000	1.000
sleep	748	0	0	0	0	748	1.000	1.000	1.000
sort	11317	9	1	0	0	11307	0.999	0.999	0.999
split	1369	0	2	0	0	1367	0.999	1.000	0.999
stat	2845	0	0	0	0	2845	1.000	1.000	1.000
stdbuf	1931	0	0	0	0	1931	1.000	1.000	1.000
stty	1527	0	0	0	0	1527	1.000	1.000	1.000
sum	2233	0	0	0	0	2233	1.000	1.000	1.000
sync	751	0	0	0	0	751	1.000	1.000	1.000
tac	12312	302	2	0	0	12008	0.975	0.975	0.975
tail	33975	0	6	0	0	33969	1.000	1.000	1.000
tee	8961	0	0	0	0	8961	1.000	1.000	1.000
test	959	0	0	0	0	959	1.000	1.000	1.000
timeout	1210	0	0	0	0	1210	1.000	1.000	1.000
touch	6684	8	6	0	0	6670	0.998	0.999	0.998
tr	10057	0	0	0	0	10057	1.000	1.000	1.000

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Table 34: Decomposed varnode recovery (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
true	718	0	0	0	0	718	1.000	1.000	1.000
truncate	801	0	0	0	0	801	1.000	1.000	1.000
tsort	757	0	0	0	0	757	1.000	1.000	1.000
tty	731	0	0	0	0	731	1.000	1.000	1.000
uname	1155	0	0	0	0	1155	1.000	1.000	1.000
unexpand	769	0	0	0	0	769	1.000	1.000	1.000
uniq	818	0	0	0	0	818	1.000	1.000	1.000
unlink	732	0	0	0	0	732	1.000	1.000	1.000
uptime	10247	0	0	0	0	10247	1.000	1.000	1.000
users	739	0	0	0	0	739	1.000	1.000	1.000
vdir	38591	1255	21	0	0	37315	0.967	0.967	0.967
wc	33696	9	0	0	0	33687	1.000	1.000	1.000
who	1345	0	0	0	0	1345	1.000	1.000	1.000
whoami	734	0	0	0	0	734	1.000	1.000	1.000
yes	742	0	0	0	0	742	1.000	1.000	1.000

Table 35: Decomposed varnode recovery (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
[	2	0	0	0	0	2	1.000	1.000	1.000
b2sum	0	0	0	0	0	0	-	-	-
base32	0	0	0	0	0	0	-	-	-
base64	0	0	0	0	0	0	-	-	-
basename	0	0	0	0	0	0	-	-	-
basenc	0	0	0	0	0	0	-	-	-
cat	0	0	0	0	0	0	-	-	-
chcon	7	0	0	0	0	7	1.000	1.000	1.000
chgrp	7	0	0	0	0	7	1.000	1.000	1.000
chmod	7	0	0	0	0	7	1.000	1.000	1.000
chown	7	0	0	0	0	7	1.000	1.000	1.000
chroot	0	0	0	0	0	0	-	-	-
cksum	3	0	0	0	0	3	1.000	1.000	1.000
comm	0	0	0	0	0	0	-	-	-
cp	7	0	0	0	0	7	1.000	1.000	1.000
csplit	0	0	0	0	0	0	-	-	-
cut	0	0	0	0	0	0	-	-	-
date	2	0	0	0	0	2	1.000	1.000	1.000

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Table 35: Decomposed varnode recovery (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
dd	7	0	0	0	0	7	1.000	1.000	1.000
df	17	0	0	0	0	17	1.000	1.000	1.000
dir	10	0	0	0	0	10	1.000	1.000	1.000
dircolors	0	0	0	0	0	0	-	-	-
dirname	0	0	0	0	0	0	-	-	-
du	10	0	0	0	0	10	1.000	1.000	1.000
echo	0	0	0	0	0	0	-	-	-
env	0	0	0	0	0	0	-	-	-
expand	0	0	0	0	0	0	-	-	-
expr	0	0	0	0	0	0	-	-	-
factor	0	0	0	0	0	0	-	-	-
false	0	0	0	0	0	0	-	-	-
fmt	0	0	0	0	0	0	-	-	-
fold	0	0	0	0	0	0	-	-	-
groups	0	0	0	0	0	0	-	-	-
head	0	0	0	0	0	0	-	-	-
hostid	0	0	0	0	0	0	-	-	-
id	0	0	0	0	0	0	-	-	-

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Table 35: Decomposed varnode recovery (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
join	0	0	0	0	0	0	-	-	-
kill	0	0	0	0	0	0	-	-	-
link	0	0	0	0	0	0	-	-	-
ln	7	0	0	0	0	7	1.000	1.000	1.000
logname	0	0	0	0	0	0	-	-	-
ls	10	0	0	0	0	10	1.000	1.000	1.000
md5sum	0	0	0	0	0	0	-	-	-
mkdir	2	0	0	0	0	2	1.000	1.000	1.000
mkfifo	0	0	0	0	0	0	-	-	-
mknod	0	0	0	0	0	0	-	-	-
mktemp	0	0	0	0	0	0	-	-	-
mv	7	0	0	0	0	7	1.000	1.000	1.000
nice	0	0	0	0	0	0	-	-	-
nl	0	0	0	0	0	0	-	-	-
nohup	0	0	0	0	0	0	-	-	-
nproc	0	0	0	0	0	0	-	-	-
numfmt	7	0	0	0	0	7	1.000	1.000	1.000
od	11	0	0	0	0	11	1.000	1.000	1.000

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Table 35: Decomposed varnode recovery (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
paste	0	0	0	0	0	0	-	-	-
pathchk	0	0	0	0	0	0	-	-	-
pinky	0	0	0	0	0	0	-	-	-
pr	0	0	0	0	0	0	-	-	-
printenv	0	0	0	0	0	0	-	-	-
printf	7	0	0	0	0	7	1.000	1.000	1.000
ptx	0	0	0	0	0	0	-	-	-
pwd	0	0	0	0	0	0	-	-	-
readlink	7	0	0	0	0	7	1.000	1.000	1.000
realpath	7	0	0	0	0	7	1.000	1.000	1.000
rm	7	0	0	0	0	7	1.000	1.000	1.000
rmdir	2	0	0	0	0	2	1.000	1.000	1.000
runcon	0	0	0	0	0	0	-	-	-
seq	14	0	0	0	0	14	1.000	1.000	1.000
sha1sum	0	0	0	0	0	0	-	-	-
sha224sum	0	0	0	0	0	0	-	-	-
sha256sum	0	0	0	0	0	0	-	-	-
sha384sum	0	0	0	0	0	0	-	-	-

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Table 35: Decomposed varnode recovery (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
sha512sum	0	0	0	0	0	0	-	-	-
shred	3	0	0	0	0	3	1.000	1.000	1.000
shuf	7	0	0	0	0	7	1.000	1.000	1.000
sleep	7	0	0	0	0	7	1.000	1.000	1.000
sort	22	0	0	0	0	22	1.000	1.000	1.000
split	0	0	0	0	0	0	-	-	-
stat	2	0	0	0	0	2	1.000	1.000	1.000
stdbuf	2	0	0	0	0	2	1.000	1.000	1.000
stty	2	0	0	0	0	2	1.000	1.000	1.000
sum	3	0	0	0	0	3	1.000	1.000	1.000
sync	0	0	0	0	0	0	-	-	-
tac	0	0	0	0	0	0	-	-	-
tail	15	0	0	0	0	15	1.000	1.000	1.000
tee	0	0	0	0	0	0	-	-	-
test	2	0	0	0	0	2	1.000	1.000	1.000
timeout	8	0	0	0	0	8	1.000	1.000	1.000
touch	2	0	0	0	0	2	1.000	1.000	1.000
tr	0	0	0	0	0	0	-	-	-

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Table 35: Decomposed varnode recovery (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
true	0	0	0	0	0	0	-	-	-
truncate	0	0	0	0	0	0	-	-	-
tsort	0	0	0	0	0	0	-	-	-
tty	0	0	0	0	0	0	-	-	-
uname	0	0	0	0	0	0	-	-	-
unexpand	0	0	0	0	0	0	-	-	-
uniq	0	0	0	0	0	0	-	-	-
unlink	0	0	0	0	0	0	-	-	-
uptime	5	0	0	0	0	5	1.000	1.000	1.000
users	0	0	0	0	0	0	-	-	-
vdir	10	0	0	0	0	10	1.000	1.000	1.000
wc	4	0	0	0	0	4	1.000	1.000	1.000
who	2	0	0	0	0	2	1.000	1.000	1.000
whoami	0	0	0	0	0	0	-	-	-
yes	0	0	0	0	0	0	-	-	-

