To Split or to Group: From Divide-and-Conquer to Sub-Task Sharing in Verifying Multiple Properties

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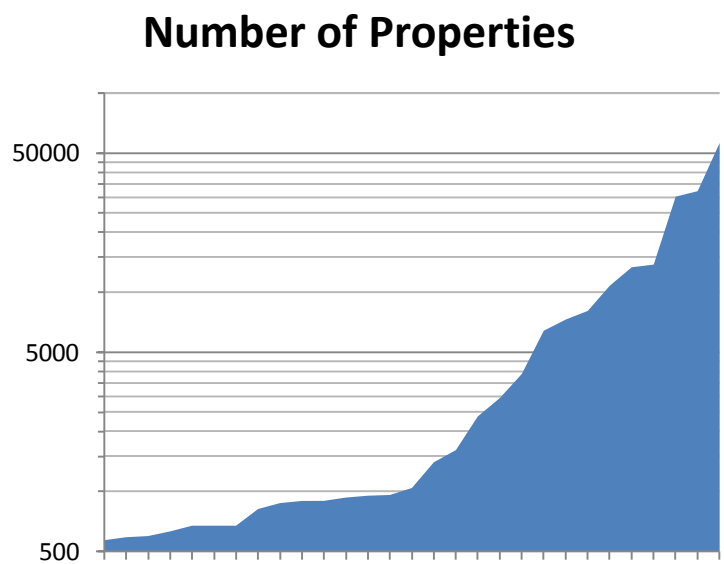
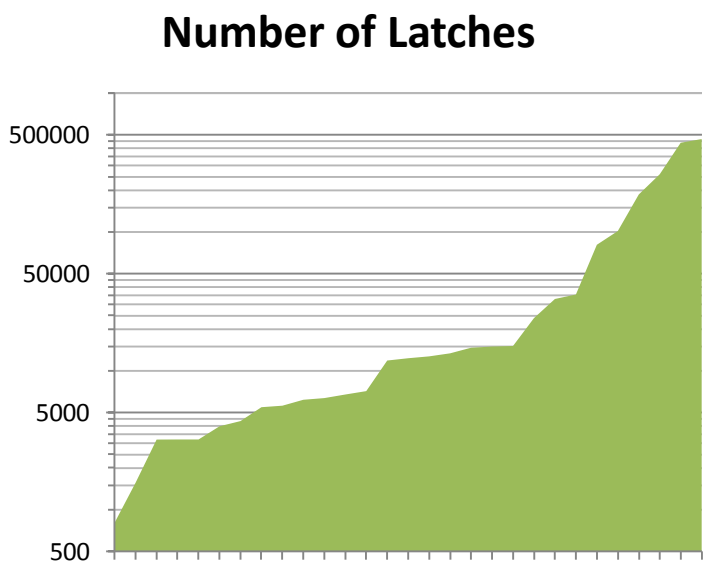
Motivation

- Multiple properties/targets for same model
  - As primary inputs
  - Generated by decomposition
- Handle different properties as sub-problems
  - Target sorting and/or grouping
- Interaction and synergy among proofs
  - Reuse reduction
  - Propagate learning

Our targets

- Focus on large circuits with several properties
  - Between 500 and 50K properties
  - Between 500 and 500K latches
- Subset of HWMCC'13 (multiple and single tracks)

