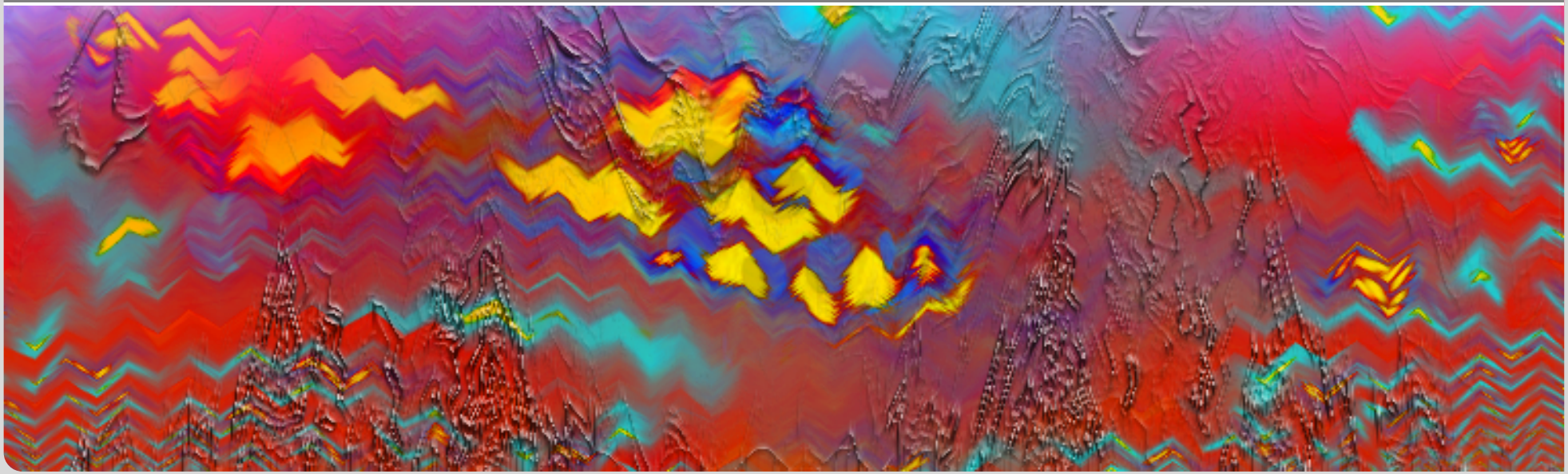
Karlsruhe Institute of Technology

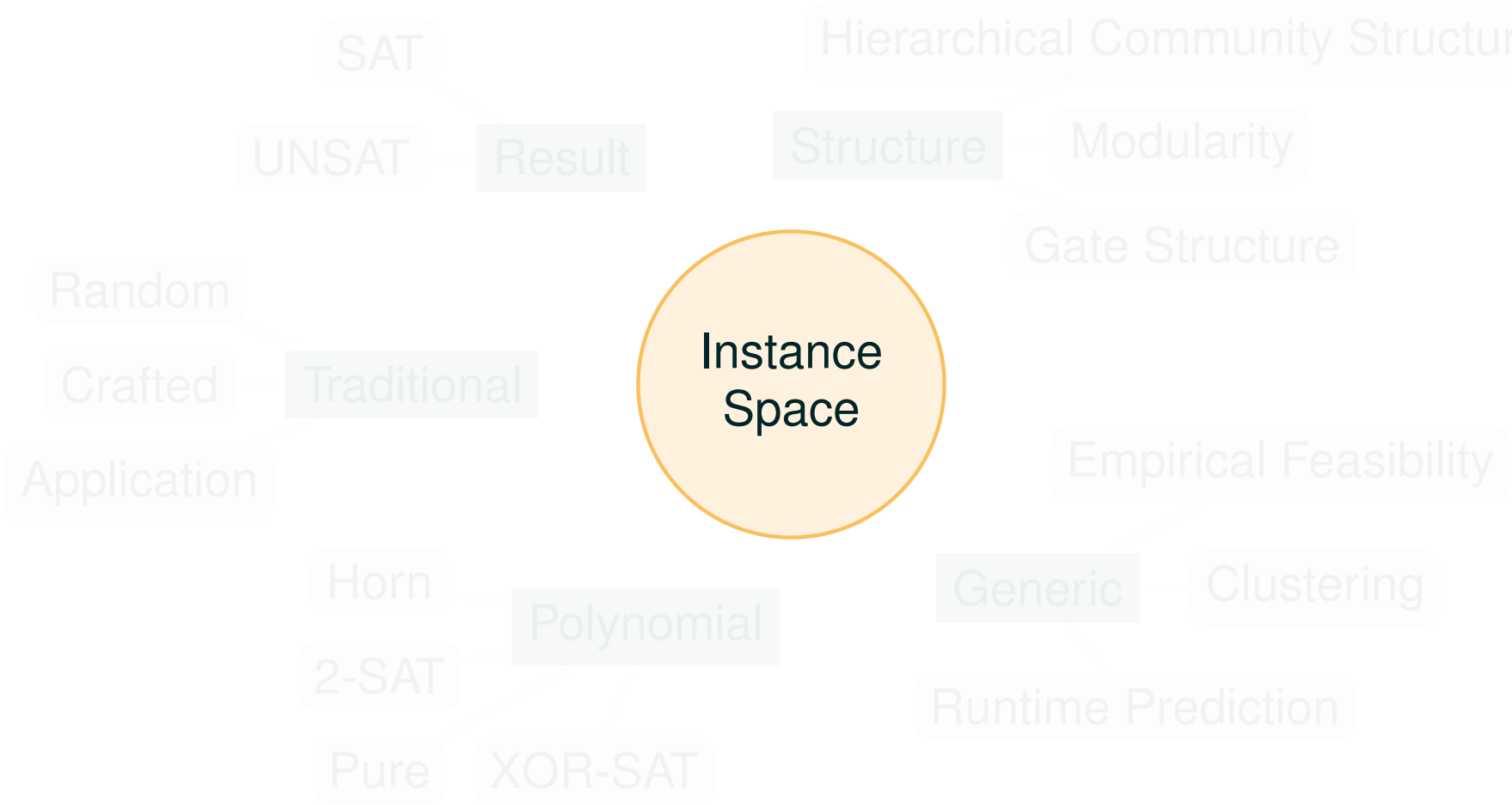
Beyond Portfolios of Stable Solvers

Markus Iser

Algorithm Engineering · Institute of Theoretical Informatics



Categories of SAT Instances



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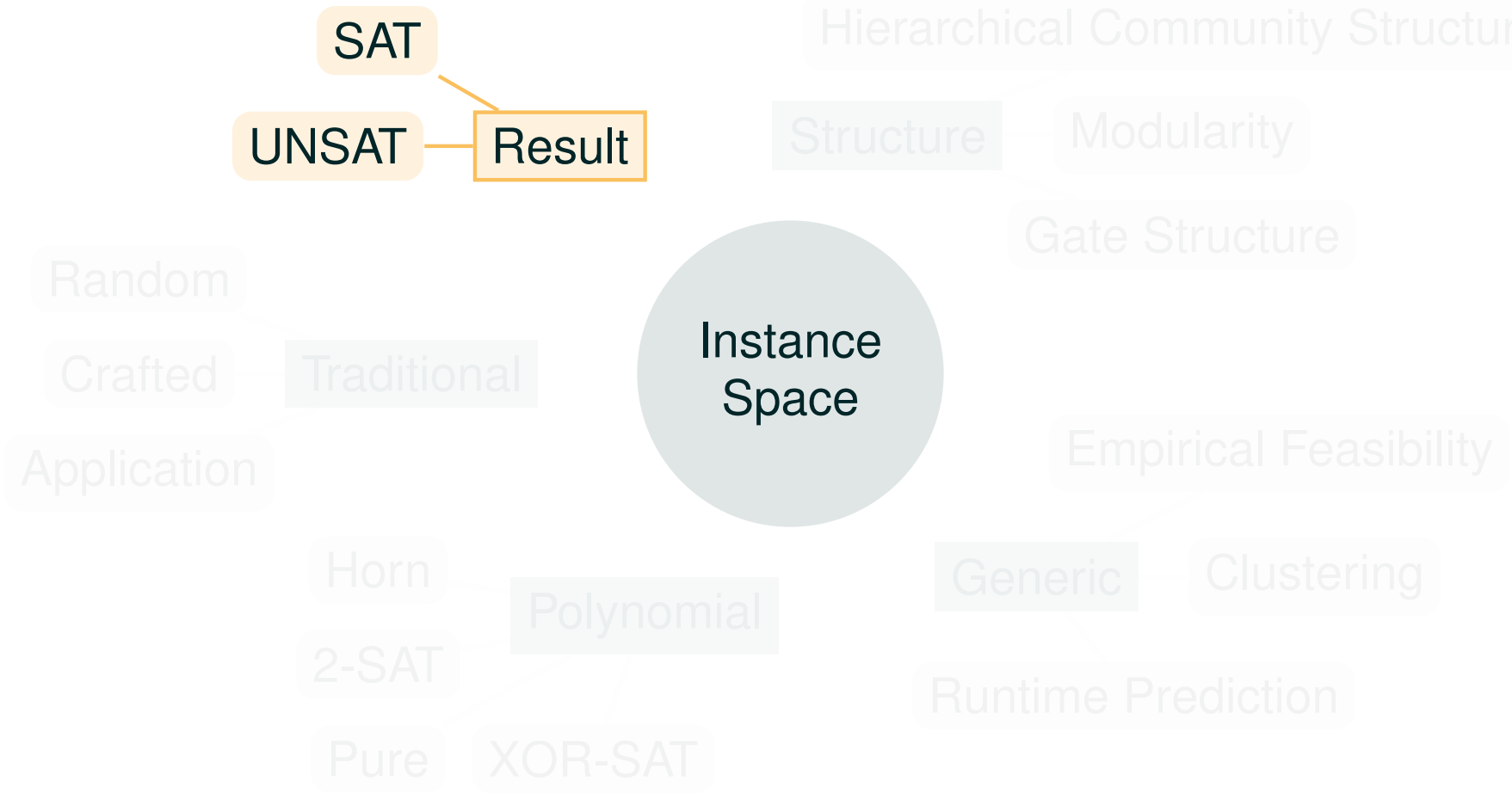

