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“Engineering the Future”

Application-Level Checkpoint/Restart for Large-Scale Attack and Compliance Graphs

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Track#3

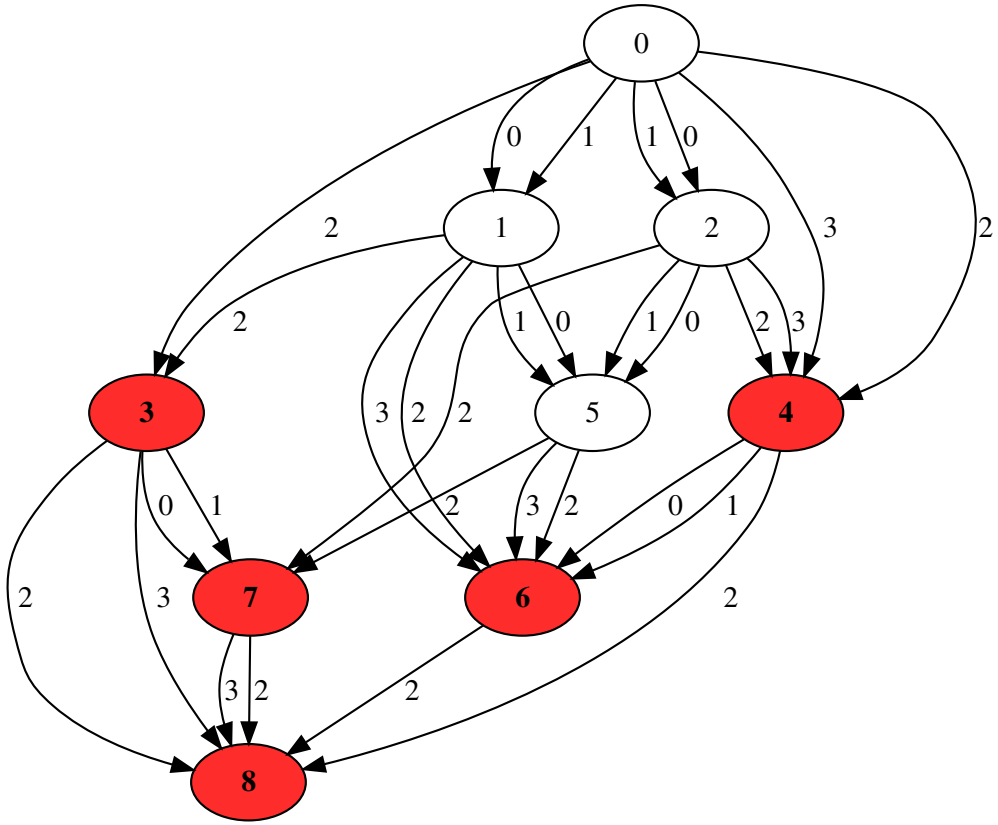
Session:

Presentation Date

Introduction (1/2)

Overview

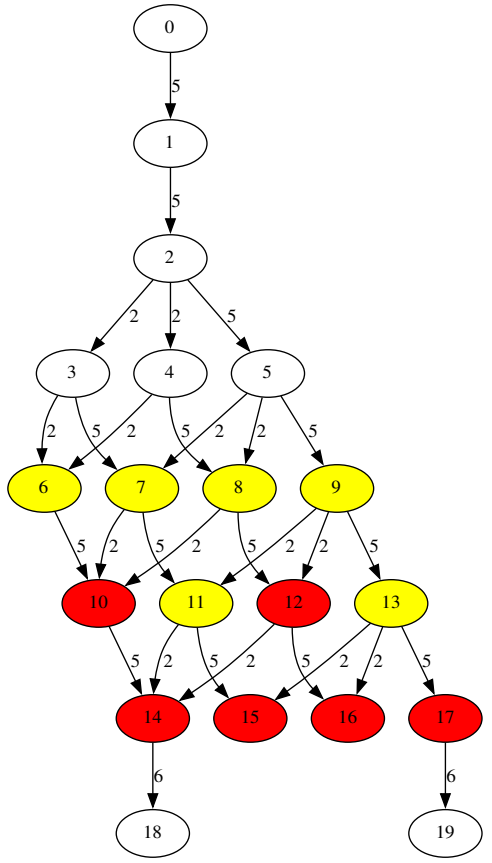
- **Attack Graph -**
  - Determine all possible ways systems may be compromised [1]
- **Compliance Graph -**
  - Determine all possible ways systems may fall out of compliance [2]



