Generation techniques for consistent, realistic, diverse, and scalable graphs

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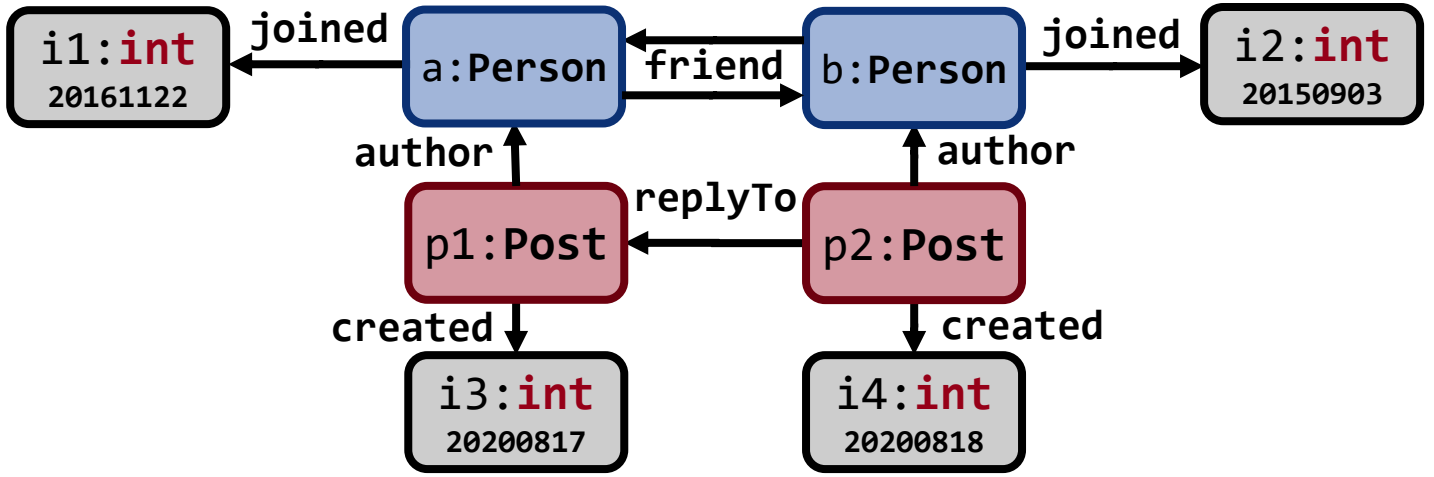
Graph Models & Model Generation



- Graph models are widely used in software engineering

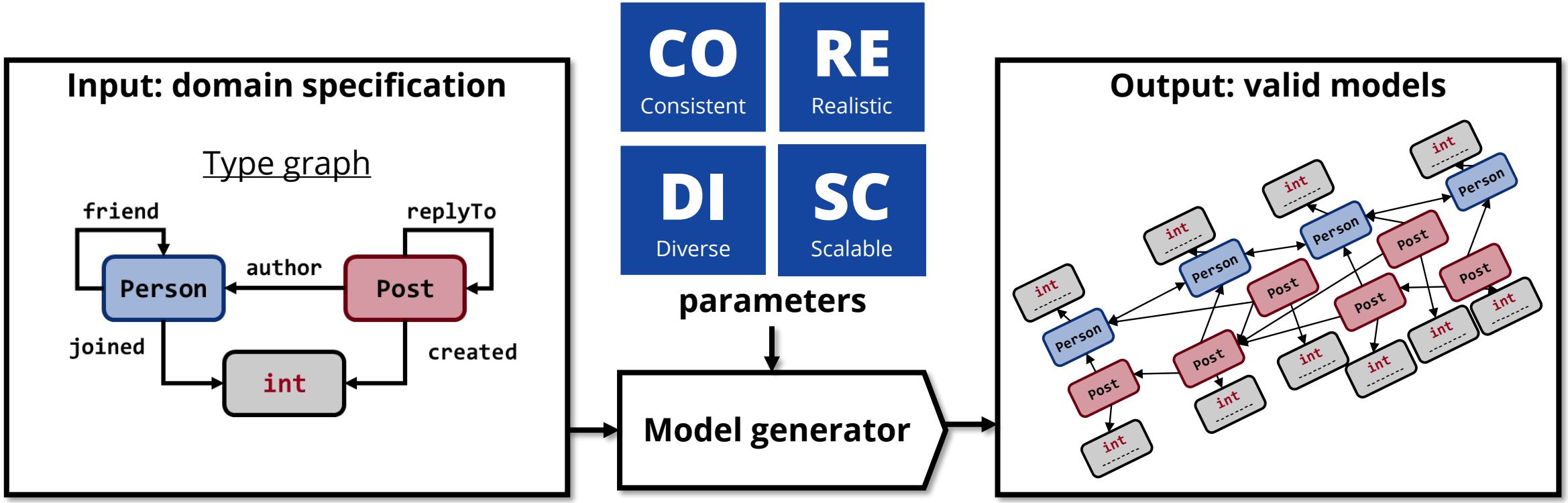
  system designs, **data structures**, **DB content**

- Testing and benchmarking scenarios rely on models

Generating (**consistent** | **realistic** | **diverse** | **scalable**) models!

