Simulation-based optimization of IT security controls

Initial experiences with meta-heuristic solution procedures

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Agenda

Introduction

Framework

- Overview
- Knowledge base
- Attack patterns
- Simulation
- Optimization

Example scenarios

- Simple
- Advanced

Conclusions

Introduction
Current IT security management challenges

- Information systems are growing ever more complex
- Today's serious threats are not opportunistic, but
  - deliberate, targeted attacks
  - that exploit multiple attack vectors
    - software vulnerabilities
    - network vulnerabilities
    - insider knowledge and access
    - social engineering techniques
    - ...
- Human threat agents are heterogeneous

  hacktivists, script kiddies, insiders, advanced persistent threats ...

  → "secure against whom?"

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  $\rightarrow$ "secure against whom?"

Introduction
Core ideas

Security:

- is meaningless without defining "against whom"
- is the result of the combined effect of all implemented security controls
- involves tradeoffs between multiple monetary and non-monetary criteria

No universally "best" solution:
Highly context-dependent, decisions must consider

1. "system" characteristics
   (physical and IT infrastructure, people etc.)
2. the threat model
3. available resources
4. decision-makers' risk preferences

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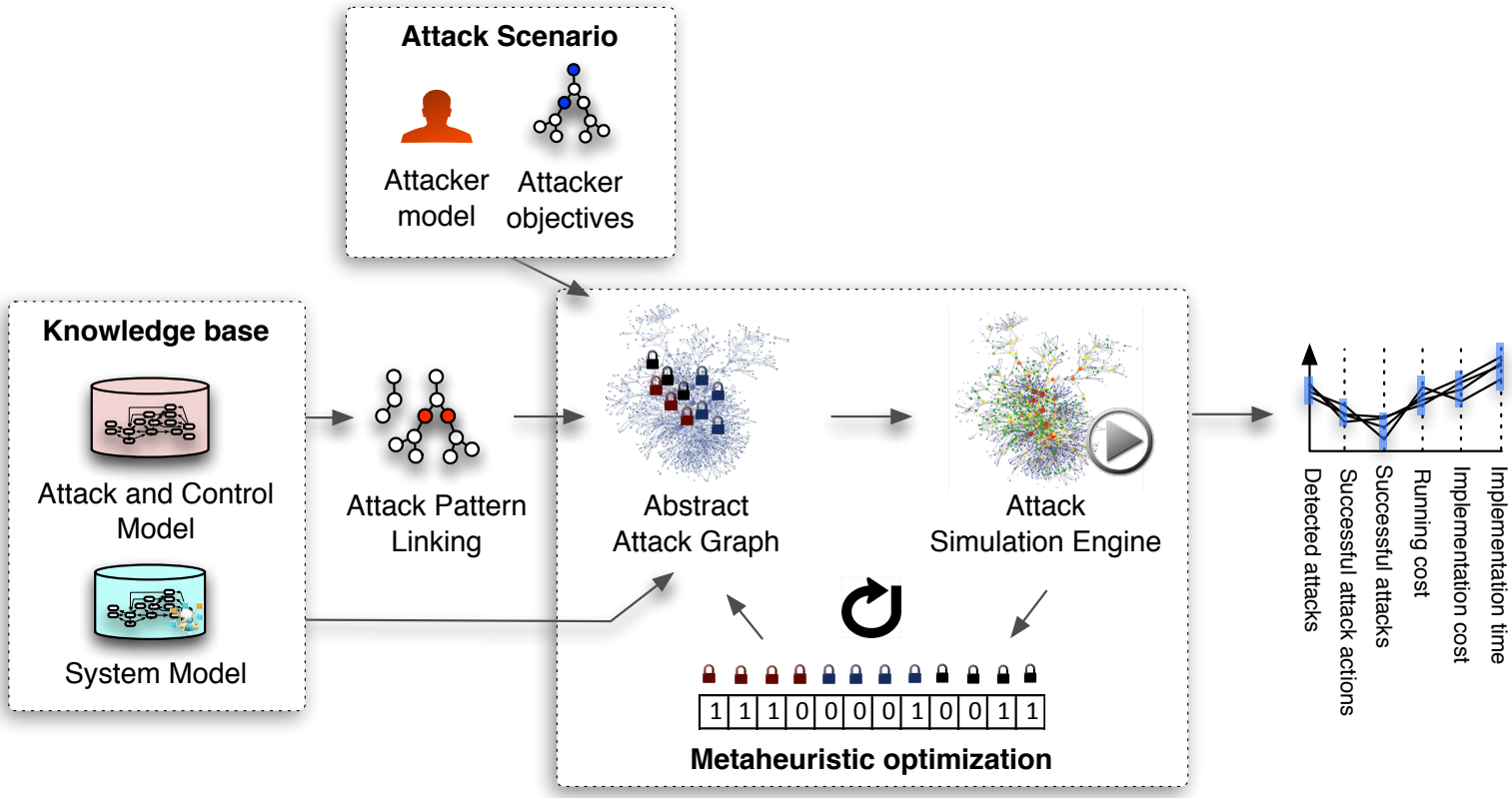
Framework
Overview

Objective: choose an “optimal" set of security controls

Approach:

1. Model
   - abstract causal structures (attack actions)
   - attack agent behavior
   - context (assets, employees . . .)
2. Apply control sets and simulating attacks
3. Identify efficient sets of controls through multi-criteria optimization

Framework
Overview



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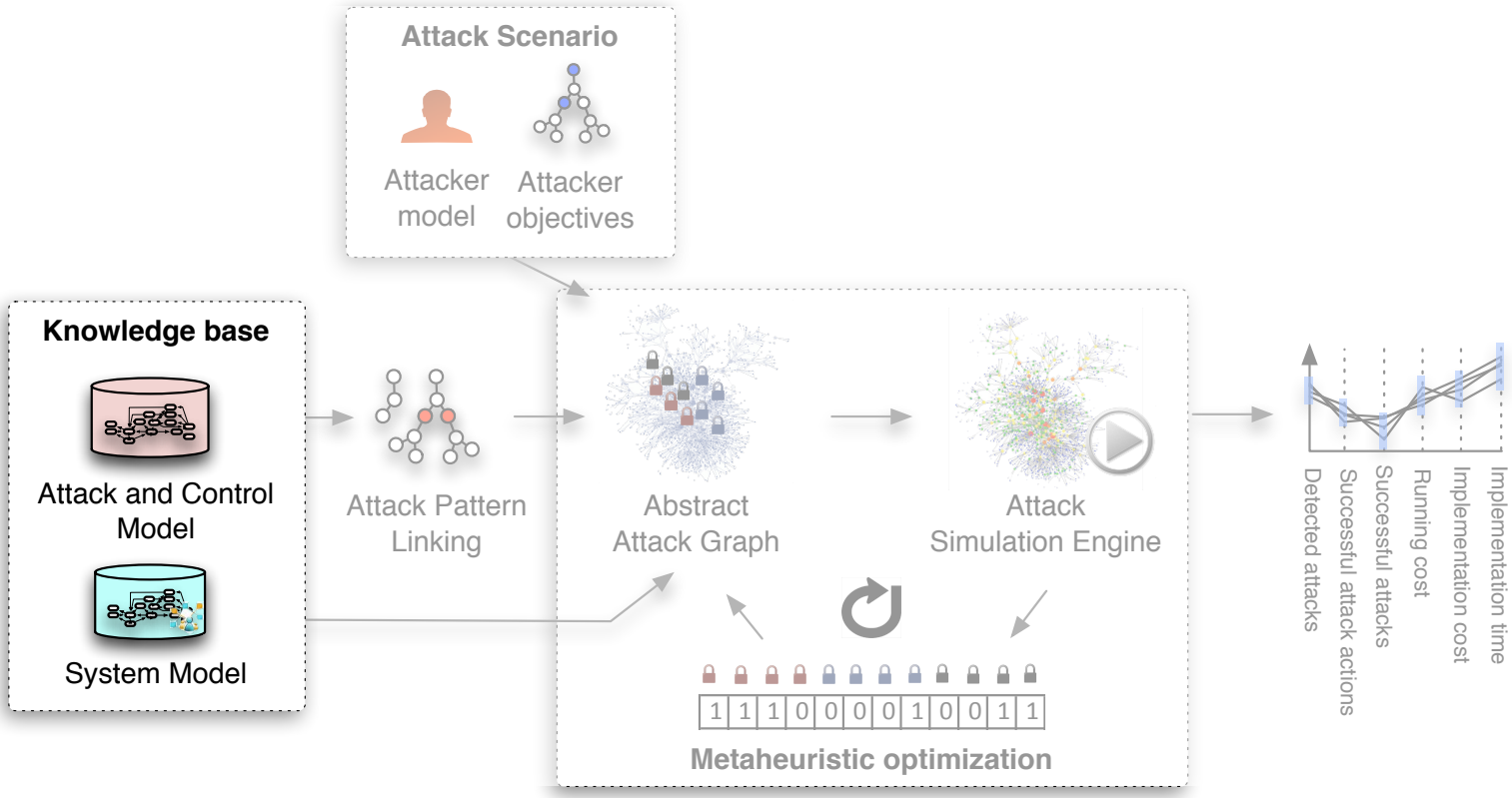

Framework
Knowledge base

- Abstract attack knowledge (causal structure) + system structure knowledge
- Initial experiments with OWL ontologies
- Current rule-based implementation: SWI-Prolog[1]

[1] http://www.swi-prolog.org/man/clpfd.html

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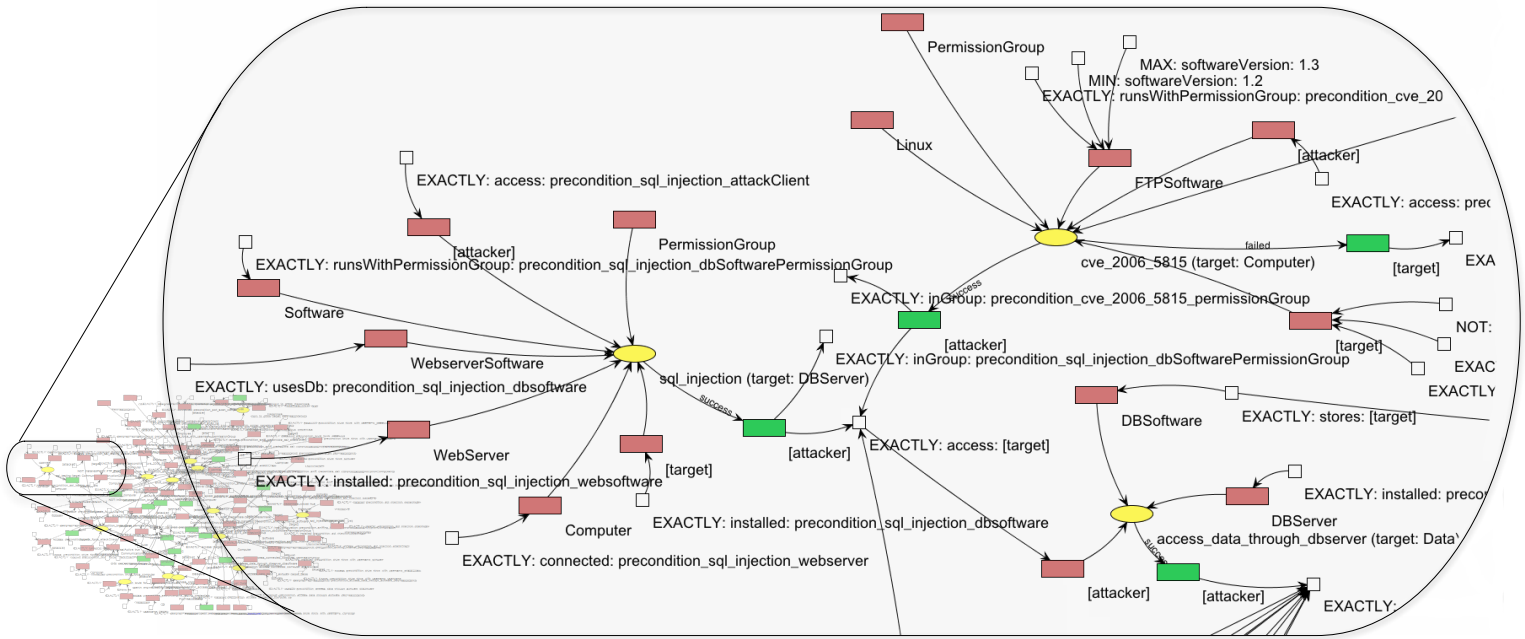
Knowledge base