Introduction (2/2)

Terminology/Descriptions

- Nodes
  - States within the graph.
  - Have system information embedded within the object.
    - Example: Windows 10 machine, pfSense firewall, 2006 Toyota Corolla
- Edges
  - Transitions within the graph.
  - Events that lead to a change in the system(s) or environment(s).
    - Example: Installing or updating software/hardware, regularly occurring maintenance, spread of malware



Challenges (1/2)

Challenges with Attack and Compliance Graphs

- Scalability (State Space Explosion) [3, 7]
  - The exponential growth of states and edges caused through minimal additions of assets, qualities, or events .
  - Leads to graphs with hundreds of millions of nodes, and billions of edges.

- High Runtime Requirements [3-7]
  - Real-world performance of graph operations does not align with the theoretical assumption.
  - Scalability – large graphs take exceedingly long to generate.
    - Example: Installing or updating software/hardware, regularly occurring maintenance, spread of malware

Challenges (2/2)

Implications

- Graphs and graph operations cannot be contained within non-volatile memory (RAM).
  - Out-of-memory killers will terminate the generation process.

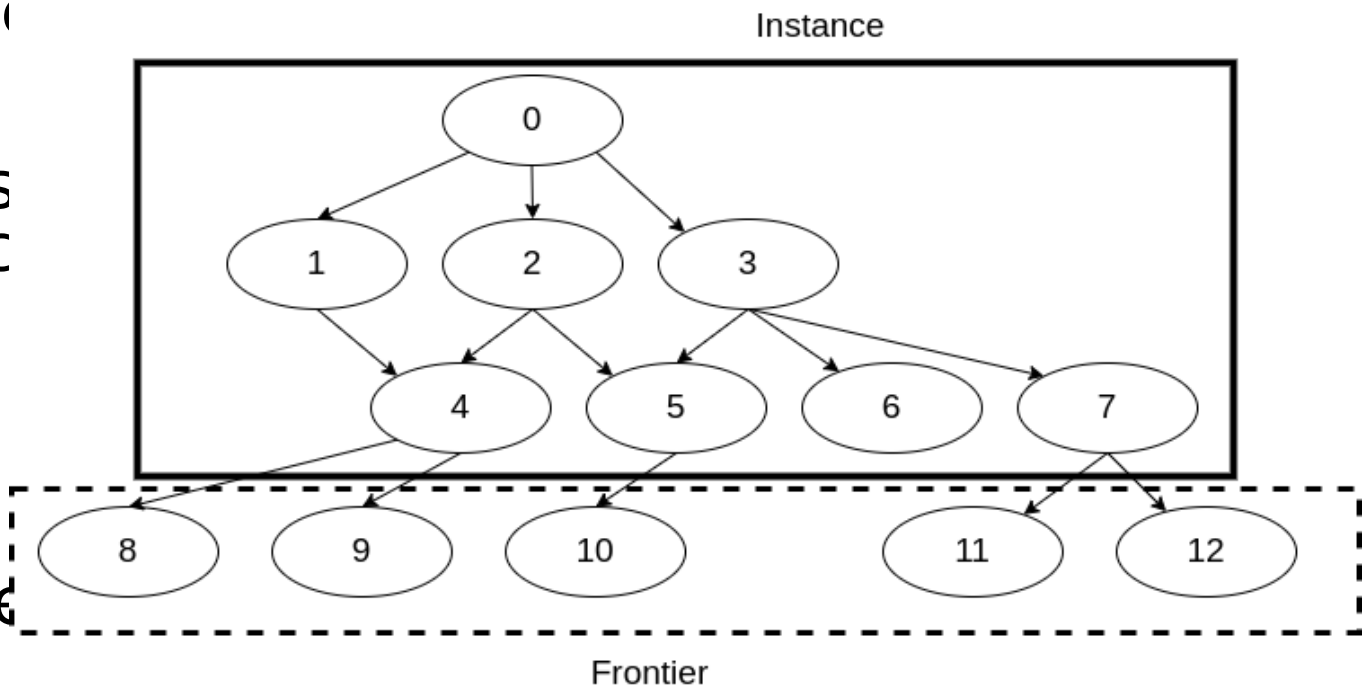
- Outages, HPC cycle exhaustion, or other interruption forces a complete re-generation of the graphs.
  - Can result in a loss of weeks' worth of processing.