- Generic, domain-independent generators

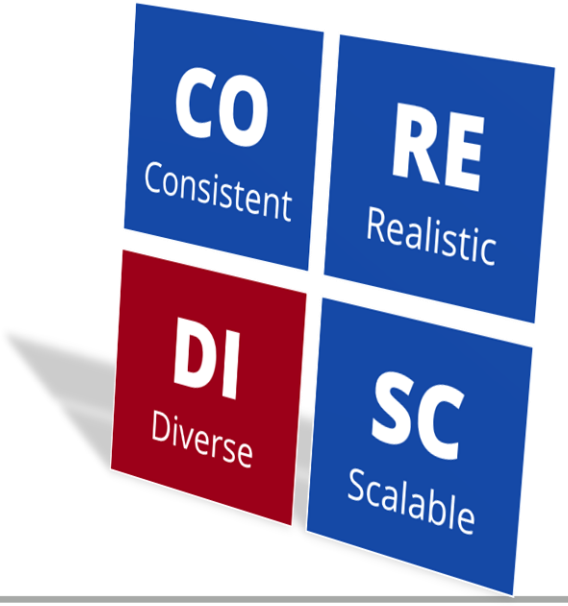
Model generation setup



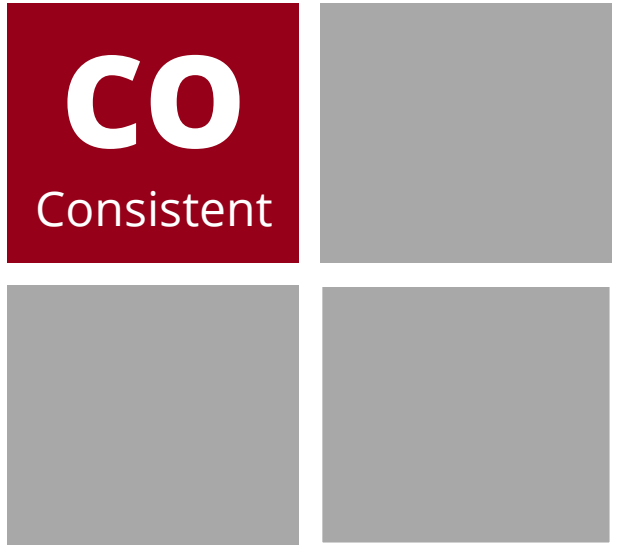
- Generation of valid models = challenging mathematical problem
- Generic, domain-independent model generation

Model generation: Requirements & Objectives

the CoREDISc model

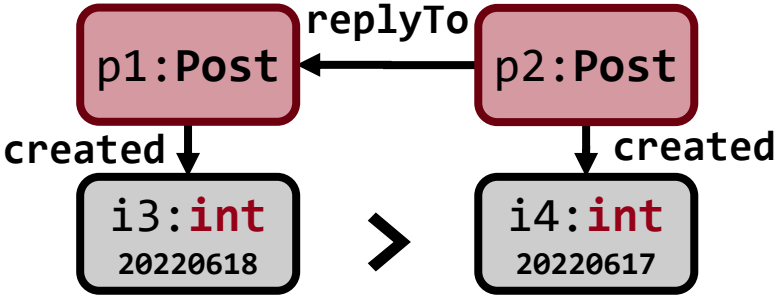


What is consistency?

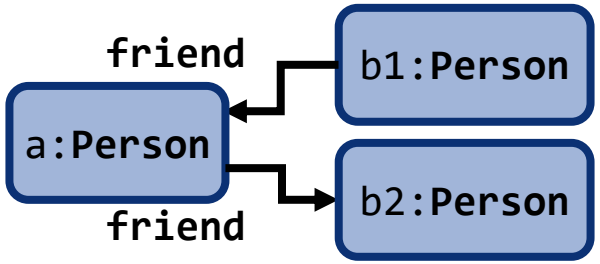


- Invalid configurations

Numerical constraint



Structural constraint

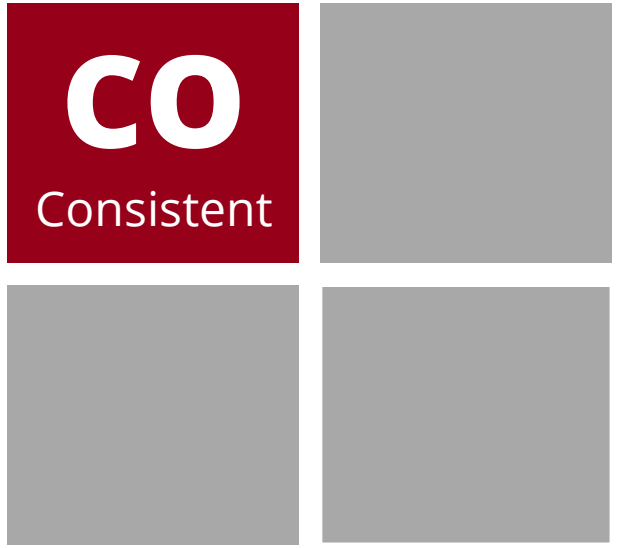


- Inconsistent models invalidate testing / benchmarking
- Constraints (queries) → validate graph models