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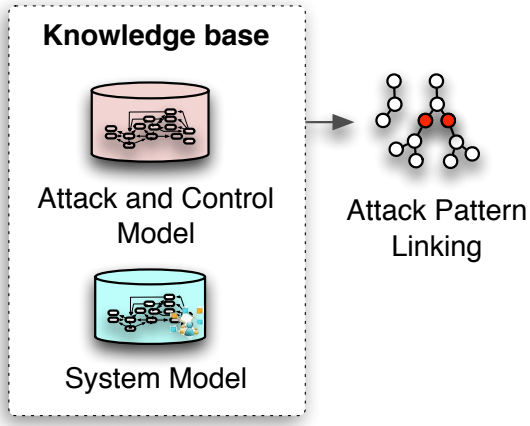
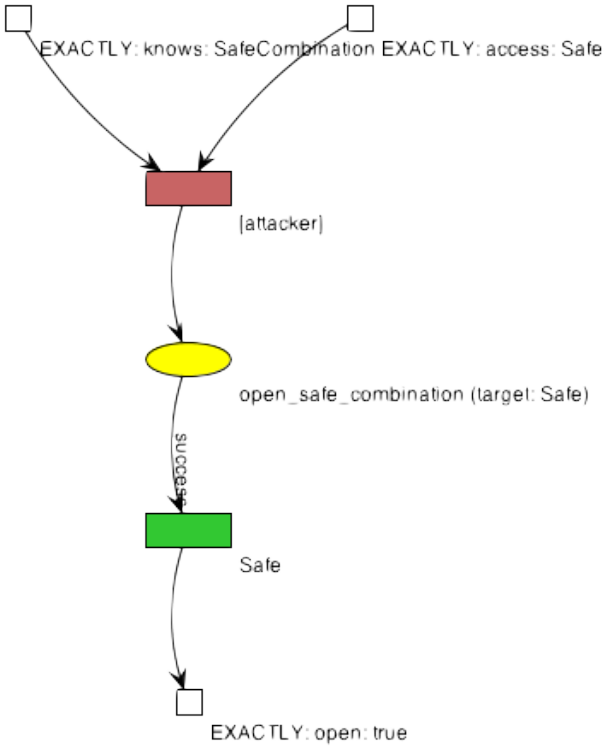


Framework
Attack pattern linking



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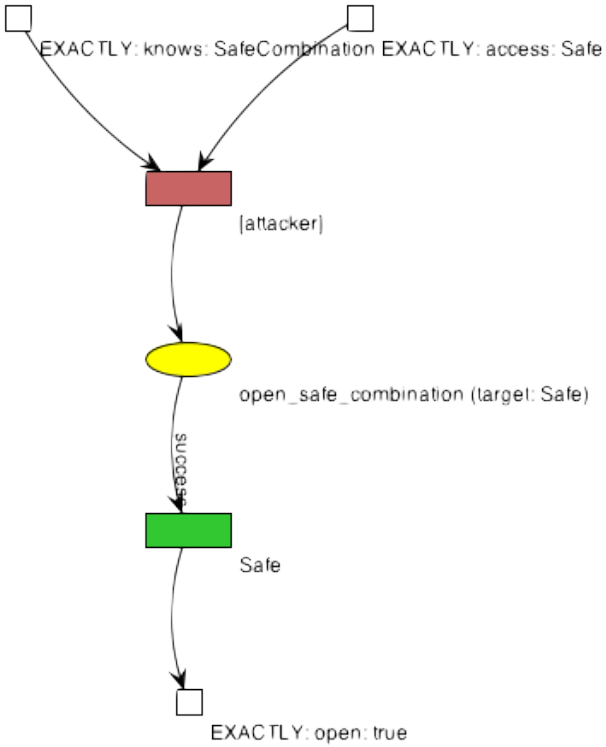

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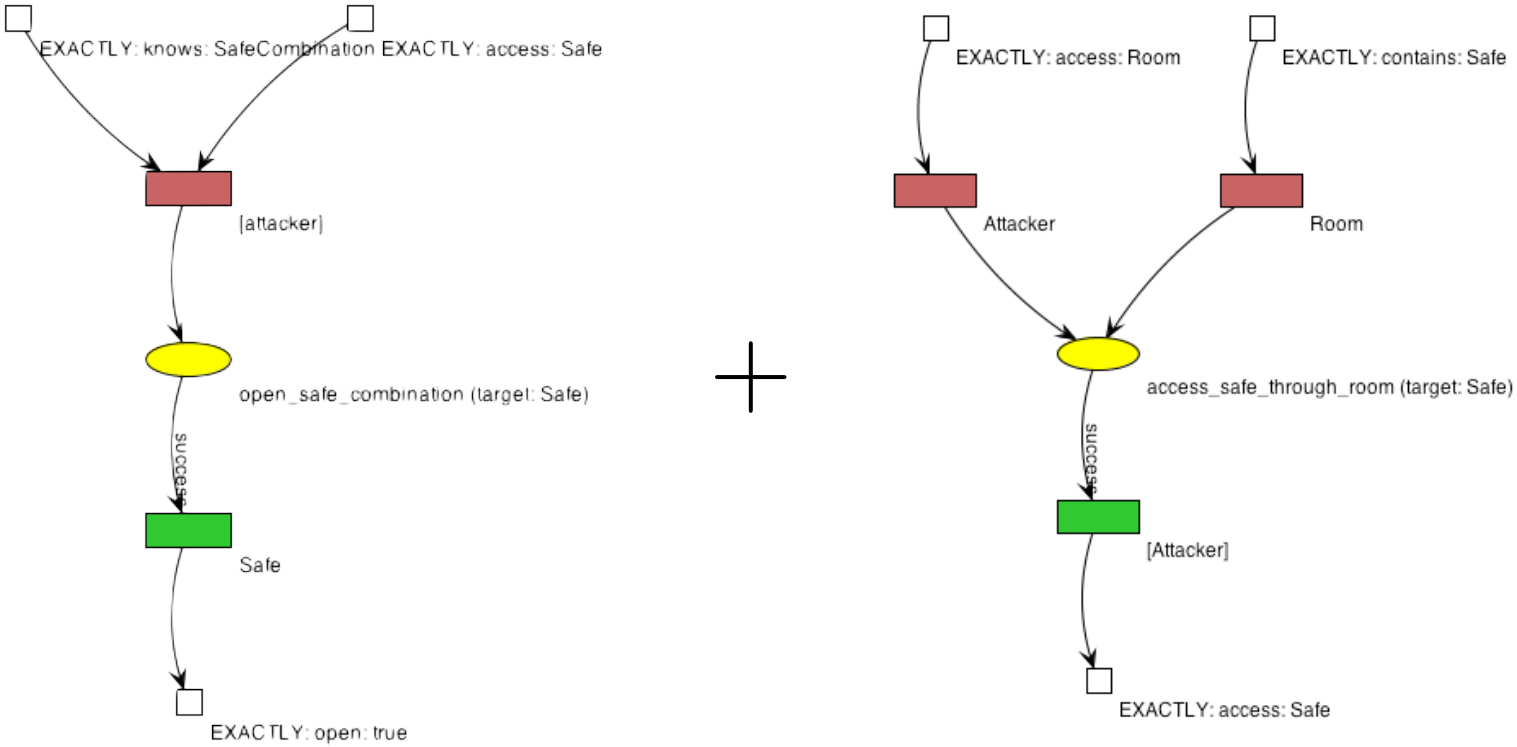

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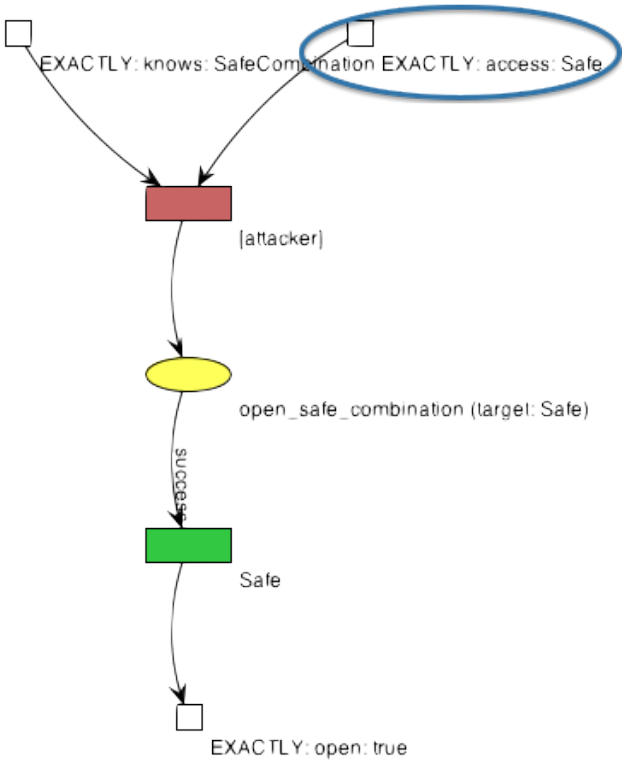

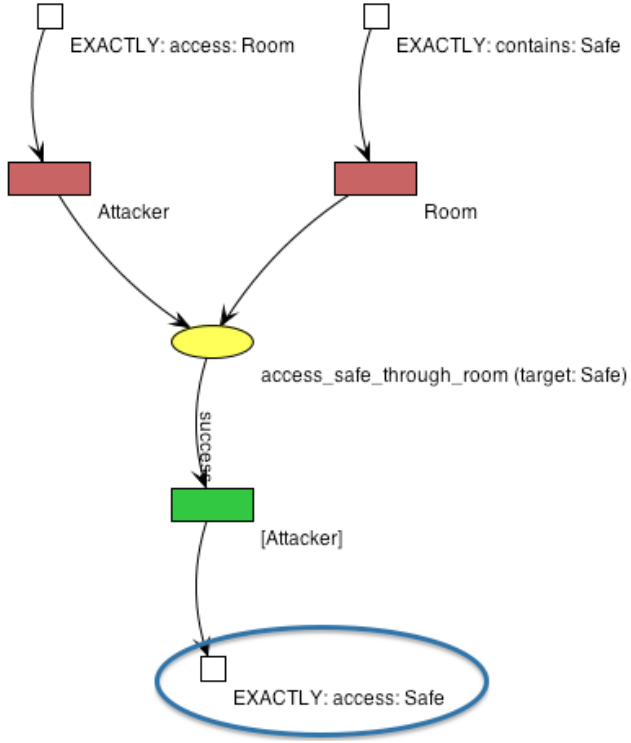

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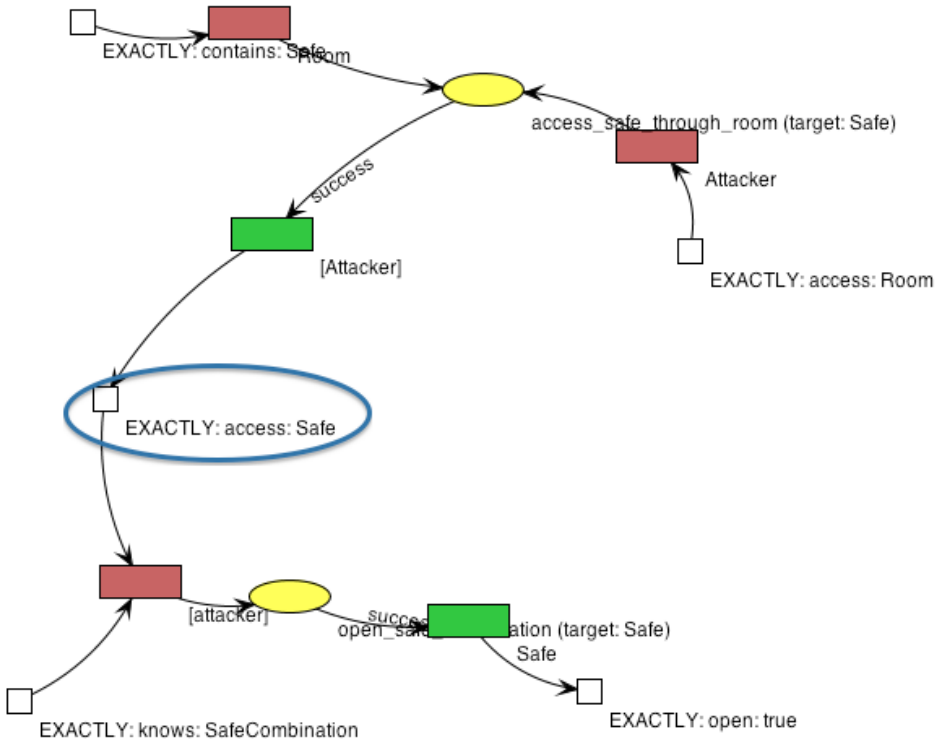