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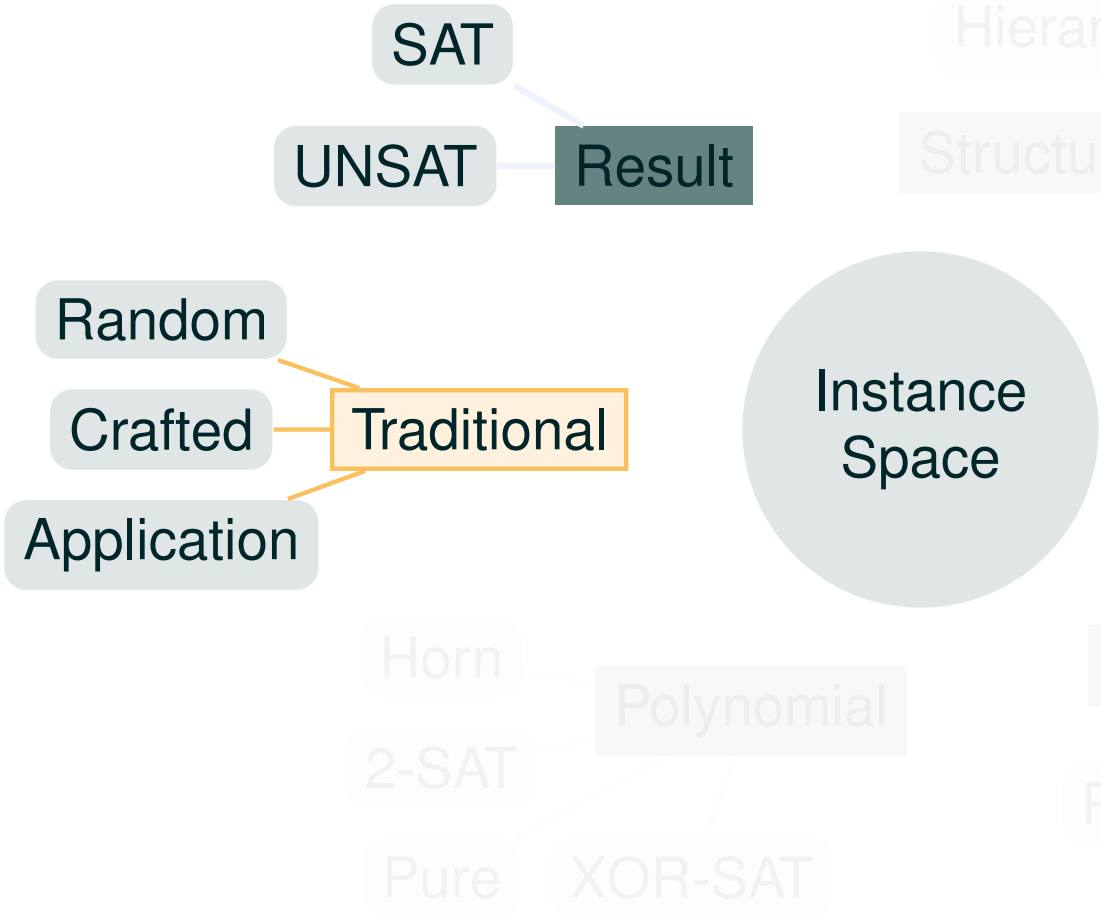
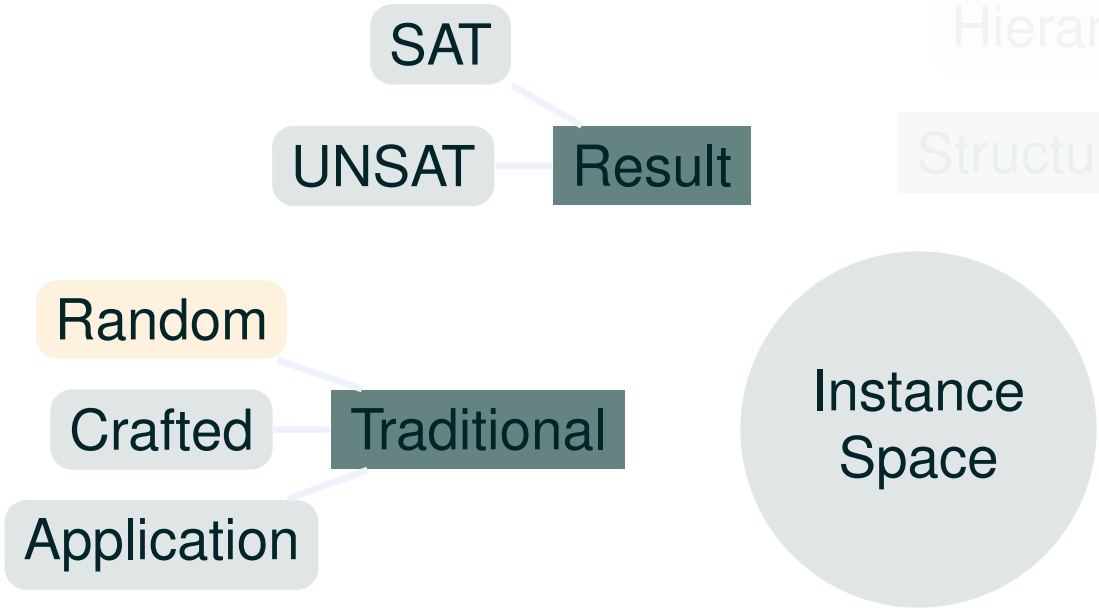


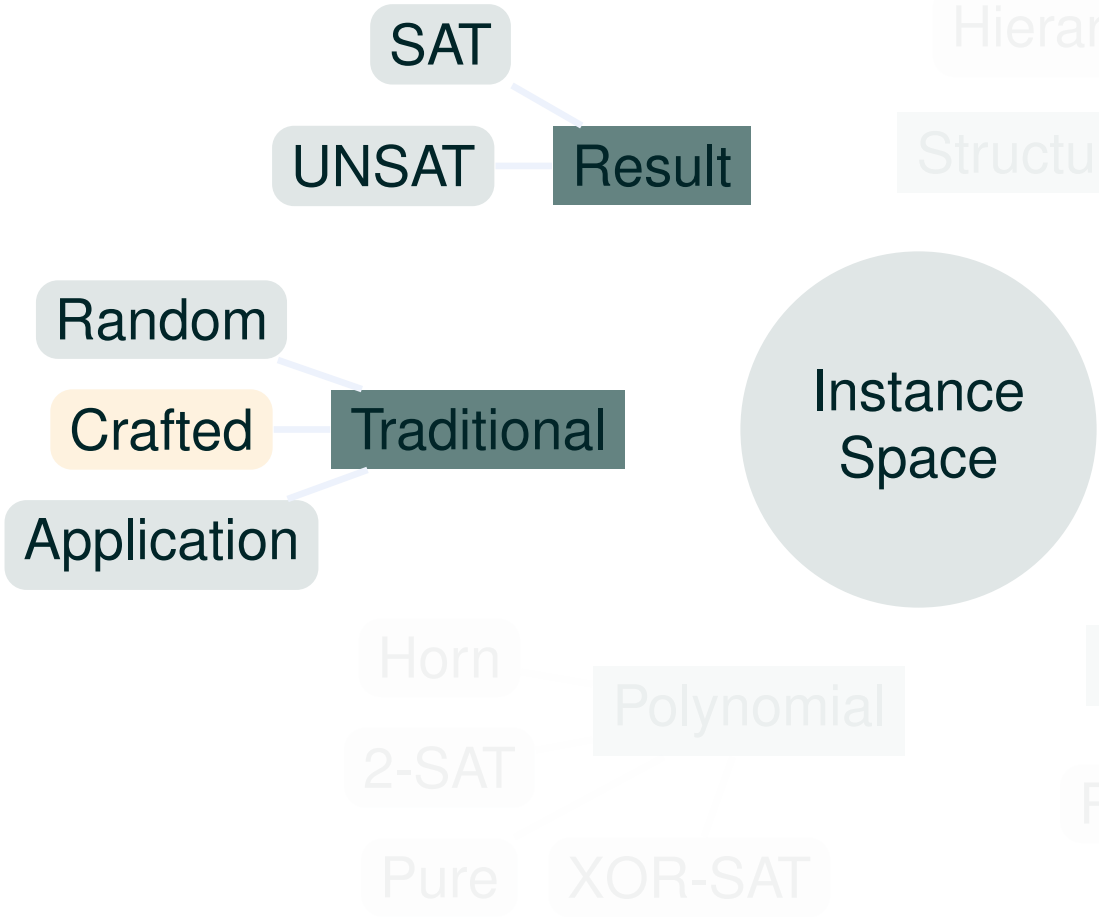
Categories of SAT Instances



Random

- Uniform Random
- Planted Solutions
- Structured Random
- ...

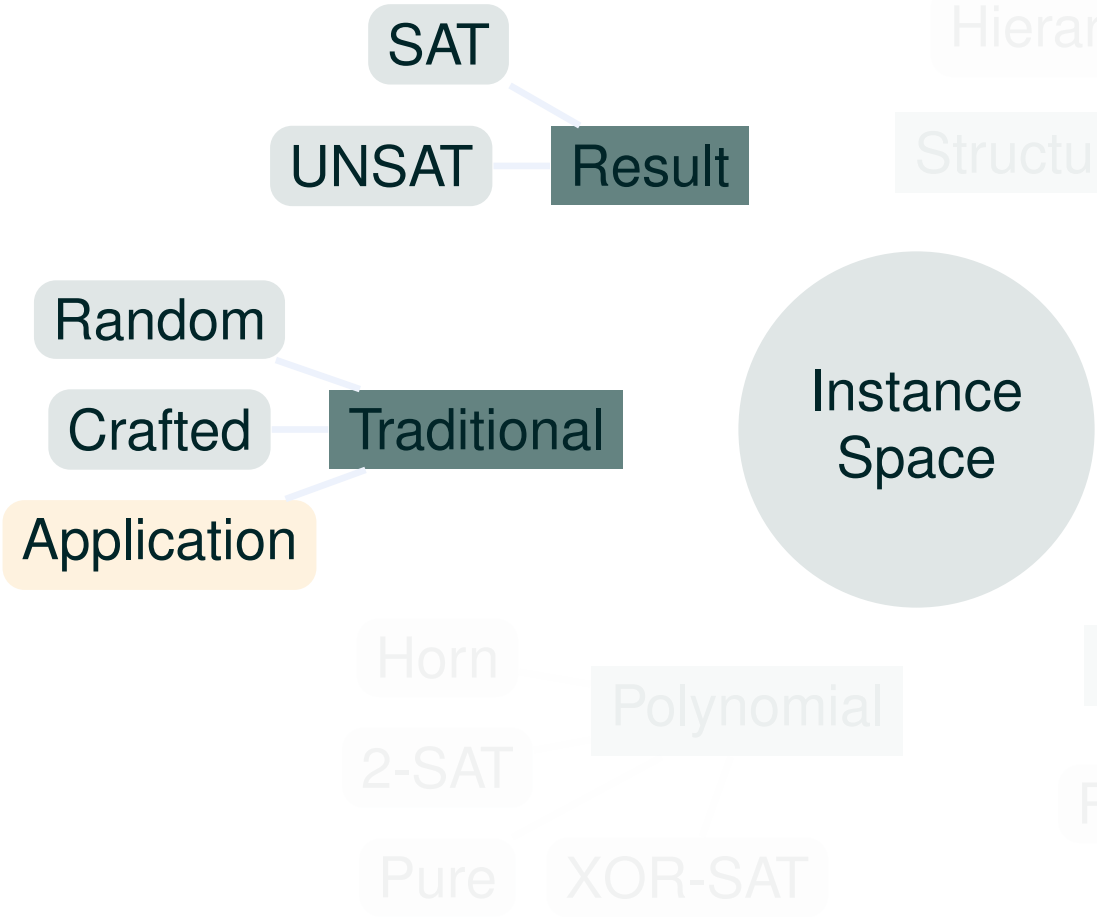
Categories of SAT Instances



Crafted

- Pigeon Hole
- Mutilated Chessboard
- Tseitin Formulas
- ...

