Filter Merging for Efficient Information Dissemination

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Introduction

- Content-based routing has been proposed as a communication primitive for advanced and mobile applications
- Information is propagated from publishers to subscribers (sinks).
- Subscriptions are described using filters. All information sent to a node must match the filters set by the node.
- Content model typically typed tuples or XML.
- Subscription-semantics
  - Primitives: *sub*, *unsub*, *pub*
  - Subscriptions are propagated throughout the system, notifications are sent on the reverse path.
- Advertisement-semantics
  - Optimization to improve scalability.

Background

- Optimizations for scalability
  - Various topologies: hierarchical, peer-to-peer, hybrid, rendezvous-point based (DHT), ..
  - Main idea: propagate the most general set of filters
    - Filter covering
    - Filter merging
- Main research question
  - How to integrate filter merging with a routing table?
- The main contributions of the paper are:
  - Formalizing filter merging in combination with content-based routing
  - Integration with filter covering-based routing tables
  - Initial experimental results with merging

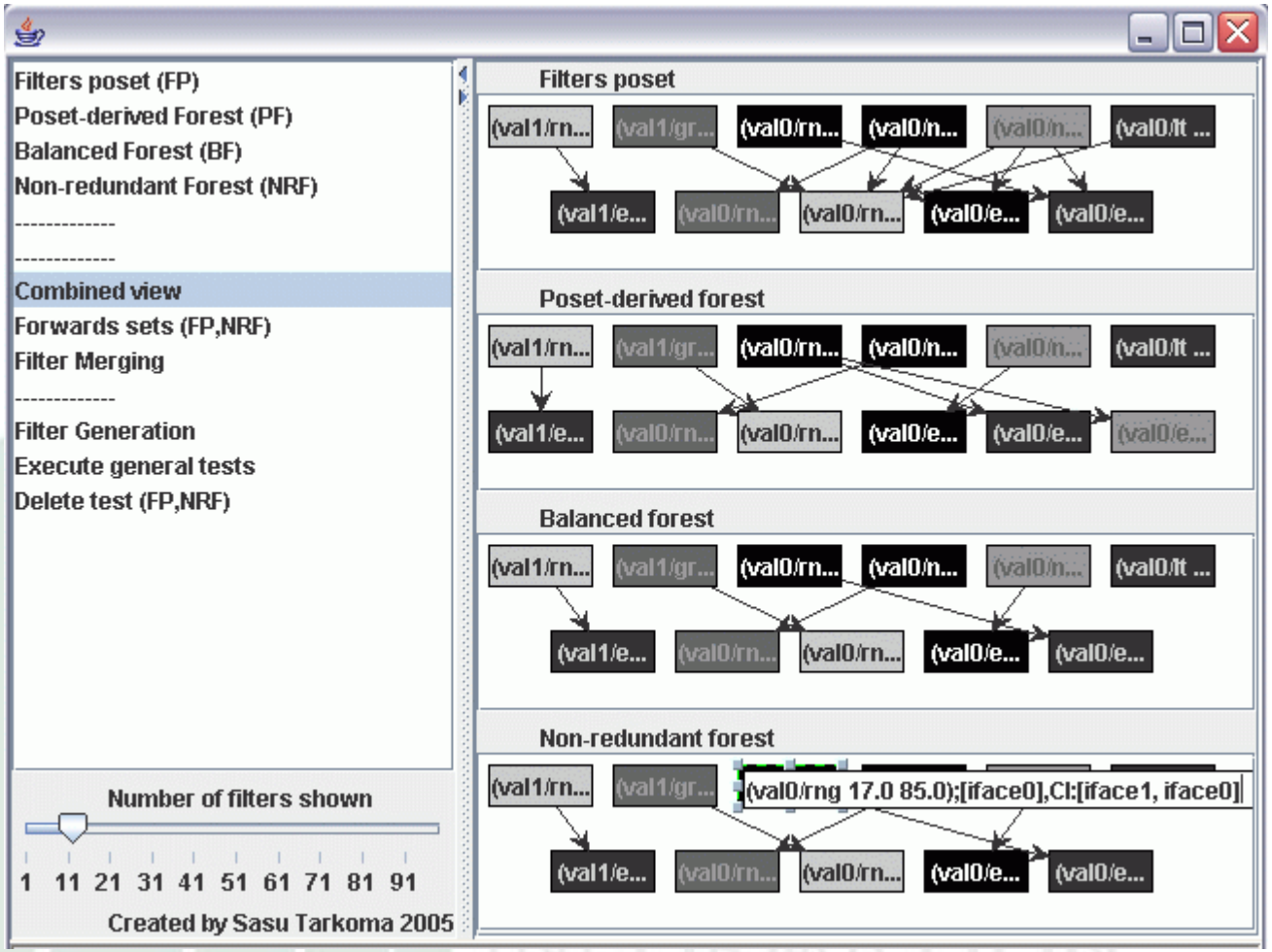
Filters

- Filters typically have two useful properties:
  - Filter F1 is said to cover filter F2 if and only if all the notifications that are matched by F2 are also matched by F1.
  - Overlap is defined similarly and happens when the two filters match the same arbitrary notification.
- The covering relation is a partial order (transitive, anti-symmetric)
- If filters are organized in a graph based on the covering relation, several optimizations are possible.
- The **root set** of the graph is the **minimal cover set**

Data Structures for Cover based Routing

- Filters Poset
  - A direct acyclic graph structure that stores the direct predecessors and successors for each filter.
  - Two first levels are used to compute the forwards sets.
    - Basic idea: never forward S from X to X if no other neighbour or local client has sent S previously.
- Poset-derived forest
  - Data structure with support for fast add/del operations.
  - Forest representation based on covering relation
  - Local clients, hierarchical, and peer-to-peer routing
- PosetBrowser
  - http://www.hiit.fi/fuego/fc/demos/

PosetBrowser



Filter Merging

- There are many ways to perform filter merging.
- We assume that a **merge**(F_1,F_2) procedure exists
  - Returns a single merged filter F_M.
  - F_M covers both F_1 and F_2.
- A merge of two or more filters is called a **merger**.
- Filter merging is useful, because it allows to further remove redundancy and keep the number of elements minimal.
- A merger is either **perfect** or **imperfect**.
  - A perfect merger does not result in false positives or negatives, whereas an imperfect merger may result in false positives.