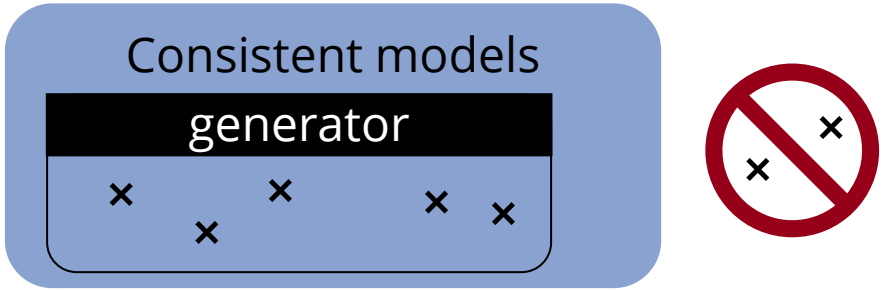
$$\texttt{invalidTime}(p1,p2) := \texttt{replyTo}(p2,p1) \wedge \texttt{created}(p1,t1) \wedge \texttt{created}(p2,t2) \wedge (t2 <= t1)$$

- Model validation + Configure generators

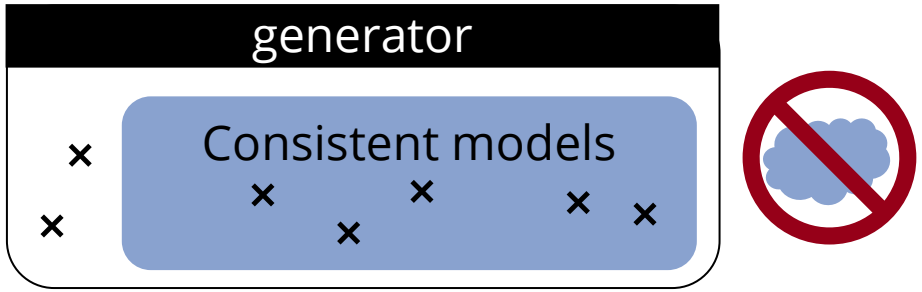
Consistent generators

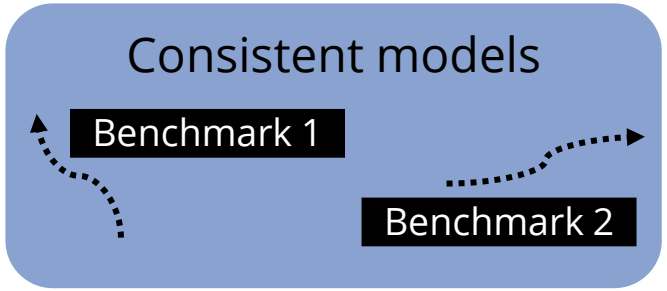


- **Correct:** all constraints are satisfied



- **Complete:** all consistent models can be derived





- **Consistent:** Correct + Complete

Extremely challenging logic + numeric reasoning problem

Results

- We constructed scalable logic solvers for the generation of valid graph models.