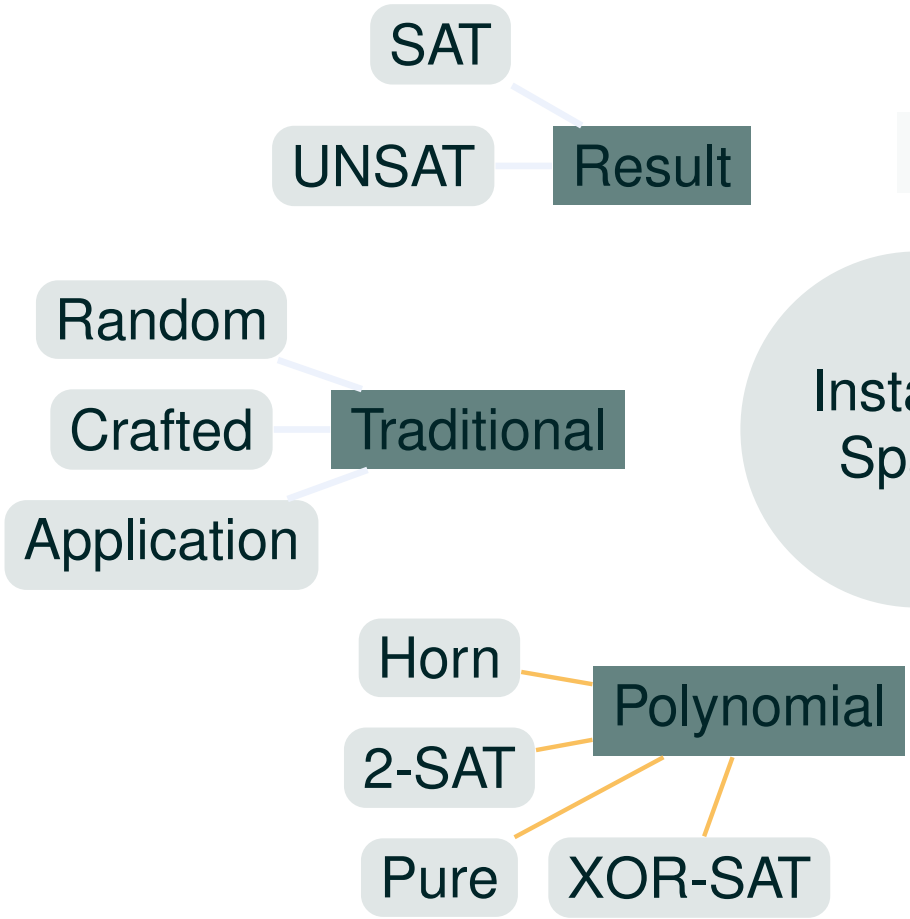
Categories of SAT Instances



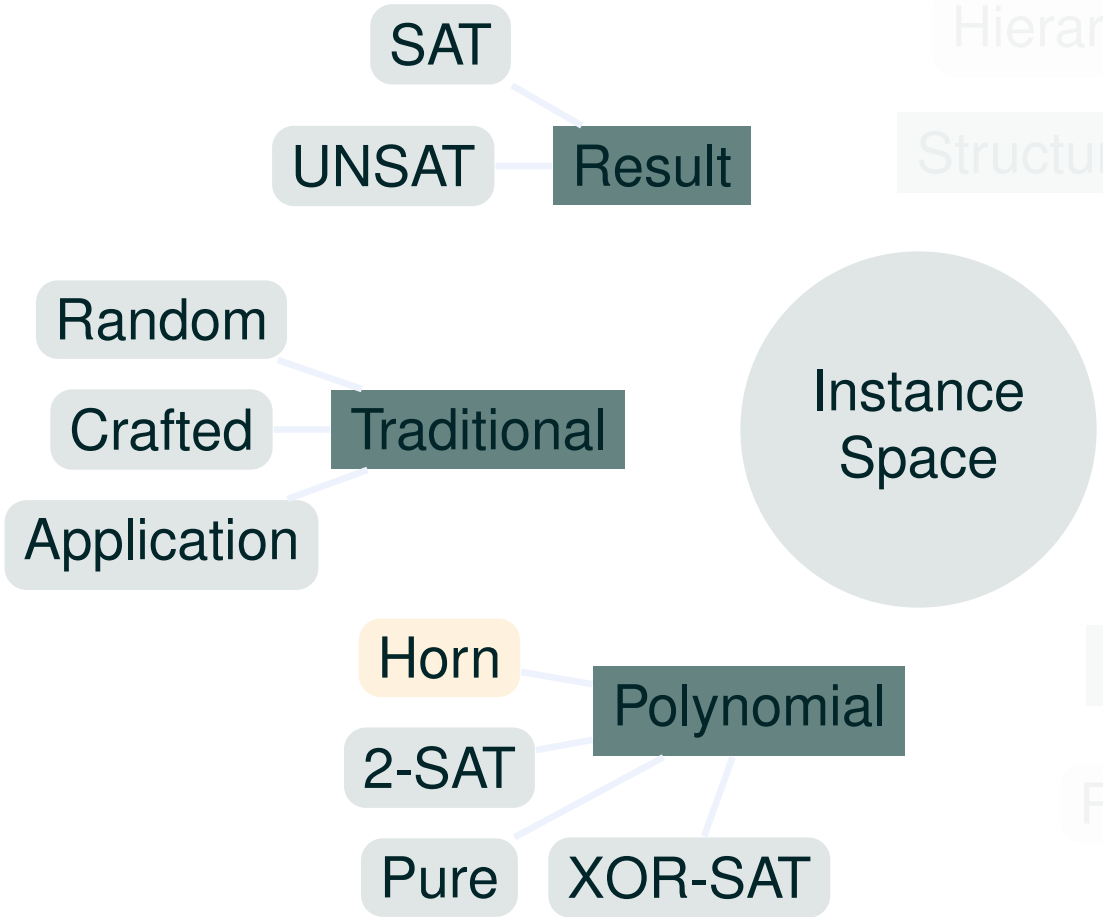
Application

- Planning
- Hardware Verification
- Product Configuration
- Cryptography
- …

Categories of SAT Instances



Categories of SAT Instances



Horn

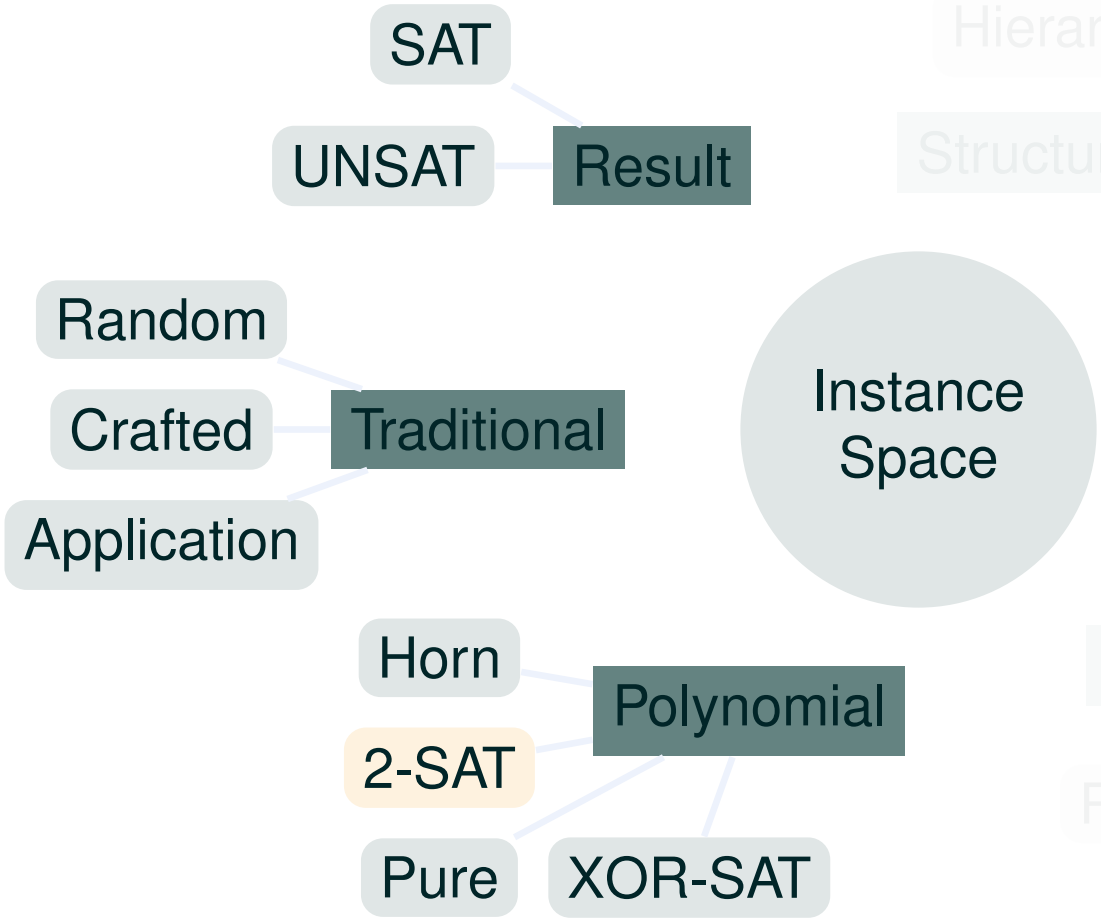
- At most one *negative* literal per clause

Inverted Horn

- At most one *positive* literal per clause

$\Rightarrow$ Unit-propagation $\in \mathcal{O}(n)$

Categories of SAT Instances

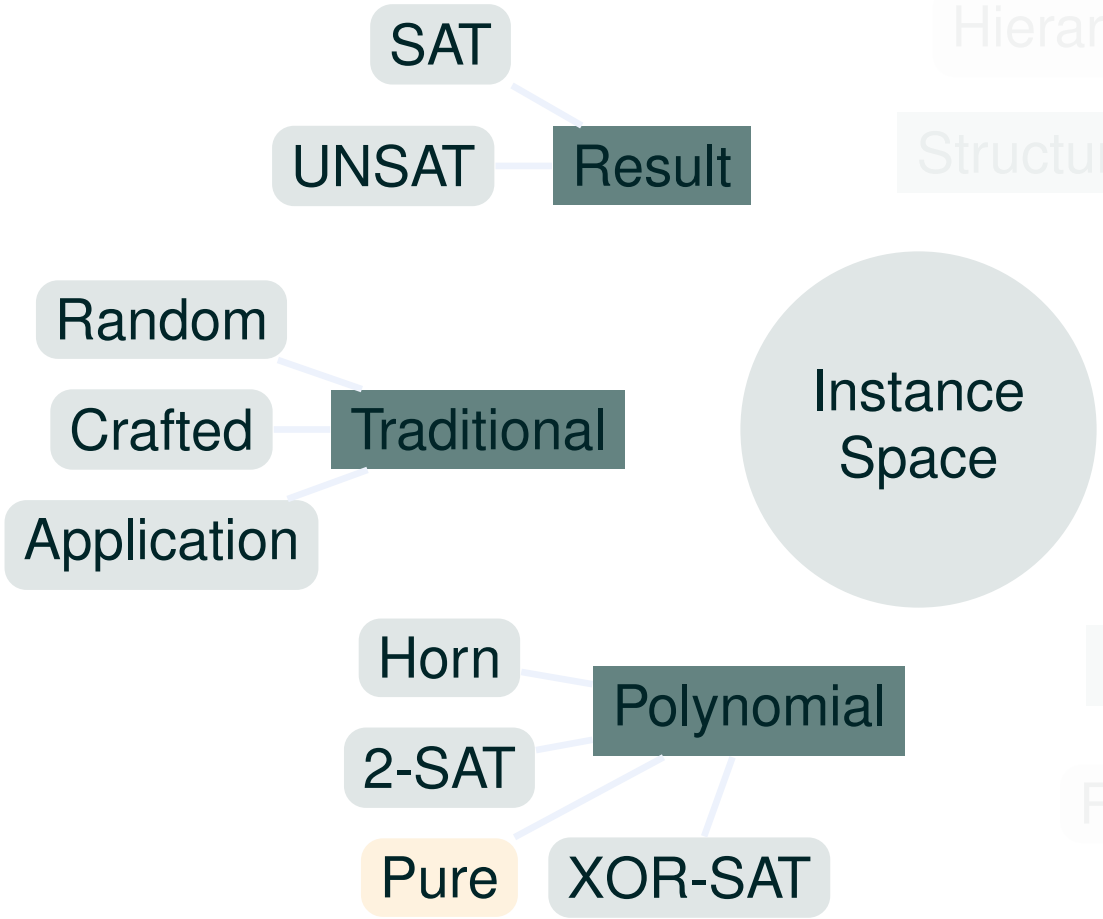


2-SAT

- All clauses have length two

$\Rightarrow$ determine connected components in implication graph $\in \mathcal{O}(n+m)$