Filter Merging

- Requirements for filter merging
  - Merging must be transparent for applications and routers.
  - Merging must maintain the set of inserted nodes.
  - An insert of **x** may result in a new merged node **merge(x,y)**, but after the delete of **x** the resulting node must cover **y**.
- Filter merging may be applied in different places in the event router.
  - local merging,
  - root merging,
  - aggregate merging.
- Two kinds of rules:
  - Mergeability rules, merging rules.

Observations on Routing

- The results are applicable for content-based routing using filter covering.
- Typically, each filter has a **forwards** set and a **subscribers** set.
- All filters that are covered by an active filter from the same interface are removed.
- It follows that the set of active [illegible]terface are incomparable.
  - There are no covering rel[illegible]t.
  - A good place to do merging.
- It also follows that the root set of the c[illegible] incomparable.
  - A good place to do merging.

Local merging: merging for a particular interface.

Root or aggregate merging: merging the root set.

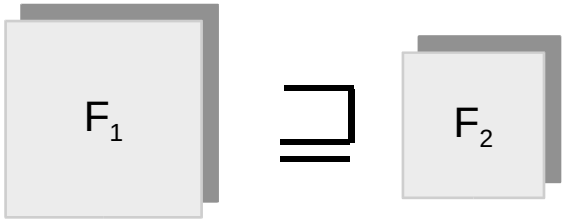
Local Merging

- In **local merging**, filter merging is performed within a data structure.
- Local merging rule:
  - The operation **merge**(F_1,F_2) may be performed if F_1 and F_2 are mergeable and the intersection of their **subscribers** sets has at least one element.
  - The **subscribers** set of the resulting merger must contain only a single element.
- The motivation for local merging is that it benefits the local router. The drawback is that it complicates the data structure.
- In the paper, we focus on **external** filter merging with the root and aggregate merging mechanisms.

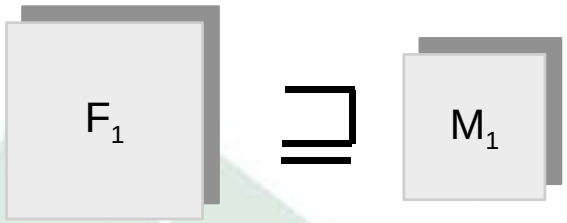
External Filter Merging

- Basic idea
  - mergers are stored outside the routing table
- Aggregate merging rule:
  - Given that the forwards sets of the filters are non-empty, the filters are mergeable only when forwards(F_1) $\cap$ forwards(F_2) $\neq$ empty set.
  - The forwards set of the resulting merger is the intersection of the two forwards sets.
- Aggregate filter merging rules are similar to the local merging rules
  - No covered nodes are deleted from the data structure.
  - Direct successors to merged nodes are maintained.
- Add is straightforward. Del is more complicated.
  - Typically adds are more frequent

Rules for Merging I



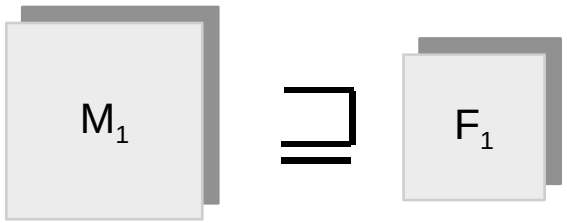
=> Del(F_2) on data structure (not necessarily removed)



=> Del(M_2)

Del(M_2) => Remove M_2 from MR, reset M_2's components and covered nodes

Rules for Merging II



=> Add F_1 to M_1's covered set

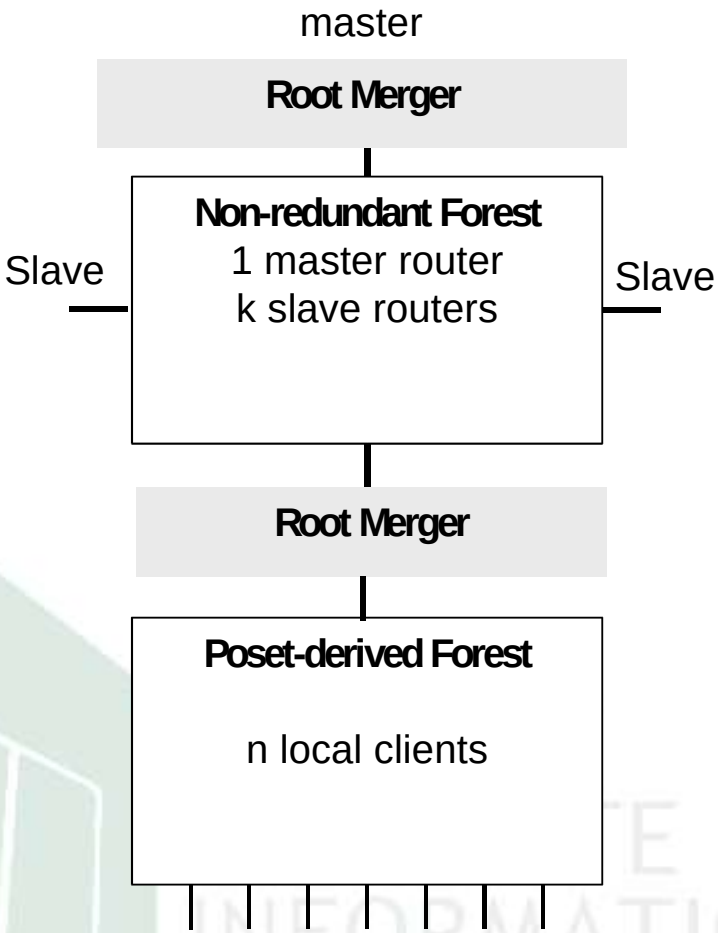
=> Add the components and covered nodes of M_2 to M_1 and remove M_2.

Del(x) and x is a component of a merger M_1 => Remove M_1 from MR, reset M_1's components and covered nodes. This makes them available for re-merging.

