# Research Statement

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## Overview

As people rely more on computers (mobile and desktop), building and maintaining a secure computing environment becomes an important research topic. However, many computer programs remain vulnerable, and more advanced techniques for breaking into a computer or a network of computers have been discovered. Vulnerabilities may permit a malicious program (malware) to take full control of the victim machine and run the attacker's code. Automatically analyzing the vulnerabilities and malware as well as detecting such intrusions are critical in securing a computer system.

My research centers on analyzing and detecting malware and intrusions, with a recent focus on mobile platforms. The following points provide an overview of my research areas while Figure 1 shows a graphical view with the main publications in each (and intersection of) research area(s).

- Analyzing and detecting malware and intrusions: binary program analysis is a hard problem especially when we assume that source code is unavailable. Software obfuscation and new attacking techniques like Return-Oriented Programming make this difficult problem more challenging. My research centers on novel techniques to accurately perform such analysis and detection.
    - Binary difference analysis: a novel idea by focusing on (control-flow) graph similarity to detect polymorphism and metamorphism in malware, making the analysis technique resistant to software obfuscations. The idea also leverages software diversity, a well-known phenomenon in software engineering, to fight against evasion attacks.
    - Return-oriented program: analyzing the capability of this latest and most powerful attacking technology, defending against it, and even taking advantage of it for benign applications.
- Mobile security: tracing the latest mobile platform architectures (mostly Android) and the corresponding security and privacy they provide, with a focus on attack and defense techniques. My research uncovers new and zero-day attacks and proposes novel ways of defending against such attacks.
- Human factors in security and cloud security: a couple of focused areas of security closely related to human behavior (keystroke dynamics and coercion attacks) and cloud.

I consider these research areas closely related and interconnected. For example, intrusion detectors focus on mechanisms a defender could use to detect an intrusion to make it more difficult for malware to exploit, while malware analysis tries to understand what malicious programs do to better defend against them.