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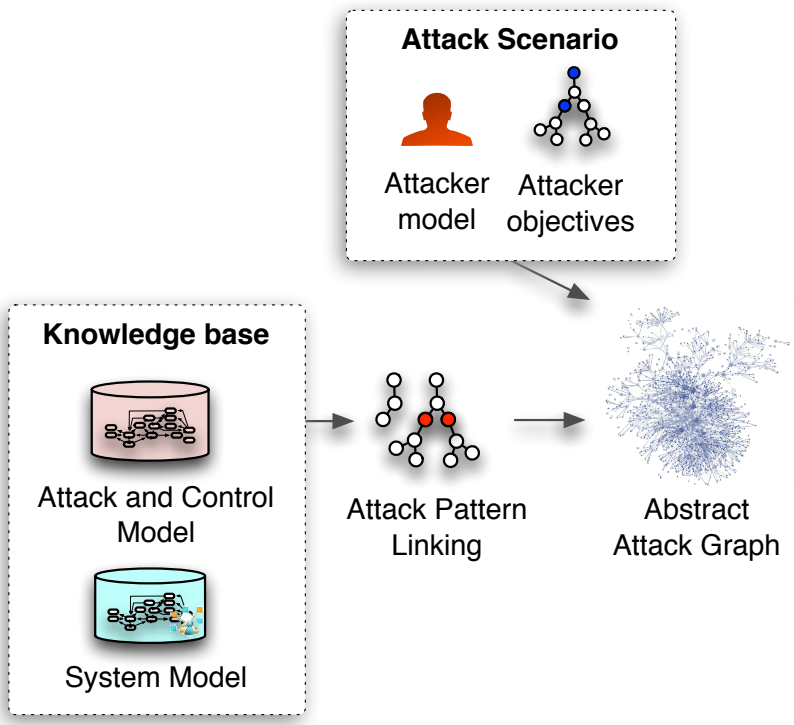

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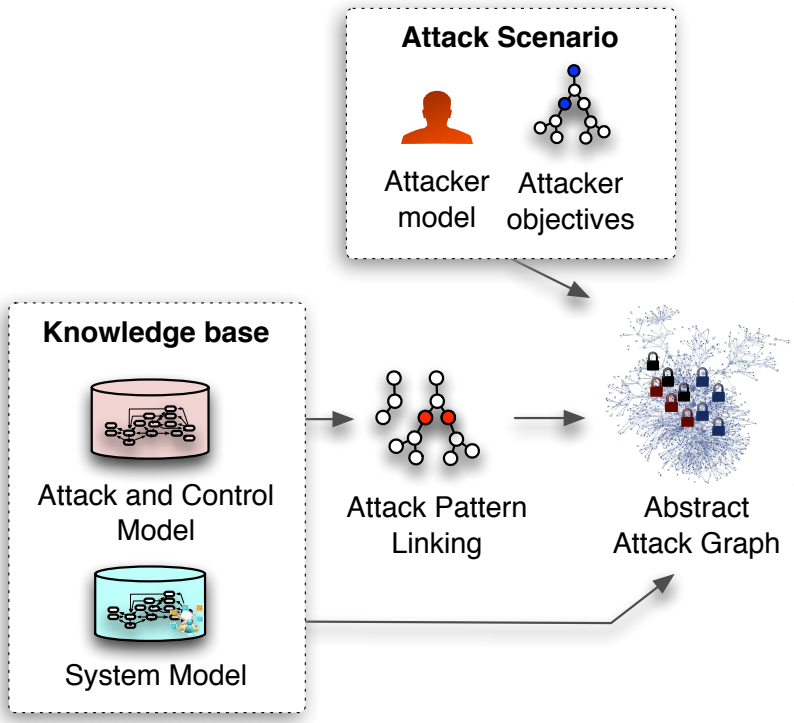

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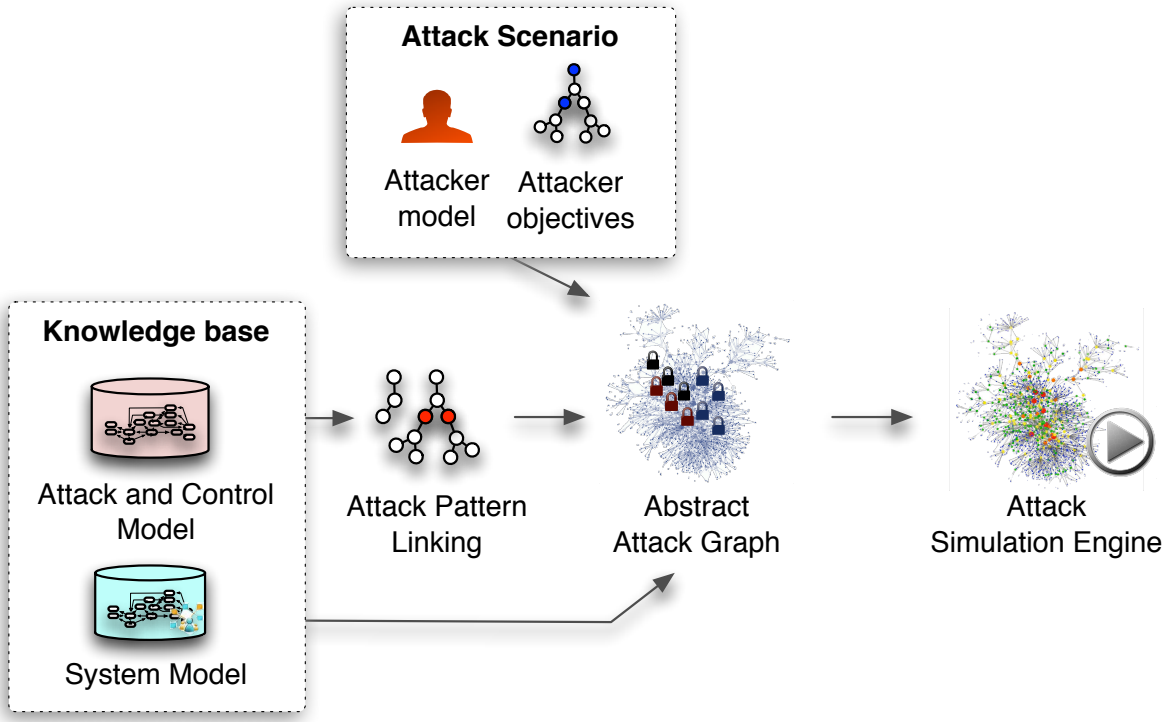

Simulation
Discrete Event Scheduling

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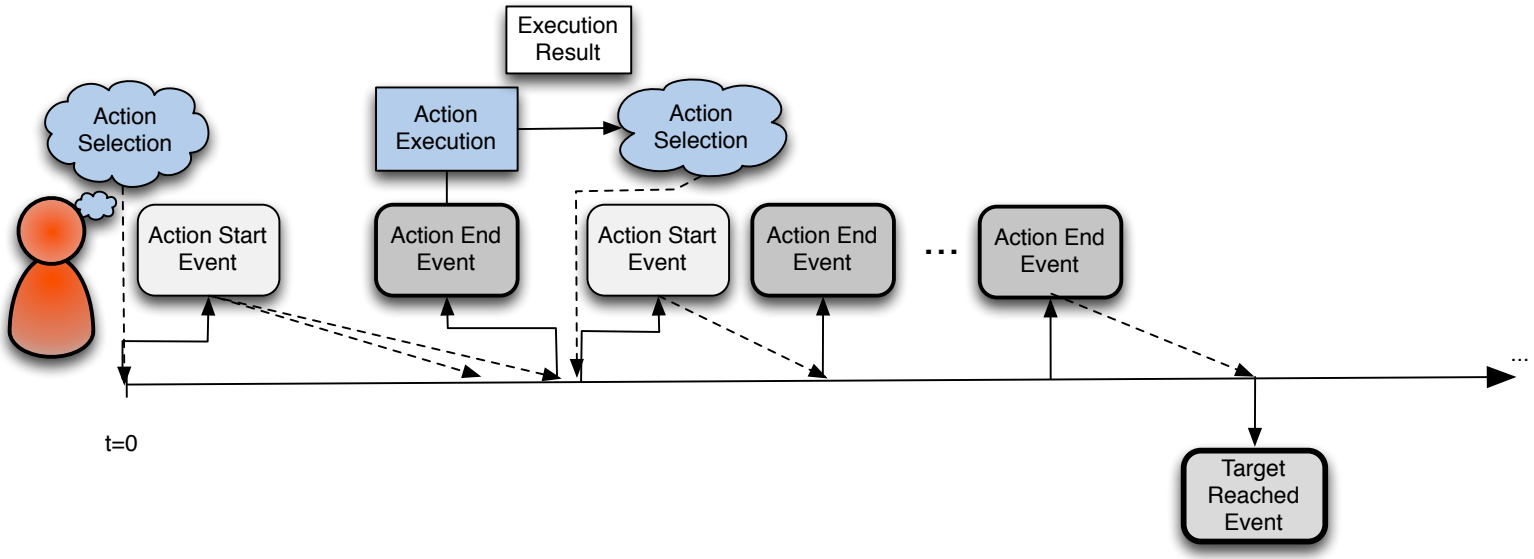