Memory Constraint

Two Primary Pain Points

1) The queue of unexplored nod
   - “Frontier”
   - Caused by the Breadth-Firs Search generation approac

2) The graph object
   - “Instance”
   - All explored nodes (and the embedded information), edges, flags, or auxiliary graph labels or features



Related Works

Specific to Attack and Compliance Graphs

- Efficient storage techniques [13, 14].
- Logic-based generation [15].
- Alternate information representation schemes [16, 17].
- Sampling [18].
- Parallelization [19].

Checkpoint/Restart (C/R)

Introduction

- A technique that saves the state of a program mid-execution, and allows for a restart from a saved state.

- Three categories [8, 9]:
  - System-level
    - Requires compatibility with the operating system, and any application libraries (e.g., MPI).
    - Large in scope: can restore process IDs, checkpoint shell scripts, sockets, threads, file processing.
  - User-level
    - Large, application-independent checkpoints that are linked through libraries.
  - Application-level
    - Built into an application's source code.
    - Goal: only handle the necessary information.

Goal of This Work

Implement Application-level C/R

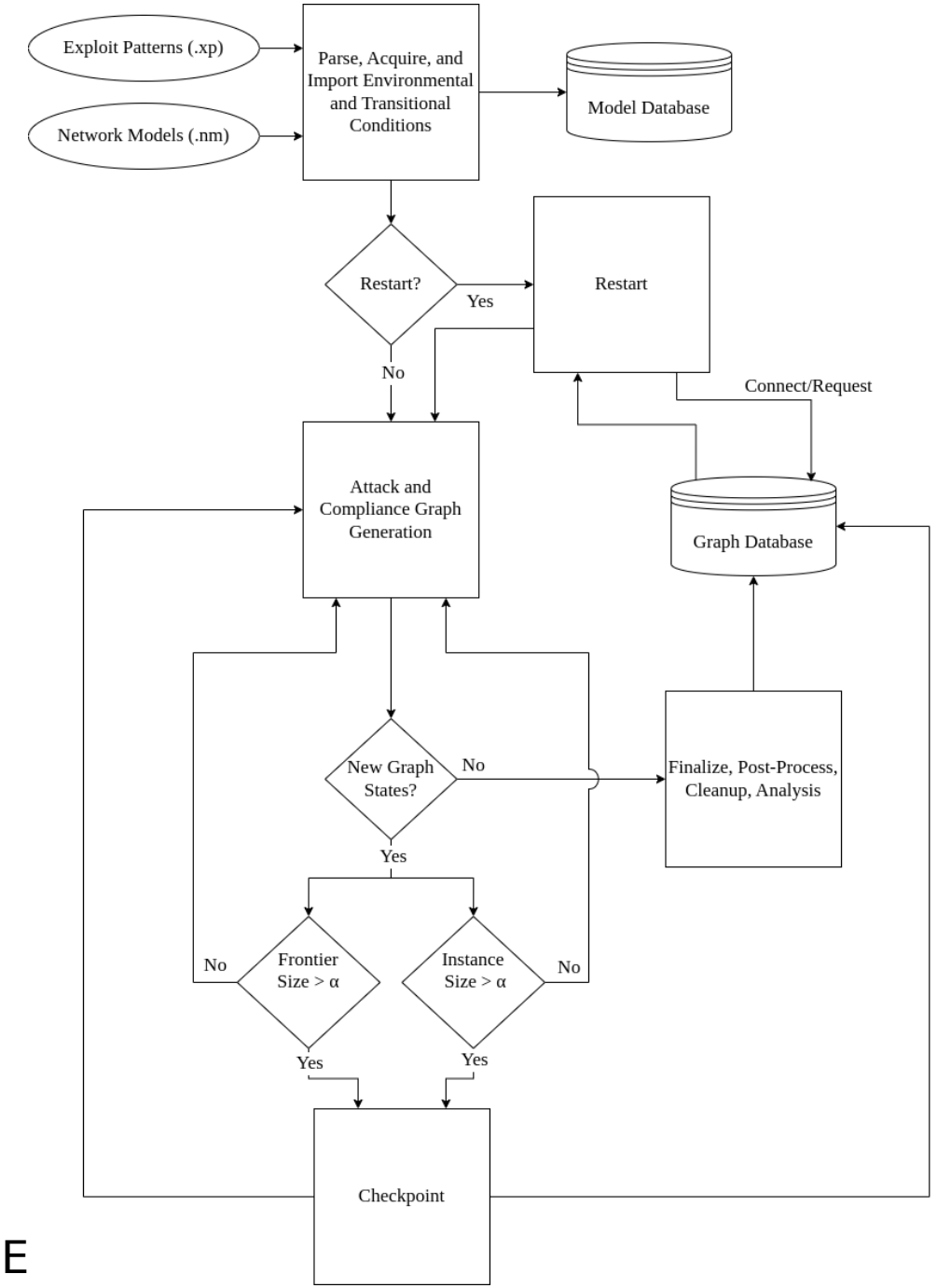
- Minimal checkpoints for fast, efficient checkpoint and restart procedures.
  - C/R will also be portable, and independent of external libraries or operating systems.

