Chair of Network Architectures and Services
Department of Informatics
Technical University of Munich

An Optimal Metric-Aware Response Selection Strategy for Intrusion Response Systems

Nadine Herold, Matthias Wachs, Stephan-A. Posselt and Georg Carle

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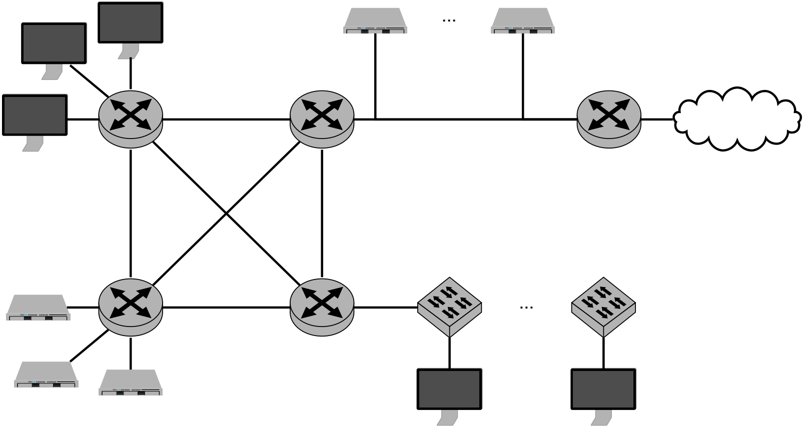
Introduction and Problem Statement

Motivation



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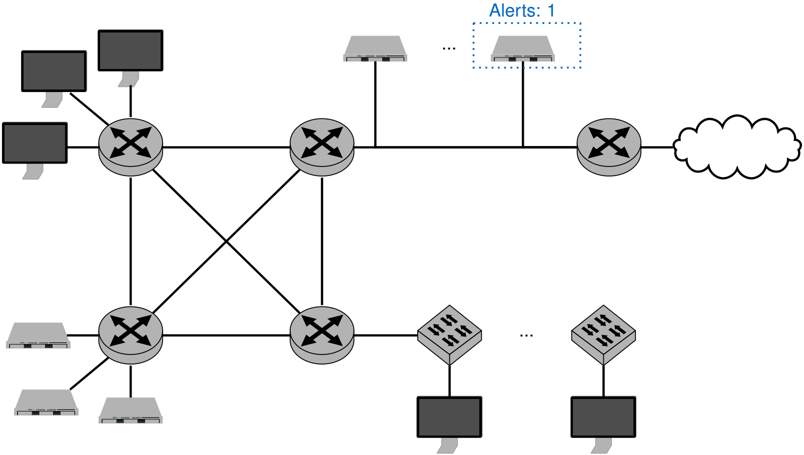

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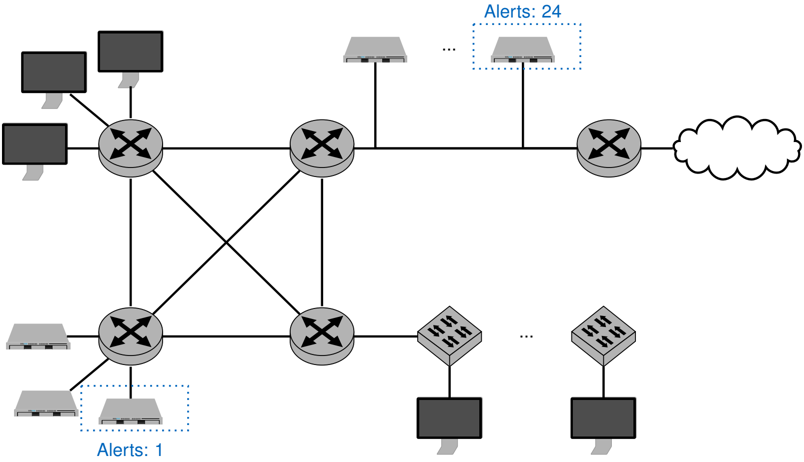