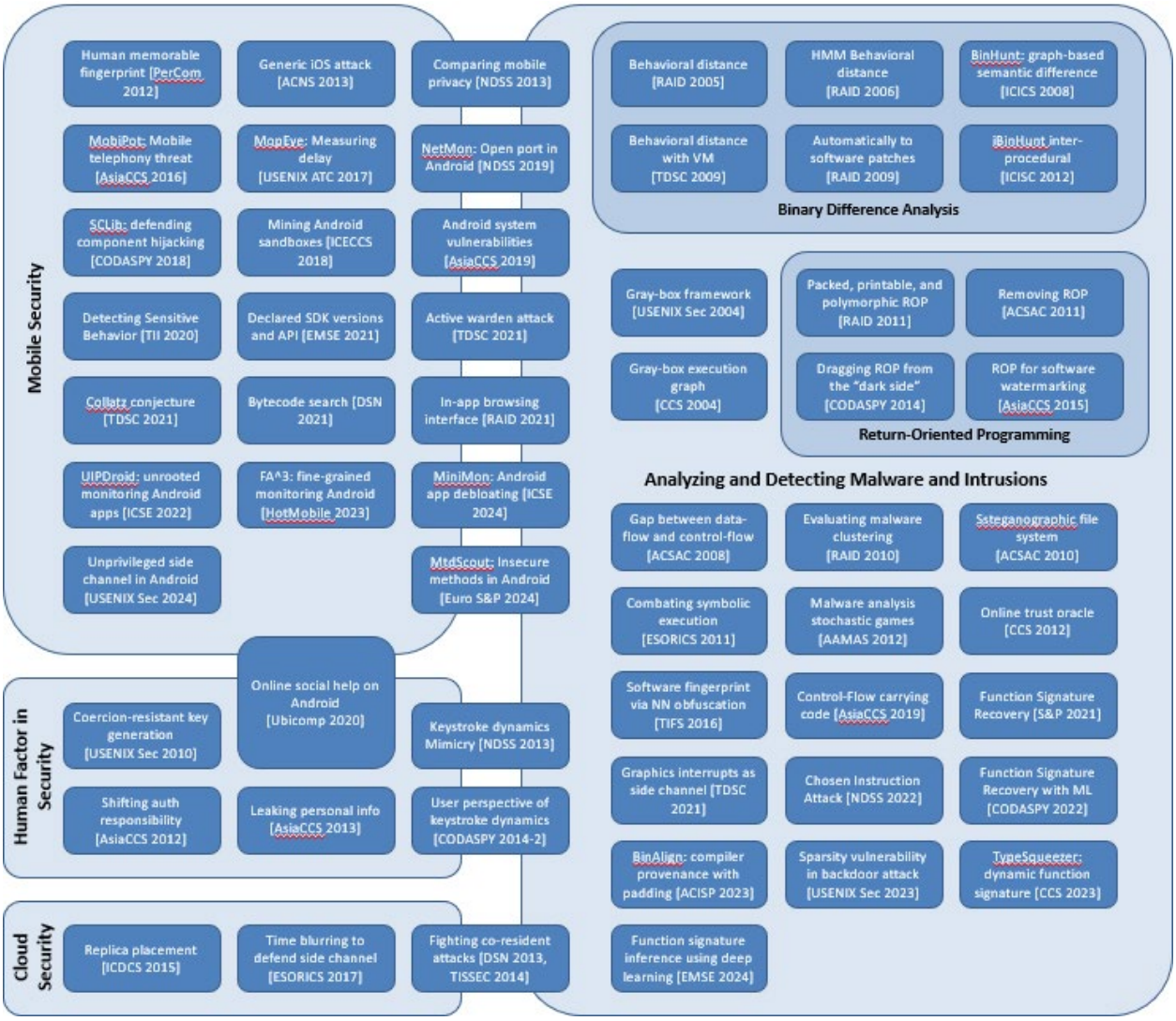


Figure 1: My research areas and selected publications

## Specific Research Areas

Malware analysis and defense (my key research theme): Malware research is a big topic, and my research covers many sub-areas including control-flow hijacking, unpackers, symbolic execution, distributed denial of service attacks, randomization, etc. One interesting way of looking at my research in this big area is that I conduct my research from both the defenders' and attackers' perspectives.

On the defense side, I make notable contributions to the topic of Control-Flow Integrity, which is widely believed to be one of the most effective approaches to software security. The main idea is to strictly enforce a policy that any piece of software execution has to follow its intended control flow. To this end, we propose a few techniques to accurately extract the control-flow policy [S&P 2021, CODASPY 2022, CCS 2023, EMSE 2024] and to effectively enforce it [AsiaCCS 2019].

On the attack side, besides focusing on some of the latest attacking techniques like Return-Oriented Programming (more on this later), I look into software obfuscation techniques malware writers could employ to make analysis difficult [NDSS 2022], and graphics interrupts serving as side channels that leak sensitive information to potential process eavesdroppers [TDSC 2021].

There are also two specific areas where I contribute significantly to the analysis of malicious programs, namely binary diffing and Return-Oriented Programming.

Polymorphic and metamorphic malware are among the most difficult ones to analyze. We propose a novel binary difference analysis tool, BinHunt, to find semantic differences between binary executables. BinHunt bases its analysis on the control flow of the programs using a novel graph isomorphism technique, symbolic execution, and theorem proving, making it resistant to most obfuscation techniques used in malware polymorphism and metamorphism [ICICS 2008]. We further propose iBinHunt by analyzing inter-procedural control flow to combat obfuscations at the function level (e.g., function inlining) [ICISC 2012]. BinHunt and iBinHunt lay the groundwork for many subsequent binary diffing research and tools and are both highly cited.