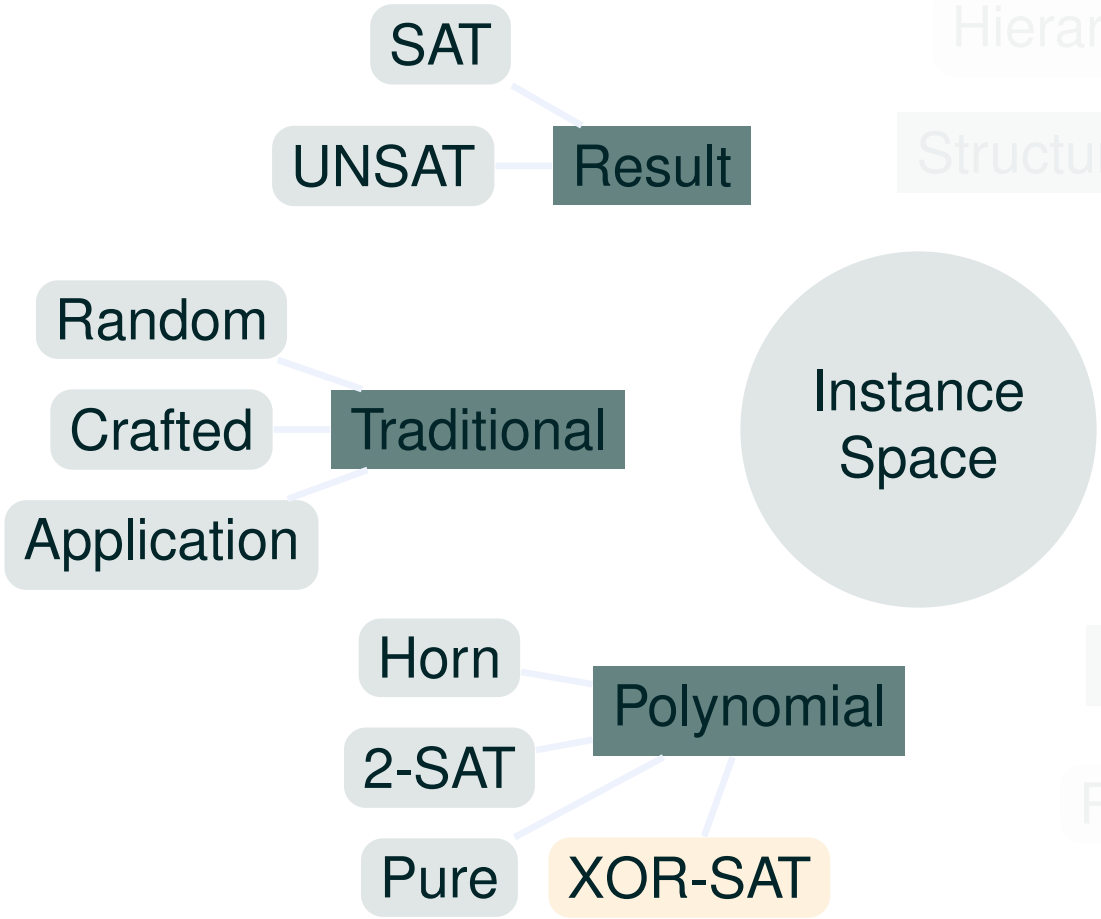
Categories of SAT Instances



Pure

- all literals are positive
- or all literals are negative

Categories of SAT Instances



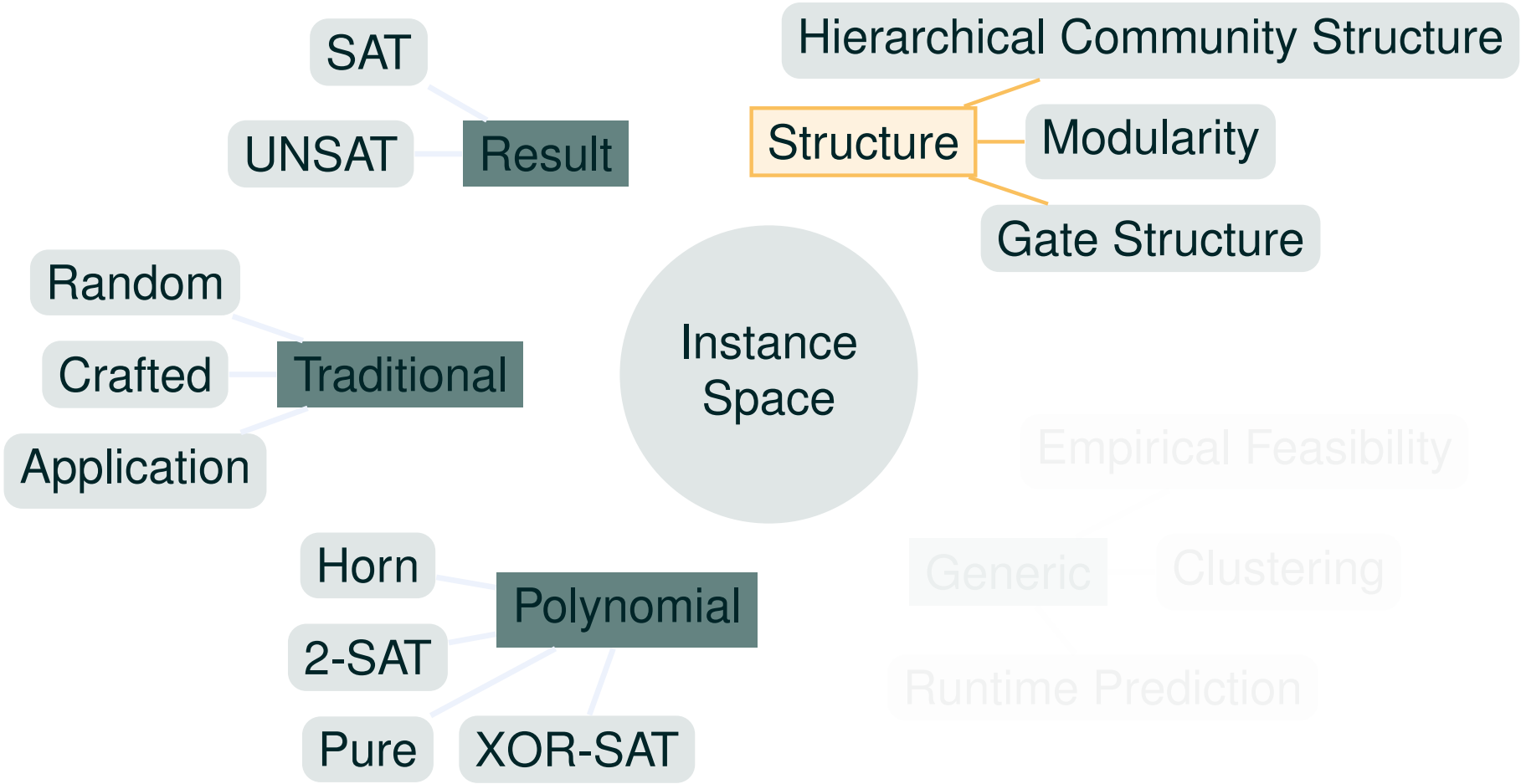
XOR-SAT

- only xors
- aka. affine formulas

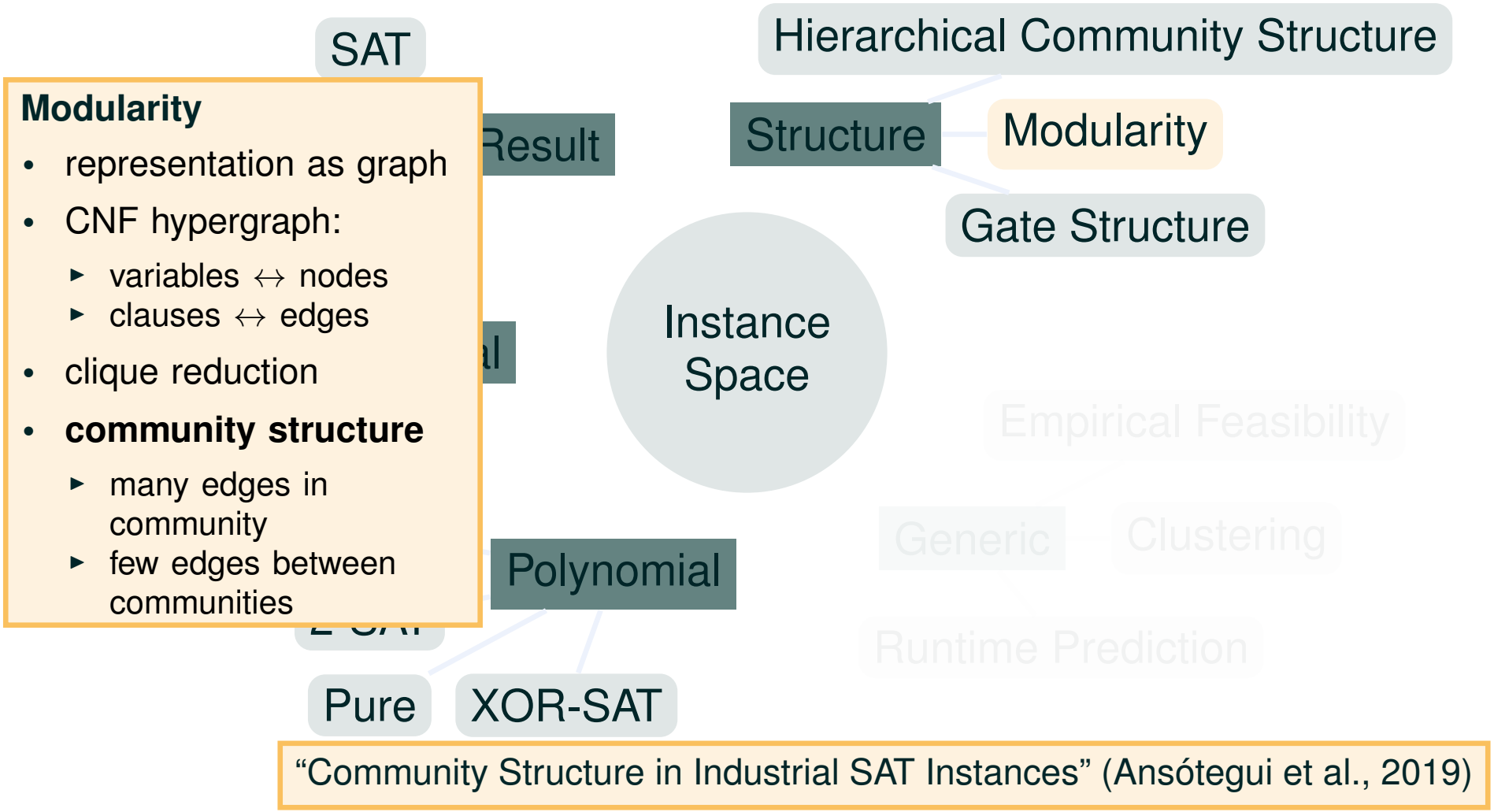
$\Rightarrow$ Gaussian elimination $\in \mathcal{O}(n^3)$

"The Complexity of Satisfiability Problems" (Schaefer, 1978)