Table 36: Decomposed varnode recovery (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
[	170	0	0	0	0	170	1.000	1.000	1.000
b2sum	140	0	0	0	0	140	1.000	1.000	1.000
base32	107	0	0	0	0	107	1.000	1.000	1.000
base64	107	0	0	0	0	107	1.000	1.000	1.000
basename	104	0	0	0	0	104	1.000	1.000	1.000
basenc	138	0	0	0	0	138	1.000	1.000	1.000
cat	115	0	0	0	0	115	1.000	1.000	1.000
chcon	234	0	0	0	0	234	1.000	1.000	1.000
chgrp	230	0	0	0	0	230	1.000	1.000	1.000
chmod	217	0	0	0	0	217	1.000	1.000	1.000
chown	241	0	0	0	0	241	1.000	1.000	1.000
chroot	133	0	0	0	0	133	1.000	1.000	1.000
cksum	234	0	0	0	0	234	1.000	1.000	1.000
comm	127	0	0	0	0	127	1.000	1.000	1.000
cp	403	0	0	0	0	403	1.000	1.000	1.000
csplit	1416	0	0	0	0	1416	1.000	1.000	1.000
cut	122	0	0	0	0	122	1.000	1.000	1.000
date	426	1	0	0	0	425	0.998	0.998	0.998

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Table 36: Decomposed varnode recovery (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
dd	216	0	0	0	0	216	1.000	1.000	1.000
df	419	0	0	0	0	419	1.000	1.000	1.000
dir	642	0	0	0	0	642	1.000	1.000	1.000
dircolors	229	0	0	0	0	229	1.000	1.000	1.000
dirname	94	0	0	0	0	94	1.000	1.000	1.000
du	1650	0	0	0	0	1650	1.000	1.000	1.000
echo	84	0	0	0	0	84	1.000	1.000	1.000
env	138	0	0	0	0	138	1.000	1.000	1.000
expand	101	0	0	0	0	101	1.000	1.000	1.000
expr	1399	0	0	0	0	1399	1.000	1.000	1.000
factor	196	12	1	0	0	183	0.935	0.939	0.934
false	82	0	0	0	0	82	1.000	1.000	1.000
fmt	2126	0	0	0	0	2126	1.000	1.000	1.000
fold	99	0	0	0	0	99	1.000	1.000	1.000
groups	100	0	0	0	0	100	1.000	1.000	1.000
head	125	0	0	0	0	125	1.000	1.000	1.000
hostid	93	0	0	0	0	93	1.000	1.000	1.000
id	134	0	0	0	0	134	1.000	1.000	1.000

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Table 36: Decomposed varnode recovery (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
join	149	0	0	0	0	149	1.000	1.000	1.000
kill	102	0	0	0	0	102	1.000	1.000	1.000
link	93	0	0	0	0	93	1.000	1.000	1.000
ln	276	0	0	0	0	276	1.000	1.000	1.000
logname	94	0	0	0	0	94	1.000	1.000	1.000
ls	642	0	0	0	0	642	1.000	1.000	1.000
md5sum	132	0	0	0	0	132	1.000	1.000	1.000
mkdir	192	0	0	0	0	192	1.000	1.000	1.000
mkfifo	100	0	0	0	0	100	1.000	1.000	1.000
mknod	105	0	0	0	0	105	1.000	1.000	1.000
mktemp	117	0	0	0	0	117	1.000	1.000	1.000
mv	379	0	0	0	0	379	1.000	1.000	1.000
nice	95	0	0	0	0	95	1.000	1.000	1.000
nl	1404	0	0	0	0	1404	1.000	1.000	1.000
nohup	106	0	0	0	0	106	1.000	1.000	1.000
nproc	96	0	0	0	0	96	1.000	1.000	1.000
numfmt	184	0	0	0	0	184	1.000	1.000	1.000
od	226	0	0	0	0	226	1.000	1.000	1.000

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Table 36: Decomposed varnode recovery (compilation = debug)

	Ground truth varn- odes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVER- LAP	Varnodes matched @ level SUB- SET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode aver- age com- pare score	Varnode frac- tion par- tially recov- ered	Varnode frac- tion ex- actly recov- ered
paste	103	0	0	0	0	103	1.000	1.000	1.000
pathchk	95	0	0	0	0	95	1.000	1.000	1.000
pinky	120	0	0	0	0	120	1.000	1.000	1.000
pr	218	0	0	0	0	218	1.000	1.000	1.000
printenv	93	0	0	0	0	93	1.000	1.000	1.000
printf	178	0	0	0	0	178	1.000	1.000	1.000
ptx	1540	0	1	0	0	1539	1.000	1.000	0.999
pwd	105	0	0	0	0	105	1.000	1.000	1.000
readlink	187	0	0	0	0	187	1.000	1.000	1.000
realpath	196	0	0	0	0	196	1.000	1.000	1.000
rm	236	0	0	0	0	236	1.000	1.000	1.000
rmdir	180	0	0	0	0	180	1.000	1.000	1.000
runcon	106	0	0	0	0	106	1.000	1.000	1.000
seq	193	0	0	0	0	193	1.000	1.000	1.000
sha1sum	131	0	0	0	0	131	1.000	1.000	1.000
sha224sum	132	0	0	0	0	132	1.000	1.000	1.000
sha256sum	132	0	0	0	0	132	1.000	1.000	1.000
sha384sum	132	0	0	0	0	132	1.000	1.000	1.000

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Table 36: Decomposed varnode recovery (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
sha512sum	132	0	0	0	0	132	1.000	1.000	1.000
shred	174	0	0	0	0	174	1.000	1.000	1.000
shuf	218	0	0	0	0	218	1.000	1.000	1.000
sleep	99	0	0	0	0	99	1.000	1.000	1.000
sort	492	0	0	0	0	492	1.000	1.000	1.000
split	162	0	0	0	0	162	1.000	1.000	1.000
stat	286	0	0	0	0	286	1.000	1.000	1.000
stdbuf	201	0	0	0	0	201	1.000	1.000	1.000
stty	331	0	0	0	0	331	1.000	1.000	1.000
sum	131	0	0	0	0	131	1.000	1.000	1.000
sync	95	0	0	0	0	95	1.000	1.000	1.000
tac	1390	0	0	0	0	1390	1.000	1.000	1.000
tail	225	0	0	0	0	225	1.000	1.000	1.000
tee	108	0	0	0	0	108	1.000	1.000	1.000
test	157	0	0	0	0	157	1.000	1.000	1.000
timeout	113	0	0	0	0	113	1.000	1.000	1.000
touch	391	1	0	0	0	390	0.997	0.997	0.997
tr	146	0	0	0	0	146	1.000	1.000	1.000

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Table 36: Decomposed varnode recovery (compilation = debug)

	Ground truth varnodes	Varnodes matched @ level NO MATCH	Varnodes matched @ level OVERLAP	Varnodes matched @ level SUBSET	Varnodes matched @ level ALIGNED	Varnodes matched @ level MATCH	Varnode average compare score	Varnode fraction partially recovered	Varnode fraction exactly recovered
true	82	0	0	0	0	82	1.000	1.000	1.000
truncate	100	0	0	0	0	100	1.000	1.000	1.000
tsort	118	0	0	0	0	118	1.000	1.000	1.000
tty	93	0	0	0	0	93	1.000	1.000	1.000
uname	118	0	0	0	0	118	1.000	1.000	1.000
unexpand	104	0	0	0	0	104	1.000	1.000	1.000
uniq	143	0	0	0	0	143	1.000	1.000	1.000
unlink	93	0	0	0	0	93	1.000	1.000	1.000
uptime	126	0	0	0	1	125	0.998	1.000	0.992
users	102	0	0	0	0	102	1.000	1.000	1.000
vdir	642	0	0	0	0	642	1.000	1.000	1.000
wc	176	0	0	0	0	176	1.000	1.000	1.000
who	222	0	0	0	0	222	1.000	1.000	1.000
whoami	94	0	0	0	0	94	1.000	1.000	1.000
yes	98	0	0	0	0	98	1.000	1.000	1.000

Table 37: Data bytes recovery (compilation = stripped)

