



One Solver to Rule All Feature Models – Or Not? Addressing the Algorithm Selection Problem for #SAT

FOSD '24 | University of Ulm | Raphael Dunkel, Chico Sundermann, Tobias Heß and Thomas Thüm | April 11, 2024

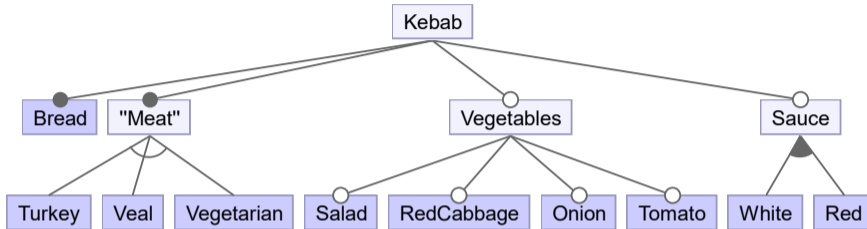


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Motivation – Feature Models

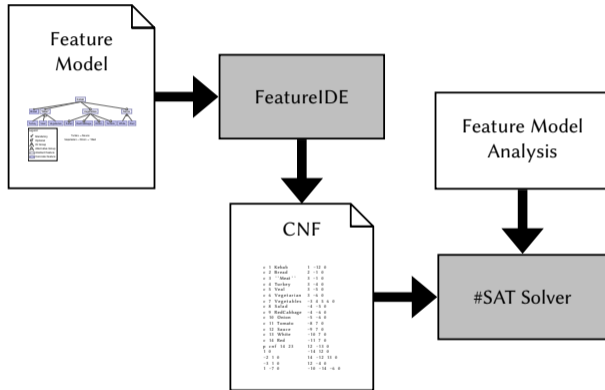


Legend:

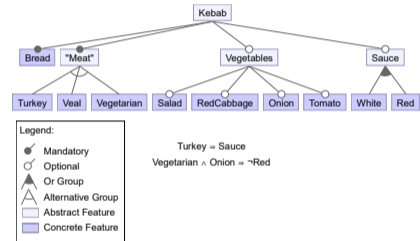
- Mandatory
- Optional
- ▲ Or Group
- △ Alternative Group
- Abstract Feature
- Concrete Feature

Turkey \Rightarrow Sauce
Vegetarian \wedge Onion $\Rightarrow \neg$ Red

Motivation – Feature Model Analysis with #SAT [SNB⁺21]



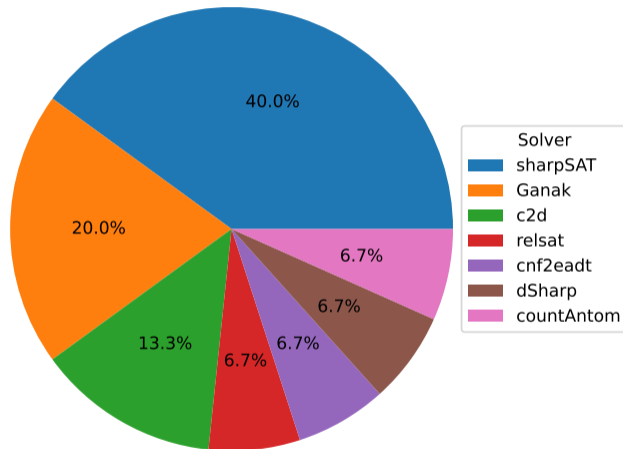
Feature Prioritization [SNB⁺21]



Prioritize *White Sauce* or *Onions*?