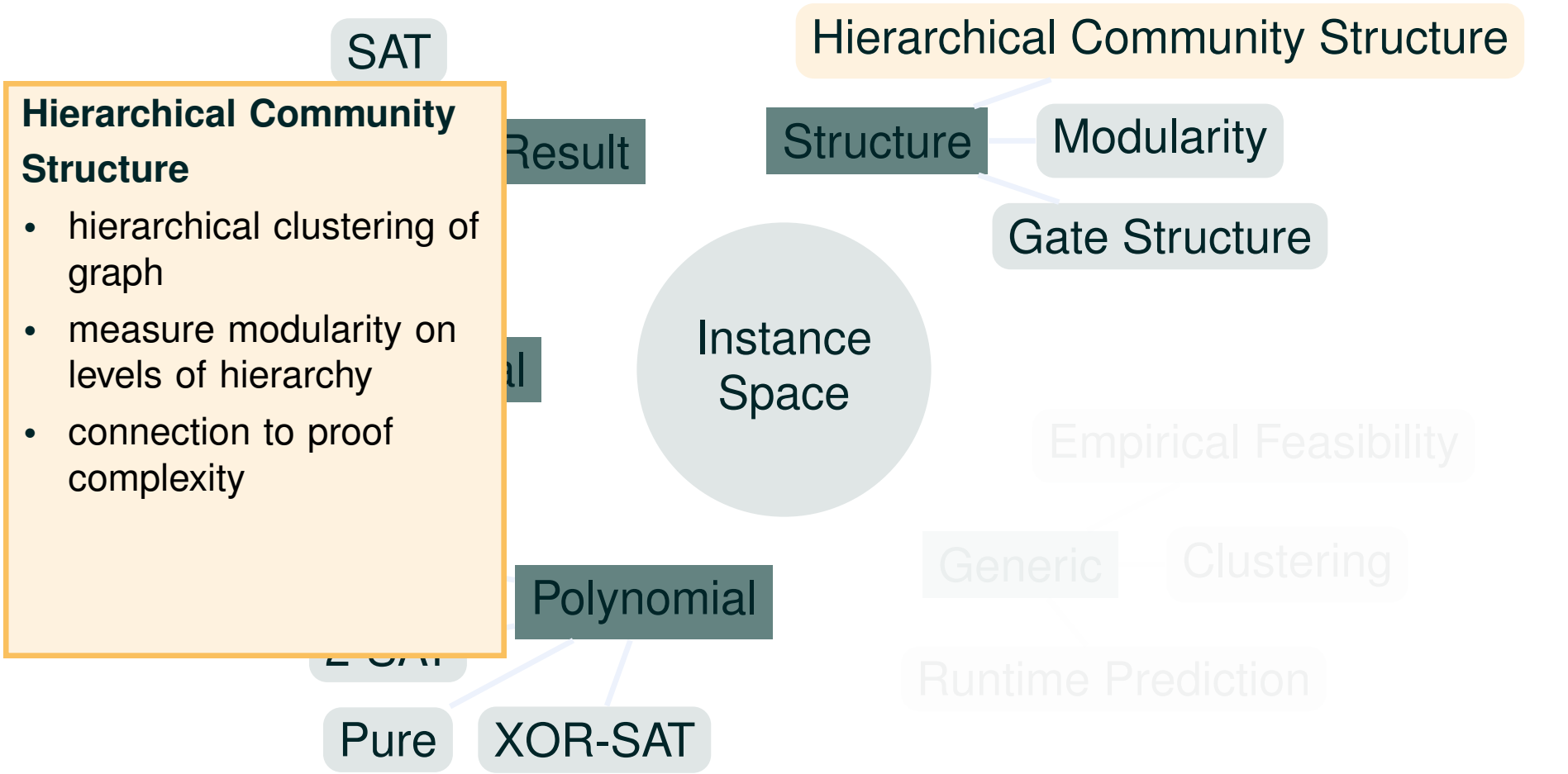
Categories of SAT Instances



Categories of SAT Instances



Categories of SAT Instances

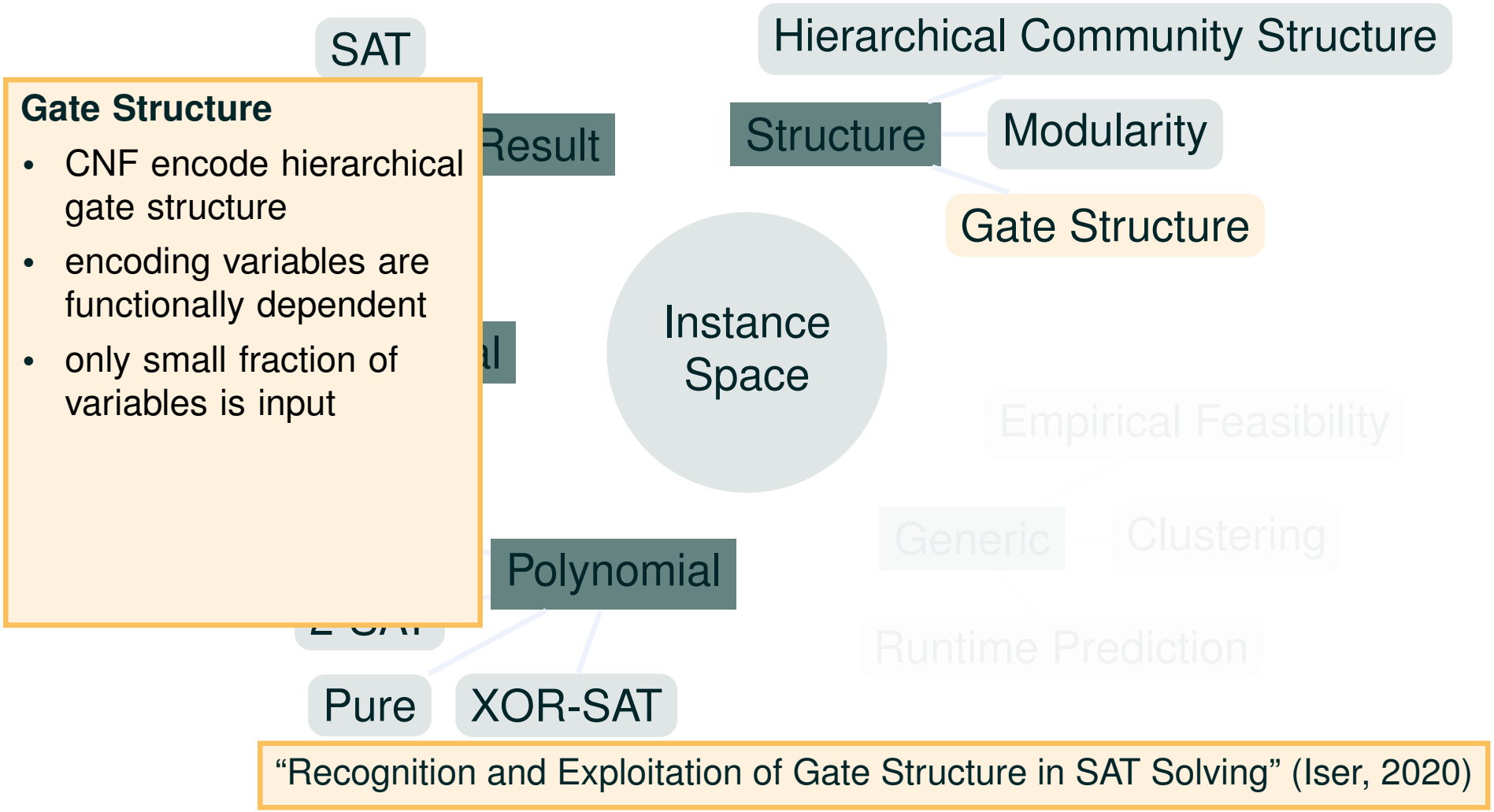


Hierarchical Community Structure

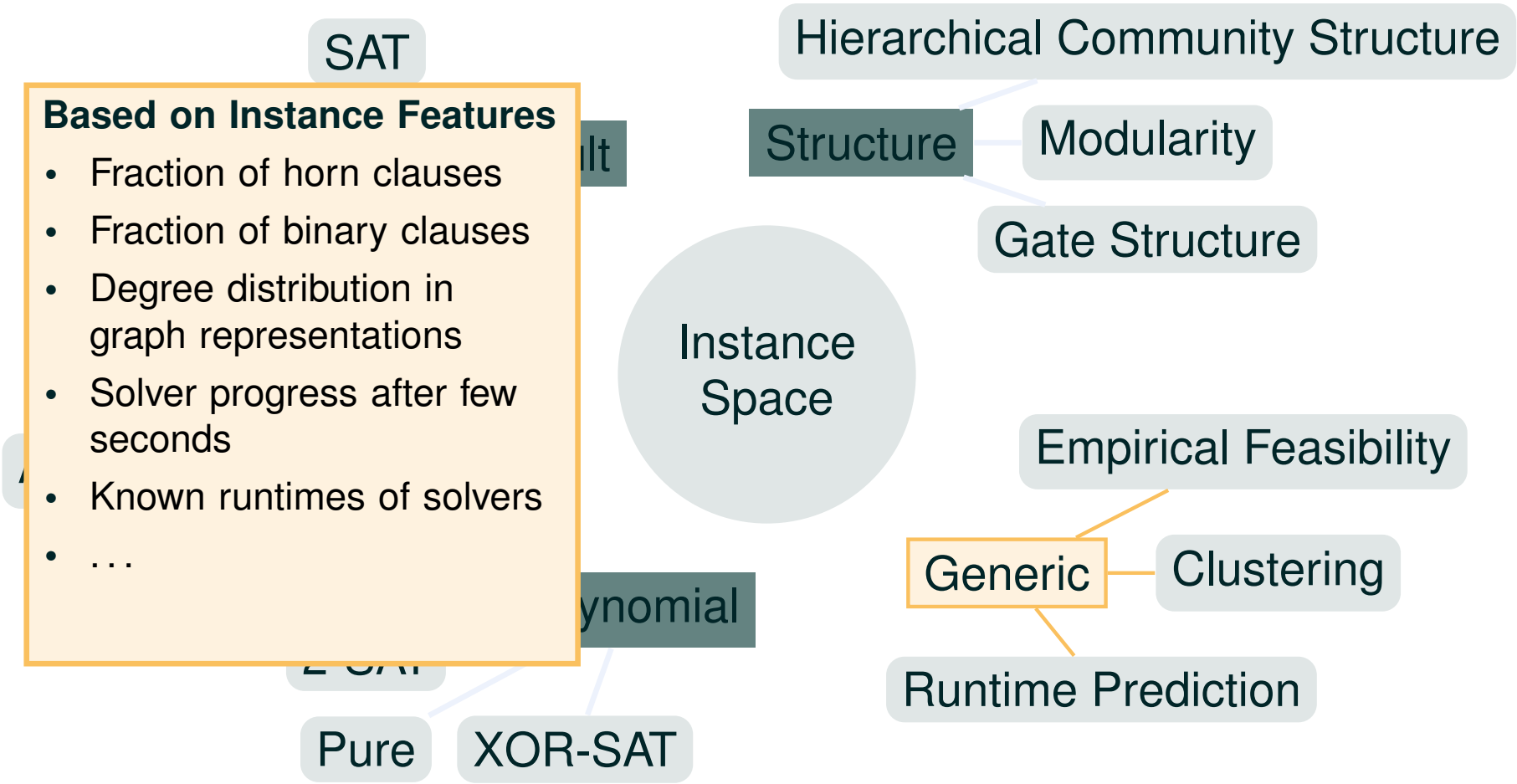
- hierarchical clustering of graph
- measure modularity on levels of hierarchy
- connection to proof complexity

“On the Hierarchical Community Structure of Practical Boolean Formulas” (Li et al., 2021)

Categories of SAT Instances



Categories of SAT Instances



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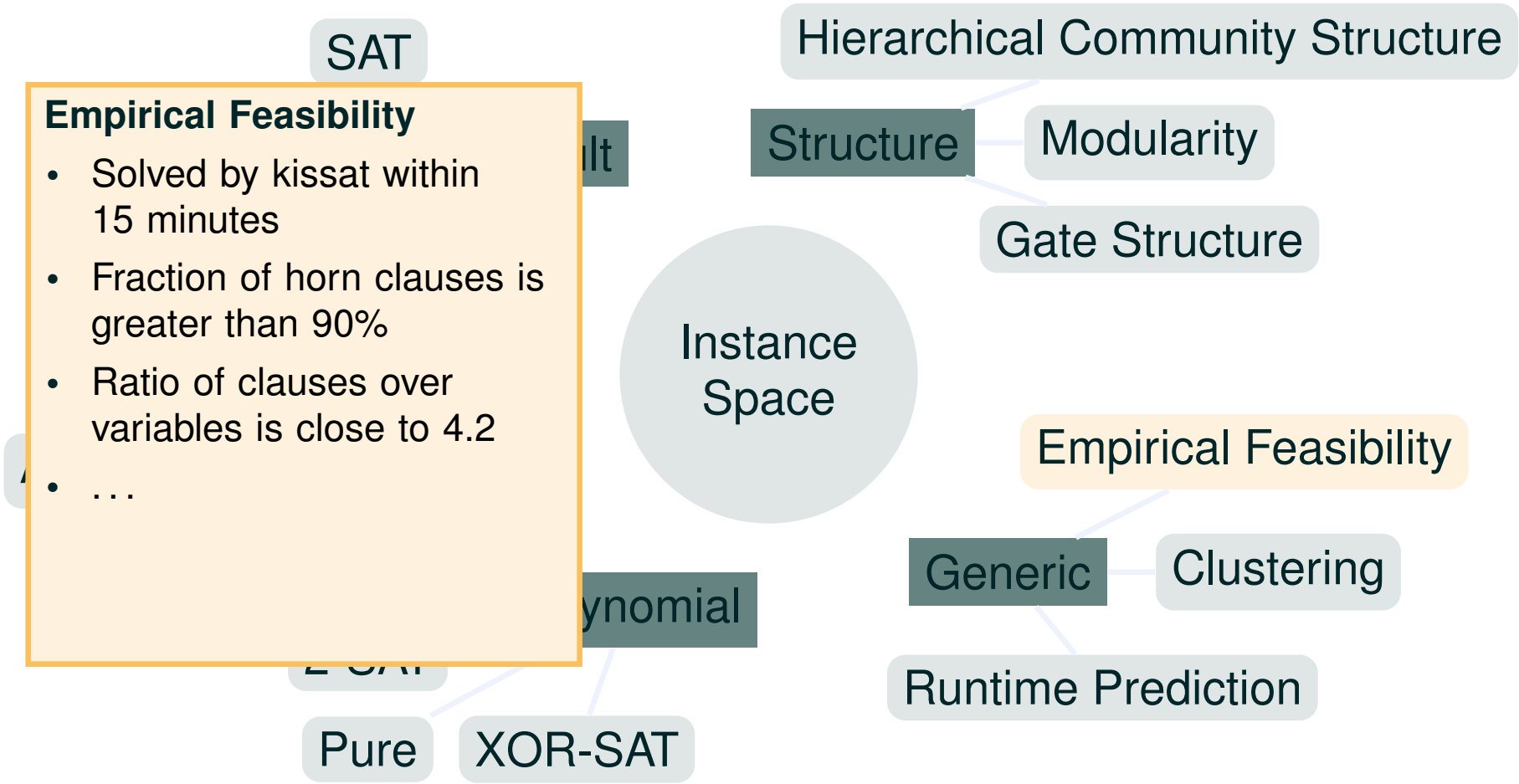
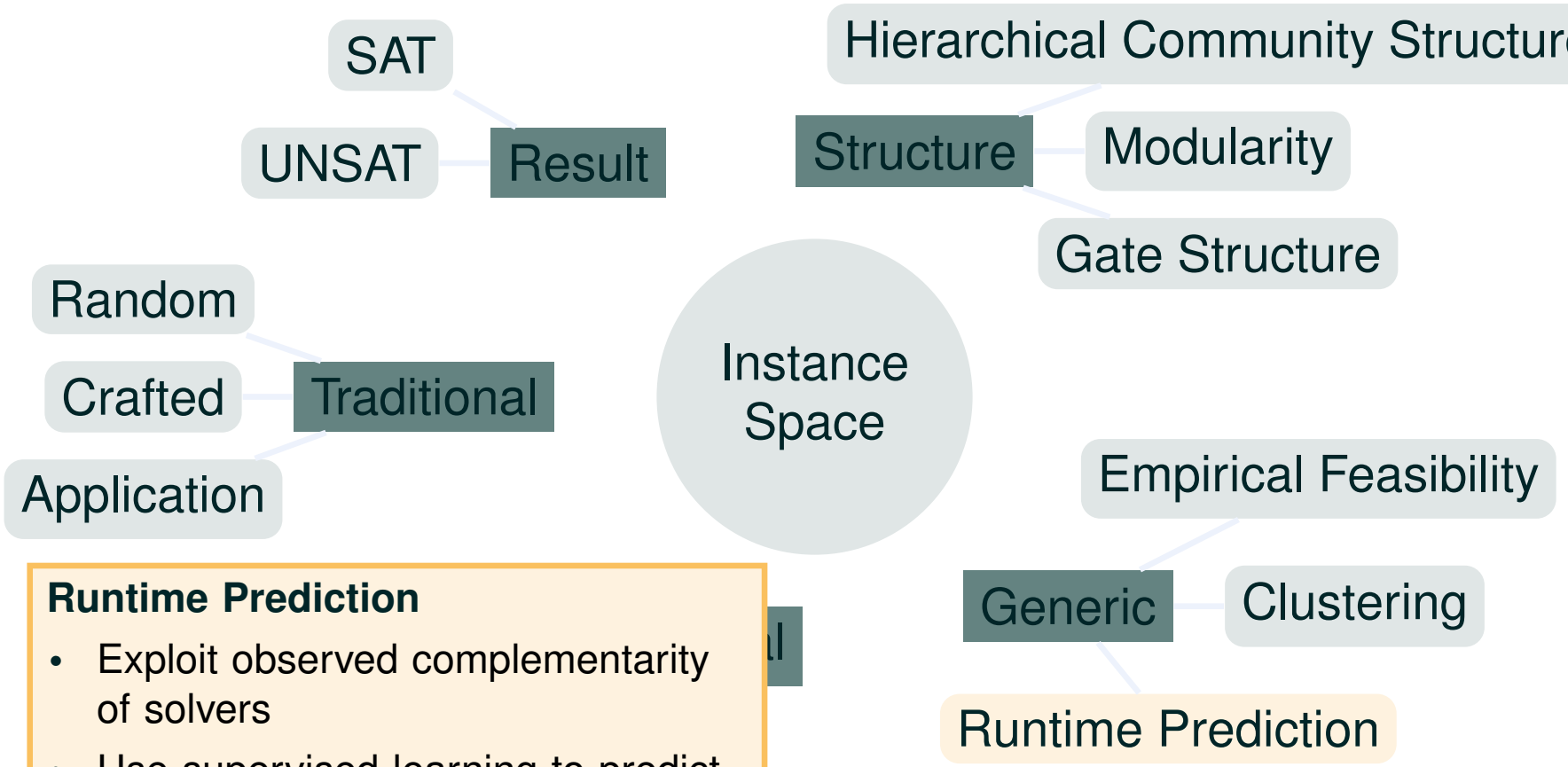