	Ground truth data bytes	Bytes found	Bytes missed	Bytes recovery fraction
[	4463	3500	963	0.784
b2sum	4472	3152	1320	0.705
base32	2671	1668	1003	0.624
base64	2699	1664	1035	0.617
basename	2193	1478	715	0.674
basenc	3793	1919	1874	0.506
cat	2644	1771	873	0.670
chcon	20631	19308	1323	0.936
chgrp	4803	3263	1540	0.679
chmod	4776	3154	1622	0.660
chown	4964	3400	1564	0.685
chroot	2626	1911	715	0.728
cksum	161248	10363	150885	0.064
comm	2785	2002	783	0.719
cp	12062	7133	4929	0.591
csplit	31324	29232	2092	0.933
cut	6800	5916	884	0.870
date	18373	13069	5304	0.711
dd	11354	8493	2861	0.748
df	13944	10093	3851	0.724
dir	52738	37069	15669	0.703
dircolors	8180	1922	6258	0.235
dirname	2101	1449	652	0.690

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Table 37: Data bytes recovery (compilation = stripped)

	Ground truth data bytes	Bytes found	Bytes missed	Bytes recovery fraction
du	37523	34187	3336	0.911
echo	1915	1392	523	0.727
env	4112	2469	1643	0.600
expand	2319	1593	726	0.687
expr	30656	28585	2071	0.932
factor	23027	9450	13577	0.410
false	1885	1362	523	0.723
fmt	47599	1764	45835	0.037
fold	2276	1525	751	0.670
groups	2165	1525	640	0.704
head	35911	34944	967	0.973
hostid	2057	1430	627	0.695
id	2721	1815	906	0.667
join	3126	2223	903	0.711
kill	2834	1586	1248	0.560
link	2053	1426	627	0.695
ln	9661	5479	4182	0.567
logname	2061	1434	627	0.696
ls	52738	37069	15669	0.703
md5sum	3345	2318	1027	0.693
mkdir	6846	5566	1280	0.813
mkfifo	2546	1610	936	0.632
mknod	2655	1719	936	0.647

Continued on next page

Table 37: Data bytes recovery (compilation = stripped)

	Ground truth data bytes	Bytes found	Bytes missed	Bytes recovery fraction
mktemp	2681	1823	858	0.680
mv	12285	7791	4494	0.634
nice	2122	1471	651	0.693
nl	31091	27958	3133	0.899
nohup	2299	1668	631	0.726
nproc	2358	1675	683	0.710
numfmt	4029	2668	1361	0.662
od	16365	14702	1663	0.898
paste	2217	1502	715	0.677
pathchk	2344	1685	659	0.719
pinky	5002	4172	830	0.834
pr	6996	5411	1585	0.773
printenv	2052	1401	651	0.683
printf	6293	5526	767	0.878
ptx	38535	34166	4369	0.887
pwd	3093	1738	1355	0.562
readlink	6662	3695	2967	0.555
realpath	6753	3602	3151	0.533
rm	5075	3610	1465	0.711
rmdir	5987	5080	907	0.849
runcon	2214	1435	779	0.648
seq	4357	3526	831	0.809
sha1sum	3349	2322	1027	0.693

Continued on next page

Table 37: Data bytes recovery (compilation = stripped)

	Ground truth data bytes	Bytes found	Bytes missed	Bytes recovery fraction
sha224sum	3869	2586	1283	0.668
sha256sum	3877	2594	1283	0.669
sha384sum	6229	4494	1735	0.721
sha512sum	6261	4526	1735	0.723
shred	6721	5128	1593	0.763
shuf	4465	3382	1083	0.757
sleep	2255	1620	635	0.718
sort	20811	16580	4231	0.797
split	4729	2821	1908	0.597
stat	9167	7372	1795	0.804
stdbuf	5343	4516	827	0.845
stty	8535	3418	5117	0.400
sum	4413	3681	732	0.834
sync	2146	1459	687	0.680
tac	38578	28162	10416	0.730
tail	38862	36536	2326	0.940
tee	10555	9788	767	0.927
test	4288	3376	912	0.787
timeout	3663	2456	1207	0.670
touch	15837	10984	4853	0.694
tr	12260	2461	9799	0.201
true	1885	1362	523	0.723
truncate	2585	1654	931	0.640

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Table 37: Data bytes recovery (compilation = stripped)

	Ground truth data bytes	Bytes found	Bytes missed	Bytes recovery fraction
tsort	2391	1756	635	0.734
tty	2062	1379	683	0.669
uname	2860	1793	1067	0.627
unexpand	2344	1621	723	0.692
uniq	2943	1912	1031	0.650
unlink	2053	1426	627	0.695
uptime	13110	12351	759	0.942
users	2167	1540	627	0.711
vdir	52738	37069	15669	0.703
wc	36613	2619	33994	0.072
who	5007	3714	1293	0.742
whoami	2069	1442	627	0.697
yes	2166	1539	627	0.711

Table 38: Data bytes recovery (compilation = standard)

	Ground truth data bytes	Bytes found	Bytes missed	Bytes recovery fraction
[	4463	4320	143	0.968
b2sum	4472	4304	168	0.962
base32	2671	2548	123	0.954
base64	2699	2608	91	0.966
basename	2193	2102	91	0.959
basenc	3793	3423	370	0.902

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Table 38: Data bytes recovery (compilation = standard)

	Ground truth data bytes	Bytes found	Bytes missed	Bytes recovery fraction
cat	2644	2553	91	0.966
chcon	20631	20496	135	0.993
chgrp	4803	4651	152	0.968
chmod	4776	4602	174	0.964
chown	4964	4820	144	0.971
chroot	2626	2535	91	0.965
cksum	161248	29876	131372	0.185
comm	2785	2690	95	0.966
cp	12062	11214	848	0.930
csplit	31324	30228	1096	0.965
cut	6800	6709	91	0.987
date	18373	17641	732	0.960
dd	11354	10131	1223	0.892
df	13944	11740	2204	0.842
dir	52738	44599	8139	0.846
dircolors	8180	3281	4899	0.401
dirname	2101	2010	91	0.957
du	37523	36212	1311	0.965
echo	1915	1824	91	0.952
env	4112	3590	522	0.873
expand	2319	2227	92	0.960
expr	30656	29313	1343	0.956
factor	23027	22319	708	0.969

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Table 38: Data bytes recovery (compilation = standard)

	Ground truth data bytes	Bytes found	Bytes missed	Bytes recovery fraction
false	1885	1794	91	0.952
fmt	47599	47508	91	0.998
fold	2276	2184	92	0.960
groups	2165	2074	91	0.958
head	35911	35820	91	0.997
hostid	2057	1958	99	0.952
id	2721	2630	91	0.967
join	3126	3023	103	0.967
kill	2834	2210	624	0.780
link	2053	1954	99	0.952
ln	9661	7423	2238	0.768
logname	2061	1962	99	0.952
ls	52738	44599	8139	0.846
md5sum	3345	3230	115	0.966
mkdir	6846	6714	132	0.981
mkfifo	2546	2438	108	0.958
mknod	2655	2547	108	0.959
mktemp	2681	2527	154	0.943
mv	12285	11168	1117	0.909
nice	2122	2031	91	0.957
nl	31091	29976	1115	0.964
nohup	2299	2196	103	0.955
nproc	2358	2267	91	0.961

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Table 38: Data bytes recovery (compilation = standard)

	Ground truth data bytes	Bytes found	Bytes missed	Bytes recovery fraction
numfmt	4029	3924	105	0.974
od	16365	16171	194	0.988
paste	2217	2126	91	0.959
pathchk	2344	2253	91	0.961
pinky	5002	4911	91	0.982
pr	6996	6799	197	0.972
printenv	2052	1961	91	0.956
printf	6293	5994	299	0.952
ptx	38535	37006	1529	0.960
pwd	3093	3002	91	0.971
readlink	6662	4499	2163	0.675
realpath	6753	4590	2163	0.680
rm	5075	4806	269	0.947
rmdir	5987	5884	103	0.983
runcon	2214	2123	91	0.959
seq	4357	4208	149	0.966
sha1sum	3349	3234	115	0.966
sha224sum	3869	3754	115	0.970
sha256sum	3877	3762	115	0.970
sha384sum	6229	5470	759	0.878
sha512sum	6261	5502	759	0.879
shred	6721	6533	188	0.972
shuf	4465	4362	103	0.977

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Table 38: Data bytes recovery (compilation = standard)