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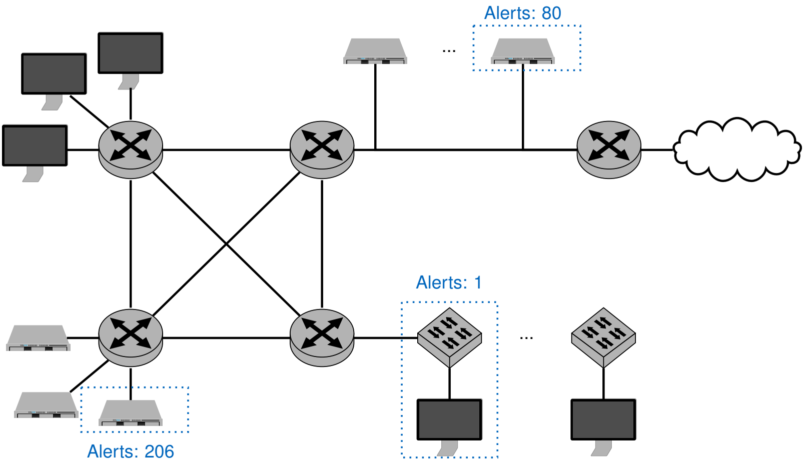

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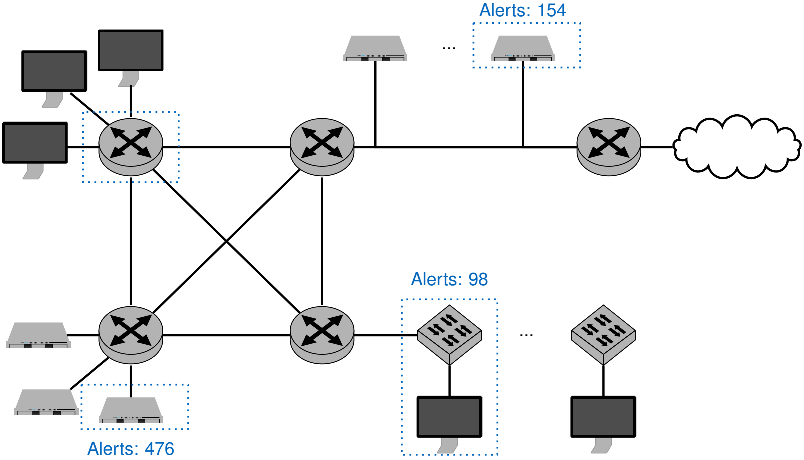

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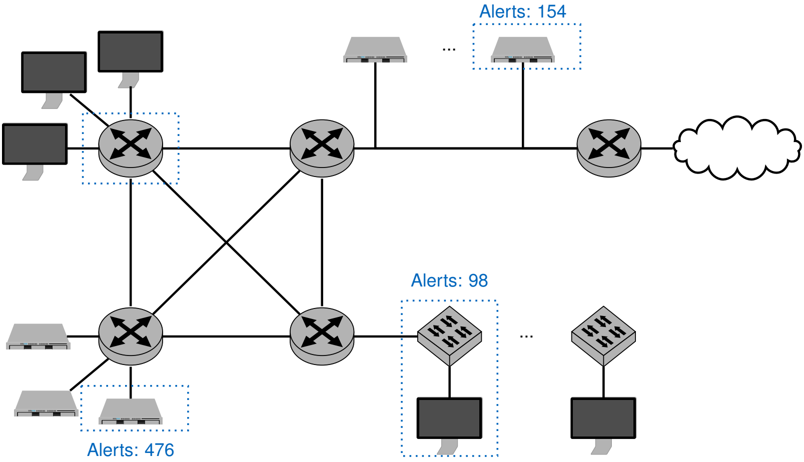
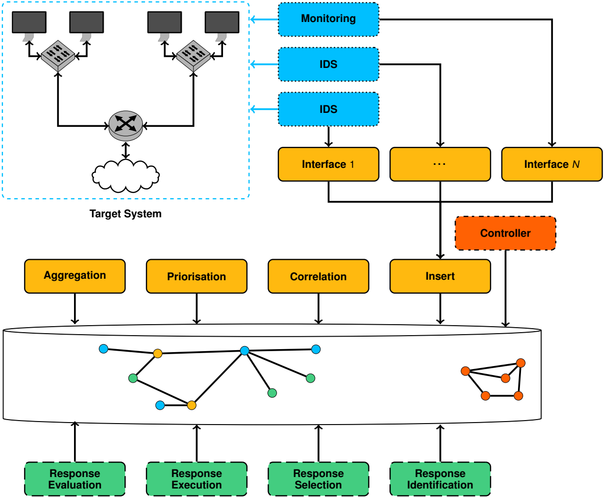


What can we do now? What options do we have?