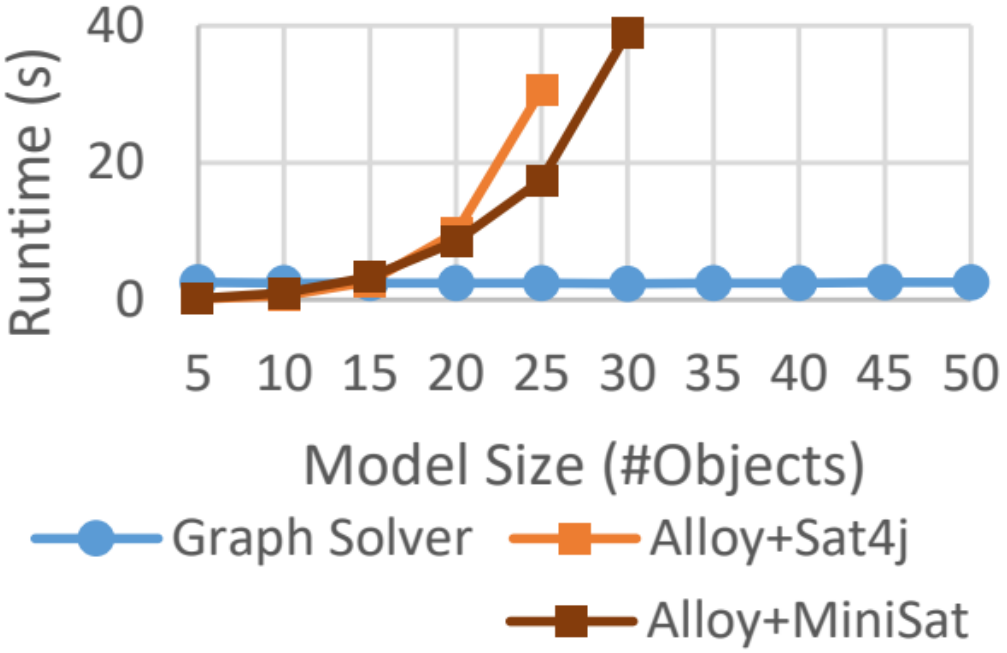
Maximal model size

	Largest model (#Objects)		
	Graph Solver	Sat4J	MiniSat
FAM+WF	6250	58	61
FAM-WF	7000	87	92
Yak+WF	1000	–	–
Yak-WF	7250	86	90
FS	4750	87	89
Ecore	2000	38	41

FAM: Industrial, Avionics
FS: File System example of Alloy
5 min timeout

Yakindu: Industrial, Statemachine
Ecore: Metamodelling language

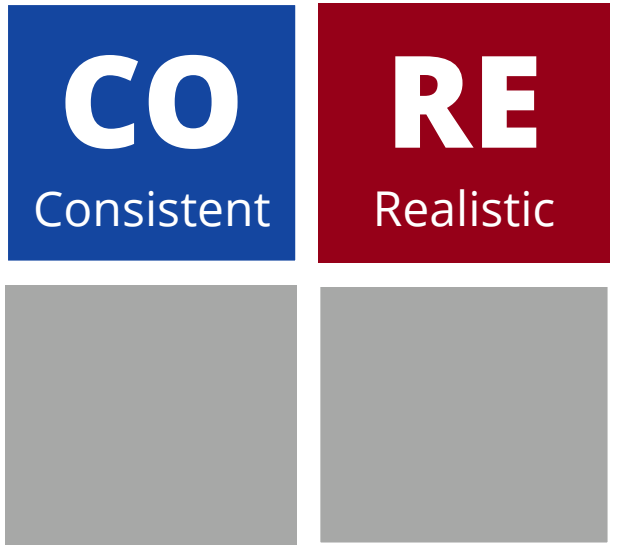
Example comparison



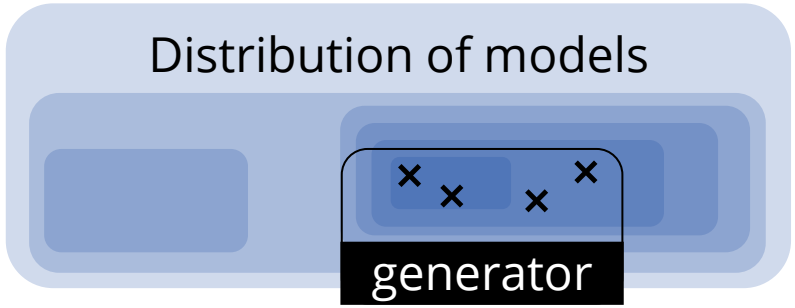
Our solver generates ~two orders of magnitude larger models

Semeráth, Oszkár, András Szabolcs Nagy, and Dániel Varró. "A graph solver for the automated generation of consistent domain-specific models." Proceedings of the 40th International Conference on Software Engineering. 2018.

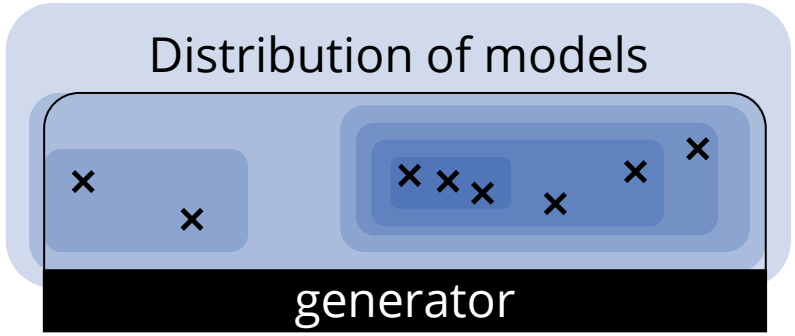
When is Realistic?