	Ground truth data bytes	Bytes found	Bytes missed	Bytes recovery fraction
sleep	2255	2148	107	0.953
sort	20811	19990	821	0.961
split	4729	4074	655	0.861
stat	9167	8617	550	0.940
stdbuf	5343	5240	103	0.981
stty	8535	8403	132	0.985
sum	4413	4290	123	0.972
sync	2146	2051	95	0.956
tac	38578	37482	1096	0.972
tail	38862	38568	294	0.992
tee	10555	10460	95	0.991
test	4288	4196	92	0.979
timeout	3663	3144	519	0.858
touch	15837	15142	695	0.956
tr	12260	12165	95	0.992
true	1885	1794	91	0.952
truncate	2585	2494	91	0.965
tsort	2391	2284	107	0.955
tty	2062	1971	91	0.956
uname	2860	2761	99	0.965
unexpand	2344	2253	91	0.961
uniq	2943	2844	99	0.966
unlink	2053	1954	99	0.952

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Table 38: Data bytes recovery (compilation = standard)

	Ground truth data bytes	Bytes found	Bytes missed	Bytes recovery fraction
uptime	13110	12971	139	0.989
users	2167	2068	99	0.954
vdir	52738	44599	8139	0.846
wc	36613	3528	33085	0.096
who	5007	4904	103	0.979
whoami	2069	1970	99	0.952
yes	2166	2067	99	0.954

Table 39: Data bytes recovery (compilation = debug)

	Ground truth data bytes	Bytes found	Bytes missed	Bytes recovery fraction
[	4463	4463	0	1.000
b2sum	4472	4472	0	1.000
base32	2671	2671	0	1.000
base64	2699	2699	0	1.000
basename	2193	2193	0	1.000
basenc	3793	3793	0	1.000
cat	2644	2644	0	1.000
chcon	20631	20631	0	1.000
chgrp	4803	4803	0	1.000
chmod	4776	4776	0	1.000
chown	4964	4964	0	1.000
chroot	2626	2626	0	1.000

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Table 39: Data bytes recovery (compilation = debug)

	Ground truth data bytes	Bytes found	Bytes missed	Bytes recovery fraction
cksum	161248	161248	0	1.000
comm	2785	2785	0	1.000
cp	12062	12062	0	1.000
csplit	31324	31084	240	0.992
cut	6800	6800	0	1.000
date	18373	18321	52	0.997
dd	11354	11354	0	1.000
df	13944	13944	0	1.000
dir	52738	51468	1270	0.976
dircolors	8180	8180	0	1.000
dirname	2101	2101	0	1.000
du	37523	37283	240	0.994
echo	1915	1915	0	1.000
env	4112	4112	0	1.000
expand	2319	2319	0	1.000
expr	30656	30416	240	0.992
factor	23027	22782	245	0.989
false	1885	1885	0	1.000
fmt	47599	47599	0	1.000
fold	2276	2276	0	1.000
groups	2165	2165	0	1.000
head	35911	35911	0	1.000
hostid	2057	2057	0	1.000

Continued on next page

Table 39: Data bytes recovery (compilation = debug)

	Ground truth data bytes	Bytes found	Bytes missed	Bytes recovery fraction
id	2721	2721	0	1.000
join	3126	3126	0	1.000
kill	2834	2834	0	1.000
link	2053	2053	0	1.000
ln	9661	9661	0	1.000
logname	2061	2061	0	1.000
ls	52738	51468	1270	0.976
md5sum	3345	3345	0	1.000
mkdir	6846	6846	0	1.000
mkfifo	2546	2546	0	1.000
mknod	2655	2655	0	1.000
mktemp	2681	2681	0	1.000
mv	12285	12285	0	1.000
nice	2122	2122	0	1.000
nl	31091	30851	240	0.992
nohup	2299	2299	0	1.000
nproc	2358	2358	0	1.000
numfmt	4029	4029	0	1.000
od	16365	16365	0	1.000
paste	2217	2217	0	1.000
pathchk	2344	2344	0	1.000
pinky	5002	4778	224	0.955
pr	6996	6996	0	1.000

Continued on next page

Table 39: Data bytes recovery (compilation = debug)

	Ground truth data bytes	Bytes found	Bytes missed	Bytes recovery fraction
printenv	2052	2052	0	1.000
printf	6293	6293	0	1.000
ptx	38535	38279	256	0.993
pwd	3093	3093	0	1.000
readlink	6662	6662	0	1.000
realpath	6753	6753	0	1.000
rm	5075	5075	0	1.000
rmdir	5987	5987	0	1.000
runcon	2214	2214	0	1.000
seq	4357	4357	0	1.000
sha1sum	3349	3349	0	1.000
sha224sum	3869	3869	0	1.000
sha256sum	3877	3877	0	1.000
sha384sum	6229	6229	0	1.000
sha512sum	6261	6261	0	1.000
shred	6721	6090	631	0.906
shuf	4465	4465	0	1.000
sleep	2255	2255	0	1.000
sort	20811	20811	0	1.000
split	4729	4729	0	1.000
stat	9167	9167	0	1.000
stdbuf	5343	5343	0	1.000
stty	8535	8535	0	1.000

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Table 39: Data bytes recovery (compilation = debug)

	Ground truth data bytes	Bytes found	Bytes missed	Bytes recovery fraction
sum	4413	4413	0	1.000
sync	2146	2146	0	1.000
tac	38578	38338	240	0.994
tail	38862	38862	0	1.000
tee	10555	10555	0	1.000
test	4288	4288	0	1.000
timeout	3663	3663	0	1.000
touch	15837	15785	52	0.997
tr	12260	12260	0	1.000
true	1885	1885	0	1.000
truncate	2585	2585	0	1.000
tsort	2391	2391	0	1.000
tty	2062	2062	0	1.000
uname	2860	2860	0	1.000
unexpand	2344	2344	0	1.000
uniq	2943	2943	0	1.000
unlink	2053	2053	0	1.000
uptime	13110	13110	0	1.000
users	2167	2167	0	1.000
vdir	52738	51468	1270	0.976
wc	36613	36613	0	1.000
who	5007	5007	0	1.000
whoami	2069	2069	0	1.000

Continued on next page

Table 39: Data bytes recovery (compilation = debug)

	Ground truth data bytes	Bytes found	Bytes missed	Bytes recovery fraction
yes	2166	2166	0	1.000

Table 40: Array recovery (compilation = stripped)

	Ground truth array varn-odes	Array com-par-isons	Array varn-odes in-ferred as array	Array varn-odes in-ferred as array frac-tion	Array length (ele-ments) aver-age error	Array length (ele-ments) aver-age error ratio	Array size (bytes) aver-age error	Array size (bytes) aver-age error ratio	Array di-men-sion match score	Array aver-age ele-ment type com-par-ison score
[	15	6	6	0.400	3.667	0.132	4.833	0.132	1.000	0.833
b2sum	24	23	13	0.542	30.522	26.451	37.348	0.522	1.000	0.319
base32	12	3	3	0.250	2.667	0.042	5.000	0.042	1.000	0.889
base64	12	3	3	0.250	2.667	0.042	5.000	0.042	1.000	0.889
basename	10	3	3	0.300	2.667	0.042	5.000	0.042	1.000	0.889
basenc	20	4	4	0.200	2.000	0.032	3.750	0.032	1.000	0.917
cat	11	3	3	0.273	2.667	0.042	5.000	0.042	1.000	0.889
chcon	18	8	8	0.444	6.000	0.048	6.875	0.048	1.000	0.792
chgrp	15	5	5	0.333	2.800	0.083	4.200	0.083	1.000	0.800
chmod	19	6	6	0.316	4.667	0.194	5.833	0.194	1.000	0.833

Continued on next page

Table 40: Array recovery (compilation = stripped)

	Ground truth array varnodes	Array comparisons	Array varnodes inferred as array	Array varnodes inferred as array fraction	Array length (elements) average error	Array length (elements) average error ratio	Array size (bytes) average error	Array size (bytes) average error ratio	Array dimension match score	Array average element type comparison score
chown	16	6	6	0.375	2.833	0.093	4.000	0.093	1.000	0.778
chroot	11	4	4	0.364	2.750	0.068	4.500	0.068	1.000	0.833
cksum	66	39	27	0.409	755.590	16.511	6749.256	0.501	1.000	0.444
comm	22	12	12	0.545	18.250	2.054	4.000	0.138	0.750	0.750
cp	40	10	9	0.225	8.200	1.485	9.300	0.185	1.000	0.767
csplit	35	23	21	0.600	123.261	0.537	359.087	0.150	0.957	0.754
cut	12	4	4	0.333	4.000	0.032	5.750	0.032	1.000	0.833
date	63	28	26	0.413	85.071	0.571	81.036	0.357	1.000	0.845
dd	34	11	9	0.265	360.455	0.230	361.091	0.230	0.727	0.788
df	25	8	8	0.320	86.125	3.893	87.000	3.893	1.000	0.792
dir	71	32	31	0.437	156.688	5.807	156.906	5.807	0.969	0.781
dircolors	13	3	3	0.231	2.667	0.042	5.000	0.042	1.000	0.889
dirname	10	3	3	0.300	2.667	0.042	5.000	0.042	1.000	0.889
du	51	26	23	0.451	148.962	0.536	357.577	0.194	0.962	0.795
echo	9	3	3	0.333	2.667	0.042	5.000	0.042	1.000	0.889