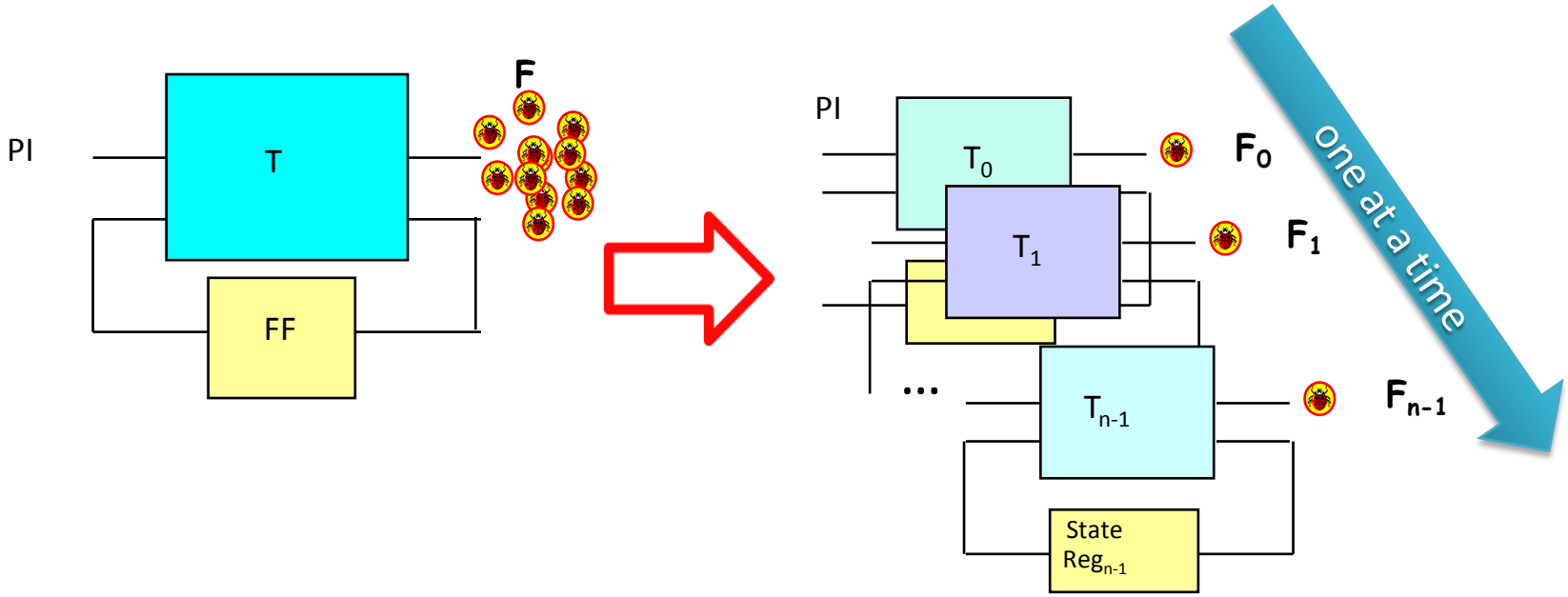




Outline

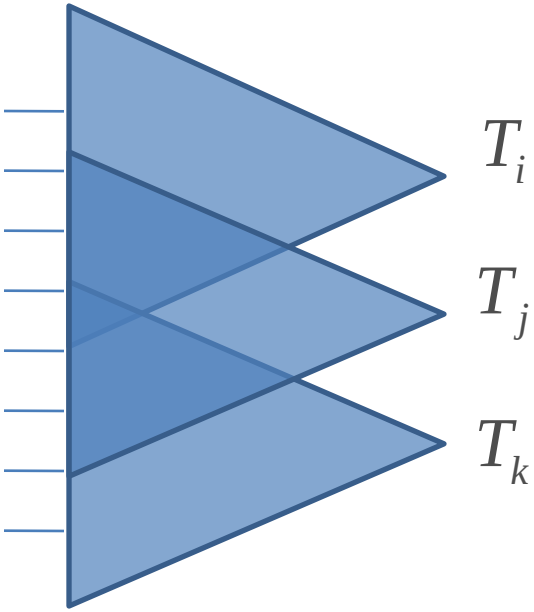
- Motivation
- **Property grouping**
  - **clustering**
  - **verification with learning**
- Property decomposition
  - partial verification
  - coverage estimation
- Conclusions and future works

Multiple properties verification



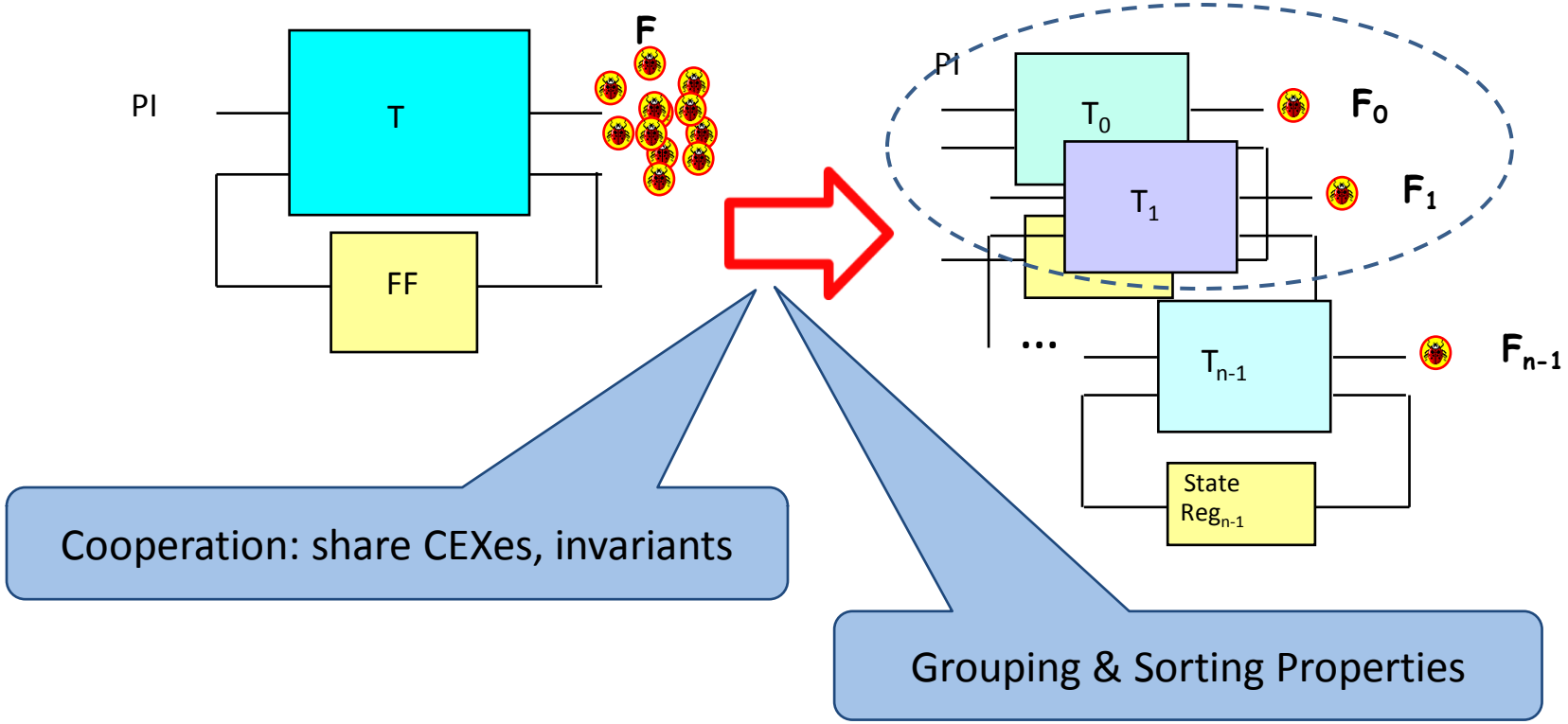
Standard approach

- Straightforward verification
  - sequential
  - individual checks
- Overhead
  - initialization and finalization of single properties
- Repetition of shared sub-tasks



Clustered verification$_1$

- Group properties together $P : p = \bigwedge_i p_i$
- Tuning to avoid scalability issues