Introduction and Problem Statement

What do we want to achieve?



Introduction and Problem Statement

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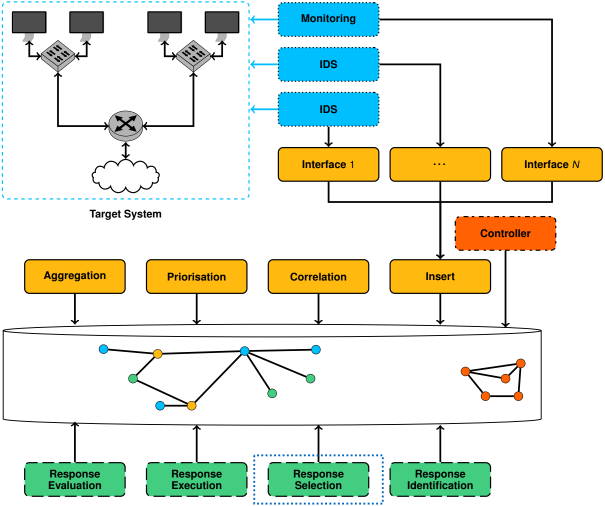

Related Work

Existing Approaches towards Response Selection

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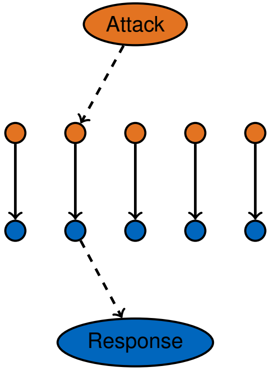
- Rule based approaches (static mappings or ECA rules) [4, 12, 21, 3, 17]



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Existing Approaches towards Response Selection

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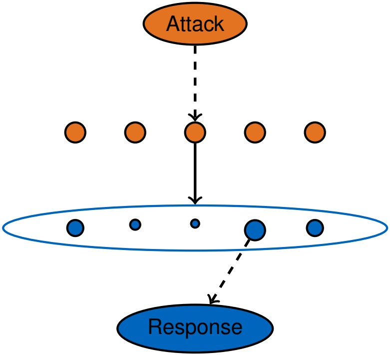

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- Rule based approaches (static mappings or ECA rules) [4, 12, 21, 3, 17]
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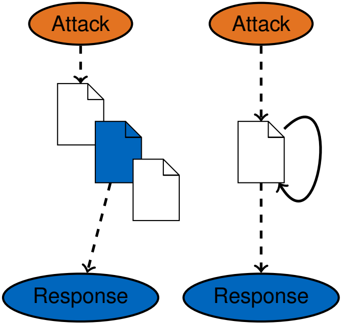
- Pre- or post-processing based approaches [8, 7, 27]



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Existing Approaches towards Response Selection

- Rule based approaches (static mappings or ECA rules) [4, 12, 21, 3, 17]
- Basic cost-sensitive approaches [6, 23, 26, 24, 25, 28, 1, 20, 16, 15, 14, 22]
- Pre- or post-processing based approaches [8, 7, 27]
- Decide whether or not to respond automated [2, 30]

System Design

Central Question and Approach

Formulating a Mixed Integer Linear Programming problem such that we can answer the following question:

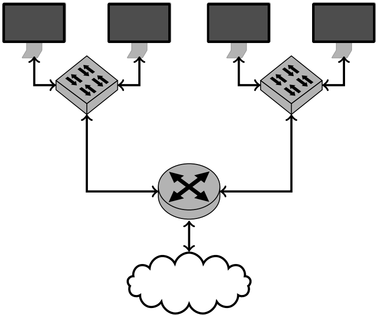
In a given model instance, which subset from the set of responses available

- *frees all affected entities from an incident,*
- *has minimal cost within the given set of metrics, and*
- *has lower cost than the incident being unmitigated?*

First, we define a set-based description that models the response selection problem. We transform this set-based description into a Linear Programming Problem. For each response selection process the instance is created and solved.