- Benefits are twofold:
  - Provides a form of fault-tolerance in the event of interruption.
  - Provides a means of memory relief by dumping excess, no longer relevant graph instances during checkpoint intervals.

Overview

Generation Process

- Details...



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Checkpointing

Description

- Details...

Restarting

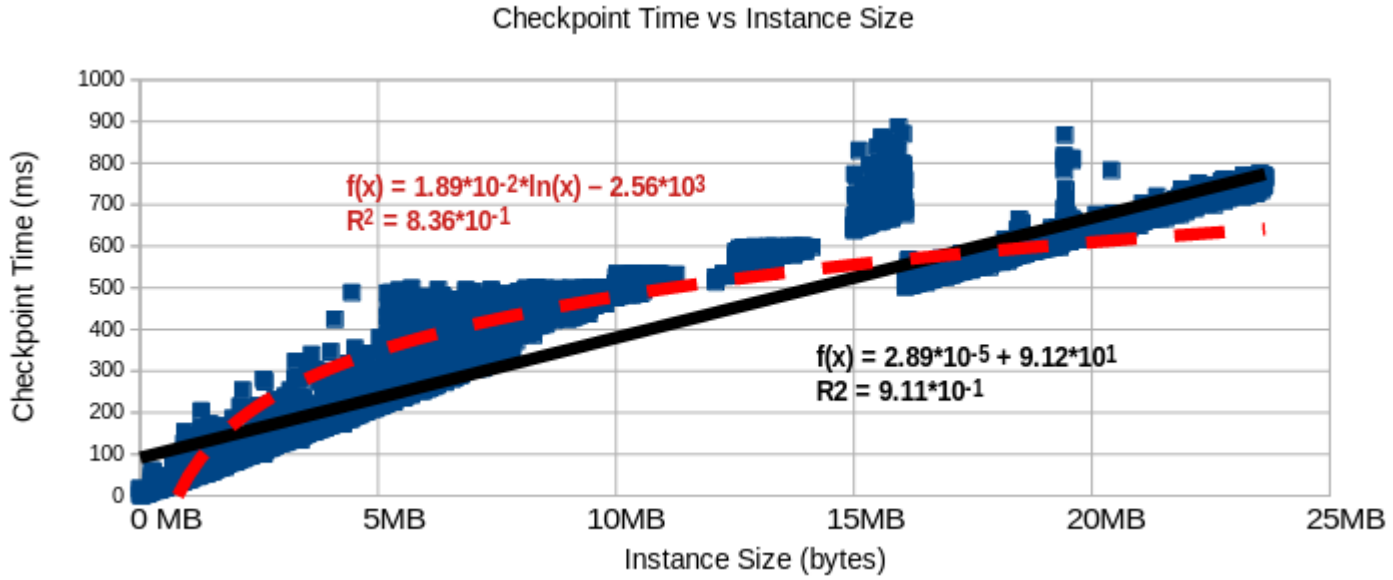