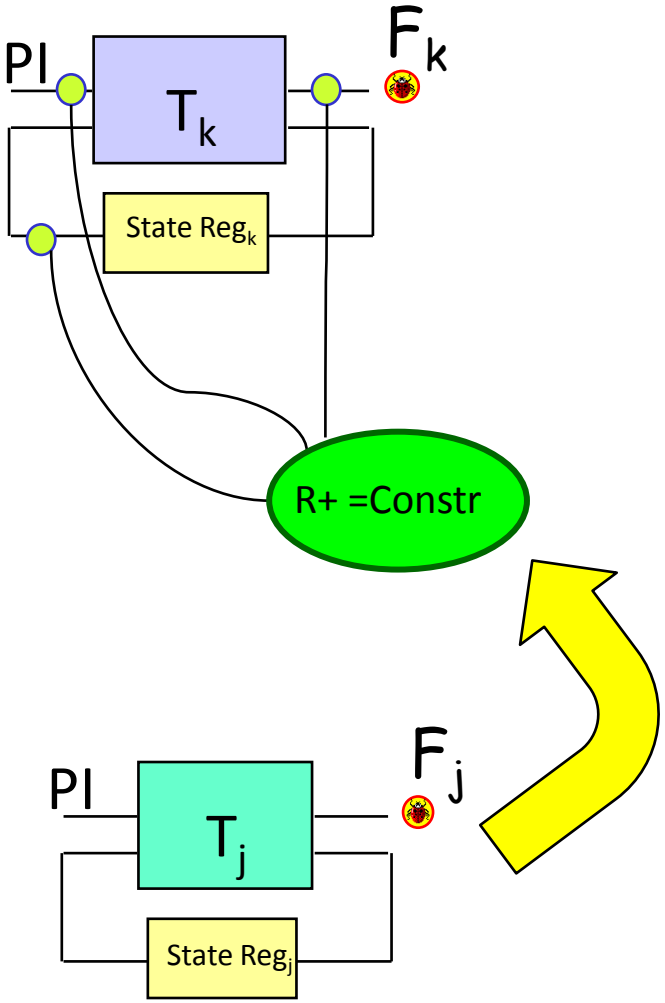


Clustered verification$_2$

- Several strategies
  - sort properties by expected verification effort
  - classify properties according to mutual affinity
- Group properties in subsets
  - tune verification within subset
- Address scalability issues
  - COIs size explosion

Cluster aware engines$_1$

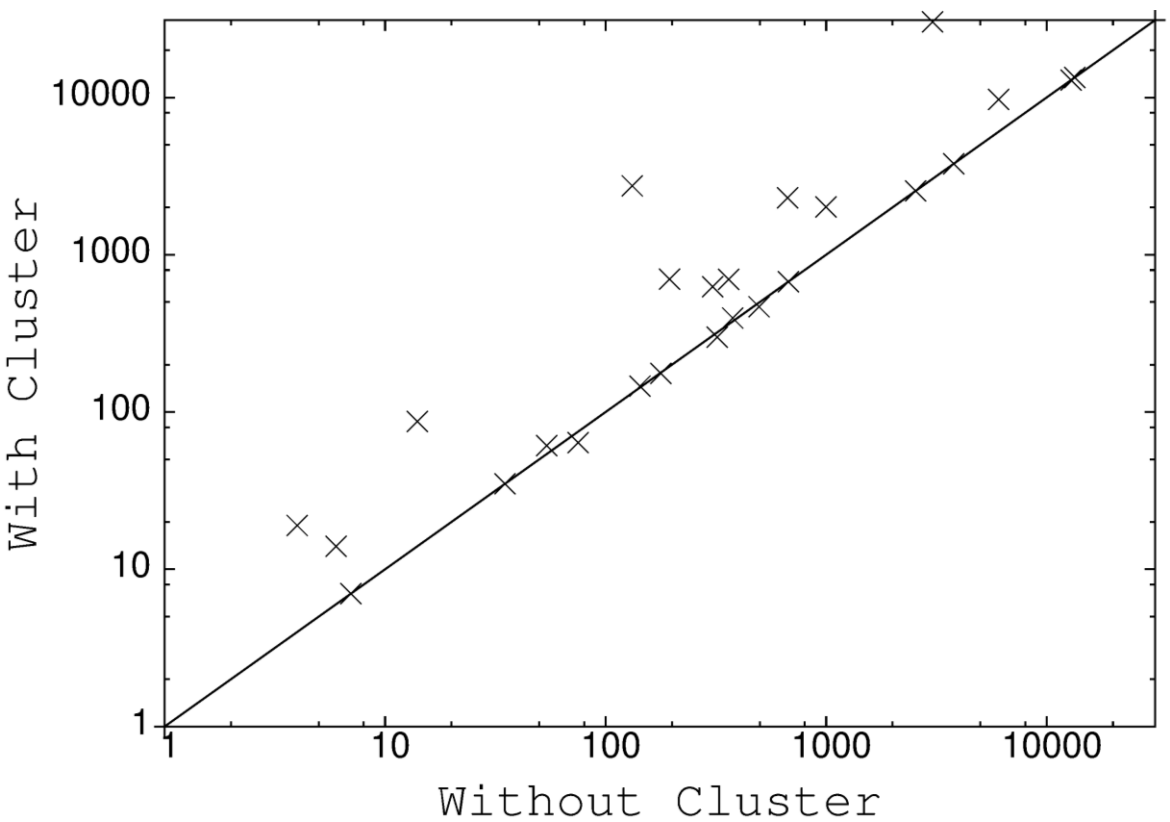
- Exploit learning
  - reuse discovered invariants
    - cluster to cluster
    - target to target
  - reuse reductions and simplifications
  - trade off between usability and size/costs
- Filter CEXes
  - reorganize clusters removing failed properties
- One hard property may hinder whole cluster verification