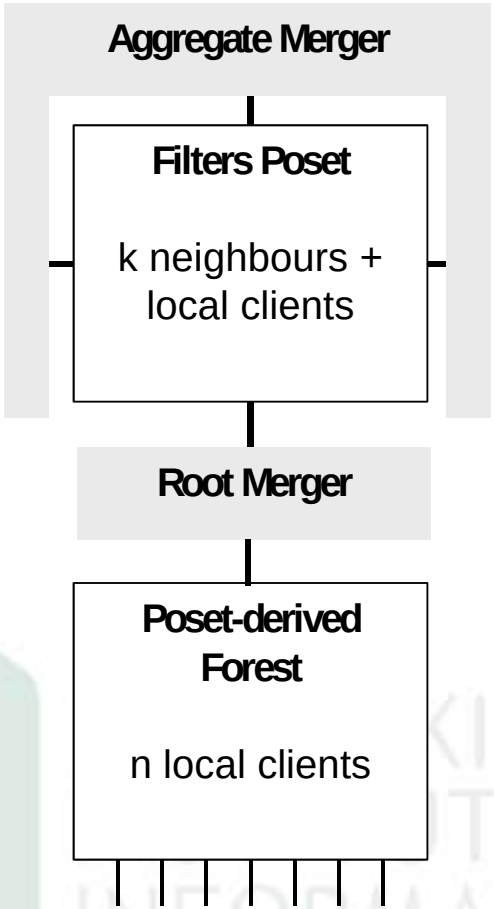
Integrating Merging with a Routing Table

- The proposed forwards set based aggregate mechanism is
  - Generic: it makes minimal assumptions on the underlying data structure.
  - It may be used with both peer-to-peer and hierarchical routing, and also for local clients.
  - Efficient. It is activated only when the root set changes, and it uses the forwards sets to aggregate merger updates. This kind of approach may be used to leverage any multicast mechanisms.
  - Relatively simple. Tracks changes in the root set and merges filters with the same forwards sets. This requires management of the merged sets.

Hierarchical



Peer-to-Peer (non-hierarchical)



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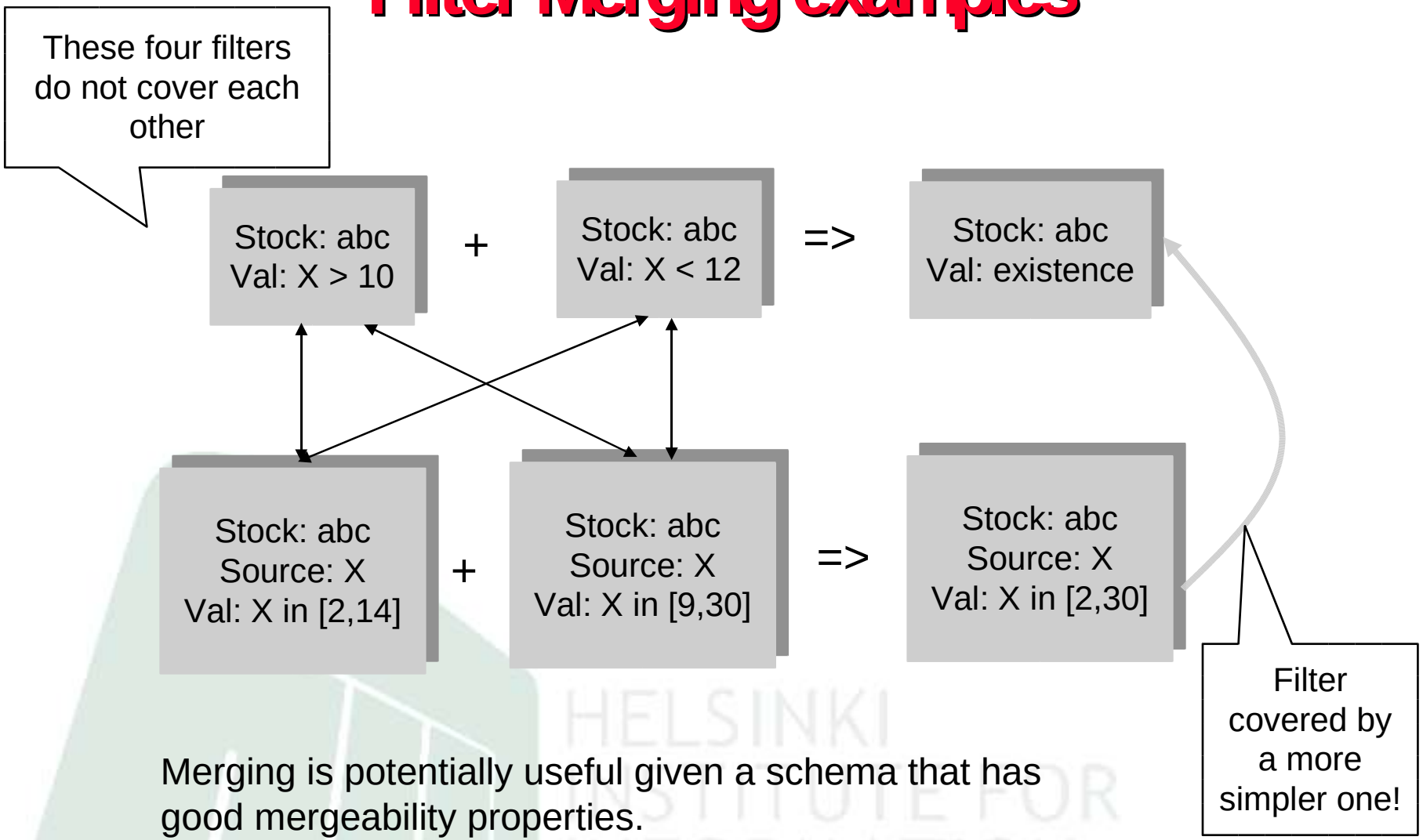
Filter Language and Merging

- The formal framework supports different filter merging mechisms.
  - Hardcoded rules, merging procedures, rules from ontologies
    - Merging rules may also be fuzzy
- We use a simple typed tuple model for experiments.
  - Each filter / event conforms to a schema.
  - Each filter is a set of attribute filters with unique name and type.
  - Relational operators are supported.
  - Cover algorithm supports disjunctions (but not conjunctions). Appendix A in the paper.
  - Two filters are mergeable if they have only one differing attribute filter that can be merged.