- Cannot be distinguished from real model



- Set of generated models is close to real ones



- In custom generators, realistic nature ensured manually

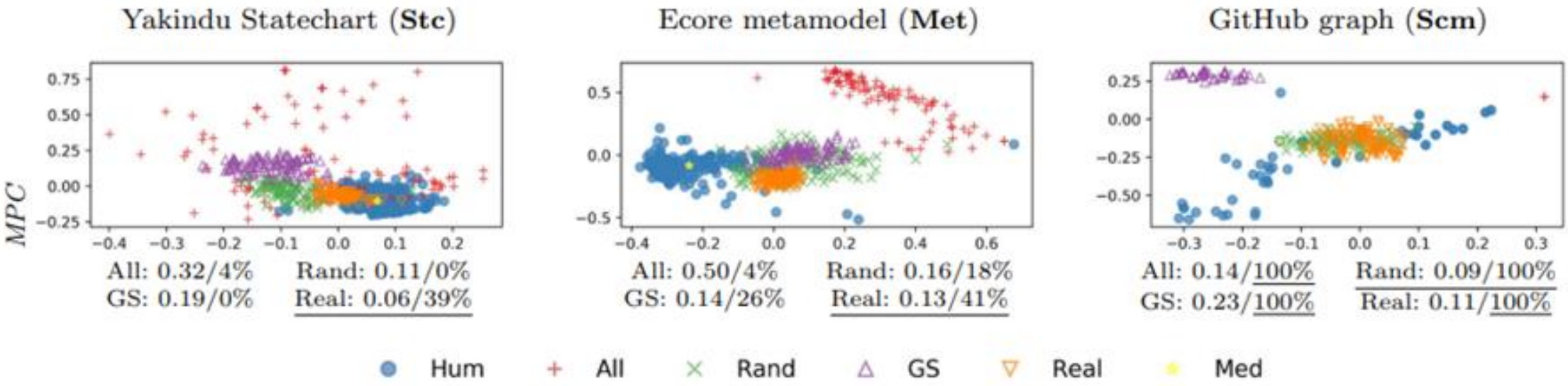
Results

- We measured several graph metrics to characterize realistic models

Szárnyas, G., Kővári, Z., Salánki, Á., & Varró, D. (2016, October). Towards the characterization of realistic models: evaluation of multidisciplinary graph metrics. In *Proceedings of the ACM/IEEE 19th International Conference on Model Driven Engineering Languages and Systems* (pp. 87-94).

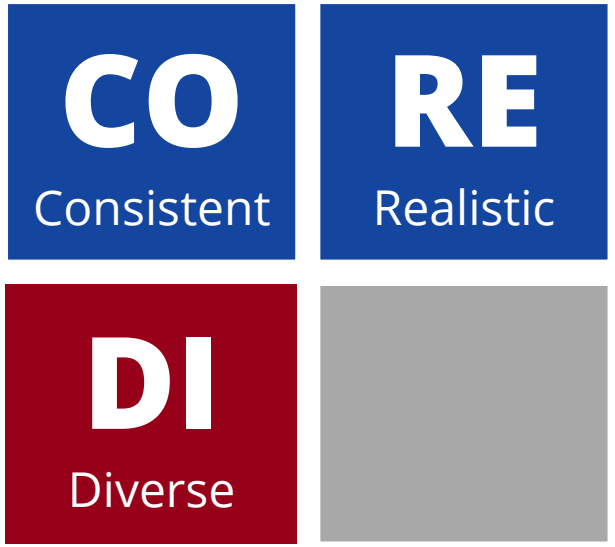
- Configured graph generator to construct models with the same values

Example evaluation of Multiplex participation coefficient



We were able to derive statistically similar graph models wrt. relevant metrics

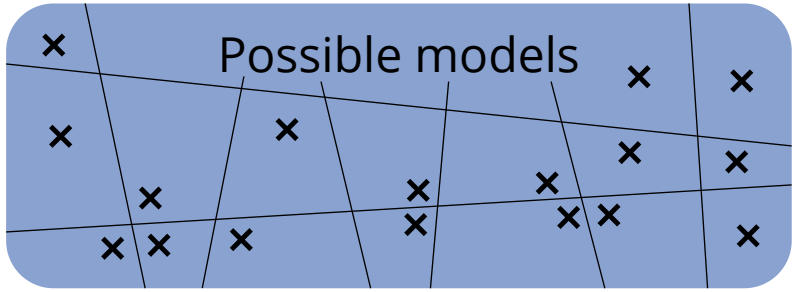
Diverse



- Single models are not symmetric

  e.g. copy-paste-models (used frequently)