Properties affinity

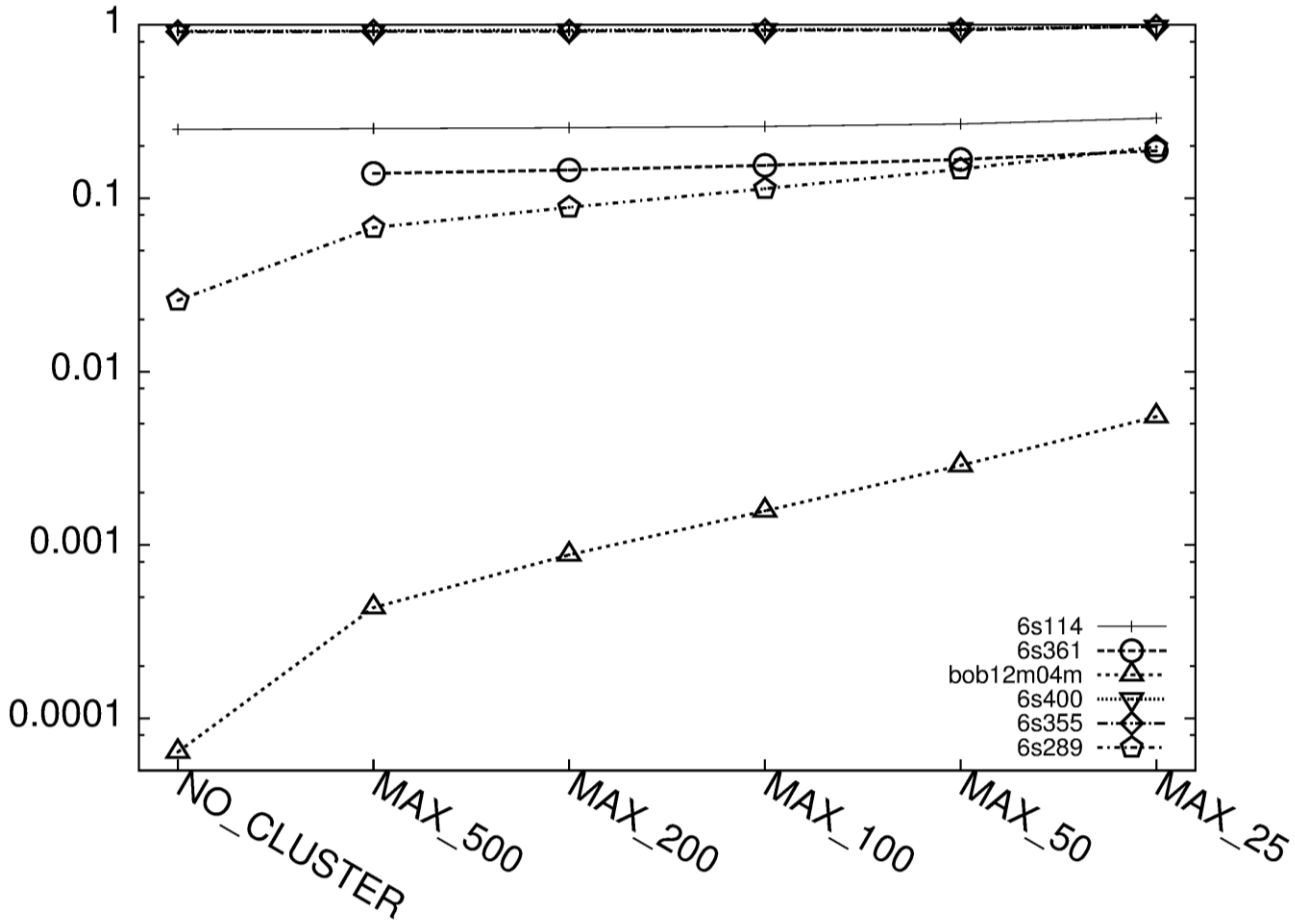
- Affinity estimated based on support variables V_p within COIs
- Jacquard Index $\alpha = \frac{|V_j \cap V_k|}{|V_j \cup V_k|}$
- Grouping performed if resulting value is above a chosen threshold
- Verification starts from properties with smaller COIs

Clustering properties



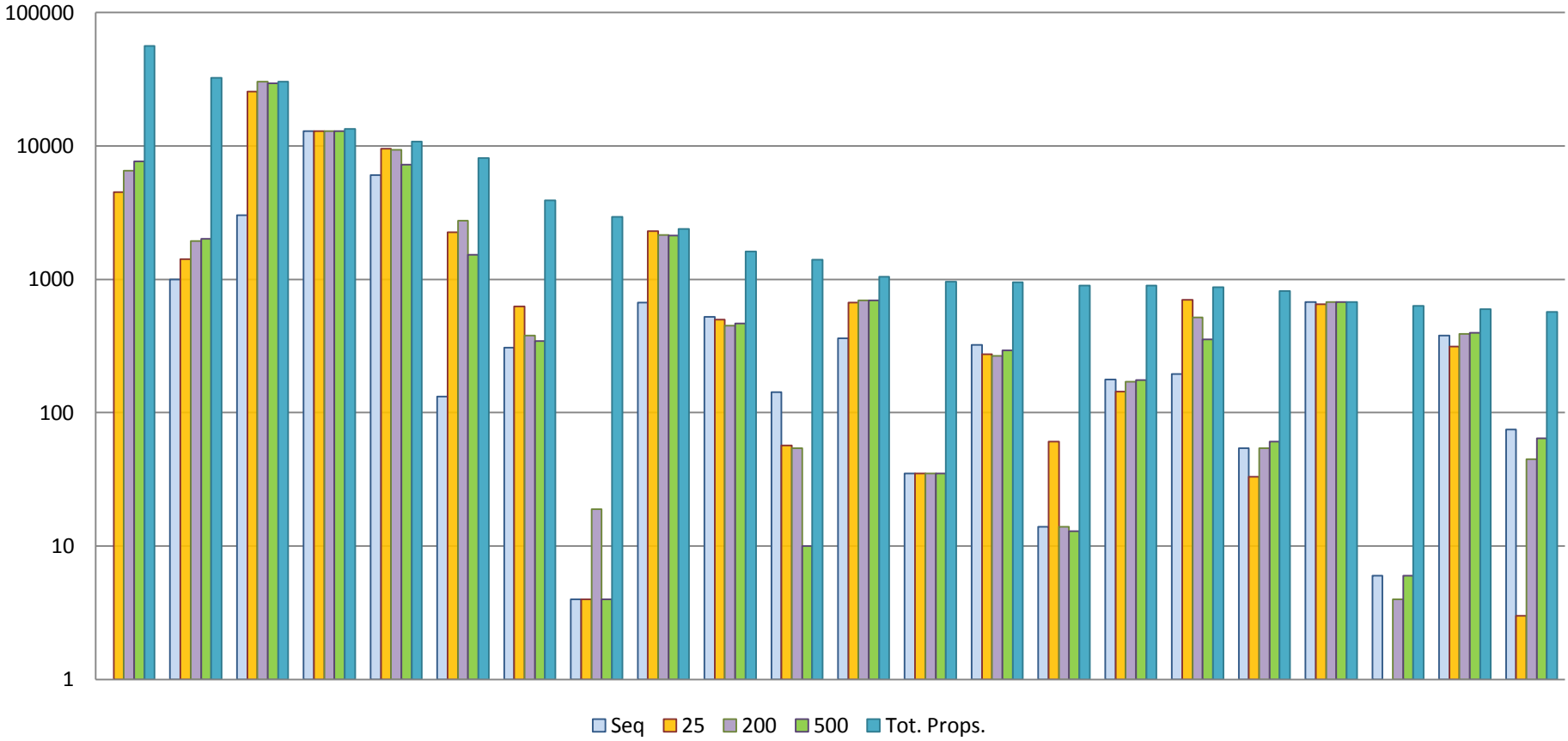
- Comparison between our sequential and cluster based approaches
- Best result among different clustering thresholds
- Usually at least as good as sequential verification