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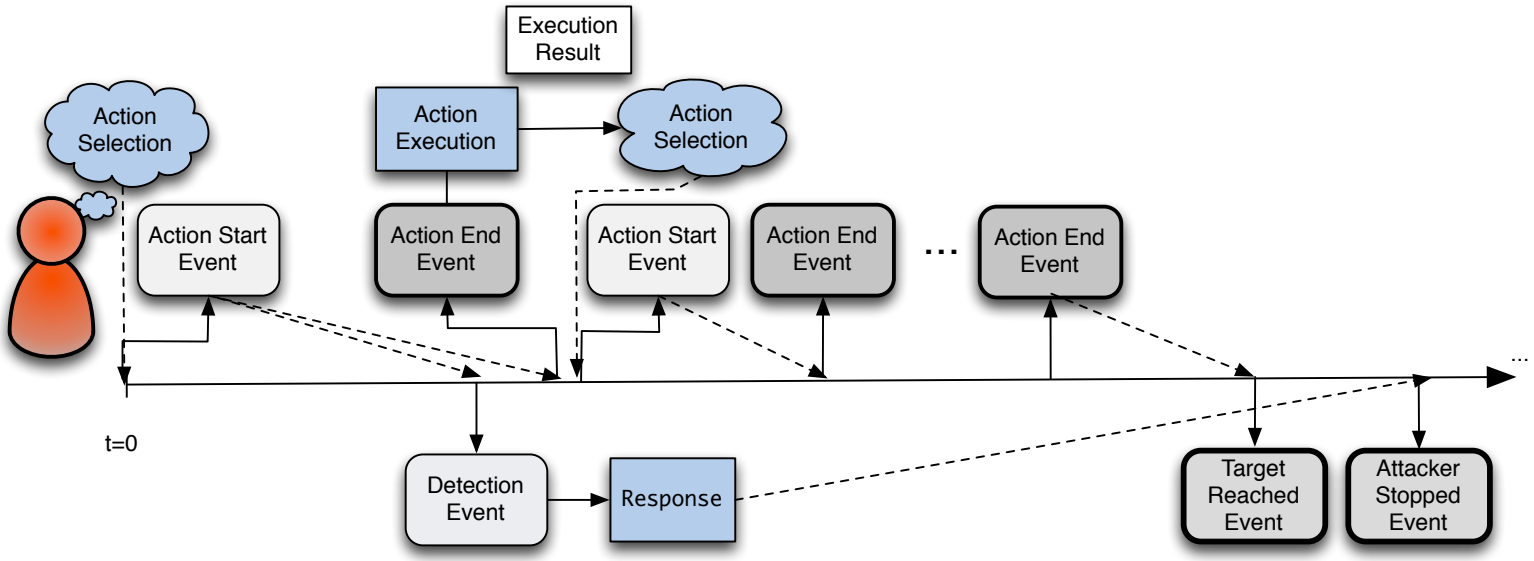
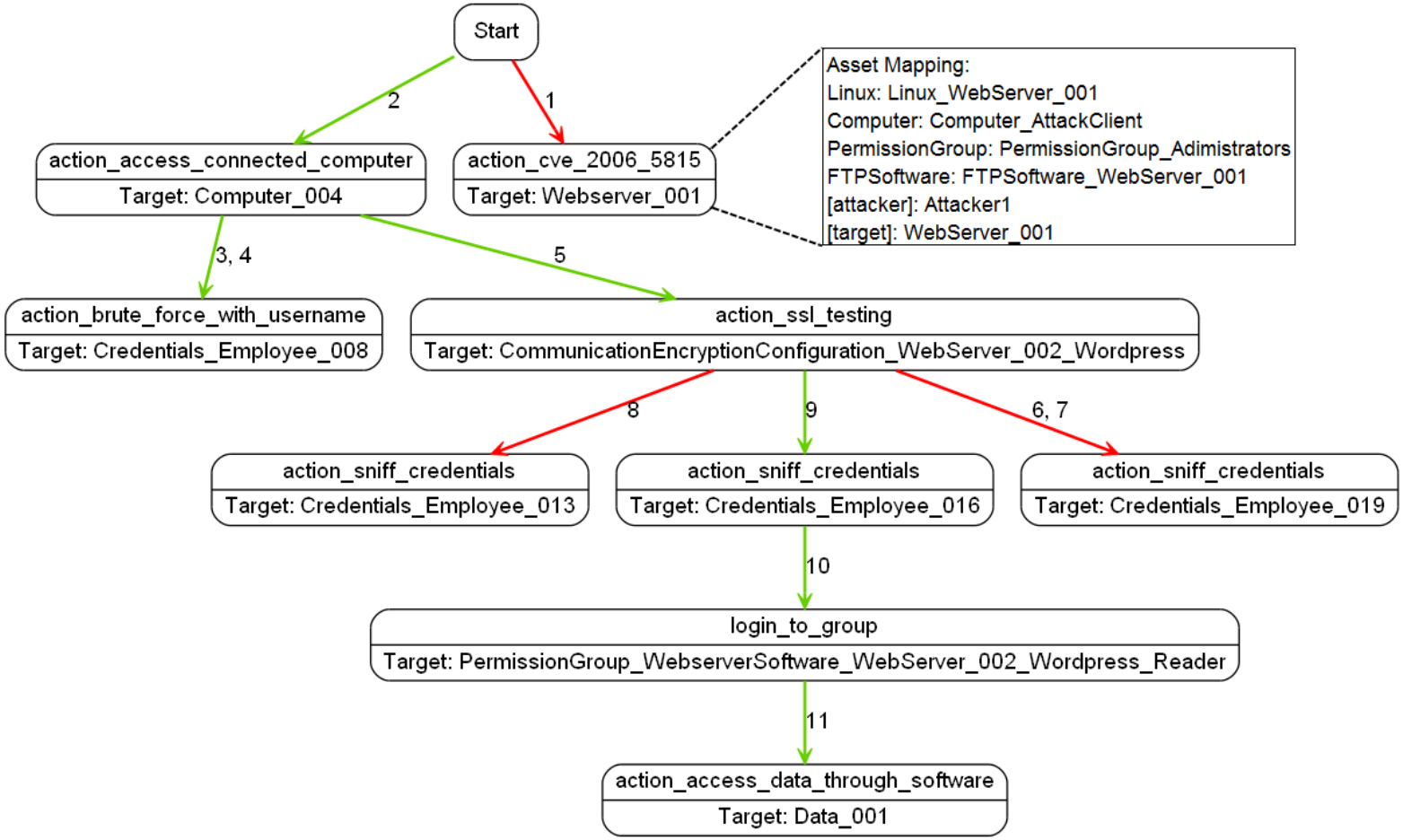


Simulation

Example attack sequence



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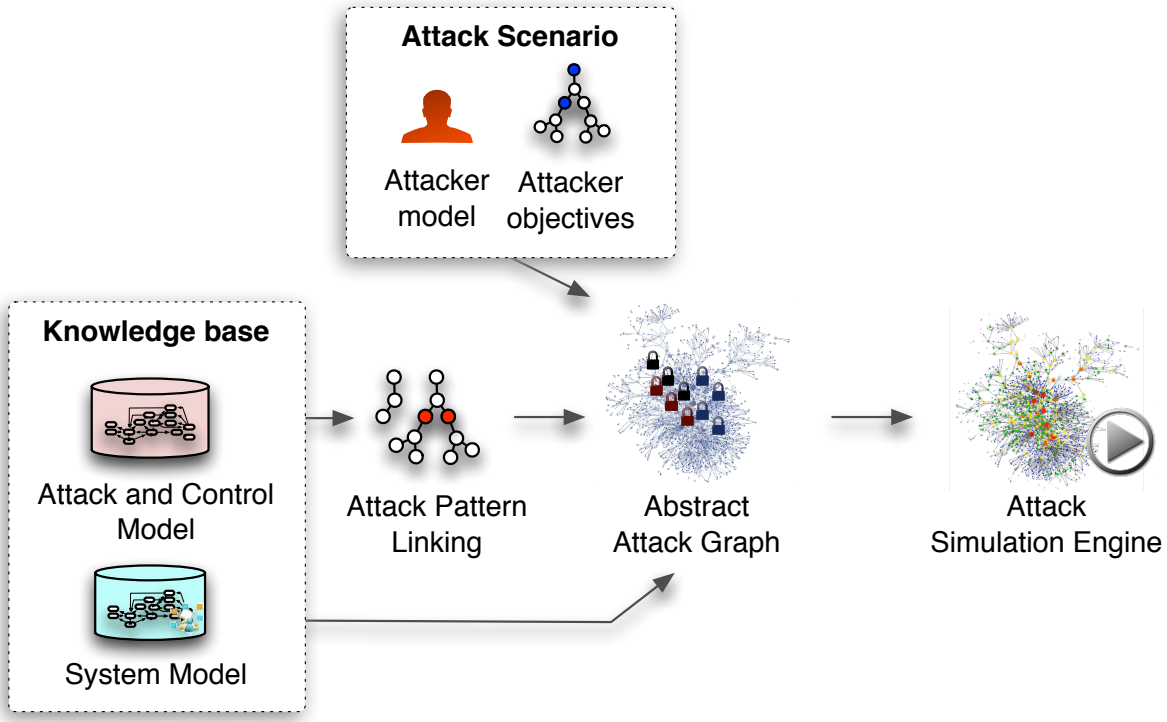

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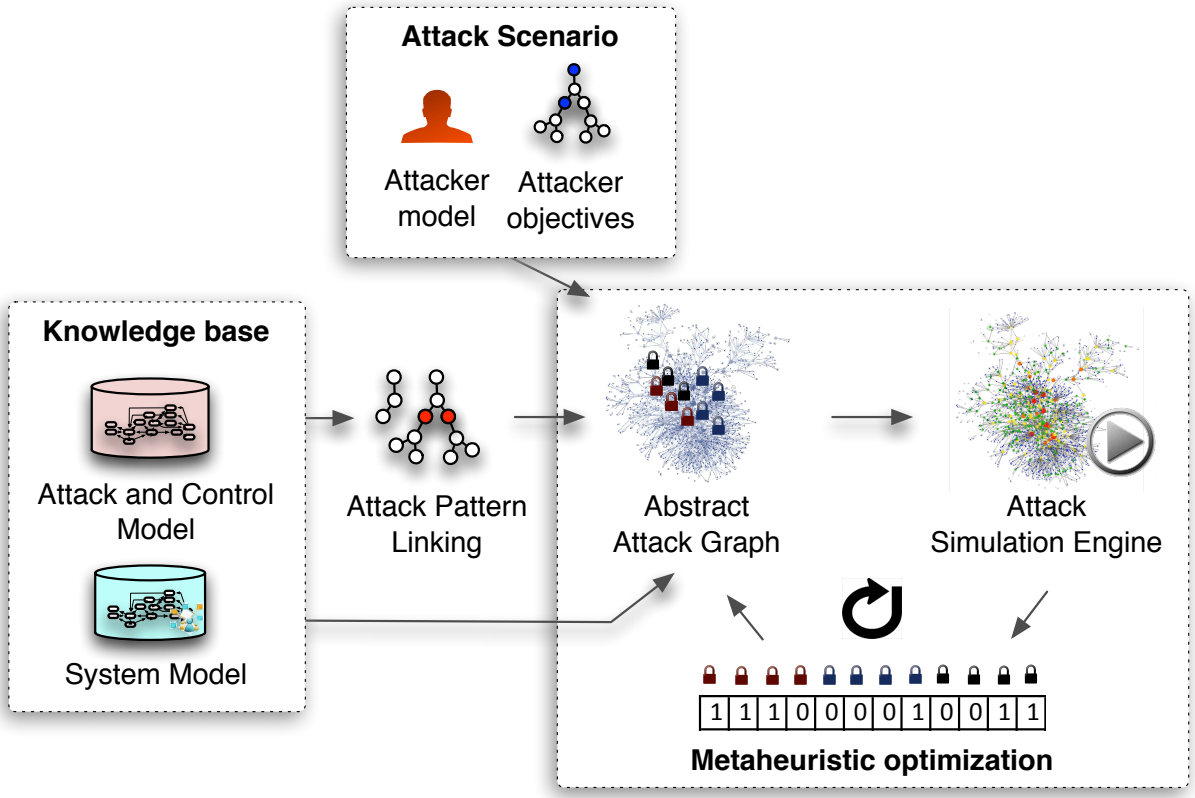