Return-oriented Programming (ROP) is one of the latest and most powerful attacking techniques used by malware writers. My research touches on both its attacking capability and its defending mechanisms. On the attacking side, we analyze the capability of ROP, and find that it could be made packed, printable, and polymorphic [RAID 2011]. On the defense side, we propose an automatic system to remove ROP from any malicious program so that the large body of existing software analysis tools can be used to analyze ROP-based malware [ACSAC 2011].

Since its introduction, ROP has always been regarded as an attacking technique. We work on a number of projects to use ROP for security applications other than malicious attacks. For example, we propose a novel idea of using ROP for software obfuscation, which is the first step in dragging ROP away from the “dark side” to perform legitimate tasks [CODASPY 2014]. Following along the same direction, we also propose using ROP for software watermarking [AsiaCCS 2015].

Mobile security (my latest research development): My research into mobile security has substantial overlapping with that in malware analysis and defense. For example, we apply the binary differencing idea in malware analysis to analyze security and privacy models in Android and iOS [NDSS 2013, SKM 2014], and analyze a wide range of malicious behaviors in Android applications, including bytecode search [DSN 2021], open ports [NDSS 2019], re-packaging mechanisms [TDSC 2021-1, TDSC 2021-2], in-app browsing interfaces [RAID 2021], adversarial machine learning for Android malware detection [USENIX 2023], and use of insecure methods [Euro S&P 2024].

Besides these topics that are highly related to my research on malware analysis, I also make significant contribution to other mobile platform security research. More specifically, we focus on security implications of the Android OS architecture. For example, we analyze the consistency between declared SDK versions of Android applications and their actual API calling and show potential security flaws that could make Android applications exploitable [EMSE 2021]. We analyze inter-component communications among Android applications and propose a library-based solution to defend against component hijacking [CODASPY 2018]. We also systematically analyze vulnerabilities on the Android OS [AsiaCCS 2019]. Our latest analysis on the Android OS shows that an unprivileged side channel can be used to break the app sandboxing protection [USENIX Security 2024].

As one of the latest research efforts in mobile security, we recently investigated the possibility of monitoring Android application's execution on non-rooted devices used by the public. We modify the Android AOSP or utilize side channel information on Android OS while deploying our monitoring apps on Google Play to crowd source usage information from many real-world users [USENIX ATC 2018, NDSS 2019, IWQOS 2019, TII 2020, ICSE 2022, HotMobile 2023, ASE 2023]. Results have enabled us to perform accurate per-app networking measurement, to identify unknown open port vulnerabilities in many Android applications [NDSS 2019], and to debloat Android super apps to trim off unwanted functionalities [ICSE 2024].

Other areas I'm known for: In my earlier career of security research, I focus on intrusion detection and propose a few novel techniques. We take a systematic view on host-based anomaly detection techniques and propose a unified framework [USENIX 2004]. This framework not only captures most existing host-based intrusion detectors but has become the framework under which new techniques are proposed. Execution graph [CCS 2004] is one of them and has a nice feature of conforming to the control-flow graph of the program (static) while being built from dynamic training. I'm one of the pioneers in proposing the use of software diversity for intrusion detection. We introduce a notion, behavioral distance, for evaluating the extent to which processes — potentially running different programs and executing on different platforms — behave similarly in response to a common input [RAID 2005]. This idea is further extended to improve its accuracy by using a customized Hidden-Markov Model [RAID 2006], and to improve efficiency by using virtual machines running on one physical computer [TDSC 2009].

I also work on a few interesting projects that are closely related to human factors in security. For example, we analyze how individual dynamic keystrokes could potentially be forged [NDSS 2013], altered [CODASPY 2014], and leaked out [ACNS 2014]. We also look into providing resistance to coercion attacks [USENIX 2010, AsiaCCS 2012].

## Selected Publications

[USENIX Security 2004] Debin Gao, Michael K. Reiter and Dawn Song, "On Gray-Box Program Tracking for Anomaly Detection", in *Proceedings of the 13th USENIX Security Symposium (USENIX Security 2004)*, San Diego, CA, USA, August 2004.

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