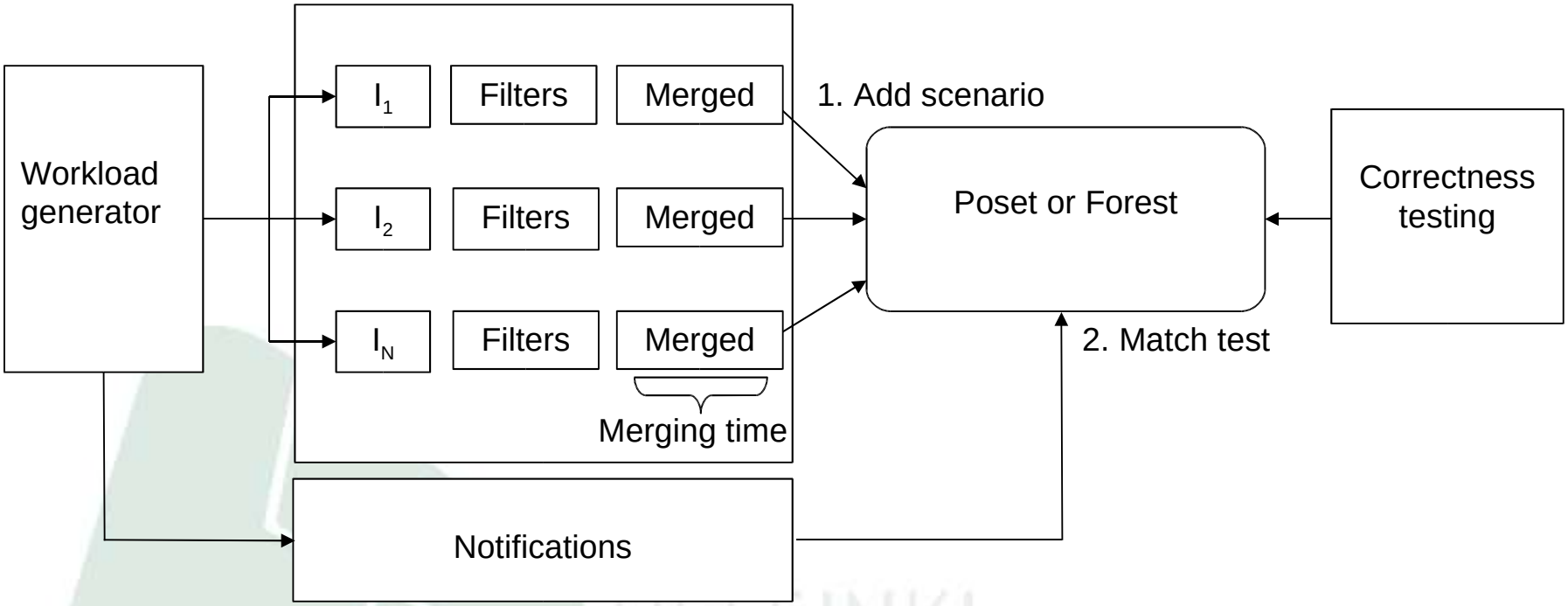
Filter Merging examples



Merging is potentially useful given a schema that has good mergeability properties.

Imperfect merging techniques may be used for improved mergeability with the cost of false positives.