Continued on next page

Table 40: Array recovery (compilation = stripped)

	Ground truth array varnodes	Array comparisons	Array varnodes inferred as array	Array varnodes inferred as array fraction	Array length (elements) average error	Array length (elements) average error ratio	Array size (bytes) average error	Array size (bytes) average error ratio	Array dimension match score	Array average element type comparison score
env	18	8	8	0.444	4.125	0.180	5.000	0.180	1.000	0.750
expand	13	3	3	0.231	2.667	0.042	5.000	0.042	1.000	0.889
expr	33	20	18	0.545	141.550	0.590	412.750	0.145	0.950	0.767
factor	37	18	18	0.486	15.667	13.571	3.667	0.168	1.000	0.222
false	9	3	3	0.333	2.667	0.042	5.000	0.042	1.000	0.889
fmt	12	3	3	0.250	2.667	0.042	5.000	0.042	1.000	0.889
fold	12	3	3	0.250	2.667	0.042	5.000	0.042	1.000	0.889
groups	11	3	3	0.273	2.667	0.042	5.000	0.042	1.000	0.889
head	18	10	10	0.556	4.900	0.192	7.700	0.192	1.000	0.767
hostid	12	3	3	0.250	2.667	0.042	5.000	0.042	1.000	0.889
id	14	4	4	0.286	2.750	0.068	4.500	0.068	1.000	0.833
join	18	5	5	0.278	2.800	0.625	3.000	0.025	1.000	0.867
kill	14	5	5	0.357	3.600	0.131	5.000	0.131	1.000	0.867
link	12	3	3	0.250	2.667	0.042	5.000	0.042	1.000	0.889
ln	22	5	5	0.227	4.800	0.038	6.200	0.038	1.000	0.933

Continued on next page

Table 40: Array recovery (compilation = stripped)

	Ground truth array varnodes	Array comparisons	Array varnodes inferred as array	Array varnodes inferred as array fraction	Array length (elements) average error	Array length (elements) average error ratio	Array size (bytes) average error	Array size (bytes) average error ratio	Array dimension match score	Array average element type comparison score
logname	12	3	3	0.250	2.667	0.042	5.000	0.042	1.000	0.889
ls	71	32	31	0.437	156.688	5.807	156.906	5.807	0.969	0.781
md5sum	16	5	5	0.312	3.200	0.105	4.600	0.105	1.000	0.800
mkdir	19	7	7	0.368	4.857	0.381	7.571	0.381	1.000	0.857
mkfifo	12	4	4	0.333	5.500	0.166	7.250	0.166	1.000	0.917
mknod	12	4	4	0.333	5.500	0.166	7.250	0.166	1.000	0.917
mktemp	12	3	3	0.250	2.667	0.042	5.000	0.042	1.000	0.889
mv	34	10	9	0.265	8.200	1.485	9.300	0.185	1.000	0.767
nice	10	3	3	0.300	2.667	0.042	5.000	0.042	1.000	0.889
nl	36	19	17	0.472	148.579	0.620	434.053	0.151	0.947	0.772
nohup	13	3	3	0.231	2.667	0.042	5.000	0.042	1.000	0.889
nproc	10	3	3	0.300	2.667	0.042	5.000	0.042	1.000	0.889
numfmt	20	5	5	0.250	12.600	0.185	5.400	0.050	1.000	0.867
od	40	12	12	0.300	3.917	0.146	5.667	0.146	1.000	0.778
paste	10	3	3	0.300	2.667	0.042	5.000	0.042	1.000	0.889

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Table 40: Array recovery (compilation = stripped)

	Ground truth array varnodes	Array comparisons	Array varnodes inferred as array	Array varnodes inferred as array fraction	Array length (elements) average error	Array length (elements) average error ratio	Array size (bytes) average error	Array size (bytes) average error ratio	Array dimension match score	Array average element type comparison score
pathchk	10	3	3	0.300	2.667	0.042	5.000	0.042	1.000	0.889
pinky	17	8	8	0.471	33.500	0.916	34.375	0.916	1.000	0.833
pr	20	10	9	0.450	103.500	0.192	104.200	0.192	1.000	0.933
printenv	10	3	3	0.300	2.667	0.042	5.000	0.042	1.000	0.889
printf	17	8	8	0.471	27.750	0.185	28.625	0.185	1.000	0.917
ptx	39	20	18	0.462	141.300	0.596	412.500	0.151	0.950	0.783
pwd	10	3	3	0.300	2.667	0.042	5.000	0.042	1.000	0.889
readlink	12	4	4	0.333	4.000	0.047	5.750	0.047	1.000	0.917
realpath	11	3	3	0.273	2.667	0.042	5.000	0.042	1.000	0.889
rm	15	3	3	0.200	2.667	0.042	5.000	0.042	1.000	0.889
rmdir	14	5	5	0.357	3.200	0.026	4.600	0.026	1.000	0.867
runcon	10	3	3	0.300	2.667	0.042	5.000	0.042	1.000	0.889
seq	15	4	4	0.267	2.000	0.032	3.750	0.032	1.000	0.917
sha1sum	16	6	6	0.375	3.333	0.146	10.500	0.146	1.000	0.833
sha224sum	17	6	6	0.353	6.000	0.230	13.167	0.230	1.000	0.833

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Table 40: Array recovery (compilation = stripped)

	Ground truth array varn-odes	Array com-par-isons	Array varn-odes in-ferred as array	Array varn-odes in-ferred as array frac-tion	Array length (ele-ments) aver-age error	Array length (ele-ments) aver-age error ratio	Array size (bytes) aver-age error	Array size (bytes) aver-age error ratio	Array di-men-sion match score	Array aver-age ele-ment type com-par-ison score
sha256sum	17	6	6	0.353	4.667	0.183	11.833	0.183	1.000	0.833
sha384sum	17	6	6	0.353	3.333	0.146	18.500	0.146	1.000	0.833
sha512sum	17	6	6	0.353	3.333	0.146	18.500	0.146	1.000	0.833
shred	27	10	10	0.370	68.600	3.114	69.300	3.114	1.000	0.800
shuf	12	4	4	0.333	2.000	0.032	3.750	0.032	1.000	0.917
sleep	12	3	3	0.250	2.667	0.042	5.000	0.042	1.000	0.889
sort	46	12	11	0.239	5.917	0.299	7.833	0.216	0.833	0.778
split	18	6	6	0.333	3.167	0.113	4.333	0.113	1.000	0.833
stat	32	10	9	0.281	103.900	0.197	104.600	0.197	1.000	0.933
stdbuf	16	5	5	0.312	3.200	0.027	4.600	0.027	1.000	0.867
stty	19	5	5	0.263	2.000	0.125	4.600	0.125	1.000	0.867
sum	22	8	8	0.364	5.875	0.066	6.750	0.066	1.000	0.750
sync	11	3	3	0.273	2.667	0.042	5.000	0.042	1.000	0.889
tac	33	19	17	0.515	148.579	0.620	434.053	0.151	0.947	0.772
tail	20	8	8	0.400	5.500	0.034	6.375	0.034	1.000	0.750

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Table 40: Array recovery (compilation = stripped)

	Ground truth array varnodes	Array comparisons	Array varnodes inferred as array	Array varnodes inferred as array fraction	Array length (elements) average error	Array length (elements) average error ratio	Array size (bytes) average error	Array size (bytes) average error ratio	Array dimension match score	Array average element type comparison score
tee	14	4	4	0.286	4.000	0.032	5.750	0.032	1.000	0.833
test	12	5	5	0.417	4.200	0.139	4.200	0.139	1.000	0.867
timeout	13	5	5	0.385	3.600	0.131	5.000	0.131	1.000	0.867
touch	56	23	22	0.393	59.087	0.618	54.174	0.357	1.000	0.826
tr	17	4	4	0.235	57.750	0.250	5.750	0.040	1.000	0.833
true	9	3	3	0.333	2.667	0.042	5.000	0.042	1.000	0.889
truncate	10	3	3	0.300	2.667	0.042	5.000	0.042	1.000	0.889
tsort	13	4	4	0.308	11.000	2.282	5.750	0.094	1.000	0.833
tty	10	3	3	0.300	2.667	0.042	5.000	0.042	1.000	0.889
uname	12	3	3	0.250	2.667	0.042	5.000	0.042	1.000	0.889
unexpand	11	3	3	0.273	2.667	0.042	5.000	0.042	1.000	0.889
uniq	15	4	4	0.267	2.250	0.157	5.750	0.157	1.000	0.917
unlink	12	3	3	0.250	2.667	0.042	5.000	0.042	1.000	0.889
uptime	18	8	7	0.389	129.500	0.220	130.375	0.220	1.000	0.958
users	12	3	3	0.250	2.667	0.042	5.000	0.042	1.000	0.889