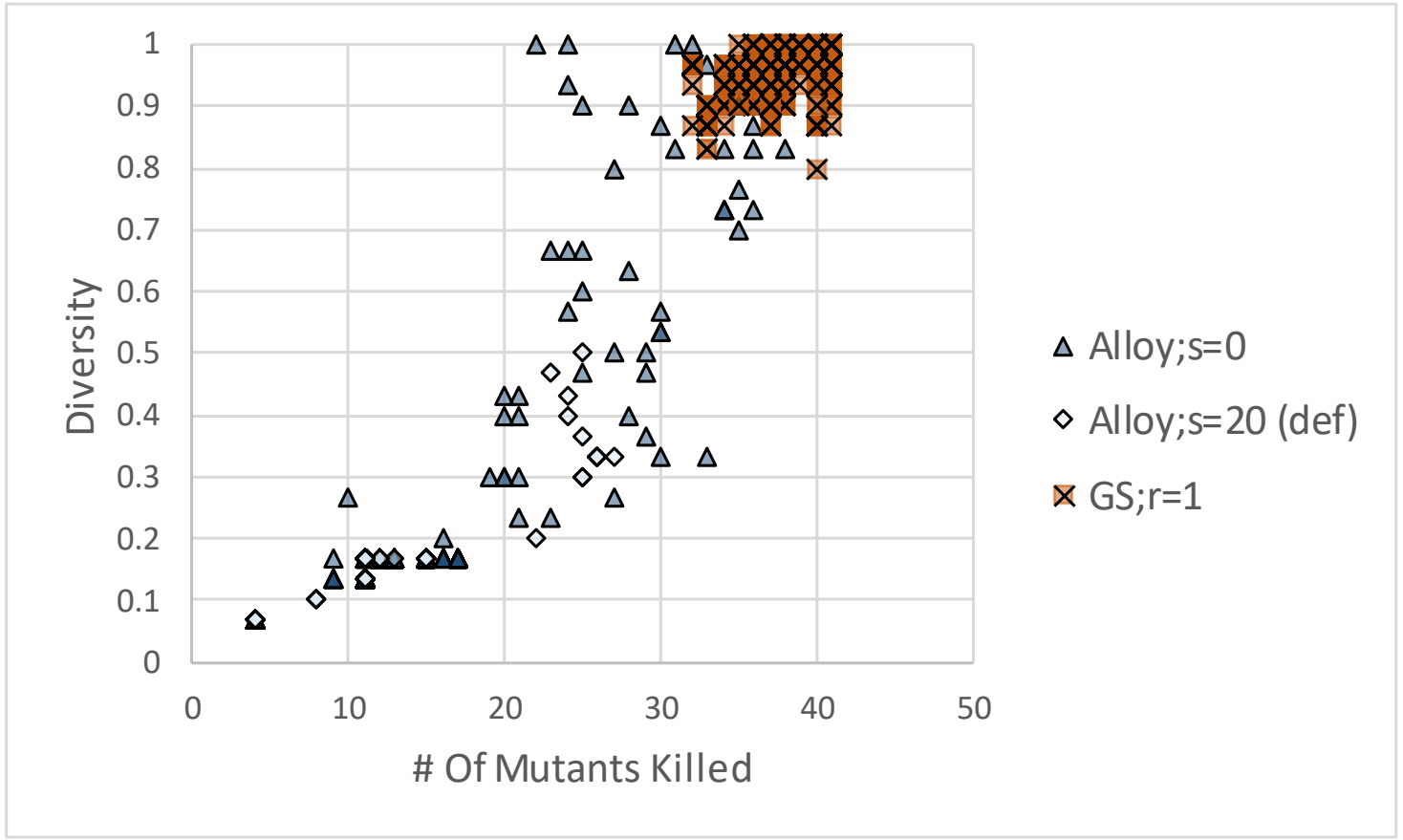
- The distance between **any pairs** of models is large
  E.g. all equivalence classes are covered



- Critical for testing graph processing systems

Results

- Proposed diversity metrics that correlate with mutation score
- Better diversity ⇔ More faults detected



Semeráth, O., Farkas, R., Bergmann, G., & Varró, D. (2020). Diversity of graph models and graph generators in mutation testing. *International Journal on Software Tools for Technology Transfer*, *22*(1), 57-78.