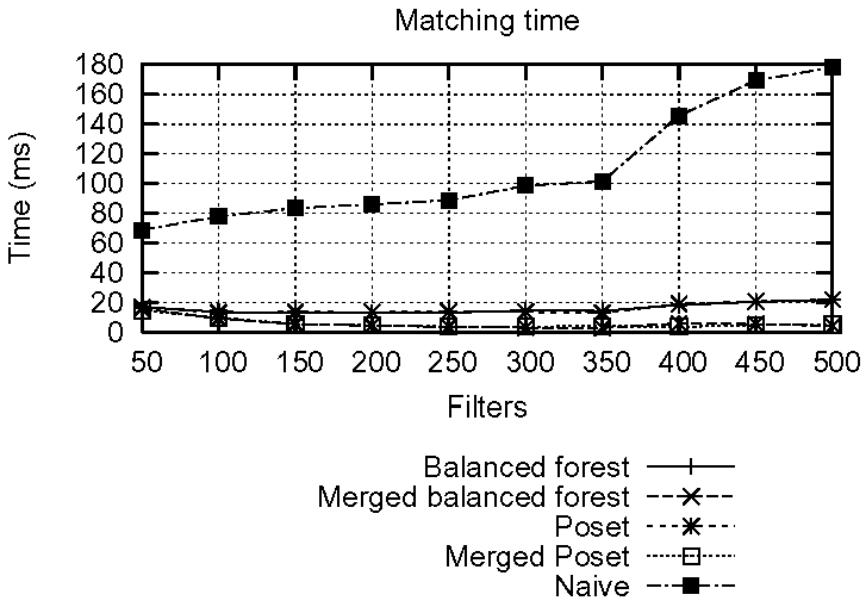
Experimental Results I

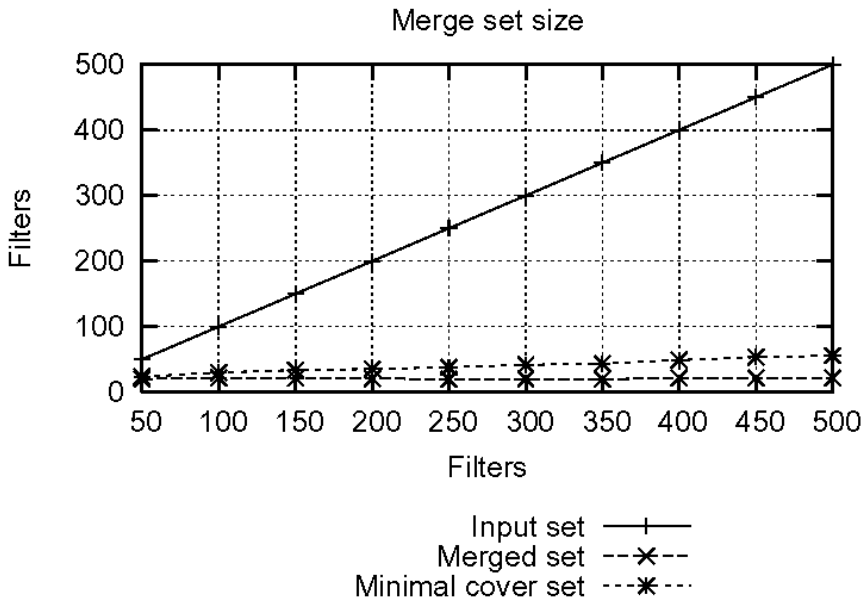


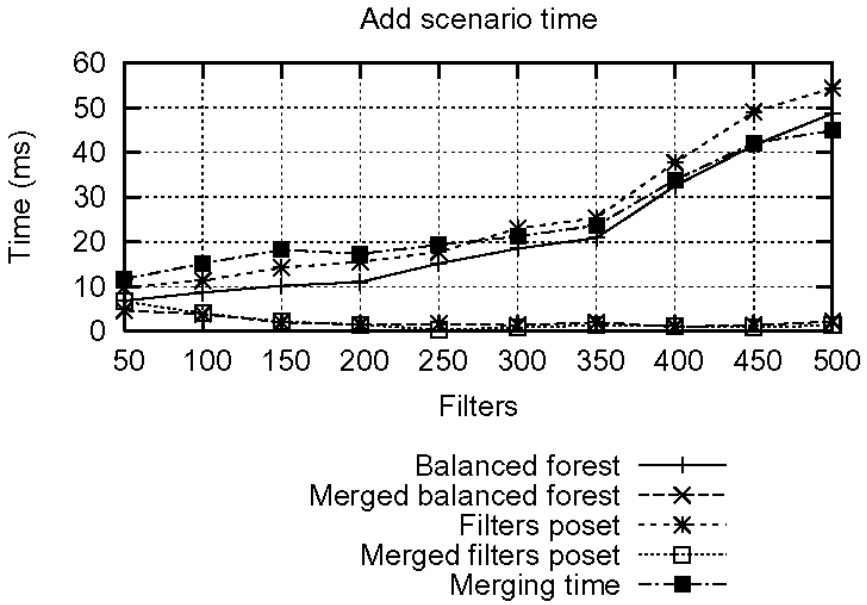
This benchmark corresponds to one-shot set-based merging.

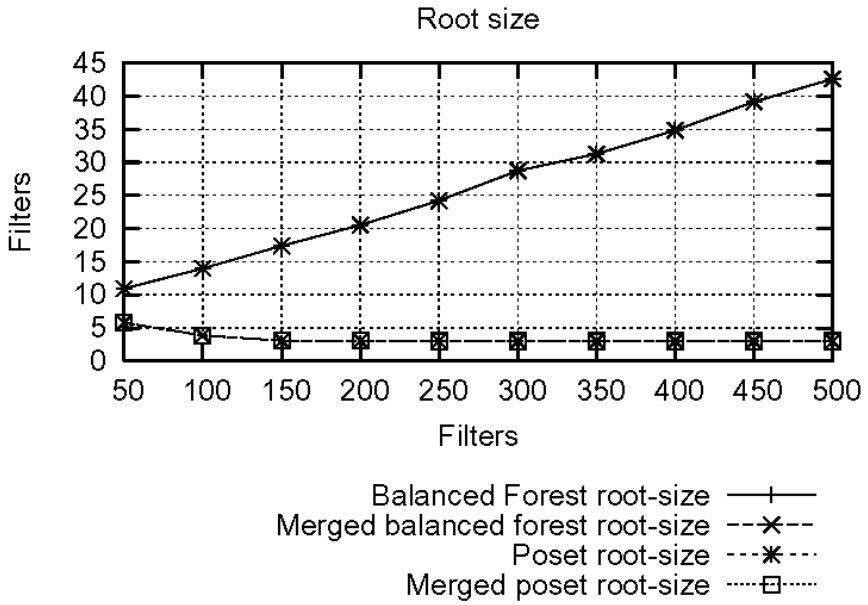
Filter model: variable number of attribute filters (1-3) + type, constraints from the set of relational operators for integers.