System Design

Illustrative Example

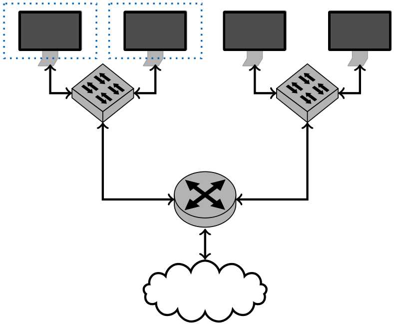


Target system with

- 4 hosts,
- 2 switches, and
- 1 router

System Design

Illustrative Example

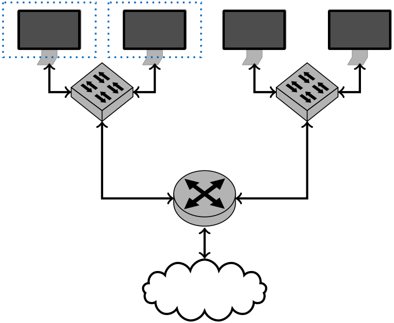


Attack on services running on

- host 1 (h_1) and
- host 2 (h_2)

System Design

Illustrative Example



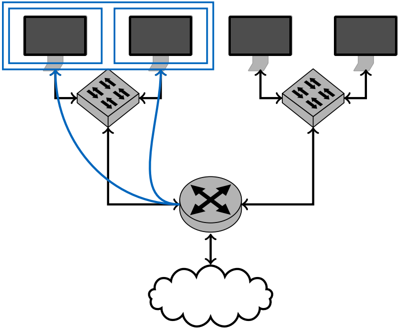
What can we do?

- What can we execute?
- Who can execute?
- Who is (positive) effected?
- What restrictions to consider?

Response	Executing	Effected			Conflicts

System Design

Illustrative Example



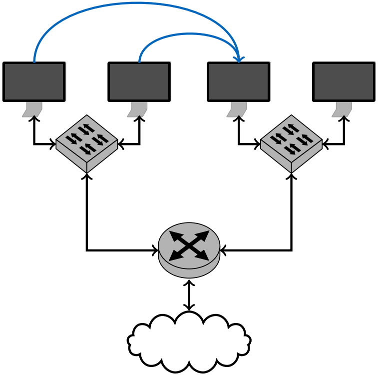
Router can block traffic to

- host 1 (h_1)
- host 2 (h_1)
- (h_1) and (h_2)

Response	Executing	Effected			Conflicts
$r_{block}(h_1)$	*router*	h_1			-
$r_{block}(h_2)$	*router*	h_2			-
$r_{block}(n)$	*router*	h_2, h_1			-

System Design

Illustrative Example



Services can be migrated to

- host 3 (h_3)

Capacity for one service!

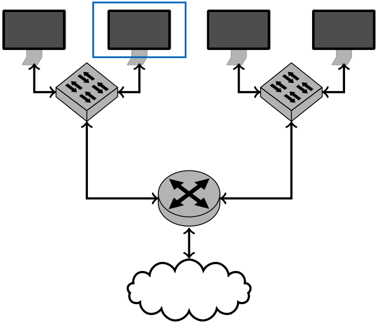
Response	Executing	Effected			Conflicts
$r_{block}(h_1)$	*router*	h_1			-
$r_{block}(h_2)$	*router*	h_2			-
$r_{block}(n)$	*router*	h_2, h_1			-
$r_{migrate}(h_1)$	h_3	h_1			$r_{migrate}(h_2)$
$r_{migrate}(h_2)$	h_3	h_2			$r_{migrate}(h_1)$

System Design

Illustrative Example

Reconfigure service running on

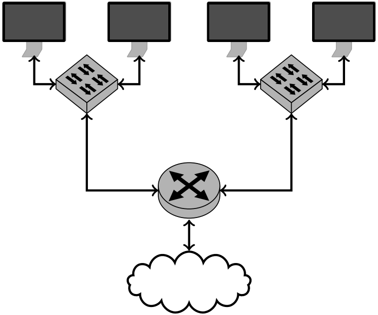
- host 2 (h_2)



Response	Executing	Effected			Conflicts
$r_{block}(h_1)$	*router*	h_1			-
$r_{block}(h_2)$	*router*	h_2			-
$r_{block}(n)$	*router*	h_2, h_1			-
$r_{migrate}(h_1)$	h_3	h_1			$r_{migrate}(h_2)$
$r_{migrate}(h_2)$	h_3	h_2			$r_{migrate}(h_1)$
$r_{reconf}(h_2)$	h_2	h_2			-

System Design

Illustrative Example



Use metrics to assess responses, e.g.