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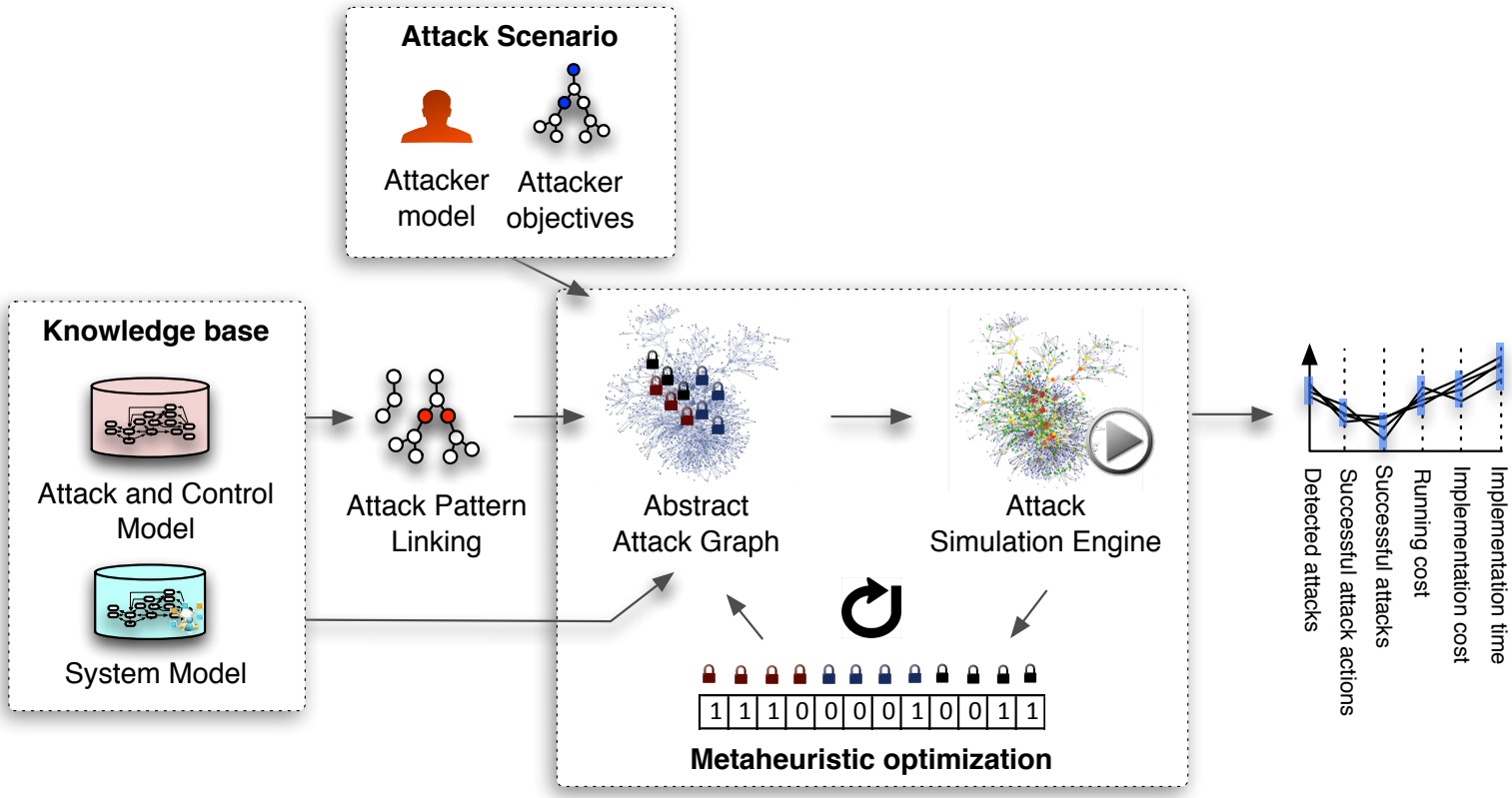
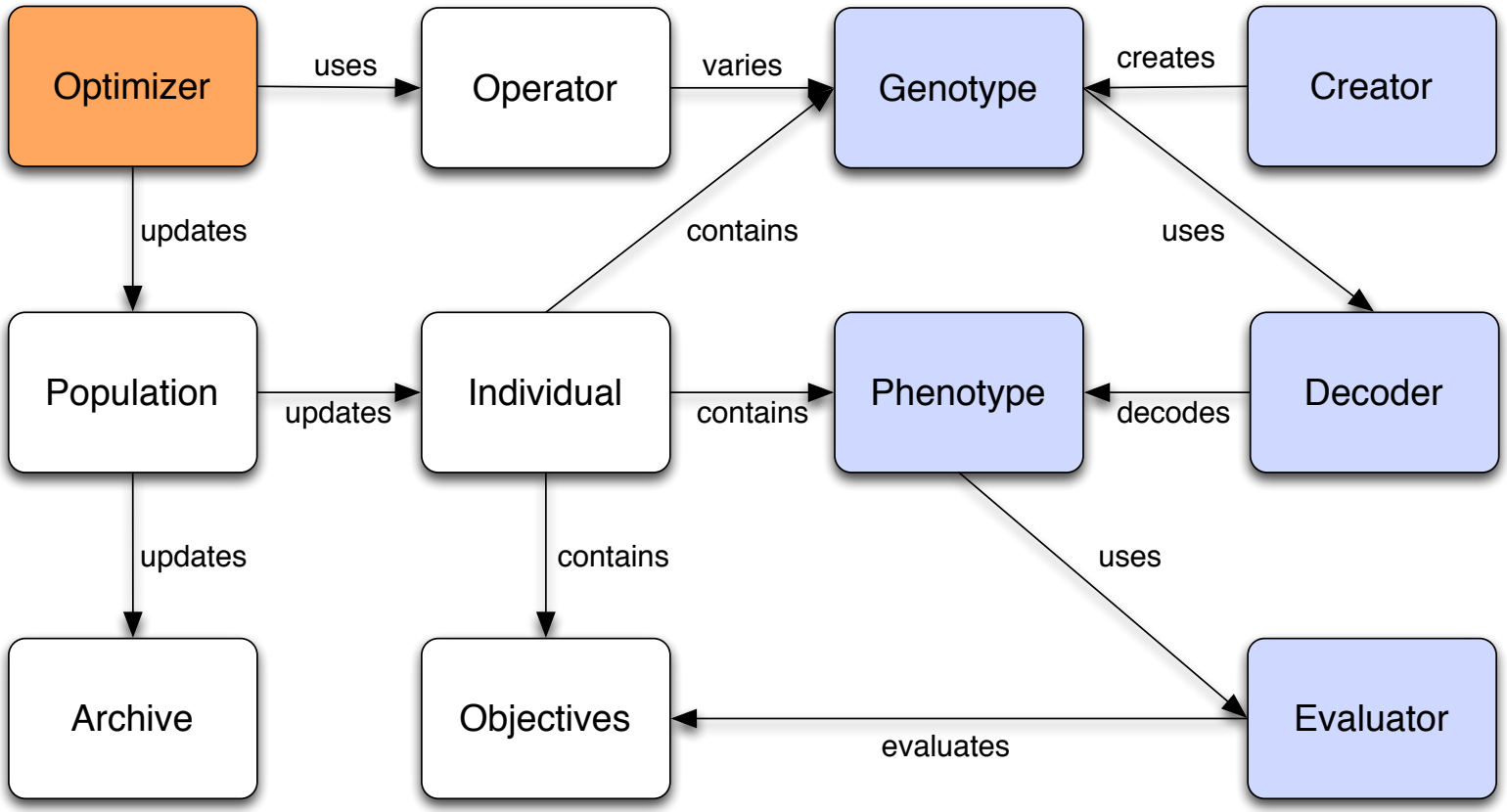


Optimization
Opt4j-based implementation



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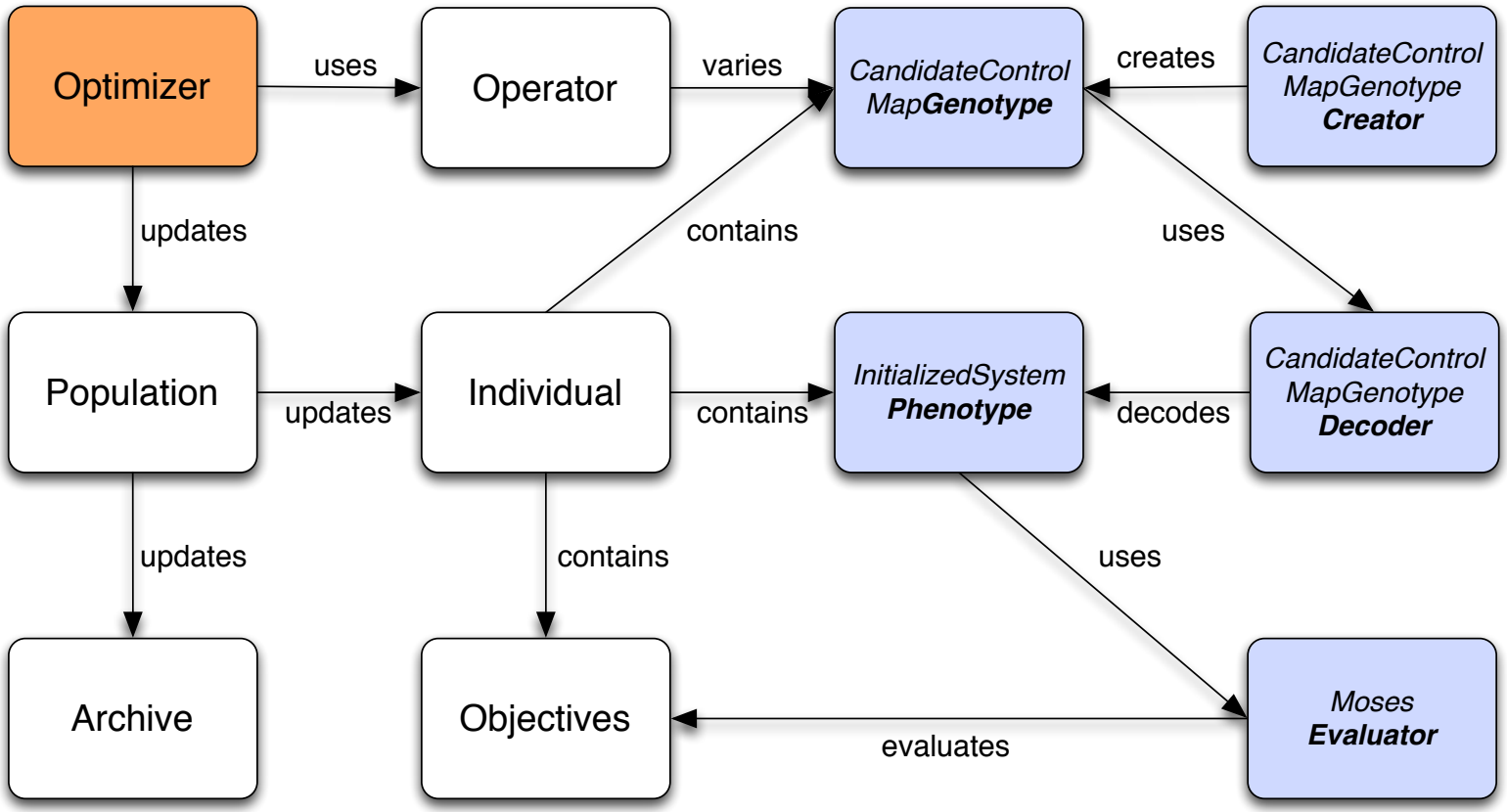