COIs sizes evaluation



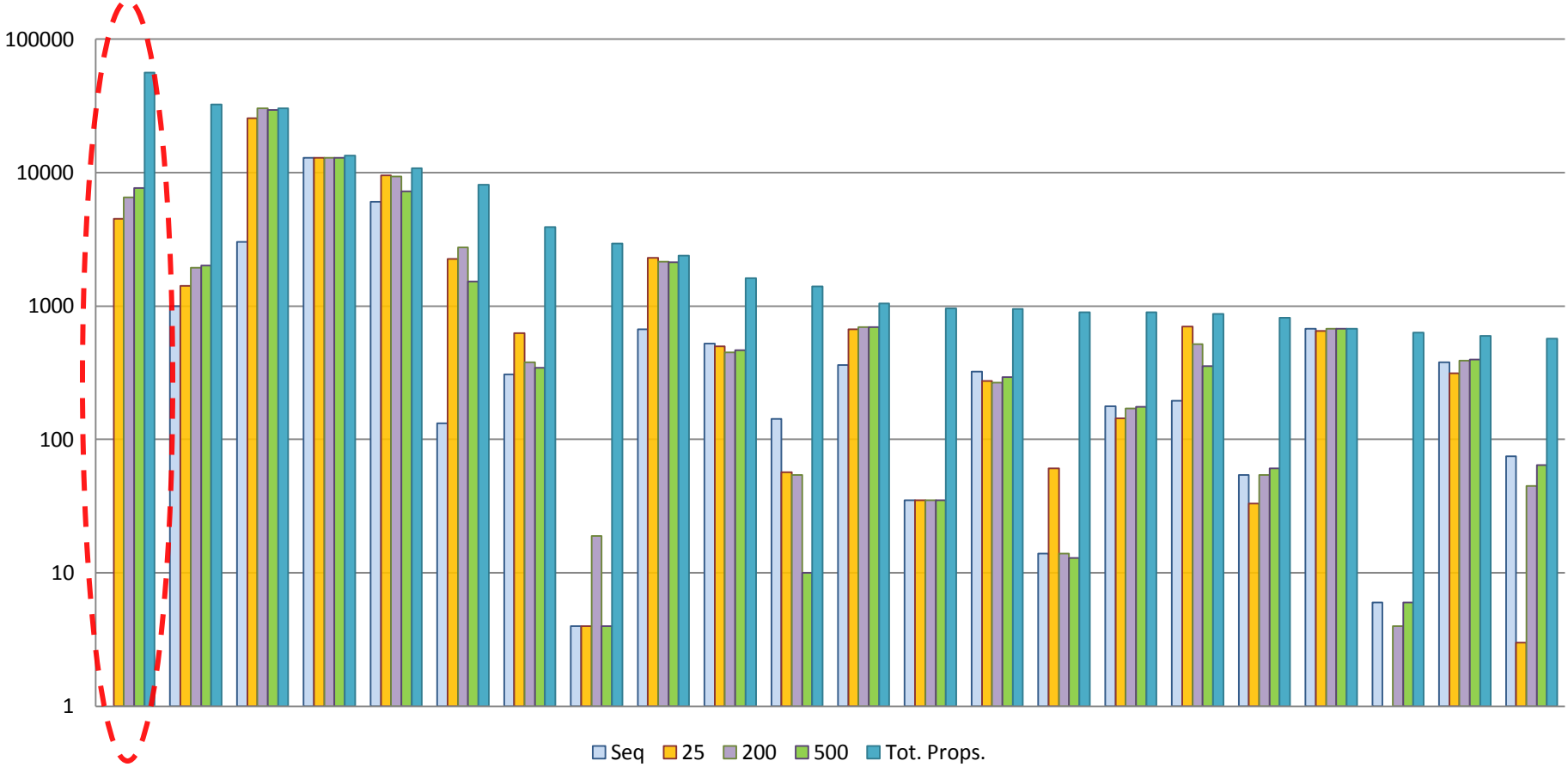
- COIs sizes tend not to grow so much to become intractable
- Values normalized considering only non-constant properties

Thresholds impact on verification



- The number of allowed clusters influences verification outcome
- Automatic tuning of thresholds is an on-going effort