- duration
- cost

Huge variety available in literature ([15, 16, 6, 31, 29, 18, 25, 24, 30, 14, 13, 5, 11, 23, 19, 22, 20, 9, 10]).

Response	Executing	Effected	Duration	Costs	Conflicts
$r_{block}(h_1)$	*router*	h_1	1.2	70	-
$r_{block}(h_2)$	*router*	h_2	1.2	50	-
$r_{block}(n)$	*router*	h_2, h_1	1.5	90	-
$r_{migrate}(h_1)$	h_3	h_1	10	20	$r_{migrate}(h_2)$
$r_{migrate}(h_2)$	h_3	h_2	10	20	$r_{migrate}(h_1)$
$r_{reconf}(h_2)$	h_2	h_2	5	10	-

System Design

Set-based Description

Description	Set	Example
Set of entities in the network	$S = \{s_1, s_2, ...\}$	$\{h_1, h_2, h_3, h_4, r\}$
Set of entities affected by the incident	$A = \{a_1, a_2, ...\} \subseteq S$	$\{h_1, h_2\}$
Set of responses to counter the incident	$R = \{r_1, r_2, ...\}$	$\{r_{b_1}, r_{b_2}, r_{b_3}, r_{m_1}, r_{m_2}, r_r\}$
Set of metrics to assess responses	$M = \{m_1, m_2, ...\}$	$\{d, c\}$
Response costs with respect to metrics	$c\colon R \times M \to \mathbb{R}_{\geq 0}$	$\{(r_r, d) = 4, (r_r, c) = 10, \cdots\}$
Potential damage of the incident	$d\colon M \to \mathbb{R}_{\geq 0}$	$\{(d) = 60, (c) = 20\}$
Information on conflicting responses	$c\colon R \times R \to \mathbb{B}$	$\{(r_{m_1}, r_{m_2}) = 1, \cdots\}$
Executor of a response	$e\colon S \times R \to \mathbb{B}$	$\{(h_2, r_r) = 1, \cdots\}$
Hosts a response effects	$f\colon A \times R \to \mathbb{B}$	$\{(h_2, r_r) = 1, (h_1, r_r) = 0, \cdots\}$

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Infrastructure information and policy given as input in advance •

System Design

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Infrastructure information and policy given as input in advance •

Information to extract from the incident $*$

System Design

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Description	Set	Example
Set of entities in the network •	$S = \{s_1, s_2, ...\}$	$\{h_1, h_2, h_3, h_4, r\}$
Set of entities affected by the incident ∗	$A = \{a_1, a_2, ...\} \subseteq S$	$\{h_1, h_2\}$
Set of responses to counter the incident •	$R = \{r_1, r_2, ...\}$	$\{r_{b_1}, r_{b_2}, r_{b_3}, r_{m_1}, r_{m_2}, r_r\}$
Set of metrics to assess responses •	$M = \{m_1, m_2, ...\}$	$\{d, c\}$
Response costs with respect to metrics †	$c: R \times M \to \mathbb{R}_{\geq 0}$	$\{(r_r, d) = 4, (r_r, c) = 10, \cdots\}$
Potential damage of the incident ∗	$d: M \to \mathbb{R}_{\geq 0}$	$\{(d) = 60, (c) = 20\}$
Information on conflicting responses •	$c: R \times R \to \mathbb{B}$	$\{(r_{m_1}, r_{m_2}) = 1, \cdots\}$
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Infrastructure information and policy given as input in advance •

Information to extract from the incident ∗

Information to collect during response execution †

System Design

MILP Definition

Objective Function

$$\min(\sum_{i=1}^{|R|} \sum_{j=1}^{|M|} n_i c_{i,j}) = \min(n_1 c_{1,1} + \cdots + n_{|R|} c_{|R|,|M|})$$