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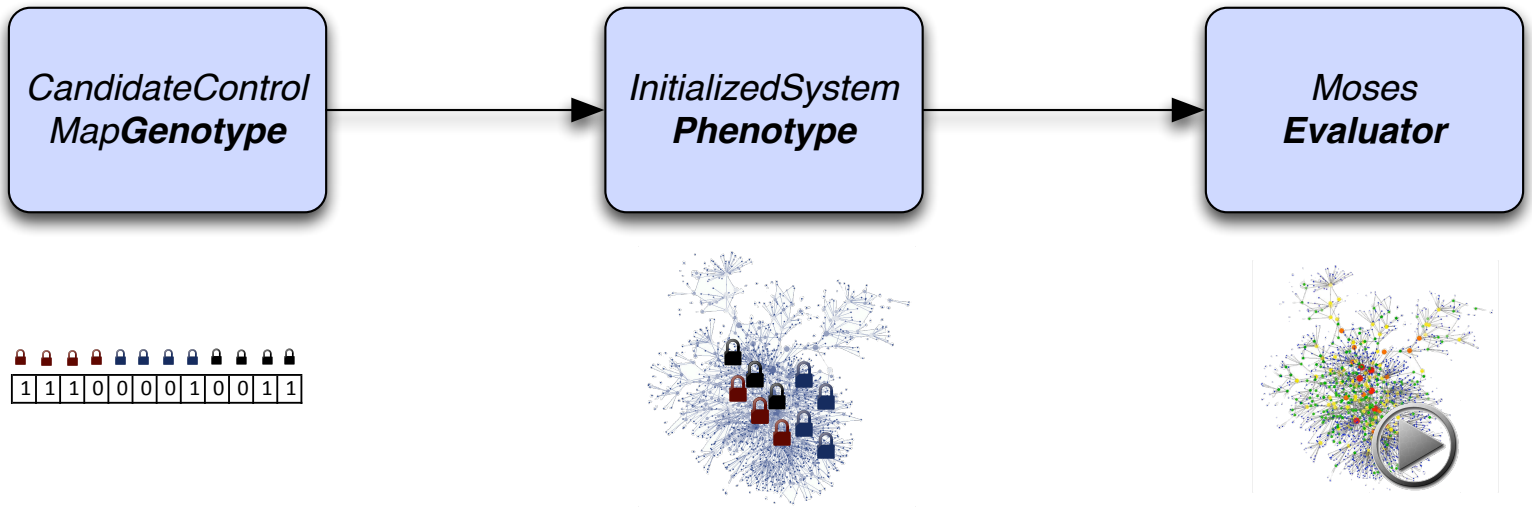
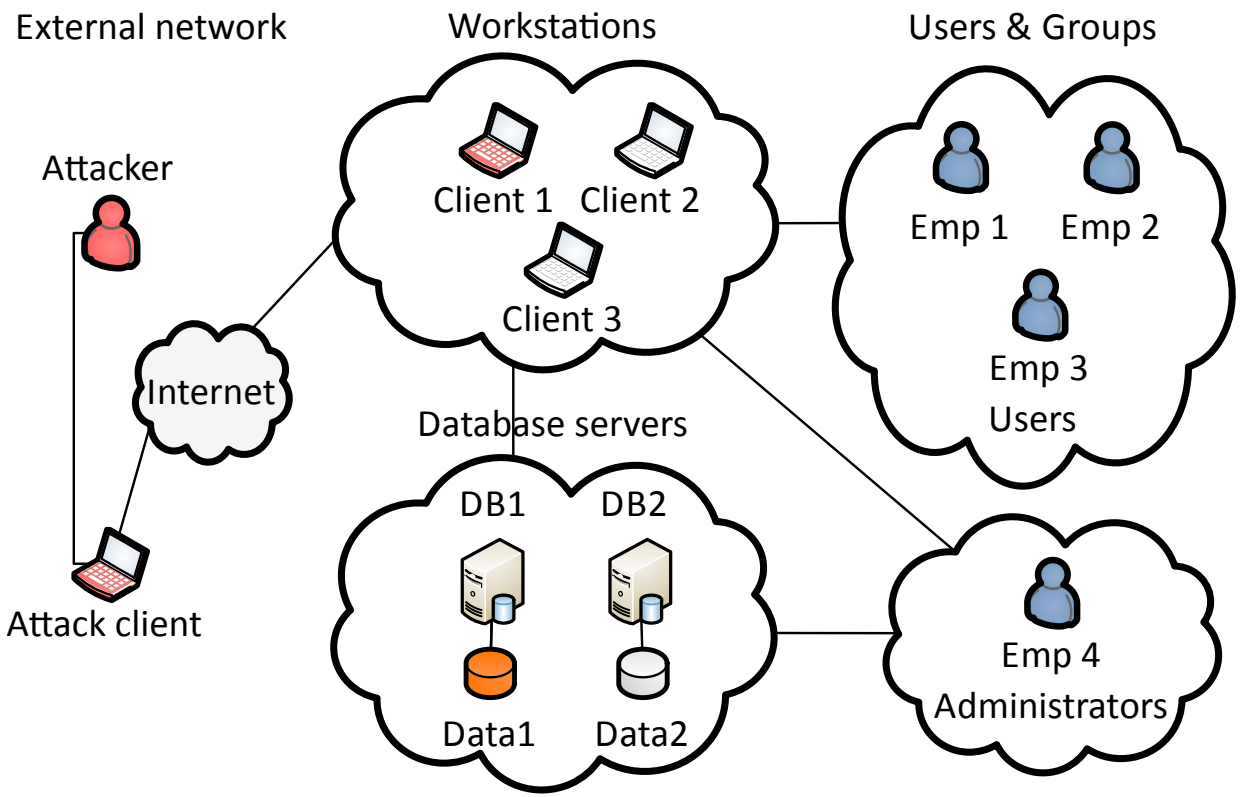
Optimization

Evaluation of candidate control portfolios



- Probabilistic, requires many replications per candidate control set
- Currently reduced to a deterministic problem using expected/median/worst case values etc.

Simple Scenario
Domain



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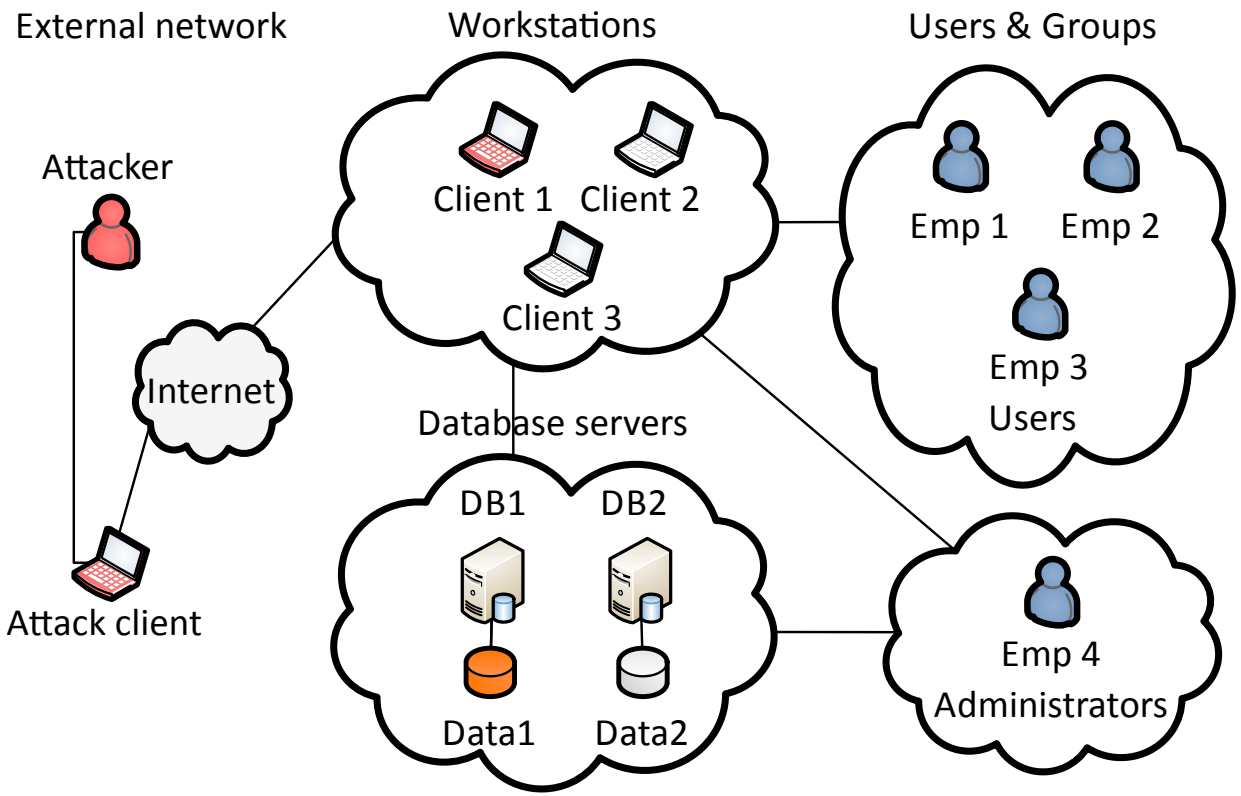

AV1 Antivirus 1 IDS1 Intrusion detection system 1 P Patch CVE_04_22
AV2 Antivirus 2 IDS2 Intrusion detection system 2 T Security Training

Simple Scenario
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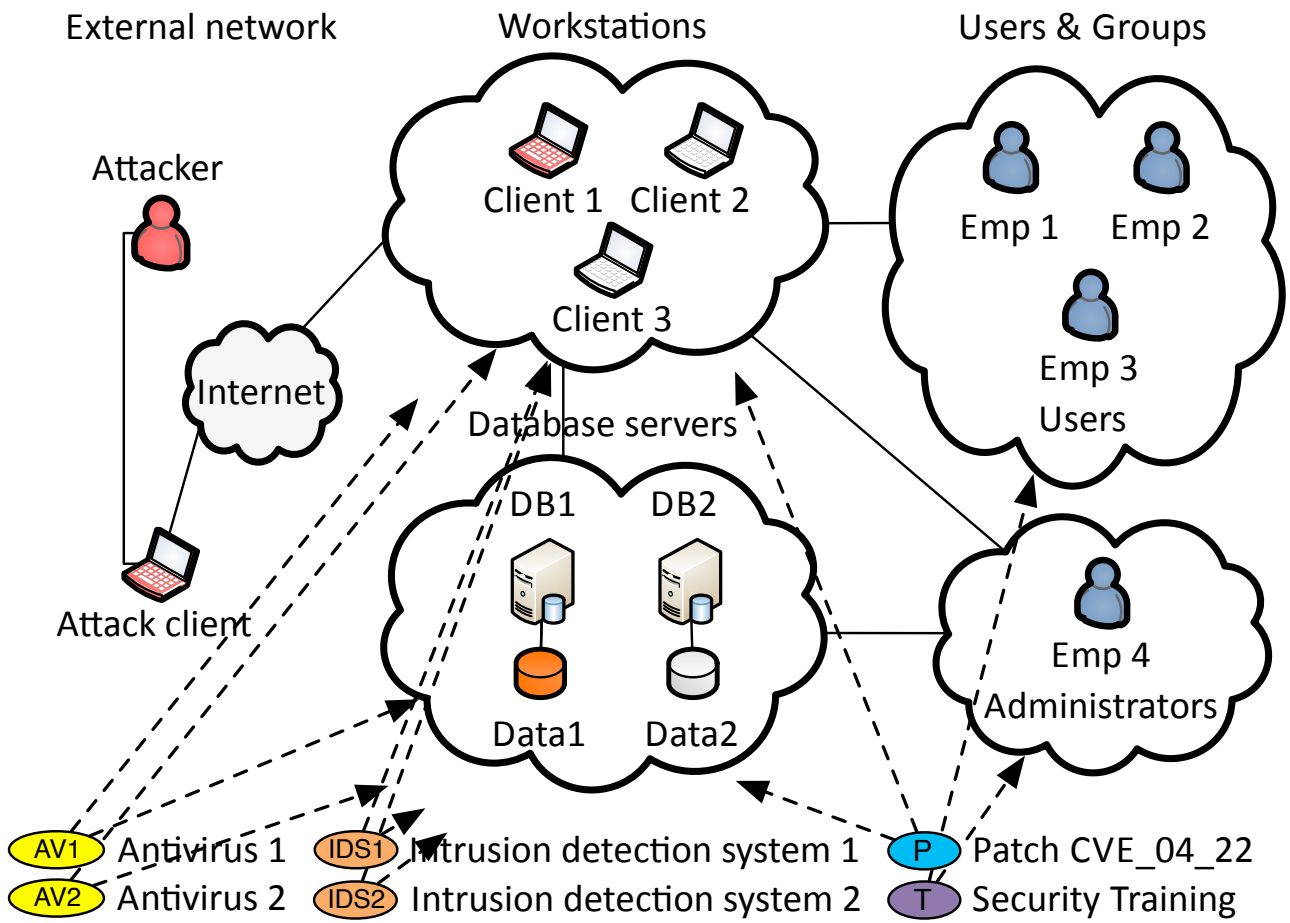


Simple Scenario
Decision variables and objectives

Decision space: 12 binary variables

Objectives:

1. Cost (MIN)
2. Successful attack actions ratio (MIN)
3. Target condition reached average (MIN)
4. Share of undetected detectable attack actions (MIN)

Attacker objective: access Data1 on DB1

Simple scenario
Algorithms and parameter settings

Simulation parameters

- 50 replications per candidate set
- Random "drill-down" decision model

Optimization parameters (NSGA2 and SPEA2)

- Generations: 100
- Population size (α): 100
- Number of parents per generation (μ): 25
- Number of offsprings per generation (λ): 25
- Crossover:
  - Rate: 0.95
  - Single crossover point
- Mutation: constant rate 0.05