Results

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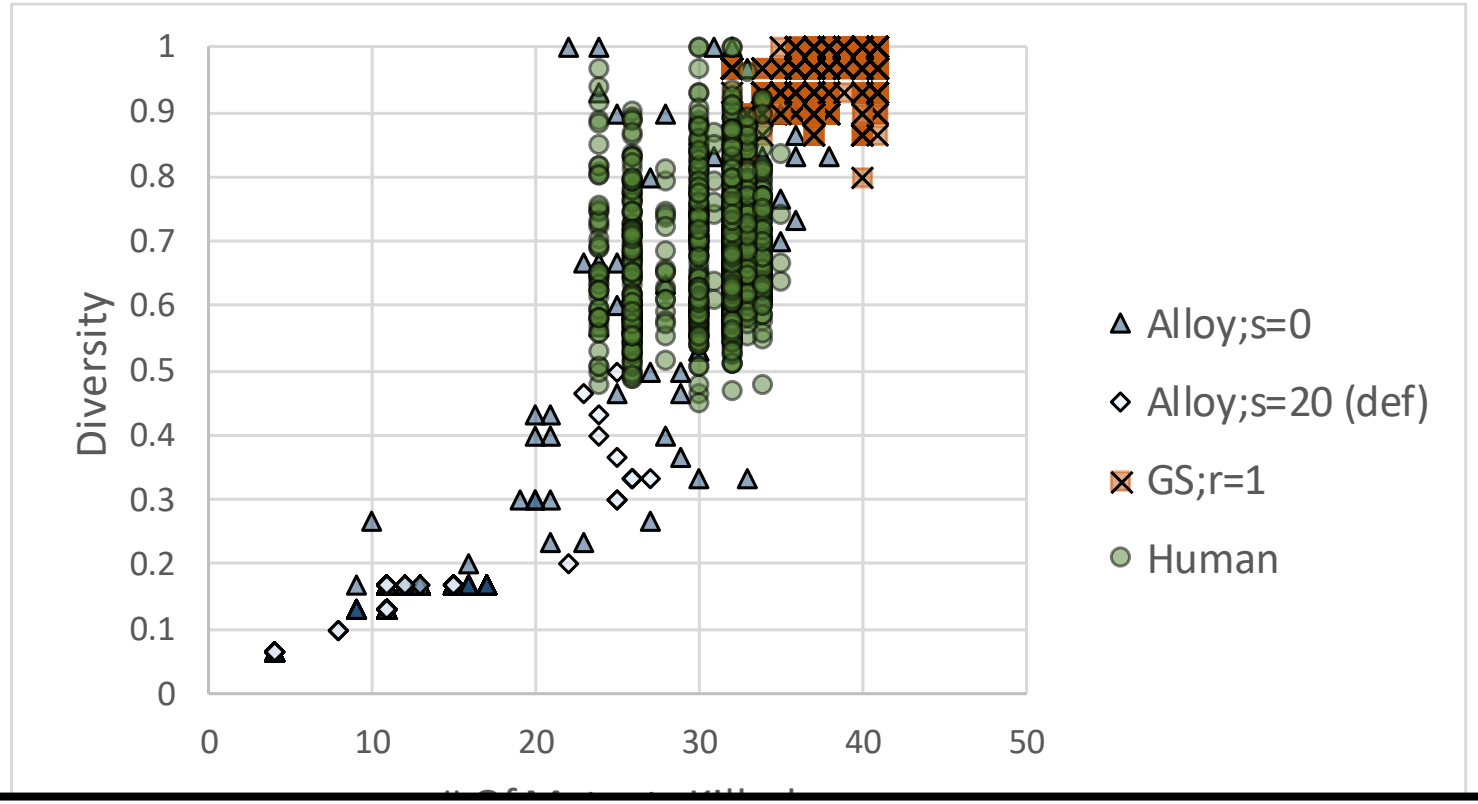
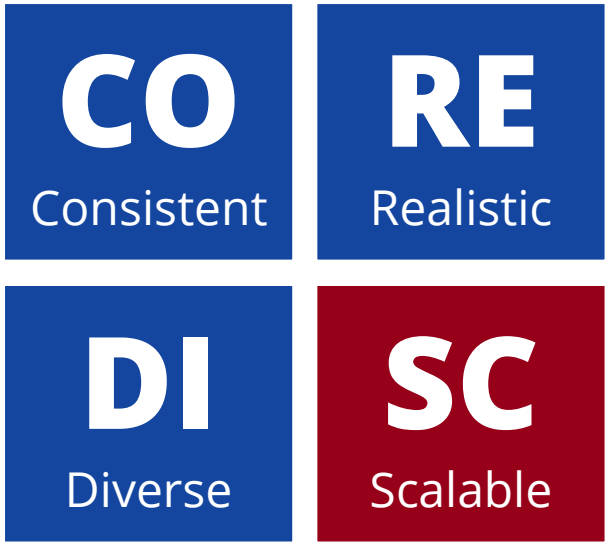


Alloy (def) < Alloy (s=0) < Human < GS

Correlation between **Diversity** and **Mutation Score** in Alloy+GS+Human

Semeráth, O., Farkas, R., Bergmann, G., & Varró, D. (2020). Diversity of graph models and graph generators in mutation testing. *International Journal on Software Tools for Technology Transfer*, *22*(1), 57-78.