Add with 3 neighbours

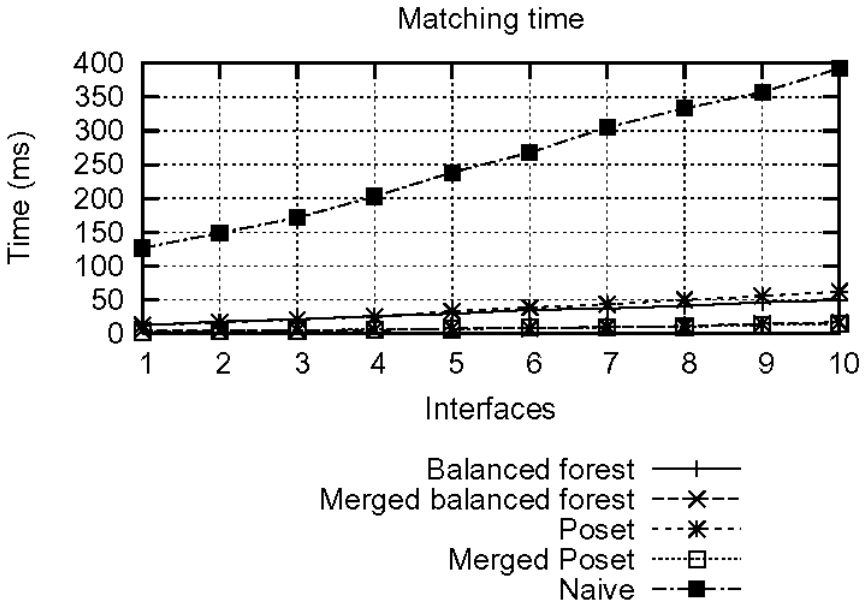


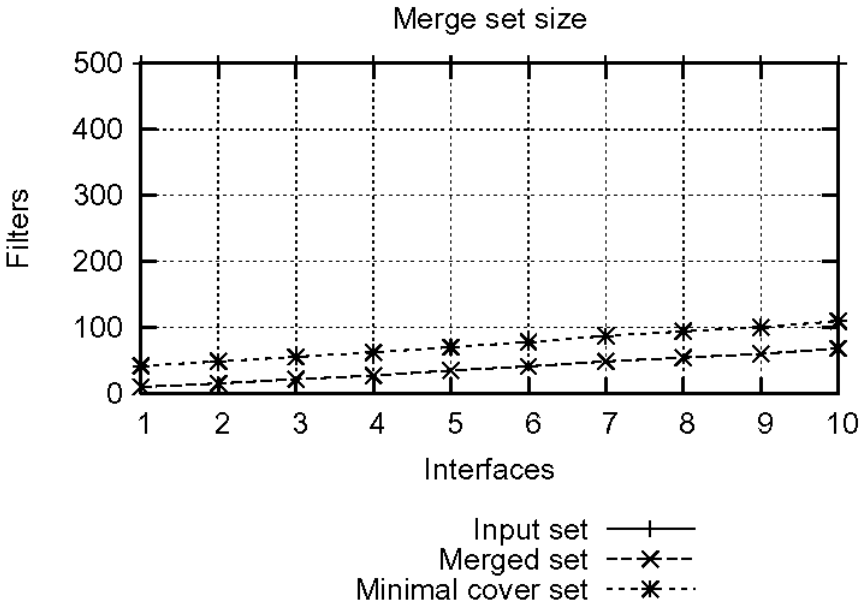


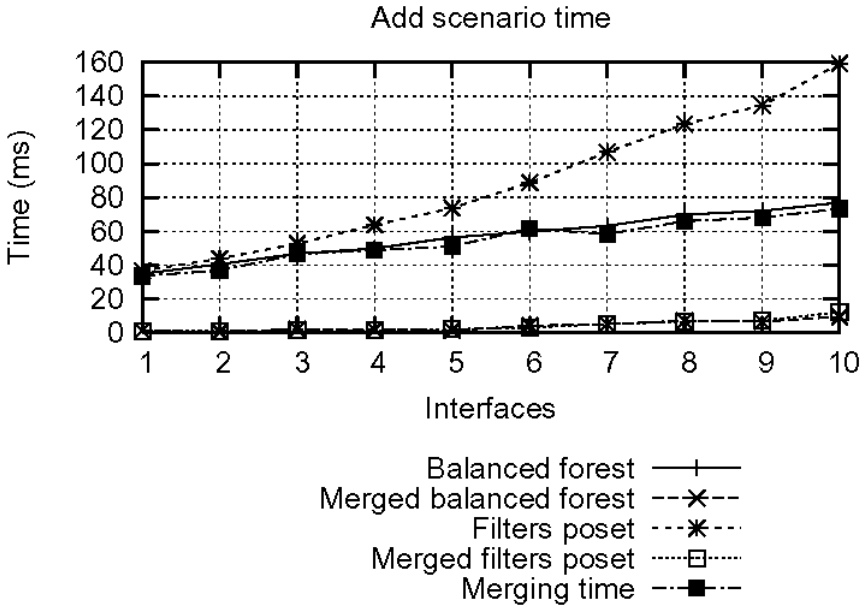


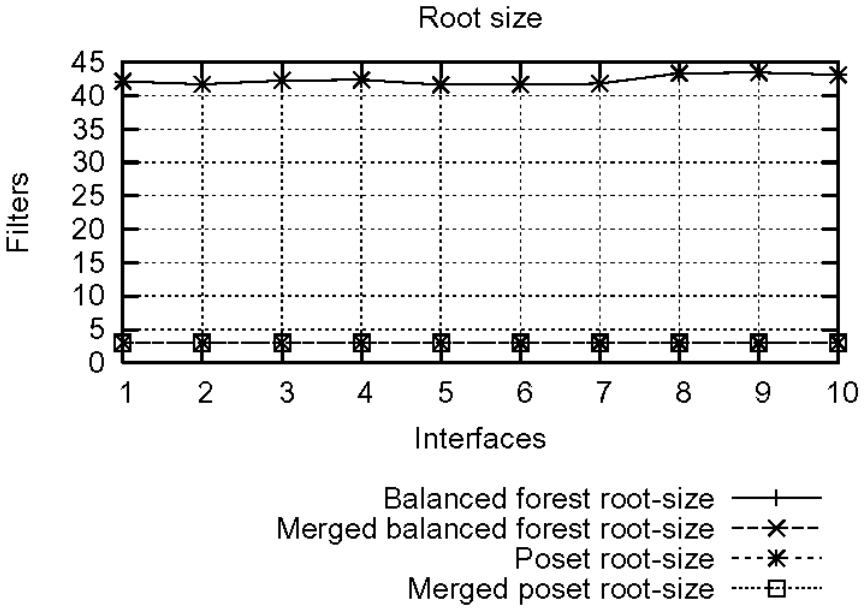


500 filters and a var number of neighbours



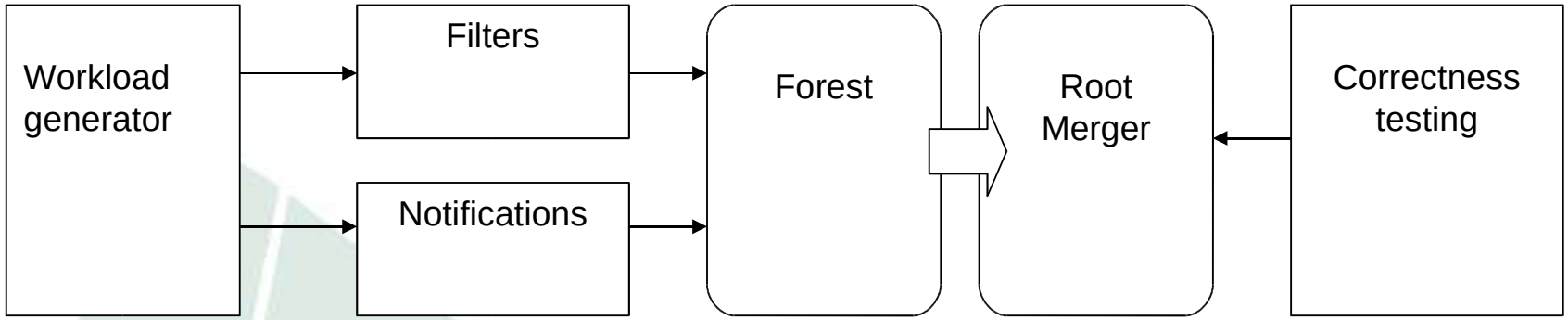