Categories of SAT Instances

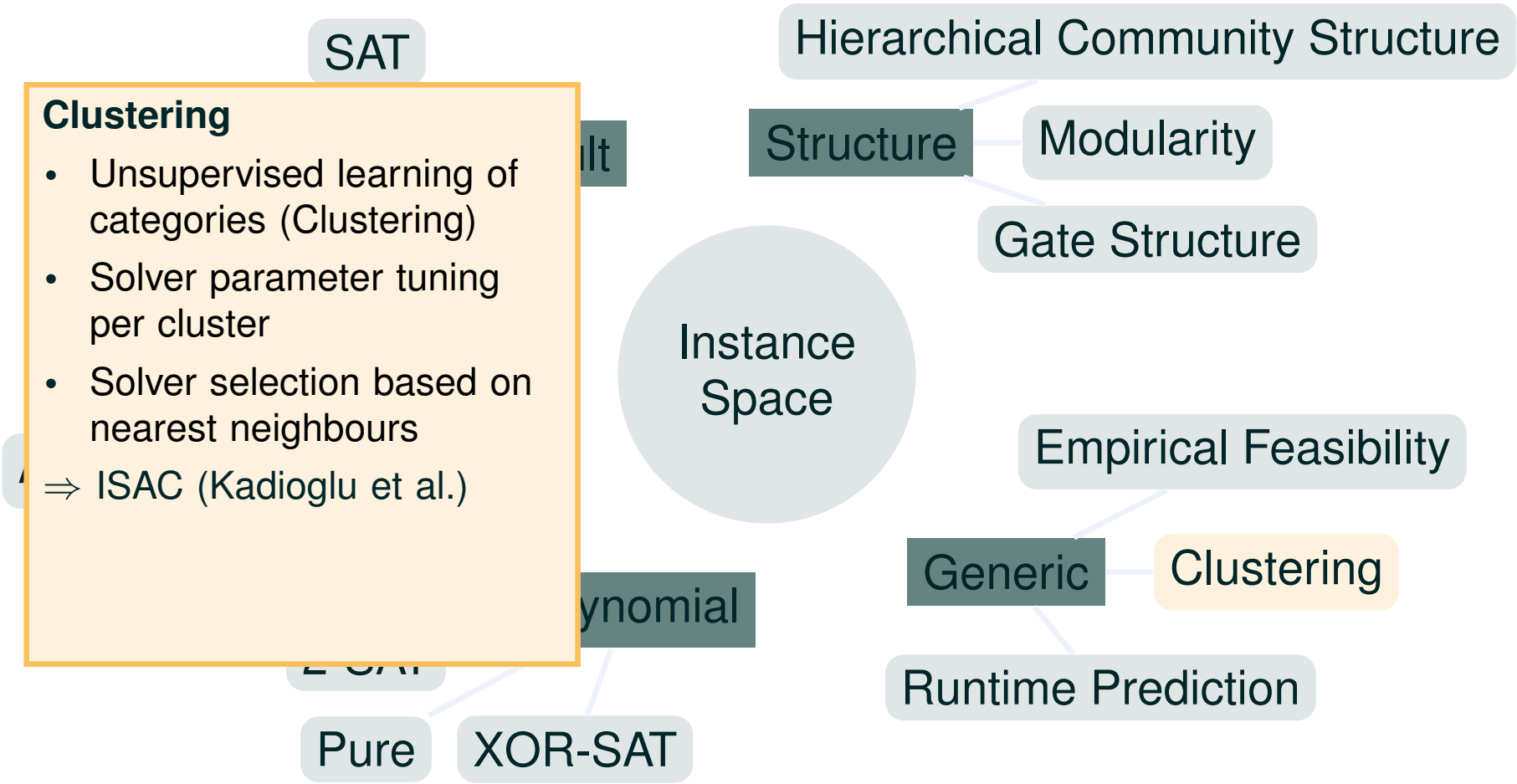


Runtime Prediction

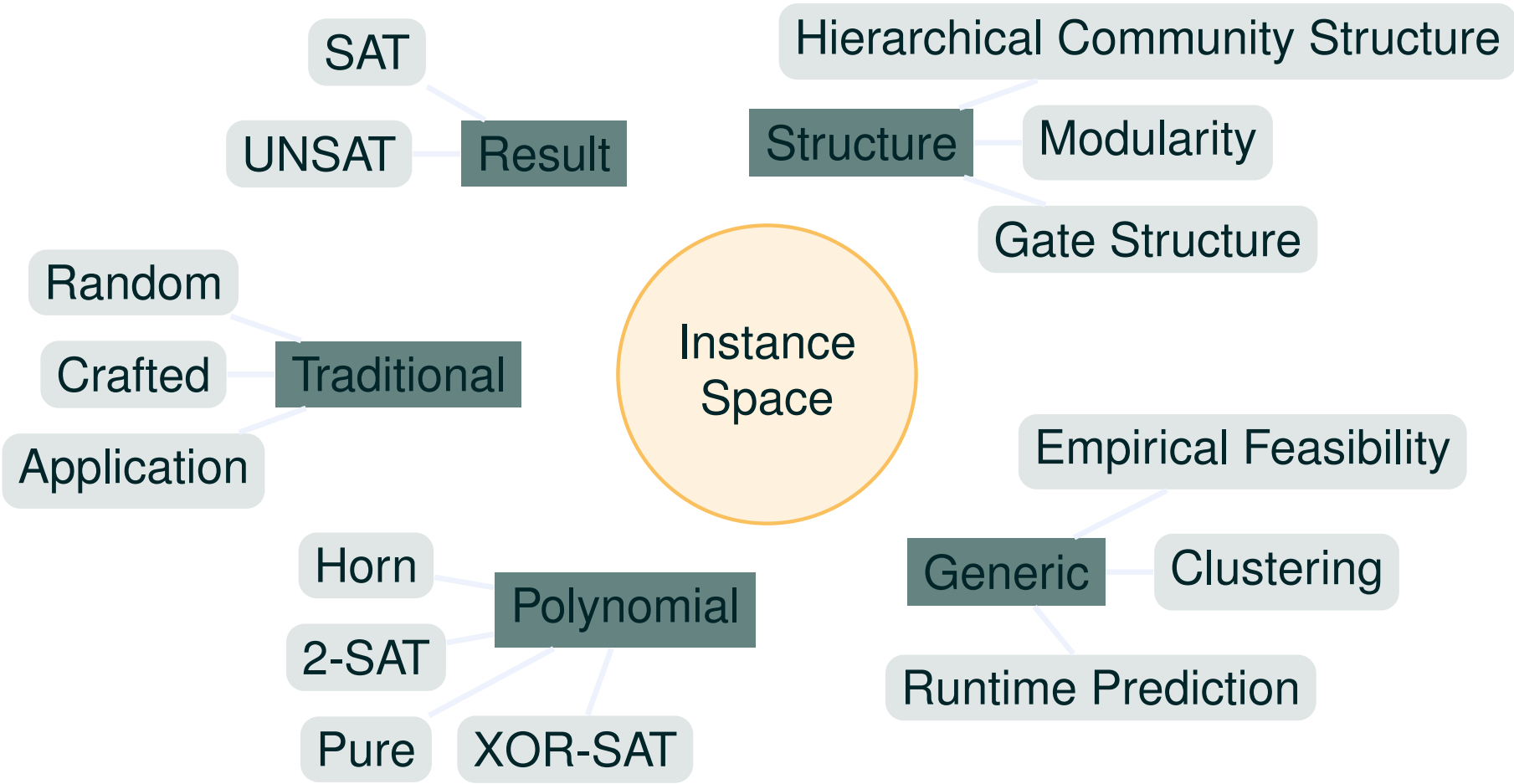
- Exploit observed complementarity of solvers
- Use supervised learning to predict fastest solver

$\Rightarrow$ SATzilla (Xu et al.)