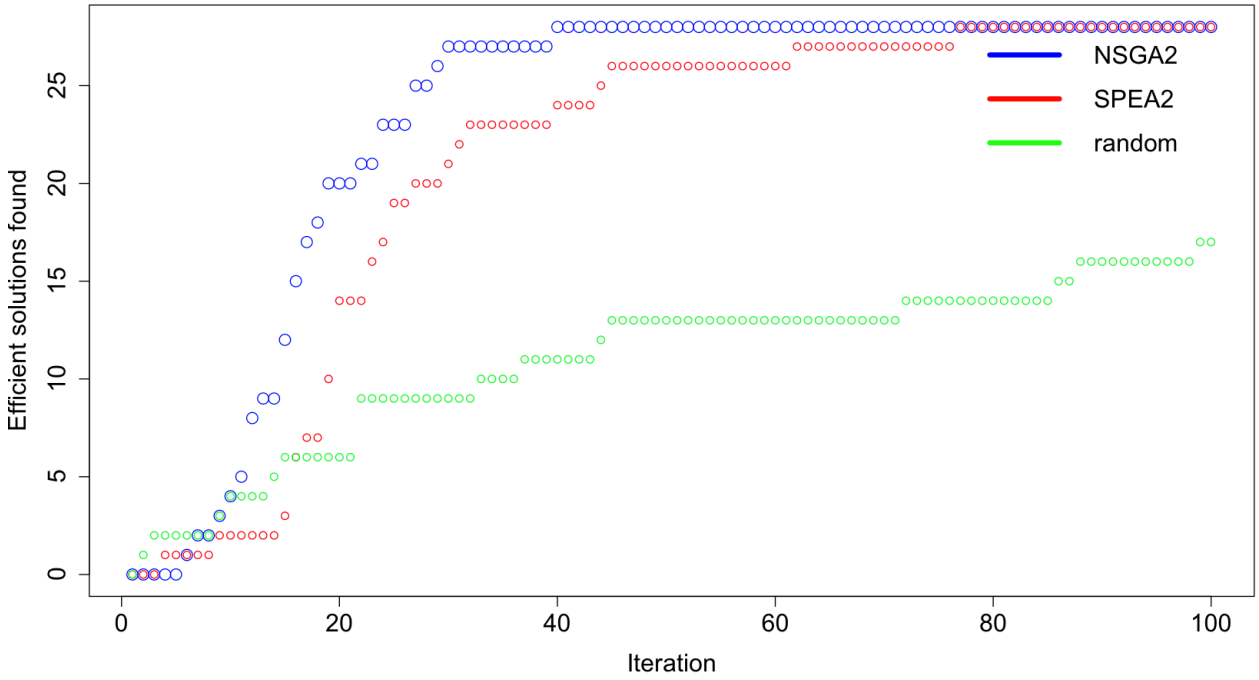
Initial Results

Simple scenario

Runtime (search space: 2^{12})

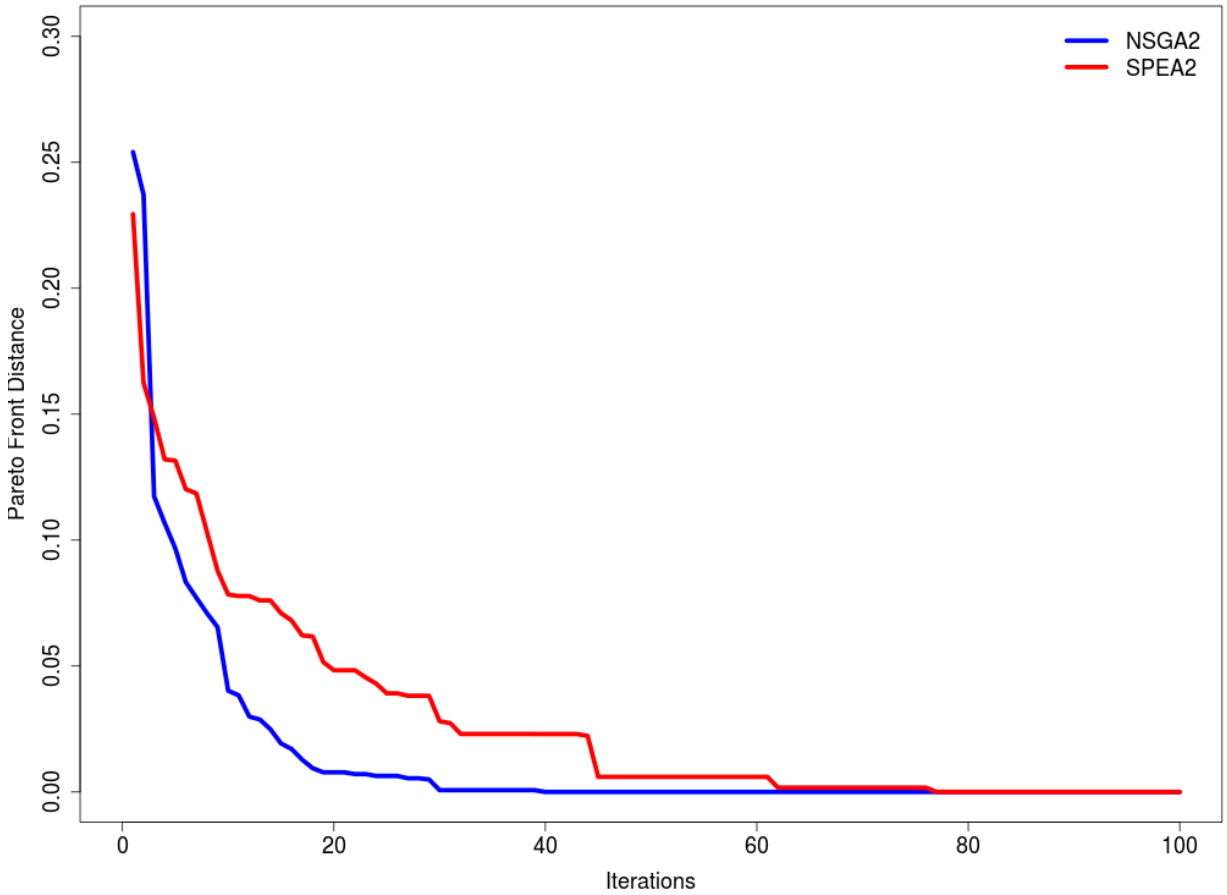
- per replication: $\sim 25ms$ (3GHz DualCore Xeon)
- per evaluation: $\sim 1,250ms$ (50 replications)
- total: CE: 183min, NSGA2: 61min, SPEA2: 70min

Efficient solutions:



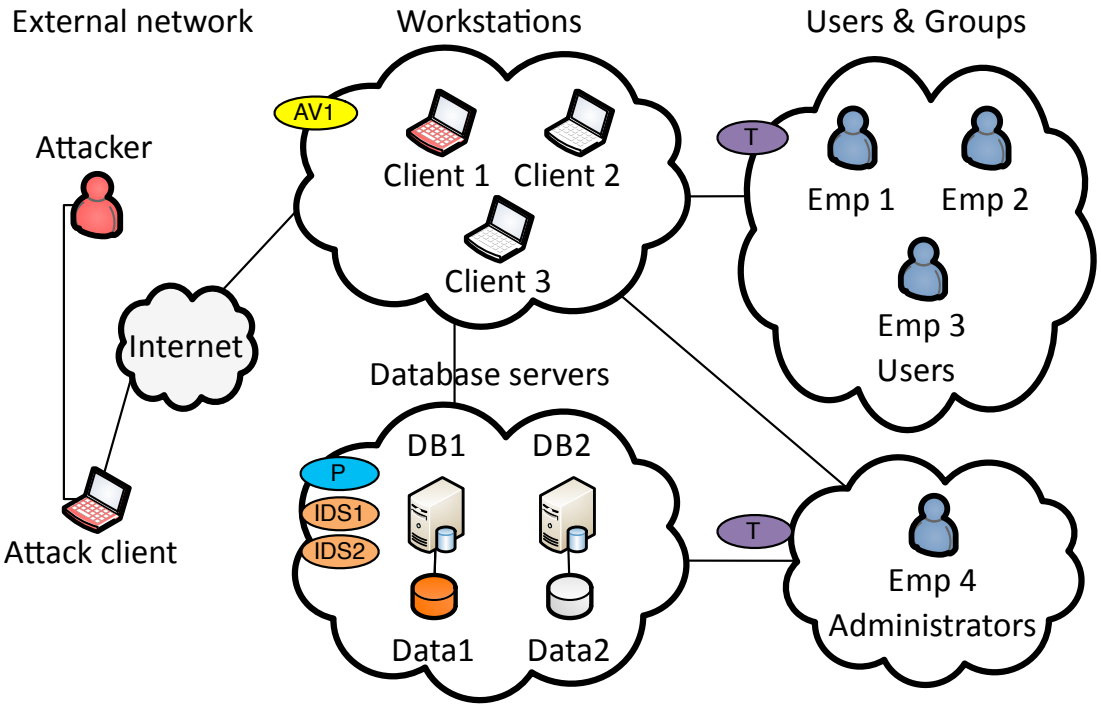
Initial Results

Simple scenario



$$Q_4(A) = \frac{1}{|CE|} \sum_{r \in CE} \min_{z \in A} D(z,r)$$

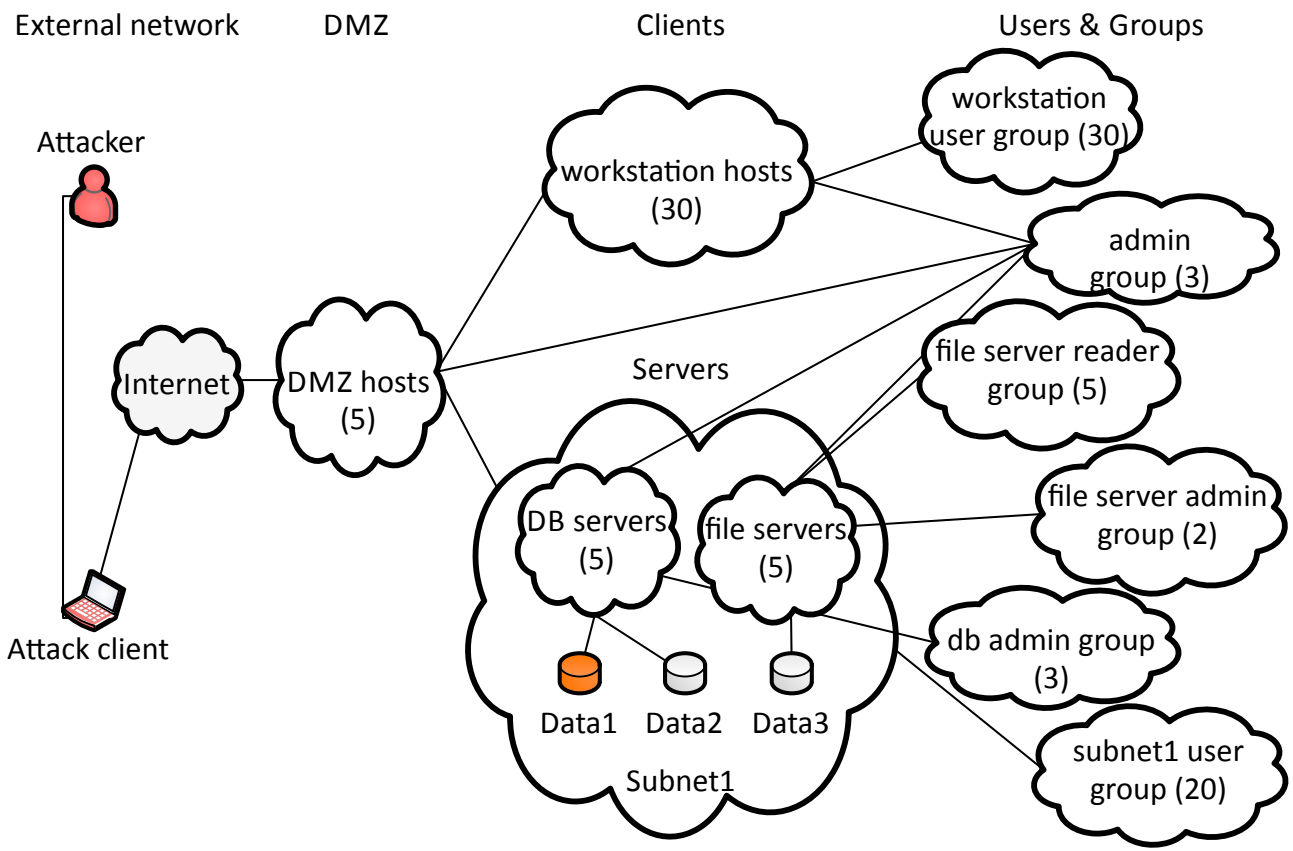
Simple scenario
Example efficient solution