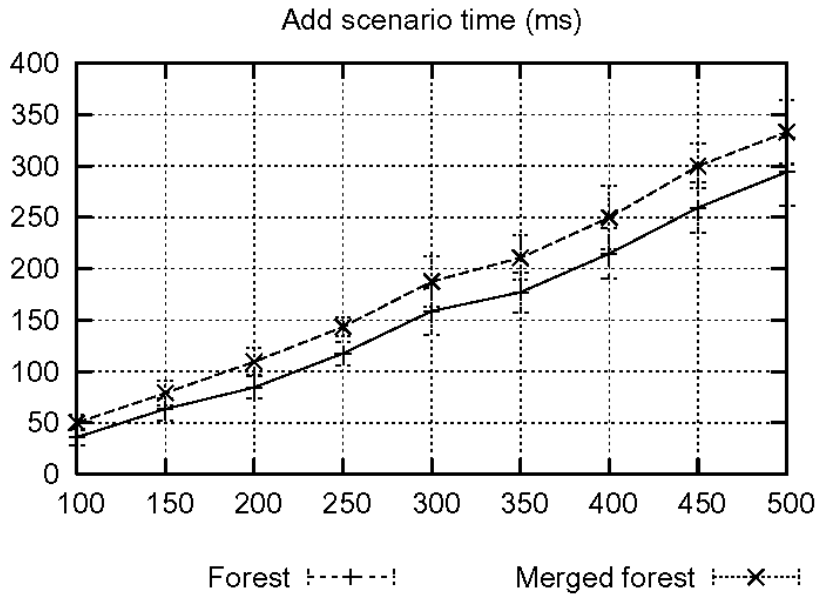
Root Merger Benchmarks

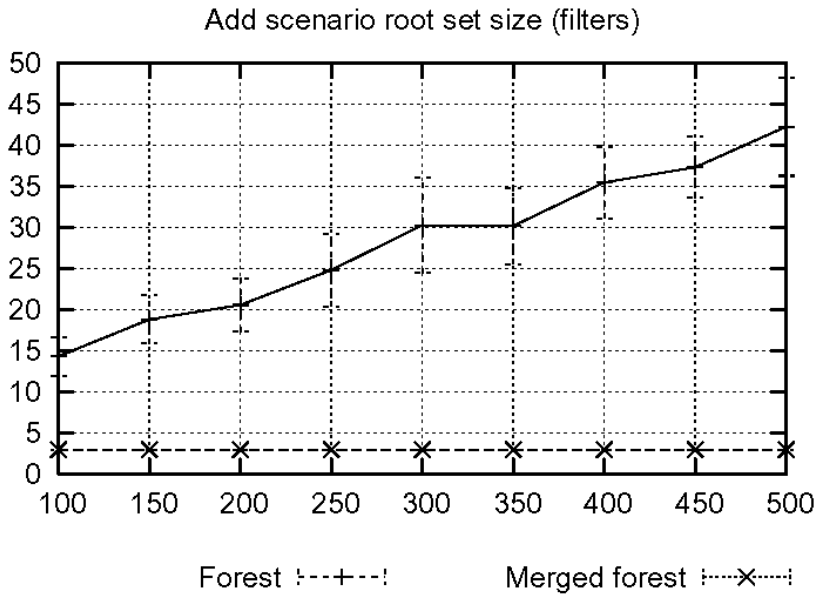
1. Add or Add/Remove scenario

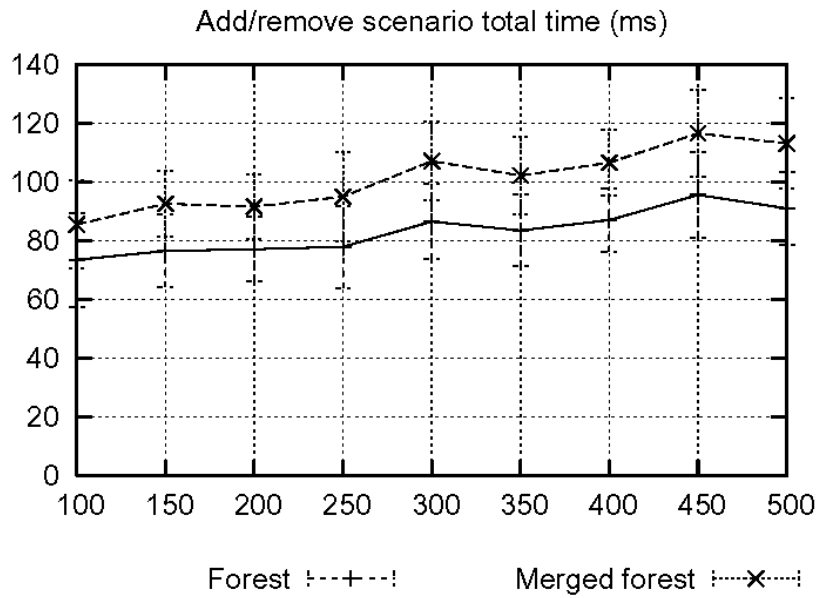


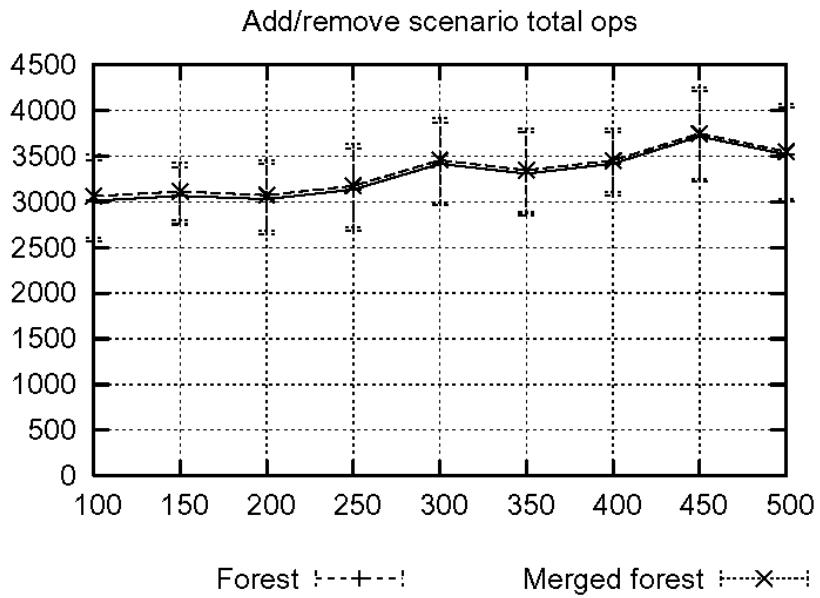
2. Matching test

Root merger: Add and Add/Del (3 var AF)

