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Mathematical Foundations of Secure Computing Clouds

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14. ABSTRACT

This project develops the mathematical foundations of cloud infrastructures and provides a sound theoretical foundation for offensive and defensive cloud cyberwar tactics. We assert that (1) new mathematics are required to handle the big data challenges present in cloud security, and that (2) close interaction between research agendas in system security, algorithms, and big data is needed to make this mathematics truly applicable.

15. SUBJECT TERMS

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The Cloud is becoming the battleground of 21st century cyberwarfare. Both industry and the military are moving the majority of their computing infrastructure to cloud-based platforms, because of their low operating overhead, versatility, and high-throughput computing potential. Clouds will provide strategic advantages via real-time tactical analysis for warfighters on the front lines, data mining for intelligence analytics, cheaper high-throughput computing for simulations, and a computational substrate for cyberwar operations by enabling dynamic and flexible access to mission-critical computational capacity in the form of warehouse-scale computers. With more and more computation being moved into computational clouds, strategic advantage in the 21st century is increasingly determined by the ability to operate cloud platforms securely securely — and to disrupt those of opponents. More and more, cyberwarriors will be fighting their battles on and over cloud computing systems.

It is difficult to secure any large-scale computing infrastructure, but the challenges are particularly acute for clouds. Clouds require external connectivity (e.g., to forward operating bases), making them vulnerable to attackers, who may gain the credentials needed to access some portion of the platform. Their frequently changing workloads make it hard to define normal behavior, and conversely to flag abnormal behavior. Finally, their sheer scale (a typical cloud today consists of half a million individual servers) makes gathering, analyzing, and assessing their security status a big data problem.

Three critical obstacles were tackled in this project in order to provide a more secure and robust cloud:

1. From the attacker's perspective, we studied how one reverse engineer a large, opaque infrastructure from a sparse collection of measurements. From a defensive standpoint, we derived bounds on how actions reveal information about the infrastructure. We studied how to change the external view of the infrastructure over time, turning it into a moving target that is more difficult to track.

2. We developed capabilities for monitoring the cloud efficiently to provide insight into performance and alert us to anomalous activities and

behaviors. We characterized which features are most salient for detecting attacks and anomalies. From an offensive side, we mathematically determined probing strategies to maximize information gain and minimizes possible detection.

3. We developed new algorithms for sensing and machine learning that are well adapted to cloud platforms. We developed new statistical signal processing and machine learning algorithms for just-in-time performance from a cloud infrastructure.

The details of these advances are covered in the publications listed in this report.

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Abstract

This research effort aims at developing the mathematical foundations of cloud infrastructures and providing a sound theoretical foundation for offensive and defensive cloud cyberwar tactics. We assert that (1) new mathematics are required to handle the big data challenges present in cloud security, and that (2) close interaction between research agendas in system security, algorithms, and big data is needed to make this mathematics truly applicable.

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Archival Publications (published) during reporting period:

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Jordan Ellenberg, Lalit Jain. "Convergence rates for ordinal embedding." Submitted, preprint available at https://arxiv.org/abs/1904.12994.

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Florian Tramer, Fan Zhang, Ari Juels, Michael Reiter, and Thomas Ristenpart
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ICML 2016: 1567-1576. Best paper.

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Learning Compressed Transforms with Low Displacement Rank Anna T. Thomas, Albert Gu, Tri Dao, Atri Rudra, Christopher Ré:. NeurIPS 2018: 9066-9078

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Tristan Nguyen

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