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Table 40: Array recovery (compilation = stripped)

	Ground truth array varnodes	Array comparisons	Array varnodes inferred as array	Array varnodes inferred as array fraction	Array length (elements) average error	Array length (elements) average error ratio	Array size (bytes) average error	Array size (bytes) average error ratio	Array dimension match score	Array average element type comparison score
vdir	71	32	31	0.437	156.688	5.807	156.906	5.807	0.969	0.781
wc	16	6	6	0.375	5455.500	0.378	5456.667	0.378	1.000	0.889
who	25	13	13	0.520	1.615	0.024	2.154	0.024	1.000	0.949
whoami	12	3	3	0.250	2.667	0.042	5.000	0.042	1.000	0.889
yes	12	3	3	0.250	2.667	0.042	5.000	0.042	1.000	0.889

Table 41: Array recovery (compilation = standard)

	Ground truth array varnodes	Array comparisons	Array varnodes inferred as array	Array varnodes inferred as array fraction	Array length (elements) average error	Array length (elements) average error ratio	Array size (bytes) average error	Array size (bytes) average error ratio	Array dimension match score	Array average element type comparison score
[	15	10	10	0.667	15.000	1.379	2.900	0.079	1.000	0.767
b2sum	24	30	20	0.833	43.300	21.879	28.633	0.400	0.967	0.378
base32	12	8	8	0.667	37.625	5.141	1.875	0.016	1.000	0.667
base64	12	9	9	0.750	33.444	4.570	1.667	0.014	1.000	0.667
basename	10	7	7	0.700	43.000	5.875	2.143	0.018	1.000	0.667
basenc	20	13	13	0.650	42.231	3.164	1.154	0.010	1.000	0.692
cat	11	8	8	0.727	53.125	5.141	1.875	0.016	1.000	0.667
chcon	18	12	12	0.667	49.083	3.449	4.583	0.032	1.000	0.694
chgrp	15	9	9	0.600	58.222	4.601	2.333	0.046	1.000	0.667
chmod	19	10	10	0.526	47.600	4.217	3.500	0.117	1.000	0.700
chown	16	10	10	0.625	55.800	4.156	2.400	0.056	1.000	0.667
chroot	11	8	8	0.727	38.000	5.159	2.250	0.034	1.000	0.667
cksum	66	62	50	0.758	738.516	12.144	4245.500	0.315	0.968	0.516
comm	22	16	16	0.727	35.875	4.103	3.000	0.103	0.812	0.688
cp	40	27	26	0.650	52.630	4.476	3.741	0.078	1.000	0.654

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Table 41: Array recovery (compilation = standard)

	Ground truth array varn-odes	Array com-par-isons	Array varn-odes in-ferred as array	Array varn-odes in-ferred as array frac-tion	Array length (ele-ments) aver-age error	Array length (ele-ments) aver-age error ratio	Array size (bytes) aver-age error	Array size (bytes) aver-age error ratio	Array di-men-sion match score	Array aver-age ele-ment type com-par-ison score
csplit	35	30	28	0.800	115.433	2.345	275.300	0.115	0.967	0.711
cut	12	8	8	0.667	58.000	5.141	2.875	0.016	1.000	0.667
date	63	57	55	0.873	91.842	3.351	39.807	0.175	0.930	0.649
dd	34	23	21	0.618	182.913	2.327	172.696	0.110	0.870	0.696
df	25	16	16	0.640	120.562	8.072	43.500	1.947	1.000	0.646
dir	71	61	60	0.845	135.951	8.784	82.311	3.046	0.934	0.694
dircolors	13	9	9	0.692	102.889	6.125	1.667	0.014	1.000	0.667
dirname	10	7	7	0.700	34.143	5.875	2.143	0.018	1.000	0.667
du	51	41	38	0.745	124.683	2.608	226.756	0.123	0.951	0.732
echo	9	6	6	0.667	19.167	1.688	2.500	0.021	1.000	0.778
env	18	13	13	0.722	41.769	3.265	3.077	0.111	1.000	0.667
expand	13	9	9	0.692	31.556	5.347	1.667	0.014	1.000	0.667
expr	33	27	25	0.758	118.593	2.585	305.741	0.108	0.963	0.716
factor	37	27	27	0.730	394.889	11.232	2.444	0.112	1.000	0.321
false	9	6	6	0.667	19.167	1.688	2.500	0.021	1.000	0.778

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Table 41: Array recovery (compilation = standard)

	Ground truth array varnodes	Array comparisons	Array varnodes inferred as array	Array varnodes inferred as array fraction	Array length (elements) average error	Array length (elements) average error ratio	Array size (bytes) average error	Array size (bytes) average error ratio	Array dimension match score	Array average element type comparison score
fmt	12	9	9	0.750	4380.556	8.903	1.667	0.014	1.000	0.593
fold	12	8	8	0.667	37.625	5.141	1.875	0.016	1.000	0.667
groups	11	8	8	0.727	26.000	5.141	1.875	0.016	1.000	0.667
head	18	15	15	0.833	32.000	3.328	5.133	0.128	1.000	0.689
hostid	12	7	7	0.583	29.714	5.875	2.143	0.018	1.000	0.667
id	14	11	11	0.786	38.909	3.752	1.636	0.025	1.000	0.667
join	18	13	13	0.722	32.692	5.548	1.154	0.010	1.000	0.692
kill	14	9	9	0.643	34.556	4.628	2.778	0.073	1.000	0.704
link	12	7	7	0.583	29.714	5.875	2.143	0.018	1.000	0.667
ln	22	13	13	0.591	56.538	4.476	2.385	0.015	1.000	0.718
logname	12	7	7	0.583	29.714	5.875	2.143	0.018	1.000	0.667
ls	71	61	60	0.845	135.951	8.784	82.311	3.046	0.934	0.694
md5sum	16	10	10	0.625	52.600	4.153	2.300	0.053	1.000	0.667
mkdir	19	11	11	0.579	34.091	4.061	3.364	0.061	1.000	0.727
mkfifo	12	8	8	0.667	35.500	5.208	3.625	0.083	1.000	0.708

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Table 41: Array recovery (compilation = standard)

	Ground truth array varnodes	Array comparisons	Array varnodes inferred as array	Array varnodes inferred as array fraction	Array length (elements) average error	Array length (elements) average error ratio	Array size (bytes) average error	Array size (bytes) average error ratio	Array dimension match score	Array average element type comparison score
mknod	12	8	8	0.667	35.500	5.208	3.625	0.083	1.000	0.708
mktemp	12	8	8	0.667	48.000	6.016	1.875	0.016	1.000	0.667
mv	34	21	20	0.588	36.857	4.326	4.810	0.100	1.000	0.651
nice	10	7	7	0.700	34.143	5.875	2.143	0.018	1.000	0.667
nl	36	28	26	0.722	125.393	2.385	294.536	0.103	0.964	0.714
nohup	13	7	7	0.538	29.714	5.875	2.143	0.018	1.000	0.667
nproc	10	7	7	0.700	38.571	5.875	2.143	0.018	1.000	0.667
numfmt	20	17	17	0.850	56.882	4.819	1.588	0.015	1.000	0.686
od	40	28	28	0.700	31.821	2.884	2.429	0.063	0.964	0.690
paste	10	7	7	0.700	43.000	5.875	2.143	0.018	1.000	0.667
pathchk	10	7	7	0.700	34.143	5.875	2.143	0.018	1.000	0.667
pinky	17	14	14	0.824	33.429	3.452	19.643	0.523	1.000	0.714
pr	20	15	14	0.700	133.667	2.928	69.467	0.128	0.933	0.800
printenv	10	7	7	0.700	34.143	5.875	2.143	0.018	1.000	0.667
printf	17	12	12	0.706	29.167	1.206	19.083	0.123	1.000	0.833

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Table 41: Array recovery (compilation = standard)