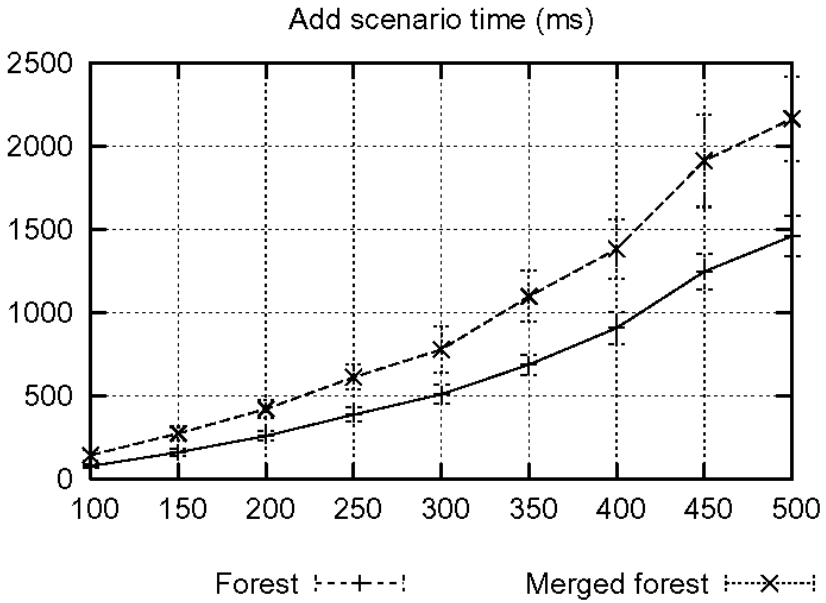


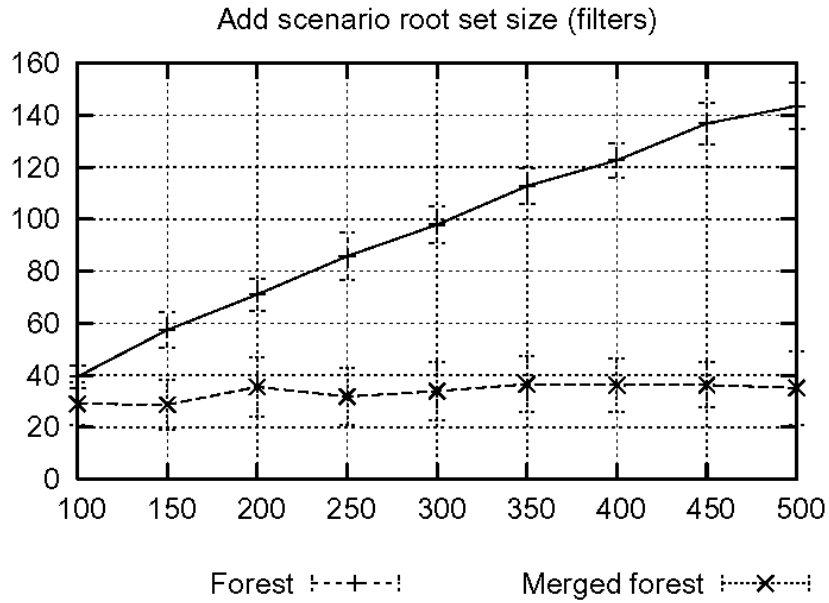


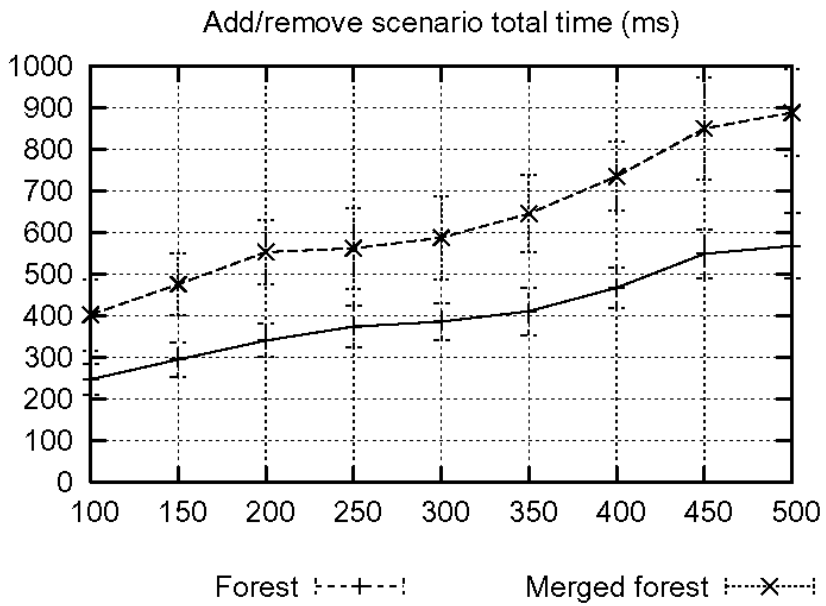


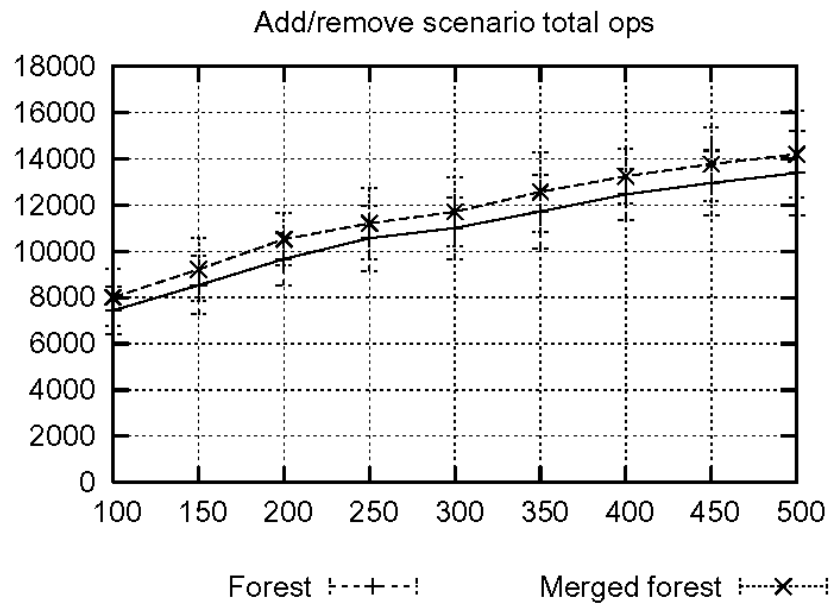


Root merger: Add and Add/Del (2 AF)









Discussion

- Results suggest that additions are manageable even in high frequency
- Deletions are problematic
  - Easiest for local clients and hierarchical routing
  - More complicated for peer-to-peer routing
- Strategies in general
  - Results show that some schemas merge well (variable number attribute filters) and some badly (static number of attribute filters)
  - The system should be prevented from trying to merge unmergeable workloads
  - Extend schema to contain mergeability hints
- Strategies for del
  - Lazy evaluation. Monitor false positive rate.
  - Periodic update

Conclusions

- We presented a formal filter merging framework
  - Mergeability and merging rules
  - Independent of the routing structure and filter language
- Integration with content-based routing table based on filter covering
  - Merging the root set
  - Aggregate merging based on the forwards set
  - Cover & merging are useful in combination
- Experimental results indicate that merging is feasible when filters exhibit good mergeability characteristics
  - One-shot merging for periodic updates
  - Runtime merging for dynamic operation
    - Del is challenging, but not expected to be frequent