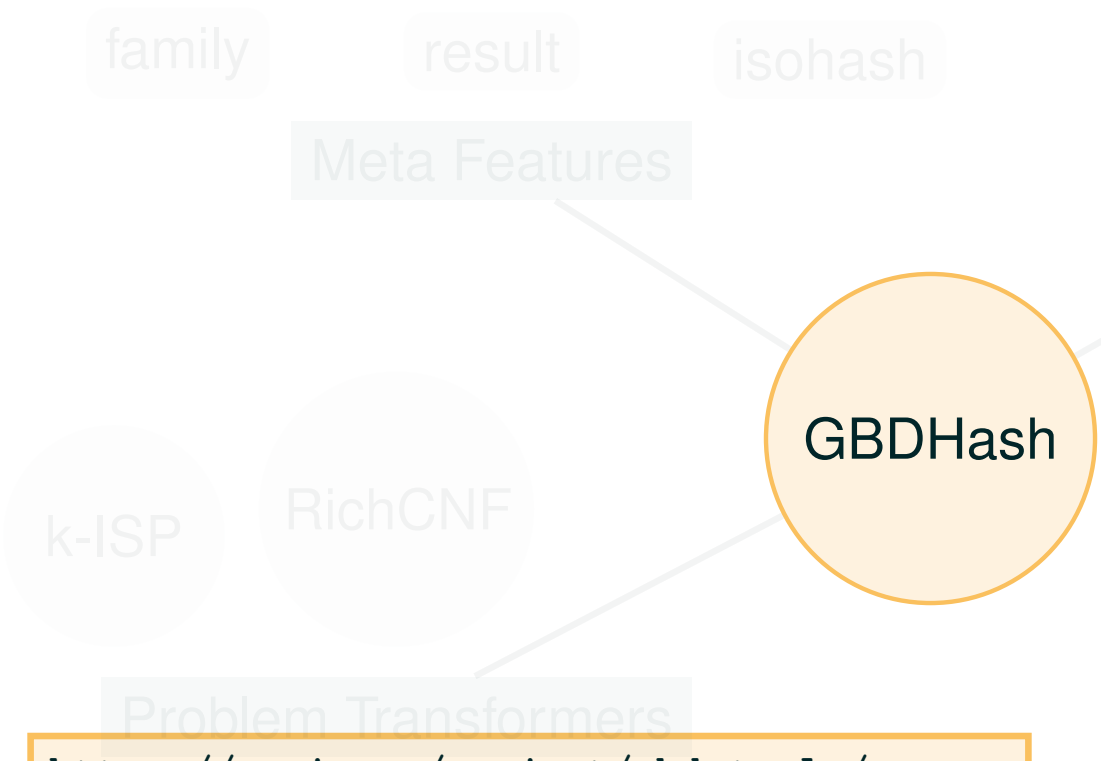
Categories of SAT Instances



Categories of SAT Instances



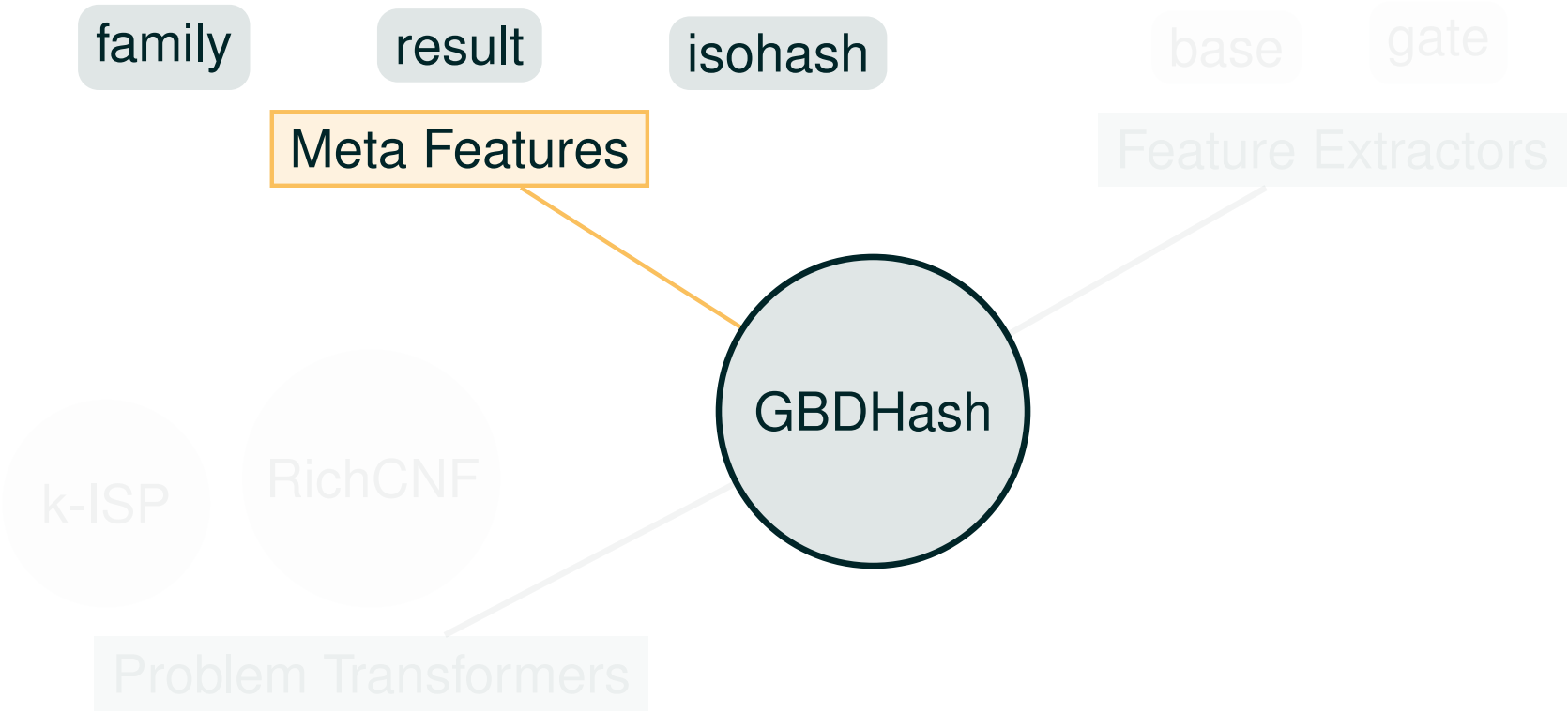
GBD Benchmark Database




```
https://pypi.org/project/gbd-tools/
https://github.com/Udopia/gbd/
https://github.com/sat-clique/cnftools
https://gbd.iti.kit.edu/
```

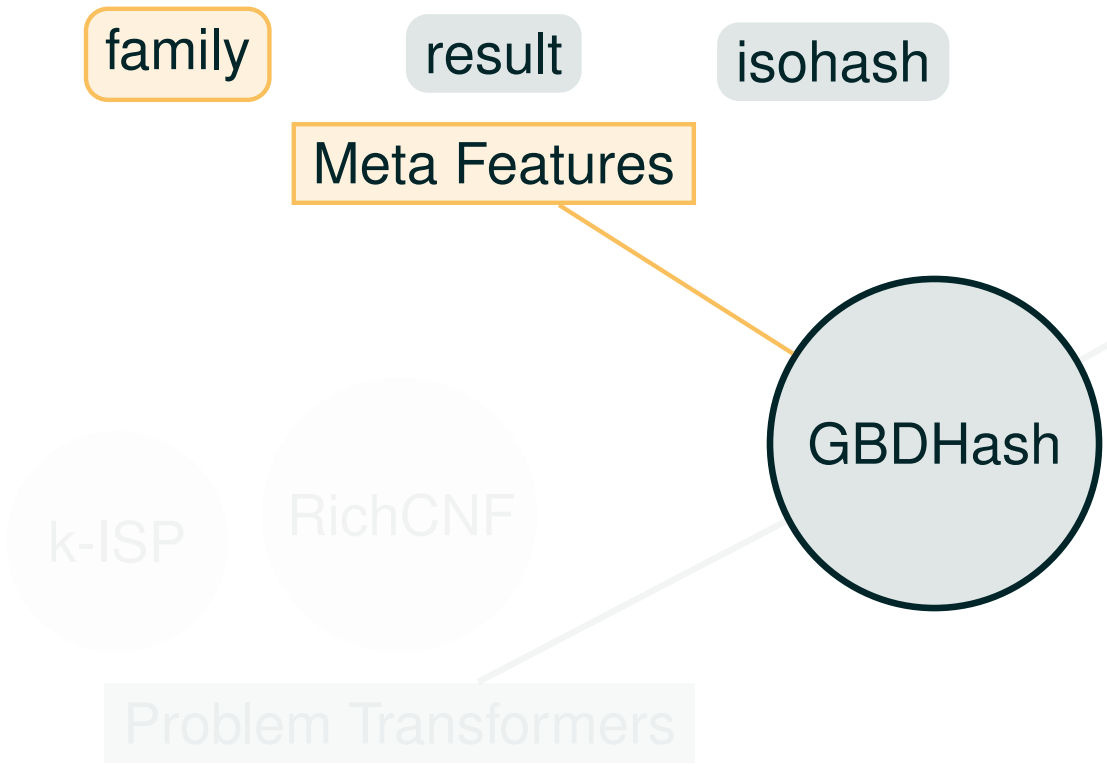
- 27647 CNF Instances
  - SAT Competition benchmarks since 2002
  - further submissions
- **Instance Identification:** GBDHash for DIMACS CNF
  - whitespaces normalized
  - comments removed
  - homogenize line-break
  - etc.

GBD Benchmark Database



`https://gbd.iti.kit.edu/getdatabase/meta_db`

GBD Benchmark Database

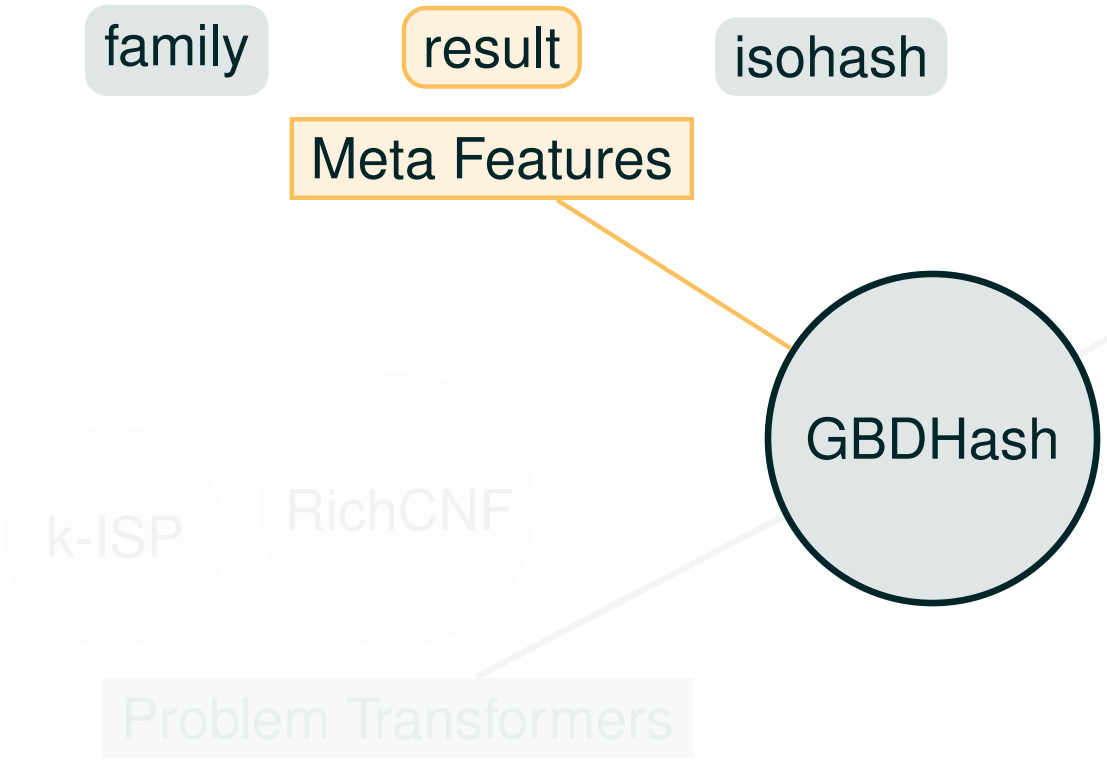


Meta-Feature "Family"

- 26794 entries, 853 unknown
- 135 unique entries

...	...
122	scheduling
210	software-verification
366	graph-coloring
483	planning
570	hardware-verification
841	cryptography
...	...