Thresholds impact on verification



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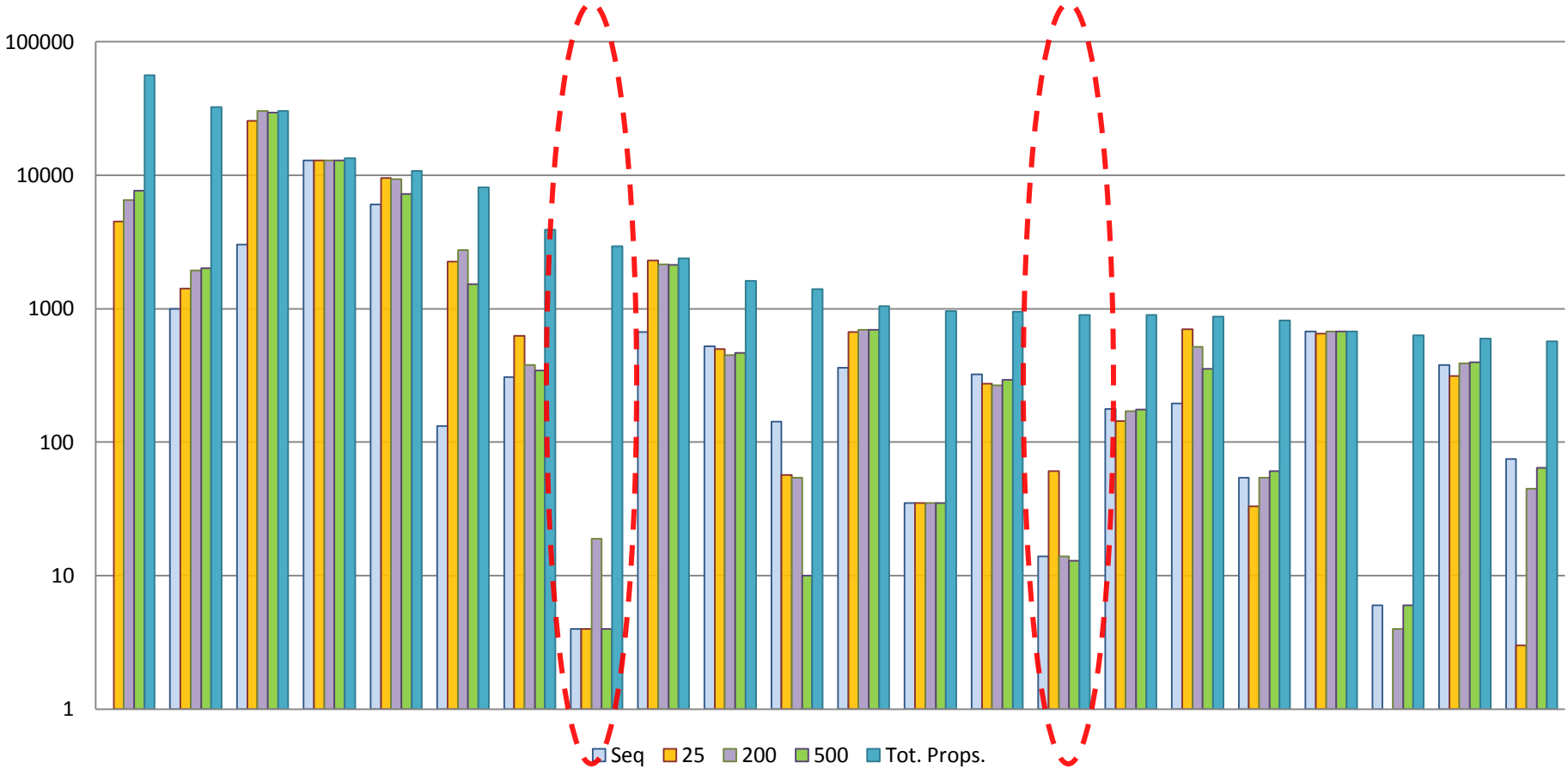

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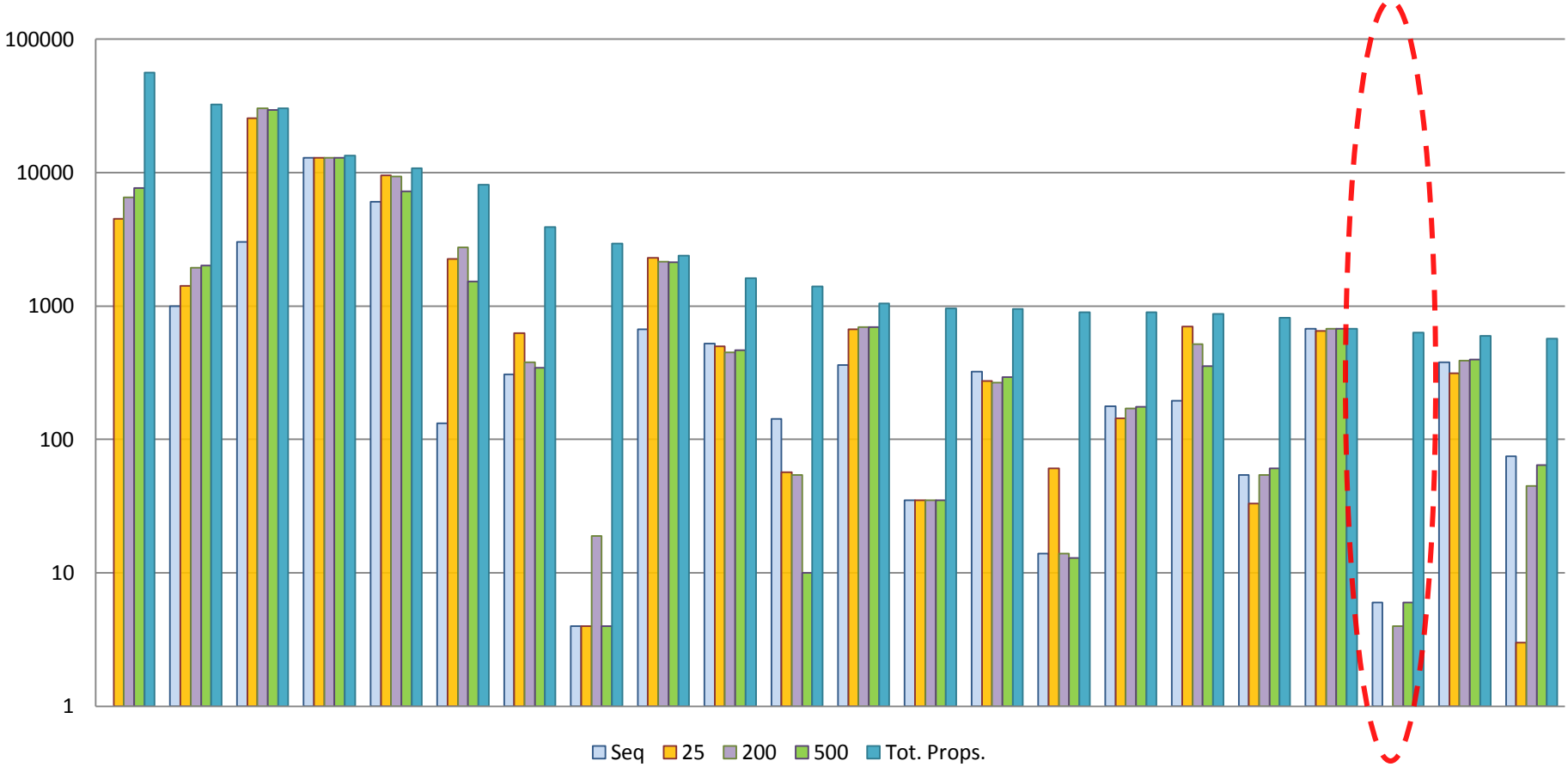