AV1 Antivirus 1 — IDS1 Intrusion detection system 1 — P Patch CVE_04_22
AV2 Antivirus 2 — IDS2 Intrusion detection system 2 — T Security Training

Cost	22.400
Successful attack actions ratio	0.000558
Target condition reached average	0.018519
Share of undetected detectable attack actions	0.083333

Advanced Scenario
Domain



Advanced Scenario

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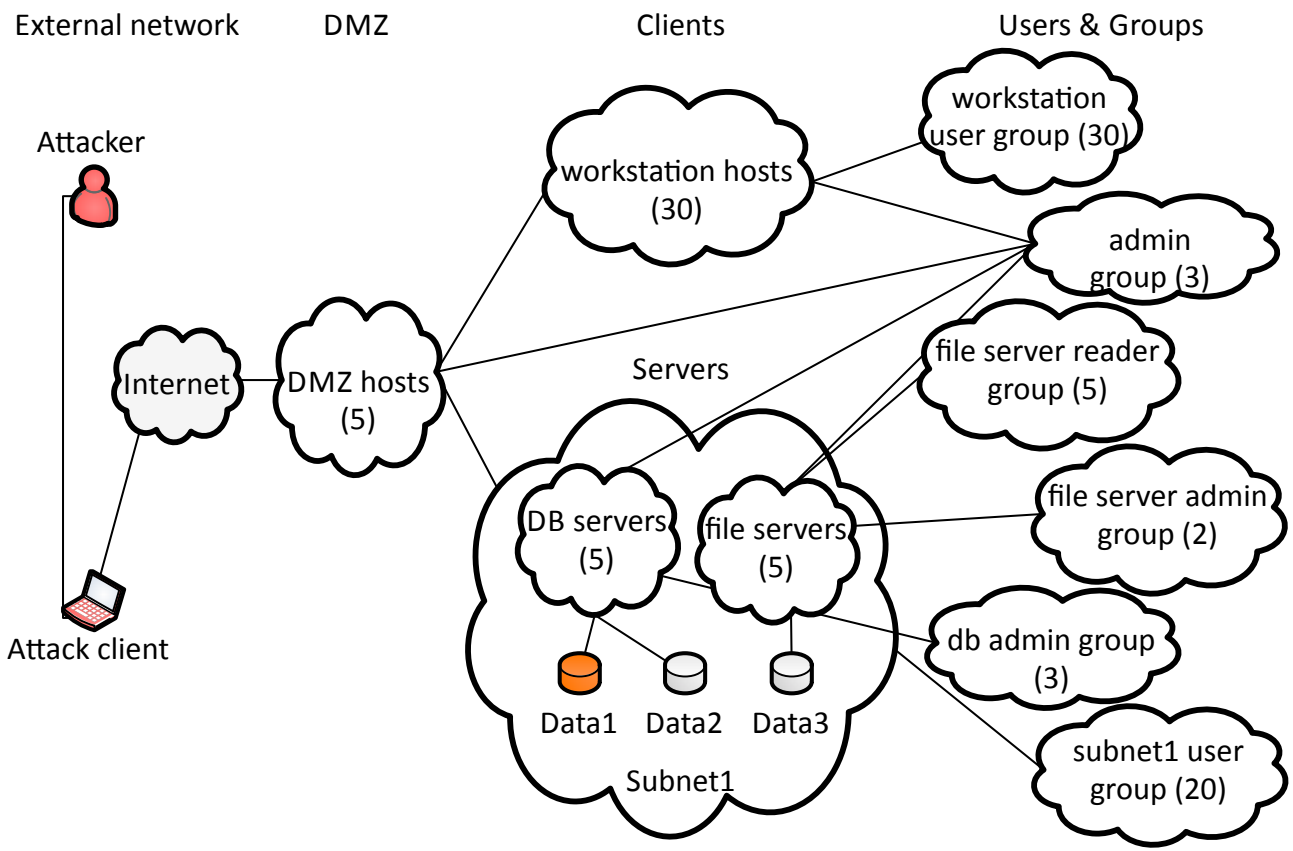

Applied controls:

1 Antivirus 1
2 Antivirus 2
1 Intrusion detection system 1
2 Intrusion detection system 2
P Patch CVE_2013_04_22
1 2 Logging Policy
1 2 3 Security Training

Advanced Scenario
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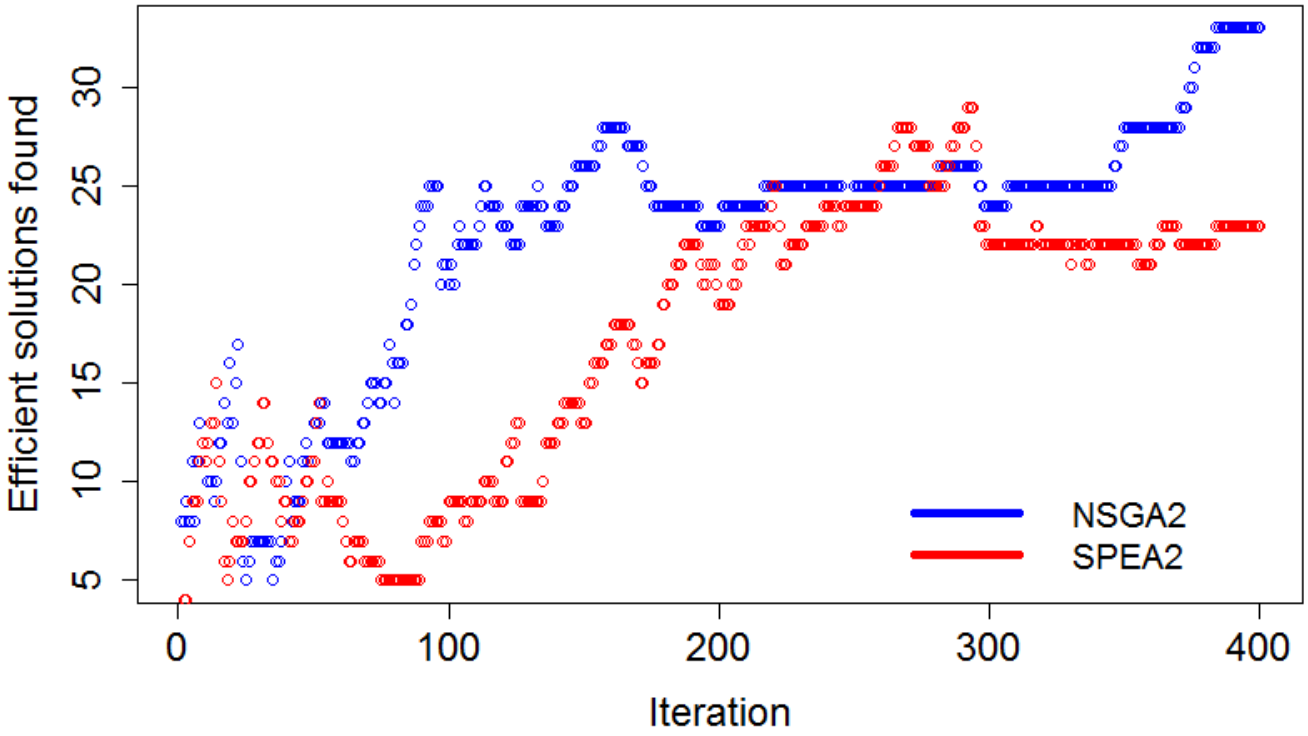
Initial Results
Advanced scenario

Runtime

- per replication $\sim 30ms$ (3GHz DualCore Xeon)
- total: $\sim 4:30h$

Proposed efficient solutions



Advanced Scenario

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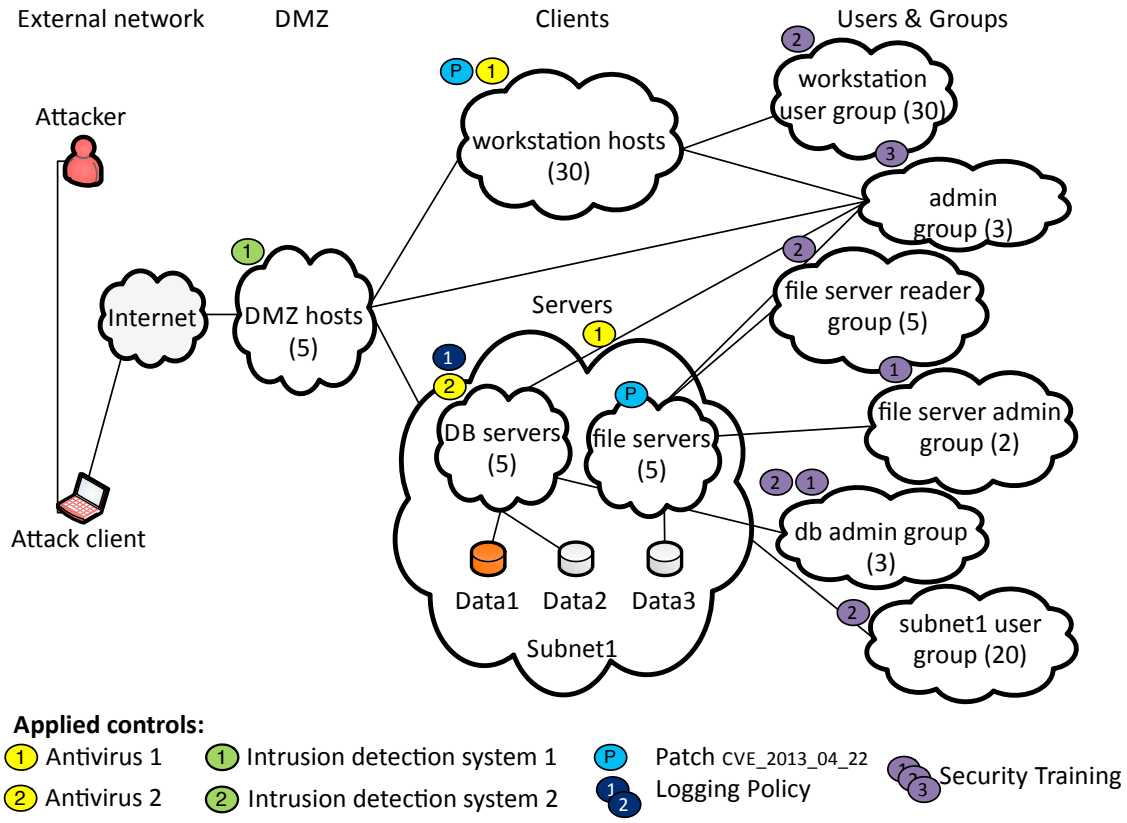

Cost	15.330
Successful attack actions ratio	0.0185
Target condition reached average	0.0
Share of undetected detectable attack actions	0.0093

Conclusions
Outlook

Current research challenges

- Simulation:
  - Cognitive and behavioral model
- Optimization:
  - Computational cost for individual portfolio evaluations
  - Uncertainty of simulation
  - Thorough testing of optimization algorithms (more alogrithms, performance measures across multiple runs, multiple problem instances etc.)

Ideas for future work

- Probabilistic dominance concepts?
- Assign replications non-uniformly?
- Control selection $\rightarrow$ system design (very large design space + constraints)

Q & A

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