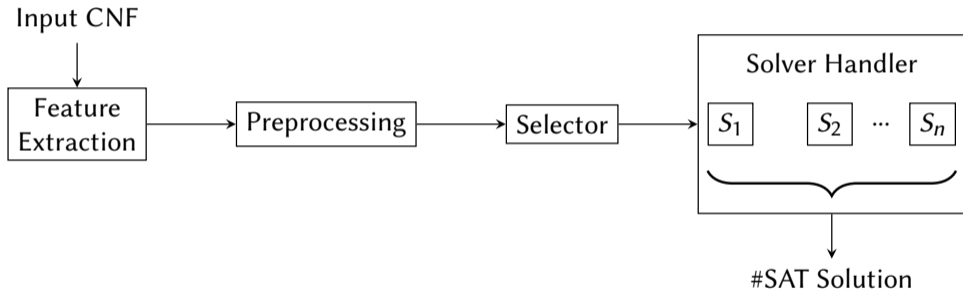
White Sauce: 94 valid configurations
Onions: 72 valid configurations

Motivation – Differences in Solver Performance



Composition of Oracle in [SHN⁺23]

Motivation – Algorithm Selection [Ric76]



Motivation – Goal

Highly successful algorithm selection in SAT, SMT, ...
SATzilla [XHHLB09, XHS⁺12], Sybil [LDF23]



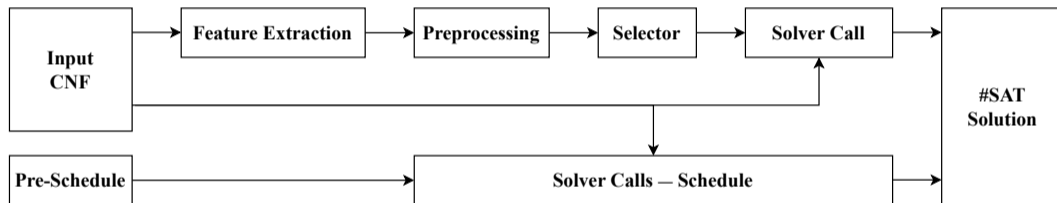
Exploration:
Can algorithm selection be used to improve #SAT solver response times?

Motivation – Runtime Comparison

11.3 % shorter response time

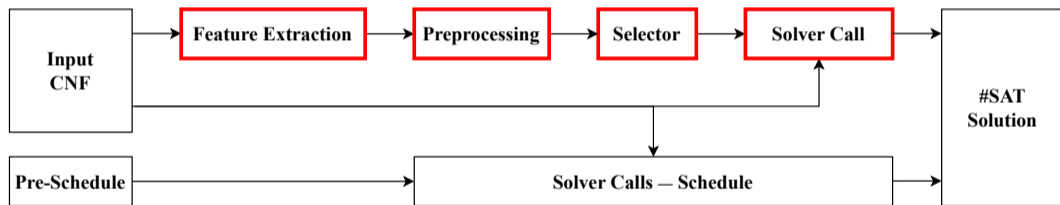
Closed Gap Score of **0.68**

as4moco



as4moco – Per-Instance Pipeline

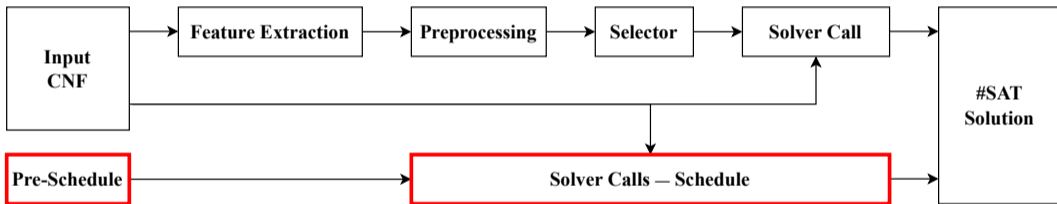
Per-Instance Algorithm Selection Pipeline



Per-Set Algorithm Selection Pipeline

as4moco – Per-Instance Pipeline

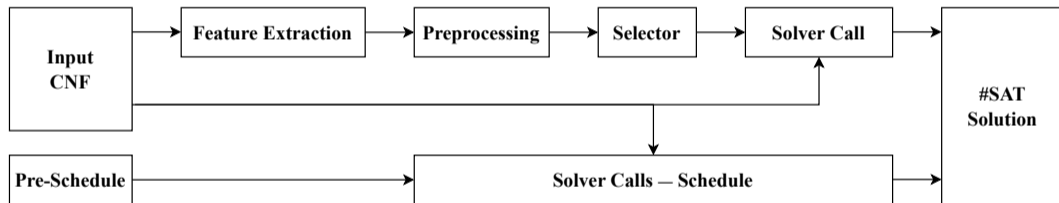
Per-Instance Algorithm Selection Pipeline