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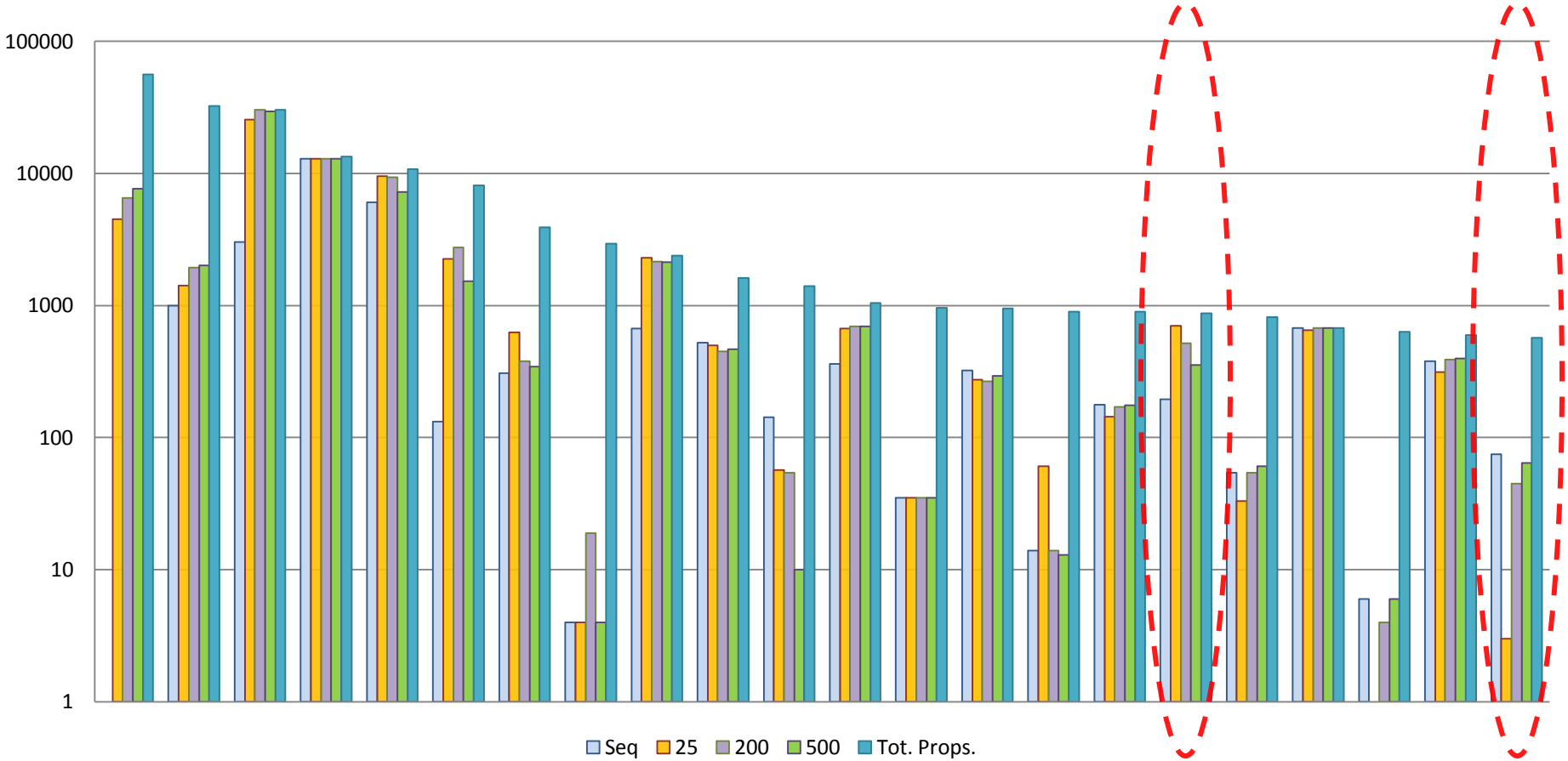

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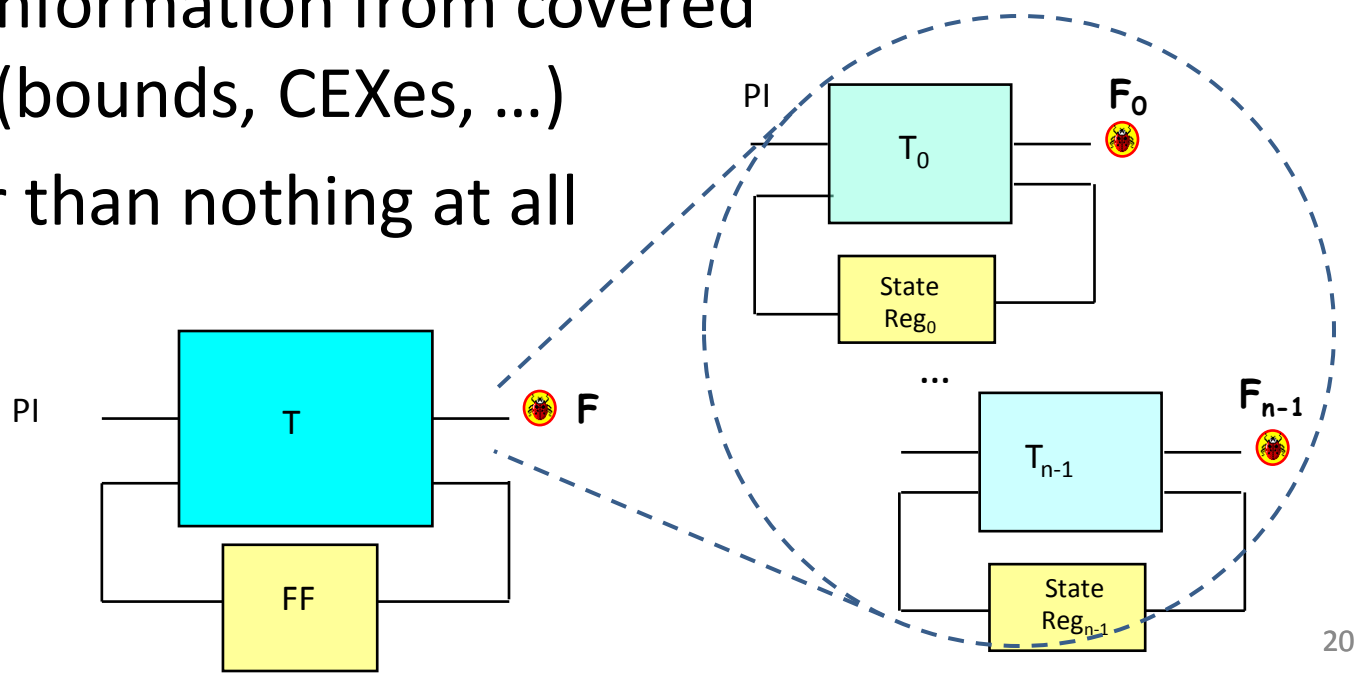
- **Property decomposition**
  - **partial verification**
  - **coverage estimation**
- Conclusions and future works

