Comparing reproduced cyber experimentation studies across different emulation testbeds

Sandia National Laboratories: Tom Tarman (tdtarma@sandia.gov), Laura Swiler, Eric Vugrin, Trevor Rollins, Jerry Cruz
Texas A&M University: Hao Huang, Abhijeet Sahu, Patrick Wlazlo, Ana Goulart, Kate Davis

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Outline

• Scenario description and background
• Motivation for this study – is the original experiment reproducible, and how do we quantitatively compare both experiments?
• Data analysis and comparison metrics
• Lessons learned in reproducing this experiment
• Conclusions and future work
SCADA network scanning/detection study

- SCADA – Supervisory Control and Data Acquisition
- In this study, a SCADA network is used to control portions of a power grid
- The attacker has a presence in the control network, and uses Nmap to scan for vulnerable control devices
  - Modeled as open ssh port
- Defender uses Snort intrusion detection to detect scanning
- Attacker’s objective is to identify as many vulnerable devices as possible without detection, using two strategies: Fast, and slow
- Sources of randomness
  - Attacker scan sequence
  - Network packet drop
Scanning/detection – mathematical model and its validation

• The original study\(^1\) developed a mathematical stochastic model of the attacker’s port discovery progress and the defender’s ability to detect scanning

• This work used the minimega emulation testbed environment\(^2\) to validate the mathematical model

• The original study showed good agreement between the models, relative to 95% confidence intervals


Can a different group reproduce original results on their testbed, and how do we compare both experiments?

- Reproducibility is key to ensuring results are correct, well documented, and unbiased.
- Did paper describe the emulation experiment sufficiently well to be reproduced?
- Texas A&M used CORE testbed\(^1\).

**Differences between minimega and CORE**

- Testbed technologies (minimega used kvm VMs on one physical machine, CORE used FreeBSD jails containers in one VM).
- Experiment orchestration (minimega used SCenario ORCHestrator [SCORCH], CORE used custom scripts).

- Both testbeds used the same topology, mechanism for packet drop, Nmap and Snort versions, and port for “vulnerable” services.

- Same experiment design: four scenarios {fast, slow} X {random, deterministic}
  - Random – random ordering of scanned host IPs, random packet drop.
  - Deterministic – fixed scan order, no packet drop.

How do we compare ensembles of results?

- There is inherent variability in cyber network results due to system timing, resources, operating systems, kernels, etc.
- We run a number of replicates (100 in this experiment) on both experimental platforms
- We want to compare distributions from the 100 TAMU CORE results vs. 100 SNL minimega results.
How do we compare ensembles of results?

Distribution comparison can be performed by the Kolmogorov-Smirnov (KS) test
- Function of the max difference between CDFs
- p-value = 1 indicates complete agreement
- p-value less than 0.05 indicates one would not accept the hypothesis the distributions are the same.

We looked at other comparison metrics: please see paper for more details.

Results: No drops, fixed port order
No replicate variability: deterministic results match

Fast

Slow
Results: with packet drops and random port ordering

* Fast scenario more consistent than slow under stochastic conditions
* Statistical tests indicate two sets of data would not be considered different

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How well was the experiment reproduced?

We may care about the differences in magnitude and not care about distributional differences.

Alert detection times

Fast – No Drop – Fixed Nmap order
- KS-test: 0.000
- Least variable experiment

Slow – Drop – Random Nmap order
- KS-test: 0.155
- Most variable experiment

The validation metrics depend on the question being asked:
Are these differences significant due to differing hypervisors, time synchronization, and experiment orchestration? Are they acceptable to be used in a larger attack model?
What did we learn about reproducing emulation experiments?

• Even after providing a comprehensive writeup and details of the experiment, both teams still required significant coordination to reproduce the experiment.

• It can be challenging to determine if small differences are due to differences in the hardware/emulation platform OR due to an implementation detail that is not correctly reproduced.
  • Subject matter expertise is critical

• Statistical tests and ensembles of replicate results can help in this comparison as they provide some estimate of the uncertainty inherent in the results on one platform.
Recommendations - what is needed to facilitate reproducibility?

- Public repositories for experimental artifacts
  - Topologies, applications, orchestration files
  - Github, SEARCCH\(^1\), etc.

- Need consensus in artifacts and how testbed technologies use them

- Understand differences between common cyber experimentation platforms
  - Virtualization technologies (CPUs, network interfaces, switching, etc.)

- Appropriate metrics, depending on experiment question/objective
  - Distance measures between experimental results
  - Metrics to determine effects of platform differences on results

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\(^1\) Sharing Expertise and Artifacts for Reuse through Cybersecurity Community Hub (SEARCCH) project. 2021. https://searcch.cyberexperimentation.org/
Thank You

Thomas D. Tarman
tdtarma@sandia.gov