Freed Constraint

$$\forall a \in A: \sum_{j=1}^{|R|} n_j f_{a,j} \geq 1$$

Uniqueness Constraint

$$\forall r_i \in R: 0 \leq n_i \leq 1$$

Damage Constraint

$$\forall m \in M: \sum_{i=1}^{|R|} n_i c_{i,m} \leq d_m$$

Conflicting Constraint

$$\sum_{i=1}^{|R|} \sum_{j=1}^{|R|} o_{i,j} n_i n_j = 0$$

Implementation and Evaluation

Implementation

- Mixed Integer Linear Programming (MILP) formulation for GLPK and CPLEX
- Heuristics for comparison (Cheapest-First and Coverage-First)
- Test-framework to generate scenarios, compare implementations, and gain statistics
- Generic solver API for embedding the solvers into other applications

Code available on GitHub using GPLv3 license:

`https://github.com/Egomania/ResponseSelection`

Evaluation Methodology

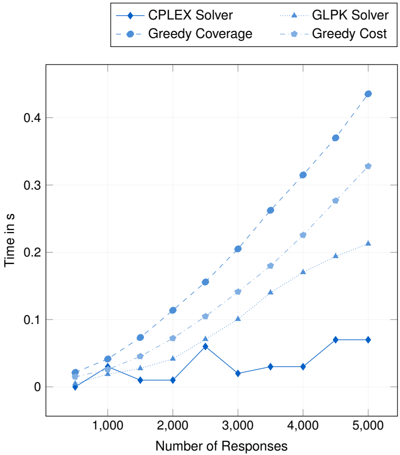
We analyze the behavior of the presented MILP approach and both heuristics in different incident scenarios by increasing problem complexity. We raise the problem complexity by increasing (one at a time) the

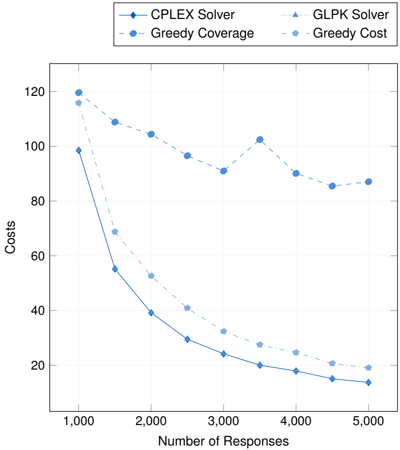
a. Number of responses
b. Number of entities
c. Number of conflicts
d. Number of entities a response is applicable to (coverage factor)

in the problem while keeping the number of remaining problem parameters fixed.

Implementation and Evaluation

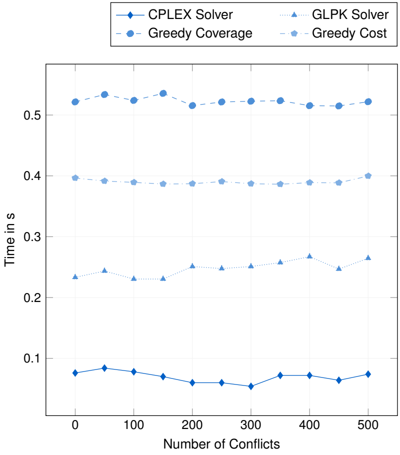
Results - Increasing Number of Responses

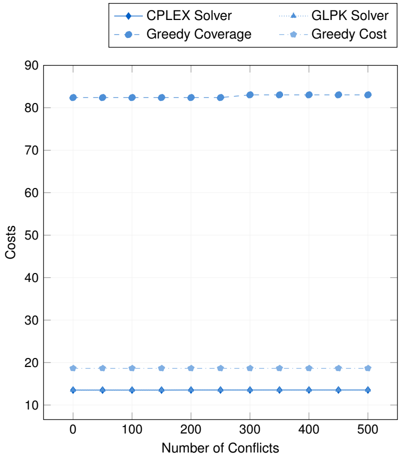




Implementation and Evaluation

Results - Increasing Number of Conflicts





Wrap Up

Conclusion and Future Work

Contributions

- Formulation of response selection as MILP Problem.
- Implementation with different solvers.
- Applicability is shown in all dimensions of the problem complexity.
- Cost and performance comparison with two different heuristics.

Improvements for the Future

- Include pre- and postconditions.
- Integrate existing assessment approaches as cost functions.
- Provide partial solutions.

Wrap Up

Contact

Thank you for the audience!

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`https://github.com/Egomania/ResponseSelection`

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