Description

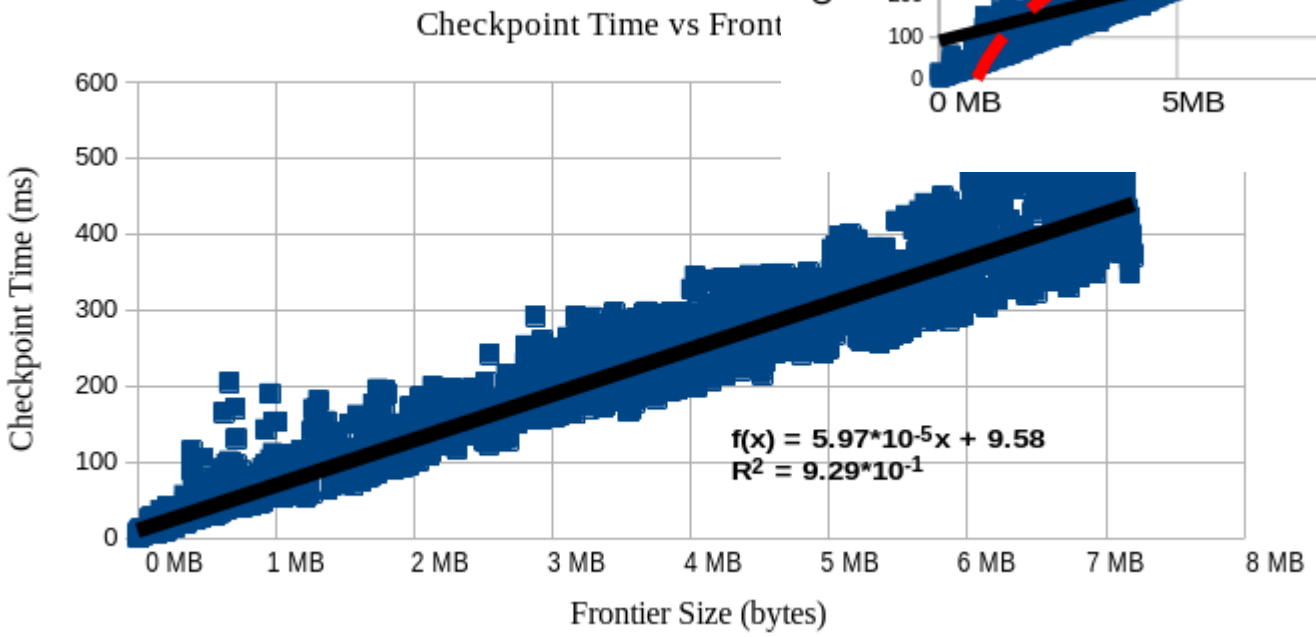
- Details...

Results - Checkpointing

Description

- Details...

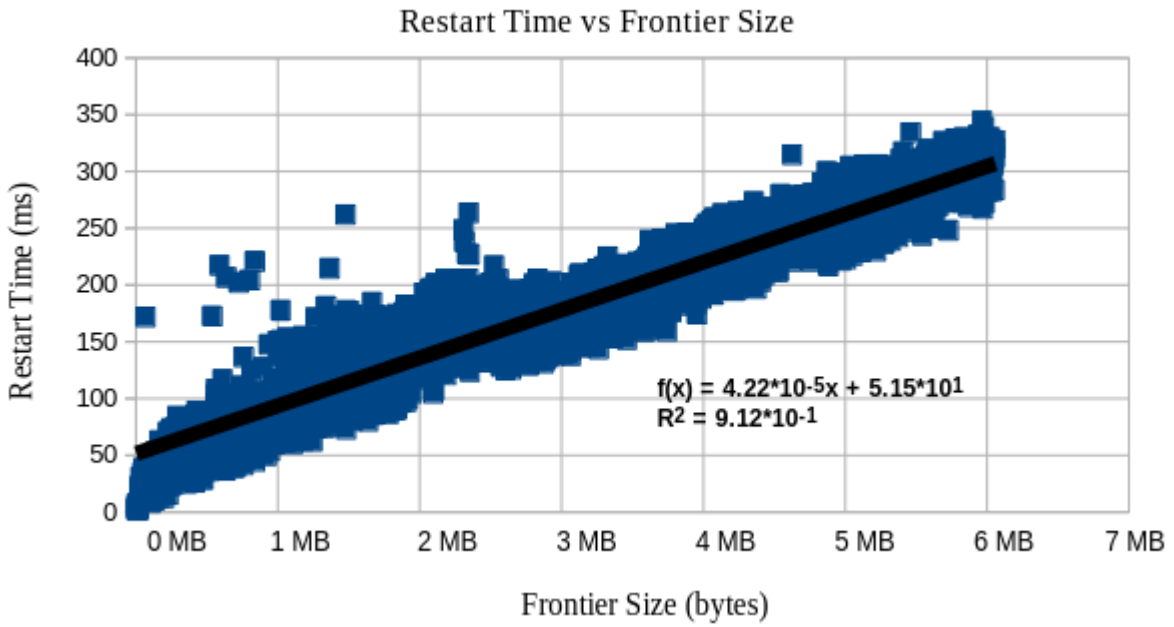




Results - Restarting

Description

- Details...



Conclusions

Description

- Details...

Future Work

Description

- Details...

References

Description

- Details...

Thank You!

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