Per-Set Algorithm Selection Pipeline

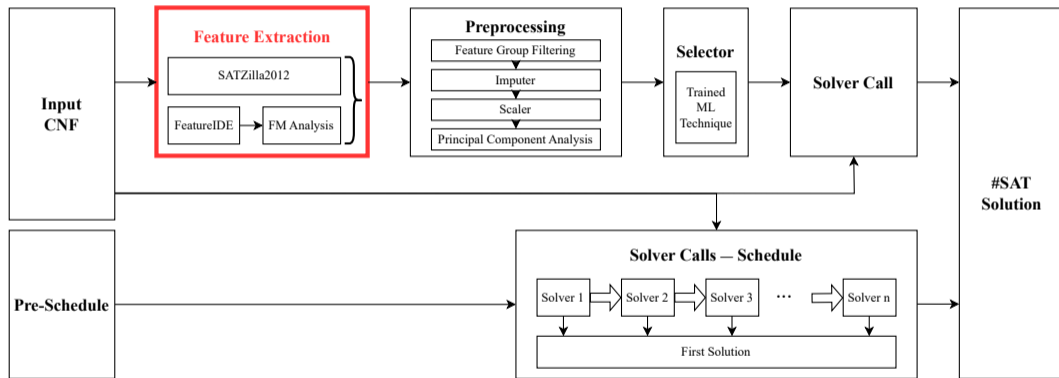
as4moco – Per-Instance Pipeline

Per-Instance Algorithm Selection Pipeline

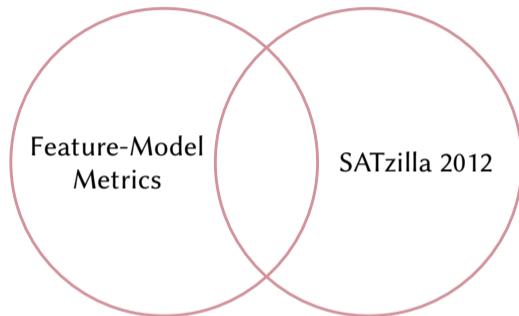


Per-Set Algorithm Selection Pipeline

Overview — as4moco



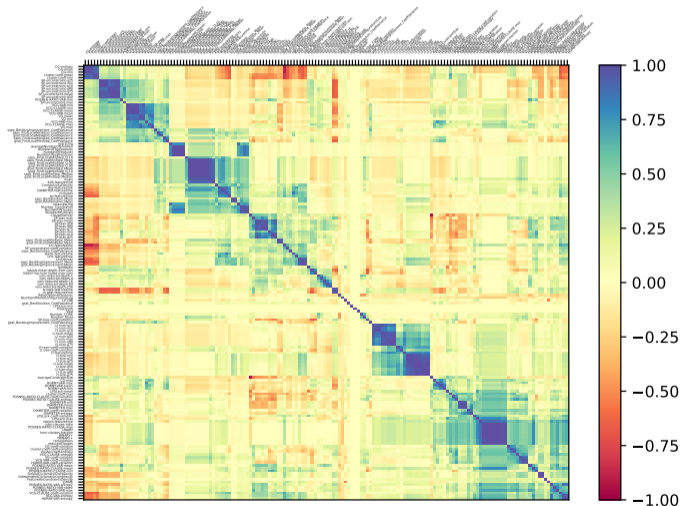
as4moco — Feature Extraction



syntactic and semantic attributes of
Feature Models
[SHN⁺23]