Premiss

- Property decomposition aimed at full verification
- Easy-to-solve properties of little interest
  - introducing overhead
  - no information to gain
- Hard-to-solve still unsolvable as a whole
  - sub-problems can be as hard as the original

Partial verification

- Compositional verification of monolithic properties
- Relax goal of full verification
  - infer information from covered parts (bounds, CEXes, …)
  - better than nothing at all



Property decomposition$_1$

- Divide & Conquer approach for hard-to-solve properties $P = \bigwedge_i p_i$
- Identify a subset of "easier" properties
  - smaller COIs
  - sub-space constrained
  - only describing sub-behaviors
- Treat original property as a grouped instance
- SAT solvers as sub-target enumerator

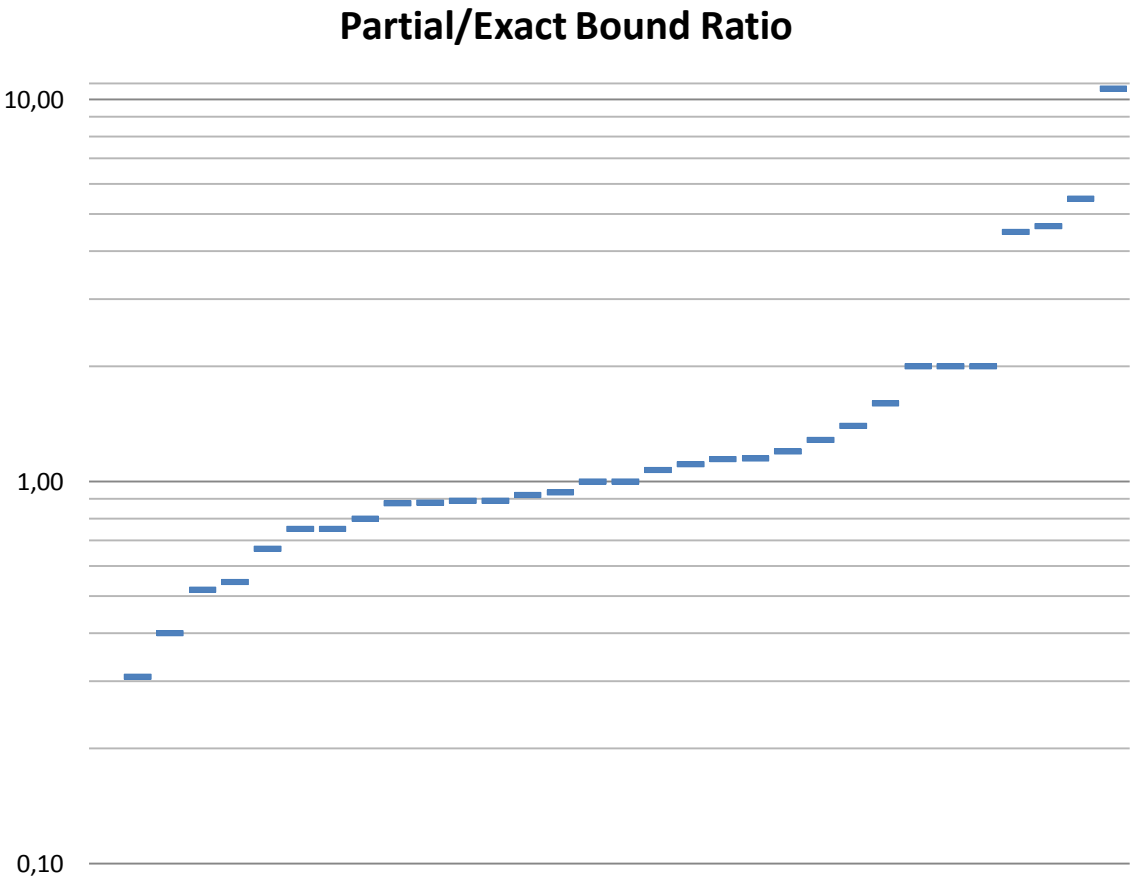
Property decomposition$_2$

- Derive target from invariant $t = \neg p$
- Consider a minterm as first sub-target $t_0 = SAT(t)$, $p_0 = \neg t_0$
- Acquire over-approximated stateset representations as sub-product of previous verification $R_0, \ldots, R_k$
- Iteratively select targets that hit the innermost reachable state ring
- Terminate upon
  - identifying a partial target as reachable, disproving the property
  - acquiring a strong enough *R* set to prove the original property

Coverage estimation

- Based on size/percentage of reachable states
- State space estimation based on graph-based algorithm
- Derived from life sciences and “capture-mark-recapture” approaches
- Inherently difficult to produce almost exact estimation
- Ongoing work in this direction

Property decomposition and Bound estimation



- Focus on hard-to-solve single property designs
- SAT properties:
  - BMC runs to identify CEX bounds
- UNSAT properties:
  - Standard verification to identify pass bounds
- Partial verification
  - Diminished time limit for sub-properties verification through UMC
  - Bound estimation derived from these runs

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Conclusions and future work

- Preliminary results are promising and show room for improvement
- Further investments in clustering techniques and heuristics
- Automatization of threshold selection and cluster parametrization
- Further research in partial verification as indicator for currently untreatable instances

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