Poster: Automatic Identification and Protection of Memory-resident Sensitive Data to Defend Against Data-Oriented Attacks

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***Abstract*—Software and hardware-based countermeasures for protecting memory-resident data and its pointers to prevent data-oriented attacks suffer from high performance overhead due to a large number of memory data objects and their pointers. In this ongoing work, we propose a framework utilizing rule-based heuristics to identify sensitive memory data and its pointers automatically from an application and protect those sensitive data and pointers utilizing existing countermeasures. Our evaluation suggests that an application needs to protect less than 30% of its total data and pointers. Besides, our preliminary result shows that this prioritized protection reduces the performance overhead of existing countermeasures by 50%.**

With the advances toward practical code pointer protection countermeasures and practical Control-Flow Integrity (CFI), we anticipate a shift towards the manipulation of memory-resident sensitive data or pointers as the attack vector as this manipulation works in the presence of Code Pointer Integrity (CPI) protections and CFI countermeasures. This is why in recent years, we observed a momentum in data-oriented attacks (DOAs), also known as non-control attacks [11]–[13], [15], [21], [22], [26] even though DOAs were introduced more than a decade ago [7].

The manipulation of memory-resident sensitive data or their pointers has become an appealing attack technique for data-oriented attacks as they conform to CFG and do not violate CFI. Ideally, DOAs [7], [11], [13] can modify all kinds of memory data to change program behavior for leaking sensitive information [4] or performing privilege escalations [9]. But the corruption of data pointers [8] is often desirable. For example, the manipulation of data pointers can lead to the leak of critical information about an application's address space layout [10], [23], gadget stitching in DOP-based attacks [12], stack-based exploitations [7], and heap-based exploitations [24].

Researchers have proposed both software and hardware-based countermeasures to stop attackers from manipulating memory-resident data or their pointers. However, software-based countermeasures such as Data-Flow-Integrity (DFI) [6], Data Space Randomization (DSR) [2], [5], [20], and memory tagging [16], [17] usually suffer from performance overhead (48-116% [16], [17]) due to using static analysis, inter-procedural DFI, encryption, and masking. On the other hand, hardware-based countermeasures (e.g., HDFI [25], Intel's CET, ARM Pointer Authentication (PA), and MPX) are efficient, but in general, limited to one or a few platforms. Furthermore, the overhead is non-negligible. For example, ARM pointer authentication and Intel's MPX cost on average around 19.5% [14] and 50% overhead, respectively, for protecting data pointers.

The key reason for this overhead to protect the memory-resident data and their pointers is that the number of such data or their pointers is huge compared to the code pointers. One solution for reducing this overhead is the identification of memory-resident sensitive data and their pointers and protecting the sensitive data and their pointers, rather than protecting all data/pointers.

The idea of protecting sensitive or critical data for preventing data-oriented attacks is not new. Researchers have designed mechanisms [11], [18], [19] to protect sensitive memory data by manually-labeled or predefined data. In this ongoing work, we aim to complement existing work by identifying sensitive data and its pointers automatically and protecting them to prevent data-oriented attacks. A few existing automated techniques [13], [15] also can determine the critical data. For example, Jia et al. [13] determined the decision-making data by recording the execution of two traces with normal execution and violated execution and observing the data that get modified and changed executions. Access-driven trace data [15] are also useful to determine and understand the critical data and their structures. However, these works are not scalable as we need huge and relevant execution and access traces.

In this ongoing work, we aim to develop a generic framework for the automatic identification of memory-resident sensitive data and their pointers for protection using existing defense mechanisms. Figure 1 shows the high-level overview of the framework. The identification process starts with attack entry points usually the external inputs from the network, file system, and keyboard. A precise taint analysis with the help of points-to analysis helps track the data flow of sensitive memory data and pointers. The generic nature of the framework enables the protection of the identified sensitive data and pointers with existing defenses such as ARM Pointer Authentication, Intel MPX, AddressSantizer, and memory tagging solutions [16], [17].

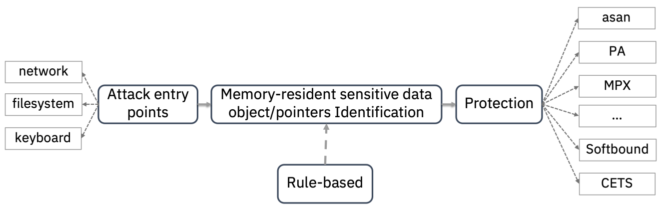

Fig. 1. High-level overview of the data object prioritization technique.

This framework can prevent attackers from modifying the integrity of sensitive memory-resident data or its pointers even with arbitrary memory read/write capabilities. The capability of identifying sensitive memory data prevents data-oriented attacks by making the existing defense mechanisms practical. Our framework utilizes rule-based heuristics to detect sensitive data objects/pointers using knowledge from advanced data-oriented exploits [7], [10], [11], [23] and vulnerabilities (CVE-2001-0820, CVE-2006-5815, CVE-2006-5815, CVE-2017-9430, CVE-2018-6151, CVE-2018-10111, CVE-2021-23017, etc.).

Our preliminary evaluation using manually constructed ground truths of vulnerable data objects/pointers by identifying vulnerable data objects/pointers from vulnerable datasets [1], [3] including 5 real-world applications shows that less than 30% of the data objects and their pointers are sensitive. Thus, in our testing environment, protecting less than 30% of total memory-resident sensitive data or their pointers is sufficient to protect the tested applications from data-orient attacks. Besides, the rule-based identification of sensitive memory data and pointers can lead to almost 50% performance improvements in existing defenses in our tested environments.

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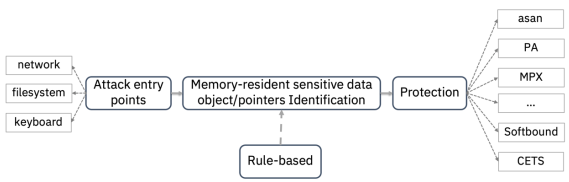
1. Motivation

Memory-resident data and its pointers need protection to defend against data-oriented attacks.

However, the protection incurs huge **performance overhead** due to a large number of memory data and pointers.

2. Approach

- ❑ **Rule-based heuristics** to detect sensitive data objects/pointers.
- ❑ Rules are based on knowledge of existing data-oriented exploits and vulnerabilities.
- ❑ **Generic** nature of the framework enables integration with existing defenses.



Overview of rule-based sensitive data and pointer detection framework

3. Challenges

How to confirm the **coverage of rules**

How to construct **ground truths** for evaluation

4. Experimental Design

- ❑ We **solve the coverage issue** by breaking down the knowledge from exploits and vulnerabilities into smaller and generic rules.
- ❑ The generic rules are applicable for wide-range of exploits and vulnerabilities, both known and unknown.
- ❑ We **manually construct ground truths** by analyzing memory-resident data and pointers from **27** programs.

DARPA Cyber Grand Challenge [1] and Software Assurance Reference [2] datasets with five real-world programs

Less than 30% of the data and their pointers are sensitive. Thus, **only this 30% need protection.**

Performance overhead is reduced by almost **50%.**

5. Conclusion

We presented a framework for identifying memory-resident sensitive data and their pointers automatically. Our experiments show that on average 30% of memory-resident data and pointers are sensitive, hence requiring protection. We can improve the performance overhead of existing defenses by 50% when protecting these sensitive data and pointers.

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