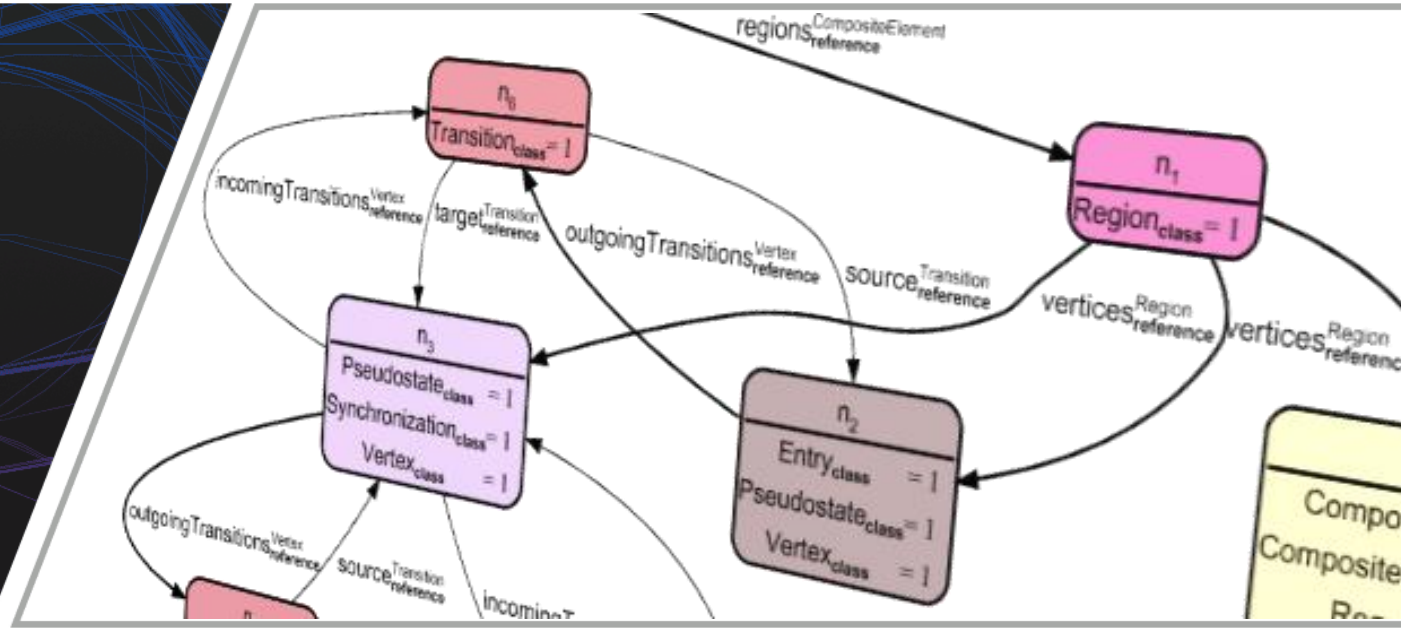
Scalability



- **In size:** ability to generate huge graphs
- **In quantity:** generation time of next model does not grow

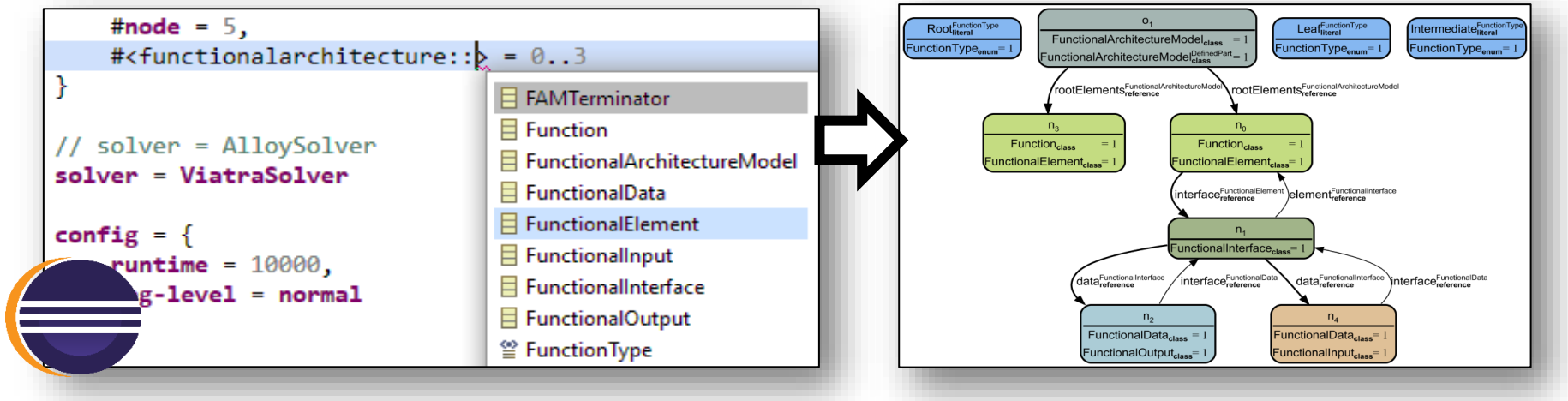
- Interactions between CoRe-DiSc elements
- Consistency is challenging
- Large inconsistent models cannot be transformed to consistent

Conclusion


regions CompositeElement reference
n0
Transition class = 1
n1
Region class = 1
incomingTransitions Vertex reference
target Transition reference
outgoingTransitions Vertex reference
source Transition reference
vertices Region reference
n3
Pseudostate class = 1
Synchronization class = 1
Vertex class = 1
n2
Entry class = 1
Pseudostate class = 1
Vertex class = 1
outgoingTransitions Vertex reference
source Transition reference

Tool support

- Implemented in the VIATRA Solver Framework
- Standard EMF as input + output| visualization | config. language



- **Structural:** VIATRA Query incremental query engine
- **Numerical:** Microsoft Z3 SMT solver
- Open source: github.com/viatra/VIATRA-Generator