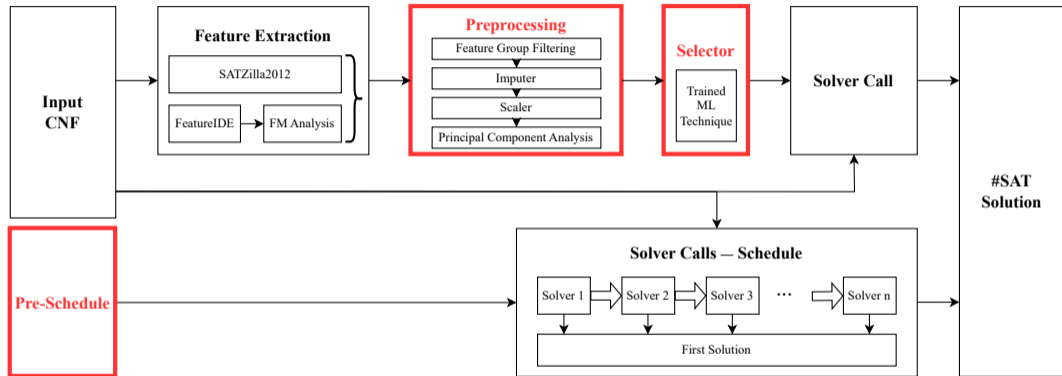
syntactic and semantic attributes of
Propositional Formulas
[XHHLB12]

as4moco — Feature Extraction



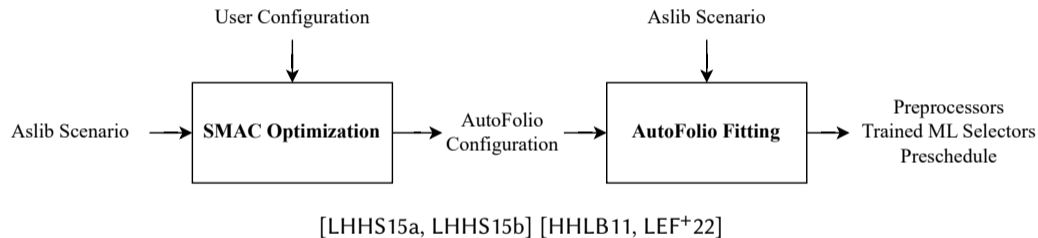
Spearman rank correlation coefficient with Ward clustering, on MCC2022 Track 1 [FHH21] data set

Overview — as4moco



AutoFolio [LHHS15a, LHHS15b]

as4moco — Algorithm Selection Offline



Evaluation — Subject Systems

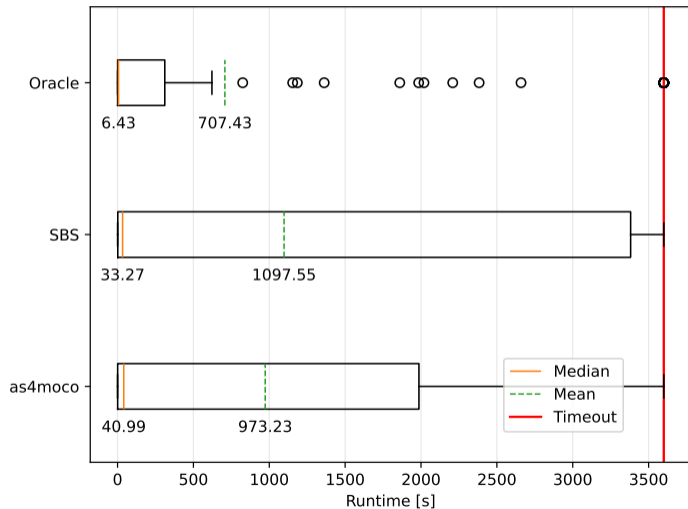
Input Instances:

- MCC2022 Track 1 [FHH21]
- IFM 30s & 60s [SRH⁺23]

Reference Systems:

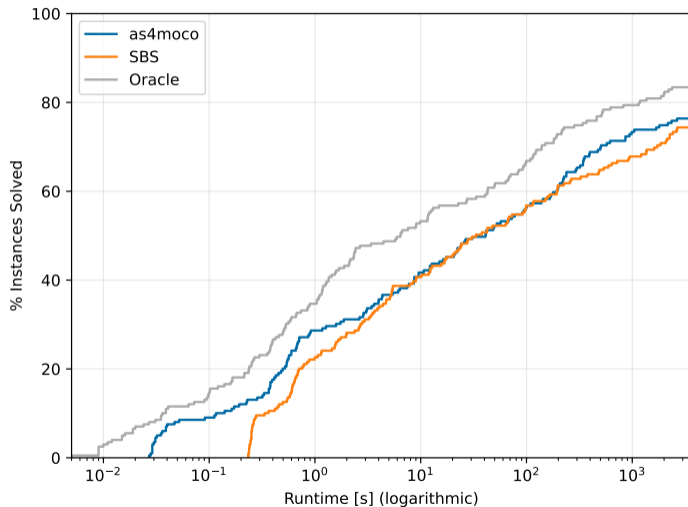
- as4mo co
- Oracle
- Single Best Solver (SBS)

Evaluation – Runtime Comparison



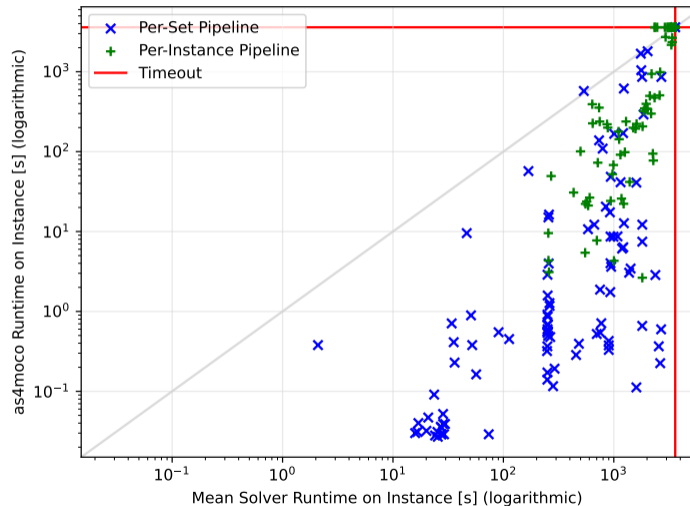
5-fold external cross-validation
on 4000 iterations MCC data
set

Evaluation – Runtime Cumulative Distribution Function



5-fold external cross-validation
on 4000 iterations MCC data
set

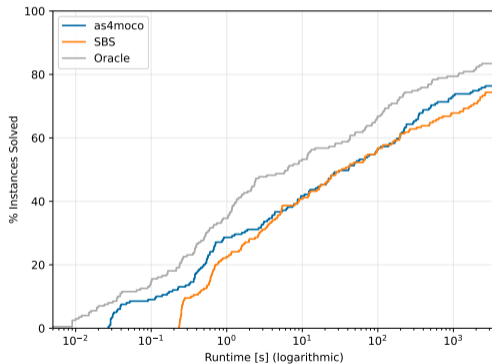
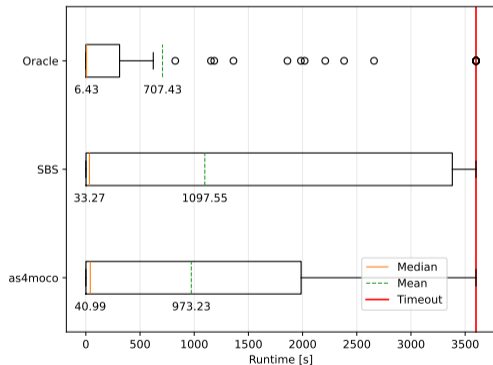
Evaluation – Successful Pipeline to Instance Hardness



Successful pipeline for each instance on 4000 iterations
MCC data set

Conclusion

Exploration: Can Algorithm Selection improve #SAT solver response times?



Future Work



Feedback Welcome!