	Ground truth array varnodes	Array comparisons	Array varnodes inferred as array	Array varnodes inferred as array fraction	Array length (elements) average error	Array length (elements) average error ratio	Array size (bytes) average error	Array size (bytes) average error ratio	Array dimension match score	Array average element type comparison score
ptx	39	31	29	0.744	119.806	2.481	266.129	0.097	0.968	0.720
pwd	10	7	7	0.700	38.571	5.875	2.143	0.018	1.000	0.667
readlink	12	8	8	0.667	58.000	5.149	2.875	0.024	1.000	0.708
realpath	11	7	7	0.636	74.000	5.875	2.143	0.018	1.000	0.667
rm	15	9	9	0.600	61.556	5.681	1.667	0.014	1.000	0.667
rmdir	14	10	10	0.714	36.100	4.413	2.300	0.013	1.000	0.700
runcon	10	7	7	0.700	51.857	5.875	2.143	0.018	1.000	0.667
seq	15	10	10	0.667	32.200	4.413	1.500	0.013	1.000	0.700
sha1sum	16	11	11	0.688	48.182	3.807	5.727	0.080	1.000	0.697
sha224sum	17	12	12	0.706	61.500	3.781	6.583	0.115	1.000	0.694
sha256sum	17	12	12	0.706	60.833	3.758	5.917	0.092	1.000	0.694
sha384sum	17	11	11	0.647	48.182	3.807	10.091	0.080	1.000	0.697
sha512sum	17	11	11	0.647	48.182	3.807	10.091	0.080	1.000	0.697
shred	27	19	19	0.704	71.421	4.850	36.474	1.639	1.000	0.702
shuf	12	8	8	0.667	53.125	5.141	1.875	0.016	1.000	0.708

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Table 41: Array recovery (compilation = standard)

	Ground truth array varnodes	Array comparisons	Array varnodes inferred as array	Array varnodes inferred as array fraction	Array length (elements) average error	Array length (elements) average error ratio	Array size (bytes) average error	Array size (bytes) average error ratio	Array dimension match score	Array average element type comparison score
sleep	12	7	7	0.583	29.714	5.875	2.143	0.018	1.000	0.667
sort	46	27	26	0.565	52.926	2.837	3.481	0.096	0.926	0.667
split	18	12	12	0.667	54.917	3.723	2.167	0.056	1.000	0.694
stat	32	22	21	0.656	68.591	2.589	47.545	0.089	0.955	0.758
stdbuf	16	11	11	0.688	36.273	6.103	2.091	0.012	1.000	0.636
stty	19	14	14	0.737	311.143	8.688	1.643	0.045	1.000	0.548
sum	22	16	16	0.727	20.438	3.908	3.375	0.033	1.000	0.667
sync	11	7	7	0.636	38.571	5.875	2.143	0.018	1.000	0.667
tac	33	28	26	0.788	117.036	2.635	294.536	0.103	0.964	0.714
tail	20	14	14	0.700	48.000	3.591	4.357	0.064	1.000	0.619
tee	14	10	10	0.714	35.600	5.113	2.300	0.013	1.000	0.667
test	12	9	9	0.750	16.556	1.522	2.333	0.077	1.000	0.778
timeout	13	9	9	0.692	41.444	4.628	2.778	0.073	1.000	0.704
touch	56	50	49	0.875	79.260	4.084	24.920	0.164	0.960	0.607
tr	17	13	13	0.765	49.154	3.769	1.769	0.012	1.000	0.667

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Table 41: Array recovery (compilation = standard)

	Ground truth array varnodes	Array comparisons	Array varnodes inferred as array	Array varnodes inferred as array fraction	Array length (elements) average error	Array length (elements) average error ratio	Array size (bytes) average error	Array size (bytes) average error ratio	Array dimension match score	Array average element type comparison score
true	9	6	6	0.667	19.167	1.688	2.500	0.021	1.000	0.778
truncate	10	7	7	0.700	47.429	5.875	2.143	0.018	1.000	0.667
tsort	13	8	8	0.615	30.500	6.266	2.875	0.047	1.000	0.667
tty	10	7	7	0.700	38.571	5.875	2.143	0.018	1.000	0.667
uname	12	8	8	0.667	80.250	9.016	1.875	0.016	1.000	0.583
unexpand	11	8	8	0.727	39.375	6.016	1.875	0.016	1.000	0.667
uniq	15	12	12	0.800	50.250	5.136	1.917	0.052	1.000	0.694
unlink	12	7	7	0.583	29.714	5.875	2.143	0.018	1.000	0.667
uptime	18	13	12	0.667	97.077	3.366	80.231	0.136	0.923	0.795
users	12	7	7	0.583	29.714	5.875	2.143	0.018	1.000	0.667
vdir	71	61	60	0.845	135.951	8.784	82.311	3.046	0.934	0.694
wc	16	11	11	0.688	3015.818	4.206	2976.364	0.206	1.000	0.727
who	25	19	19	0.760	37.211	2.332	1.474	0.016	1.000	0.825
whoami	12	7	7	0.583	29.714	5.875	2.143	0.018	1.000	0.667
yes	12	7	7	0.583	29.714	5.875	2.143	0.018	1.000	0.667

Table 42: Array recovery (compilation = debug)

	Ground truth array varnodes	Array comparisons	Array varnodes inferred as array	Array varnodes inferred as array fraction	Array length (elements) average error	Array length (elements) average error ratio	Array size (bytes) average error	Array size (bytes) average error ratio	Array dimension match score	Array average element type comparison score
[	15	16	15	1.000	0.000	0.000	0.000	0.000	1.000	1.000
b2sum	24	25	24	1.000	0.000	0.000	0.000	0.000	1.000	1.000
base32	12	13	12	1.000	0.000	0.000	0.000	0.000	1.000	1.000
base64	12	12	12	1.000	0.000	0.000	0.000	0.000	1.000	1.000
basename	10	10	10	1.000	0.000	0.000	0.000	0.000	1.000	1.000
basenc	20	21	20	1.000	0.000	0.000	0.000	0.000	1.000	1.000
cat	11	12	11	1.000	0.000	0.000	0.000	0.000	1.000	1.000
chcon	18	18	18	1.000	0.000	0.000	0.000	0.000	1.000	1.000
chgrp	15	15	15	1.000	0.000	0.000	0.000	0.000	1.000	1.000
chmod	19	20	19	1.000	0.000	0.000	0.000	0.000	1.000	1.000
chown	16	16	16	1.000	0.000	0.000	0.000	0.000	1.000	1.000
chroot	11	11	11	1.000	0.000	0.000	0.000	0.000	1.000	1.000
cksum	66	67	66	1.000	0.000	0.000	0.000	0.000	1.000	1.000
comm	22	22	22	1.000	0.000	0.000	0.000	0.000	1.000	1.000
cp	40	44	39	0.975	0.000	0.000	0.000	0.000	1.000	1.000

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Table 42: Array recovery (compilation = debug)

	Ground truth array varn-odes	Array com-par-isons	Array varn-odes in-ferred as array	Array varn-odes in-ferred as array frac-tion	Array length (ele-ments) aver-age error	Array length (ele-ments) aver-age error ratio	Array size (bytes) aver-age error	Array size (bytes) aver-age error ratio	Array di-men-sion match score	Array aver-age ele-ment type com-par-ison score
csplit	35	36	35	1.000	6.667	0.026	6.667	0.026	1.000	1.000
cut	12	12	12	1.000	0.000	0.000	0.000	0.000	1.000	1.000
date	63	70	63	1.000	31.071	0.100	31.071	0.100	1.000	1.000
dd	34	37	34	1.000	0.000	0.000	0.000	0.000	1.000	1.000
df	25	26	25	1.000	24.269	1.156	24.269	1.156	1.000	1.000
dir	71	75	71	1.000	47.200	0.840	47.200	0.840	1.000	1.000
dircolors	13	13	13	1.000	0.000	0.000	0.000	0.000	1.000	1.000
dirname	10	10	10	1.000	0.000	0.000	0.000	0.000	1.000	1.000
du	51	54	51	1.000	23.259	0.036	23.259	0.036	1.000	1.000
echo	9	9	9	1.000	0.000	0.000	0.000	0.000	1.000	1.000
env	18	19	18	1.000	0.000	0.000	0.000	0.000	1.000	1.000
expand	13	13	13	1.000	0.000	0.000	0.000	0.000	1.000	1.000
expr	33	33	33	1.000	7.273	0.028	7.273	0.028	1.000	1.000
factor	37	32	32	0.865	0.000	0.000	0.000	0.000	1.000	1.000
false	9	9	9	1.000	0.000	0.000	0.000	0.000	1.000	1.000

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Table 42: Array recovery (compilation = debug)

	Ground truth array varnodes	Array comparisons	Array varnodes inferred as array	Array varnodes inferred as array fraction	Array length (elements) average error	Array length (elements) average error ratio	Array size (bytes) average error	Array size (bytes) average error ratio	Array dimension match score	Array average element type comparison score
fmt	12	12	12	1.000	0.000	0.000	0.000	0.000	1.000	1.000
fold	12	12	12	1.000	0.000	0.000	0.000	0.000	1.000	1.000
groups	11	12	11	1.000	0.000	0.000	0.000	0.000	1.000	1.000
head	18	19	18	1.000	0.000	0.000	0.000	0.000	1.000	1.000
hostid	12	12	12	1.000	0.000	0.000	0.000	0.000	1.000	1.000
id	14	17	14	1.000	0.000	0.000	0.000	0.000	1.000	1.000
join	18	18	18	1.000	0.000	0.000	0.000	0.000	1.000	1.000
kill	14	14	14	1.000	0.000	0.000	0.000	0.000	1.000	1.000
link	12	12	12	1.000	0.000	0.000	0.000	0.000	1.000	1.000
ln	22	23	22	1.000	0.000	0.000	0.000	0.000	1.000	1.000
logname	12	12	12	1.000	0.000	0.000	0.000	0.000	1.000	1.000
ls	71	75	71	1.000	47.200	0.840	47.200	0.840	1.000	1.000
md5sum	16	17	16	1.000	0.000	0.000	0.000	0.000	1.000	1.000
mkdir	19	20	18	0.947	0.000	0.000	0.000	0.000	1.000	1.000
mkfifo	12	13	12	1.000	0.000	0.000	0.000	0.000	1.000	1.000

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Table 42: Array recovery (compilation = debug)

	Ground truth array varnodes	Array comparisons	Array varnodes inferred as array	Array varnodes inferred as array fraction	Array length (elements) average error	Array length (elements) average error ratio	Array size (bytes) average error	Array size (bytes) average error ratio	Array dimension match score	Array average element type comparison score
mknod	12	13	12	1.000	0.000	0.000	0.000	0.000	1.000	1.000
mktemp	12	13	12	1.000	0.000	0.000	0.000	0.000	1.000	1.000
mv	34	36	33	0.971	0.000	0.000	0.000	0.000	1.000	1.000
nice	10	10	10	1.000	0.000	0.000	0.000	0.000	1.000	1.000
nl	36	36	36	1.000	6.667	0.026	6.667	0.026	1.000	1.000
nohup	13	13	13	1.000	0.000	0.000	0.000	0.000	1.000	1.000
nproc	10	10	10	1.000	0.000	0.000	0.000	0.000	1.000	1.000
numfmt	20	20	20	1.000	0.000	0.000	0.000	0.000	1.000	1.000
od	40	42	40	1.000	0.000	0.000	0.000	0.000	1.000	1.000
paste	10	10	10	1.000	0.000	0.000	0.000	0.000	1.000	1.000
pathchk	10	10	10	1.000	0.000	0.000	0.000	0.000	1.000	1.000
pinky	17	19	17	1.000	11.789	0.046	11.789	0.046	1.000	1.000
pr	20	21	20	1.000	48.381	0.047	48.381	0.047	1.000	1.000
printenv	10	10	10	1.000	0.000	0.000	0.000	0.000	1.000	1.000
printf	17	18	17	1.000	0.000	0.000	0.000	0.000	1.000	1.000

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Table 42: Array recovery (compilation = debug)

	Ground truth array varnodes	Array comparisons	Array varnodes inferred as array	Array varnodes inferred as array fraction	Array length (elements) average error	Array length (elements) average error ratio	Array size (bytes) average error	Array size (bytes) average error ratio	Array dimension match score	Array average element type comparison score
ptx	39	39	39	1.000	6.154	0.024	6.154	0.024	1.000	1.000
pwd	10	10	10	1.000	0.000	0.000	0.000	0.000	1.000	1.000
readlink	12	12	12	1.000	0.000	0.000	0.000	0.000	1.000	1.000
realpath	11	11	11	1.000	0.000	0.000	0.000	0.000	1.000	1.000
rm	15	15	15	1.000	0.000	0.000	0.000	0.000	1.000	1.000
rmdir	14	15	14	1.000	0.000	0.000	0.000	0.000	1.000	1.000
runcon	10	10	10	1.000	0.000	0.000	0.000	0.000	1.000	1.000
seq	15	17	15	1.000	0.000	0.000	0.000	0.000	1.000	1.000
sha1sum	16	17	16	1.000	0.000	0.000	0.000	0.000	1.000	1.000
sha224sum	17	18	17	1.000	0.000	0.000	0.000	0.000	1.000	1.000
sha256sum	17	18	17	1.000	0.000	0.000	0.000	0.000	1.000	1.000
sha384sum	17	18	17	1.000	0.000	0.000	0.000	0.000	1.000	1.000
sha512sum	17	18	17	1.000	0.000	0.000	0.000	0.000	1.000	1.000
shred	27	27	27	1.000	23.370	0.036	23.370	0.036	1.000	1.000
shuf	12	12	12	1.000	0.000	0.000	0.000	0.000	1.000	1.000

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Table 42: Array recovery (compilation = debug)

	Ground truth array varnodes	Array comparisons	Array varnodes inferred as array	Array varnodes inferred as array fraction	Array length (elements) average error	Array length (elements) average error ratio	Array size (bytes) average error	Array size (bytes) average error ratio	Array dimension match score	Array average element type comparison score
sleep	12	12	12	1.000	0.000	0.000	0.000	0.000	1.000	1.000
sort	46	50	46	1.000	0.320	0.010	0.320	0.010	1.000	1.000
split	18	18	17	0.944	0.000	0.000	0.000	0.000	1.000	1.000
stat	32	37	32	1.000	27.459	0.027	27.459	0.027	1.000	1.000
stdbuf	16	17	16	1.000	0.000	0.000	0.000	0.000	1.000	1.000
stty	19	21	19	1.000	0.000	0.000	0.000	0.000	1.000	1.000
sum	22	23	22	1.000	0.000	0.000	0.000	0.000	1.000	1.000
sync	11	11	11	1.000	0.000	0.000	0.000	0.000	1.000	1.000
tac	33	35	33	1.000	6.857	0.027	6.857	0.027	1.000	1.000
tail	20	19	19	0.950	0.000	0.000	0.000	0.000	1.000	1.000
tee	14	14	14	1.000	0.000	0.000	0.000	0.000	1.000	1.000
test	12	13	12	1.000	0.000	0.000	0.000	0.000	1.000	1.000
timeout	13	13	13	1.000	0.000	0.000	0.000	0.000	1.000	1.000
touch	56	60	56	1.000	19.317	0.100	19.317	0.100	1.000	0.983
tr	17	17	17	1.000	0.000	0.000	0.000	0.000	1.000	1.000

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Table 42: Array recovery (compilation = debug)

	Ground truth array varnodes	Array comparisons	Array varnodes inferred as array	Array varnodes inferred as array fraction	Array length (elements) average error	Array length (elements) average error ratio	Array size (bytes) average error	Array size (bytes) average error ratio	Array dimension match score	Array average element type comparison score
true	9	9	9	1.000	0.000	0.000	0.000	0.000	1.000	1.000
truncate	10	10	10	1.000	0.000	0.000	0.000	0.000	1.000	1.000
tsort	13	13	13	1.000	0.000	0.000	0.000	0.000	1.000	1.000
tty	10	10	10	1.000	0.000	0.000	0.000	0.000	1.000	1.000
uname	12	13	12	1.000	0.000	0.000	0.000	0.000	1.000	1.000
unexpand	11	11	11	1.000	0.000	0.000	0.000	0.000	1.000	1.000
uniq	15	15	15	1.000	0.000	0.000	0.000	0.000	1.000	1.000
unlink	12	12	12	1.000	0.000	0.000	0.000	0.000	1.000	1.000
uptime	18	19	18	1.000	53.474	0.052	53.474	0.052	1.000	1.000
users	12	12	12	1.000	0.000	0.000	0.000	0.000	1.000	1.000
vdir	71	75	71	1.000	47.200	0.840	47.200	0.840	1.000	1.000
wc	16	18	16	1.000	0.000	0.000	0.000	0.000	1.000	1.000
who	25	29	25	1.000	0.000	0.000	0.000	0.000	1.000	1.000
whoami	12	12	12	1.000	0.000	0.000	0.000	0.000	1.000	1.000
yes	12	12	12	1.000	0.000	0.000	0.000	0.000	1.000	1.000