Future Work

- Solver Portfolio Optimization
 - Highly Specialized Solvers
- Feature Extraction Optimization
 - Feature Importance Analysis
 - Optimization of feature model metrics
 - Representation learning
- Selector Optimization
 - Advanced categorization and regression approaches
 - Neural networks
- Algorithm Configuration Optimization
 - Advances in Algorithm Configuration
 - Optimization of Hyperparameter Space

as4moco



<https://github.com/SoftVarE-Group/as4moco>

Bibliography I

- [FHH21] Johannes K. Fichte, Markus Hecher, and Florim Hamiti, *The Model Counting Competition 2020*, ACM J. of Experimental Algorithmics (JEA) **26** (2021).
- [HHLB11] Frank Hutter, Holger H Hoos, and Kevin Leyton-Brown, *Sequential Model-Based Optimization for General Algorithm Configuration*, Learning and Intelligent Optimization (Berlin, Heidelberg, Germany), Springer, 2011, pp. 507–523.
- [LDF23] Will Leeson, Matthew B Dwyer, and Antonio Filieri, *Sibyl: Improving Software Engineering Tools with SMT Selection*, Proc. Int’l Conf. on Software Engineering (ICSE) (Piscataway, NJ, USA), IEEE, 2023.
- [LEF⁺22] Marius Lindauer, Katharina Eggensperger, Matthias Feurer, André Biedenkapp, Difan Deng, Carolin Benjamins, Tim Ruhkopf, René Sass, and Frank Hutter, *SMAC3: A Versatile Bayesian Optimization Package for Hyperparameter Optimization*, Journal of Machine Learning Research **23** (2022), no. 1, 2475–2483.
- [LHHS15a] Marius Lindauer, Holger H Hoos, Frank Hutter, and Torsten Schaub, *AutoFolio: Algorithm Configuration for Algorithm Selection*, AAAI Workshop: Algorithm Configuration (Palo Alto, CA, USA), AAAI Workshops, vol. WS-15-01, AAAI Press, 2015.

Bibliography II

- [LHHS15b] _____, *Autofolio: An Automatically Configured Algorithm Selector*, Artificial Intelligence (AIJ) **53** (2015), 745–778.
- [Ric76] John R. Rice, *The Algorithm Selection Problem*, Advances in Computers **15** (1976), 65–118.
- [SHN⁺23] Chico Sundermann, Tobias Heß, Michael Nieke, Paul Maximilian Bittner, Jeffrey M. Young, Thomas Thüm, and Ina Schaefer, *Evaluating State-of-the-Art #SAT Solvers on Industrial Configuration Spaces*, Empirical Software Engineering (EMSE) **28** (2023).
- [SNB⁺21] Chico Sundermann, Michael Nieke, Paul Maximilian Bittner, Tobias Heß, Thomas Thüm, and Ina Schaefer, *Applications of #SAT Solvers on Feature Models*, Proc. Int’l Working Conf. on Variability Modelling of Software-Intensive Systems (VaMoS) (New York, NY, USA), ACM, February 2021.
- [SRH⁺23] Chico Sundermann, Heiko Raab, Tobias Heß, Thomas Thüm, and Ina Schaefer, *Exploiting d-DNNFs for Repetitive Counting Queries on Feature Models*, Tech. Report arXiv:2303.12383, Cornell University Library, March 2023.

Bibliography III

- [XHHLB09] Lin Xu, Frank Hutter, Holger H Hoos, and Kevin Leyton-Brown, *SATzilla2009: an Automatic Algorithm Portfolio for SAT*, Proc. Int'l Conf. on Theory and Applications of Satisfiability Testing (SAT) 4 (2009), 53–55.
- [XHHLB12] Lin Xu, Frank Hutter, Holger Hoos, and Kevin Leyton-Brown, *Features for SAT*, University of British Columbia, Tech. Rep (2012).
- [XHS⁺12] L. Xu, F. Hutter, J. Shen, Holger Hoos, and Kevin Leyton-Brown, *SATzilla2012: Improved Algorithm Selection based on Cost-Sensitive Classification Models*, Proceedings of SAT Challenge 2012: Solver and Benchmark Descriptions (2012), 55–58.