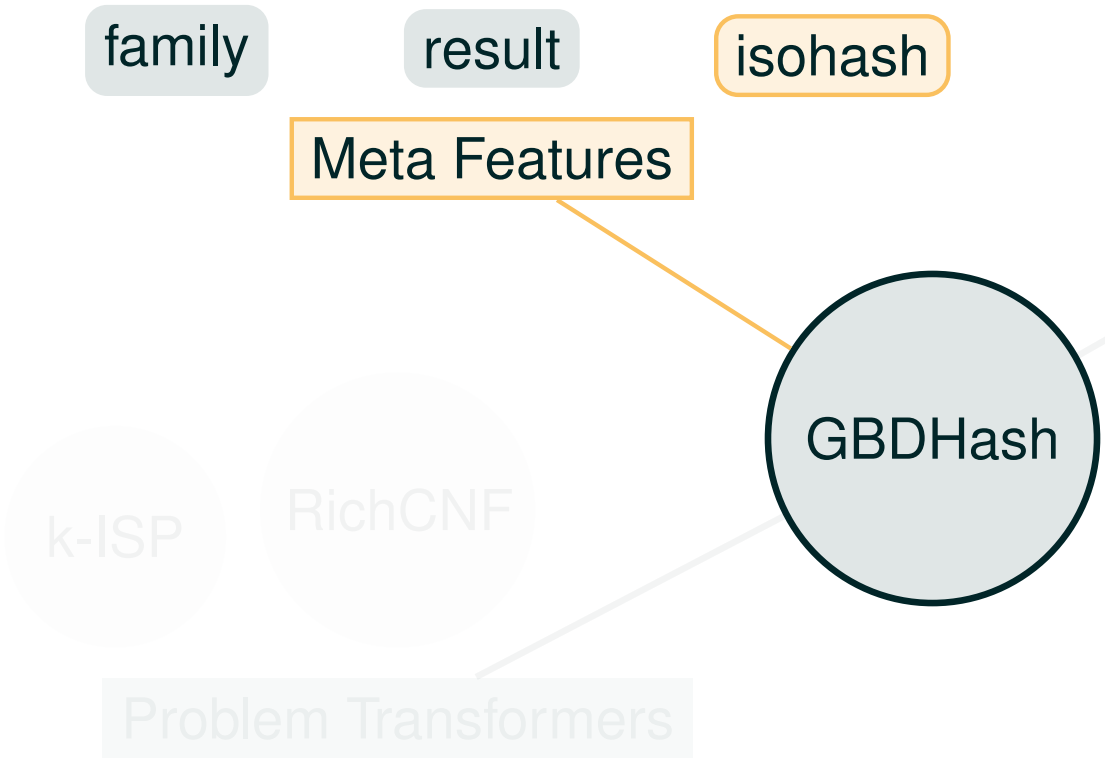
GBD Benchmark Database



Meta-Feature “Result”:

- 11159 entries
  - 5536 unsat
  - 5623 sat
- 16488 unknown

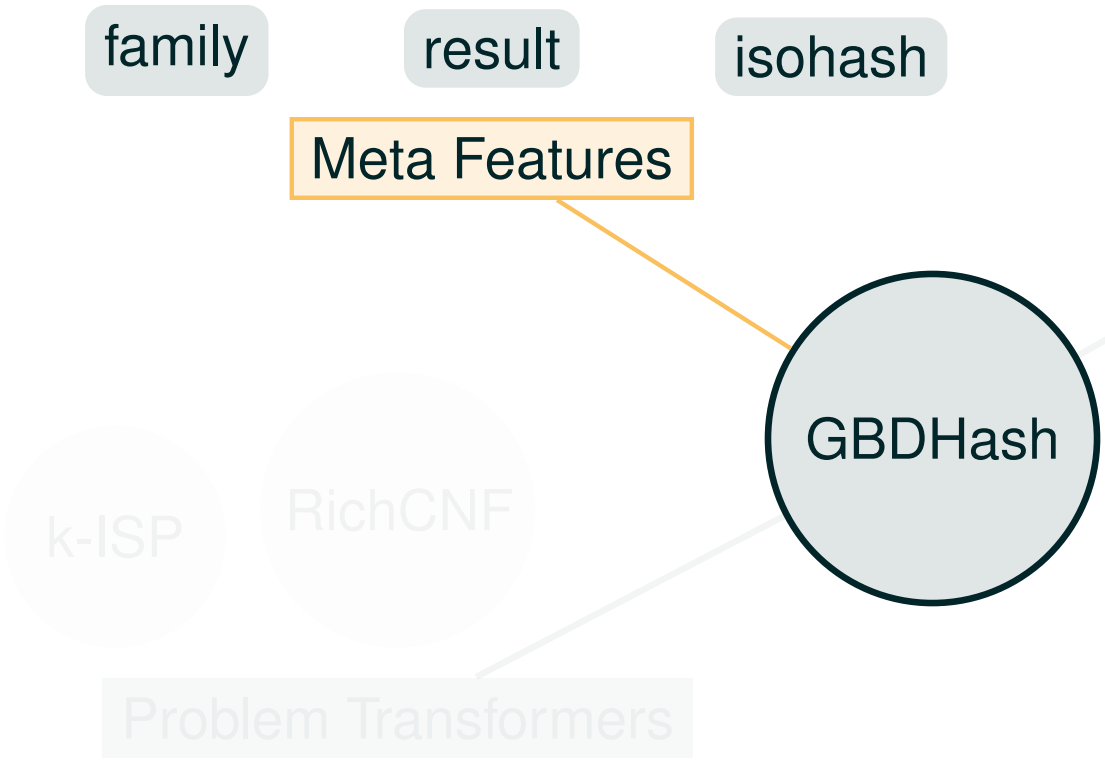
GBD Benchmark Database



Meta-Feature “IsoHash”:

- over-approximates isomorphic instances
  - transform CNF to graph by clique expansion
  - hash sorted degree sequence
- 25713 instances modulo isomorphism

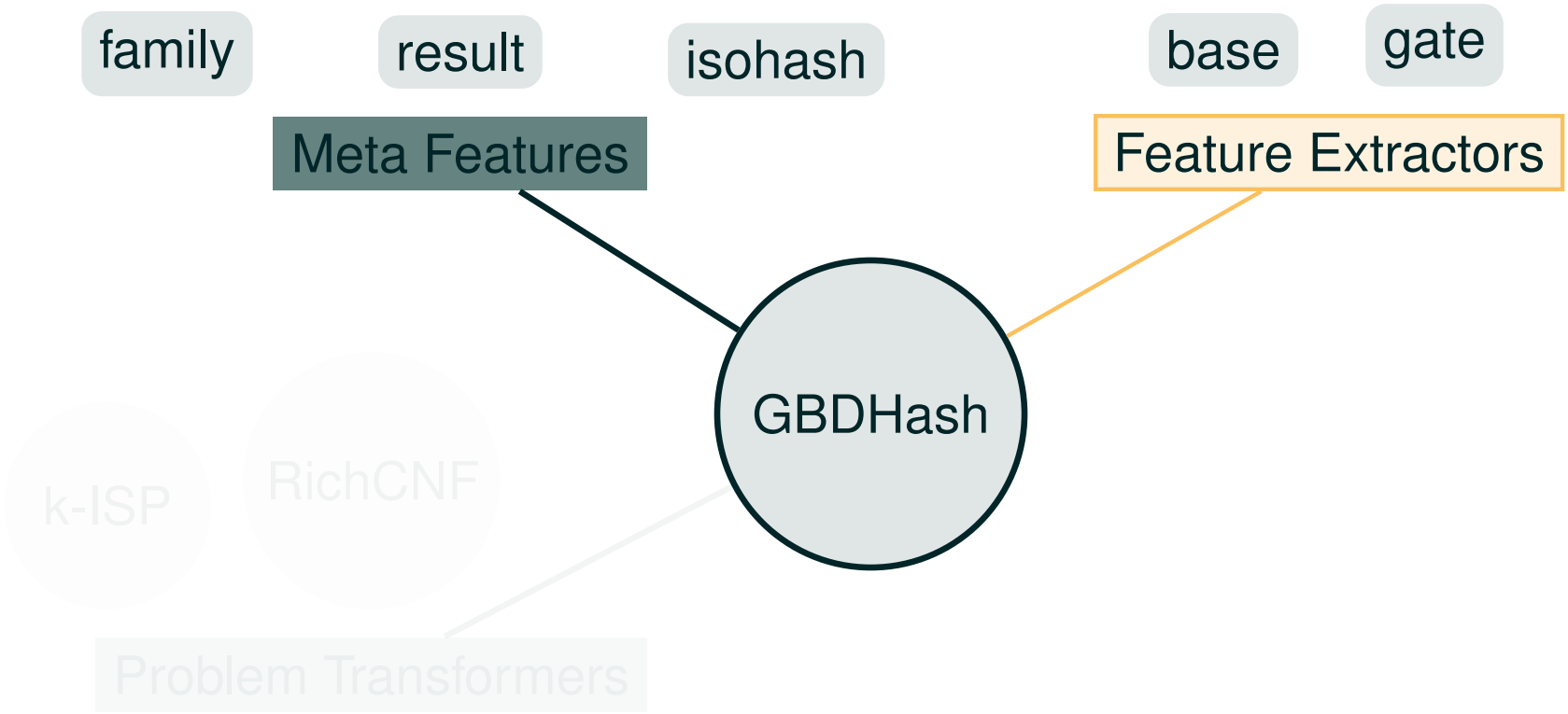
GBD Benchmark Database



More Meta-Features:

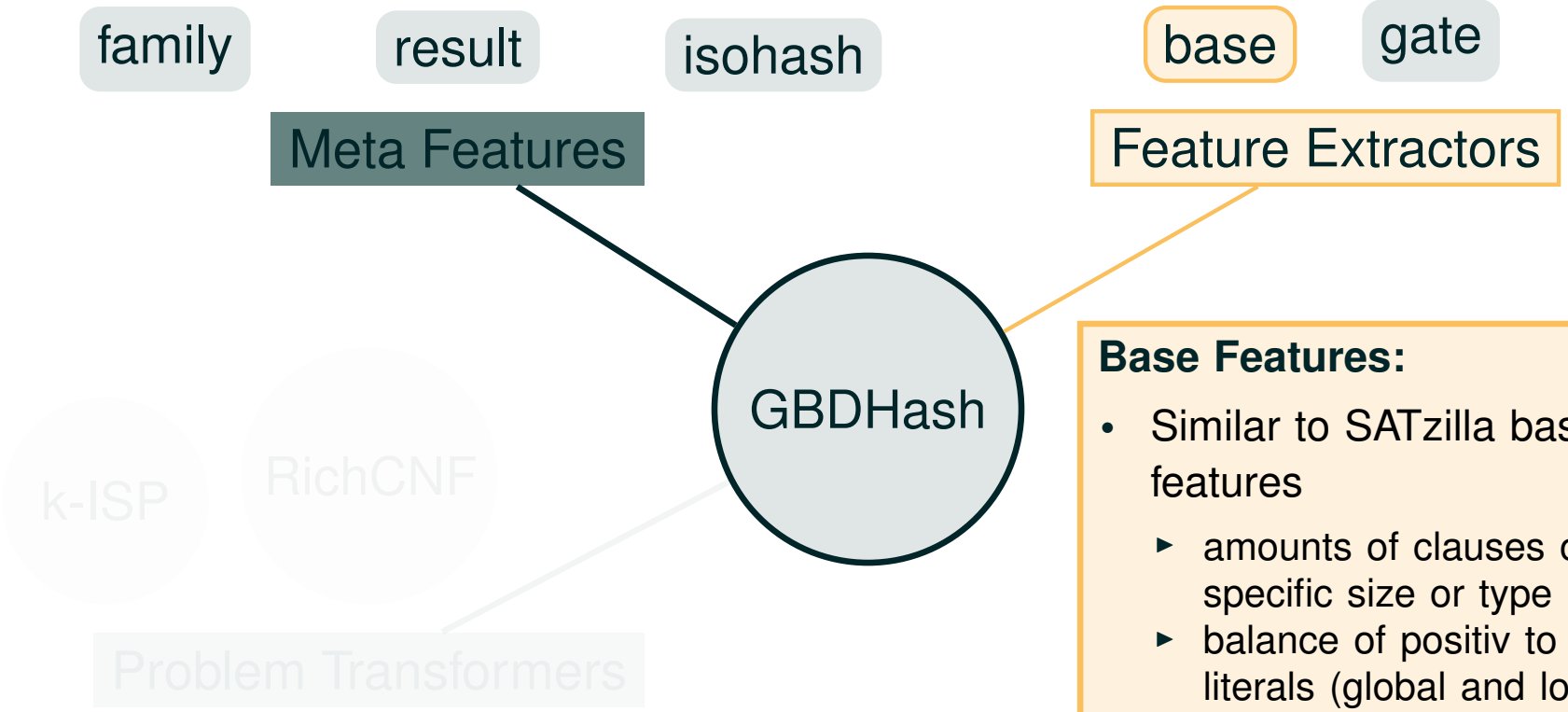
- **author**: who submitted the instance
- **track**: competition benchmark set membership
- **description**: link to benchmark description page in competition proceedings
- ...

GBD Benchmark Database




```
https://github.com/sat-clique/cnftools
https://gbd.iti.kit.edu/getdatabase/base_db
https://gbd.iti.kit.edu/getdatabase/gate_db
```

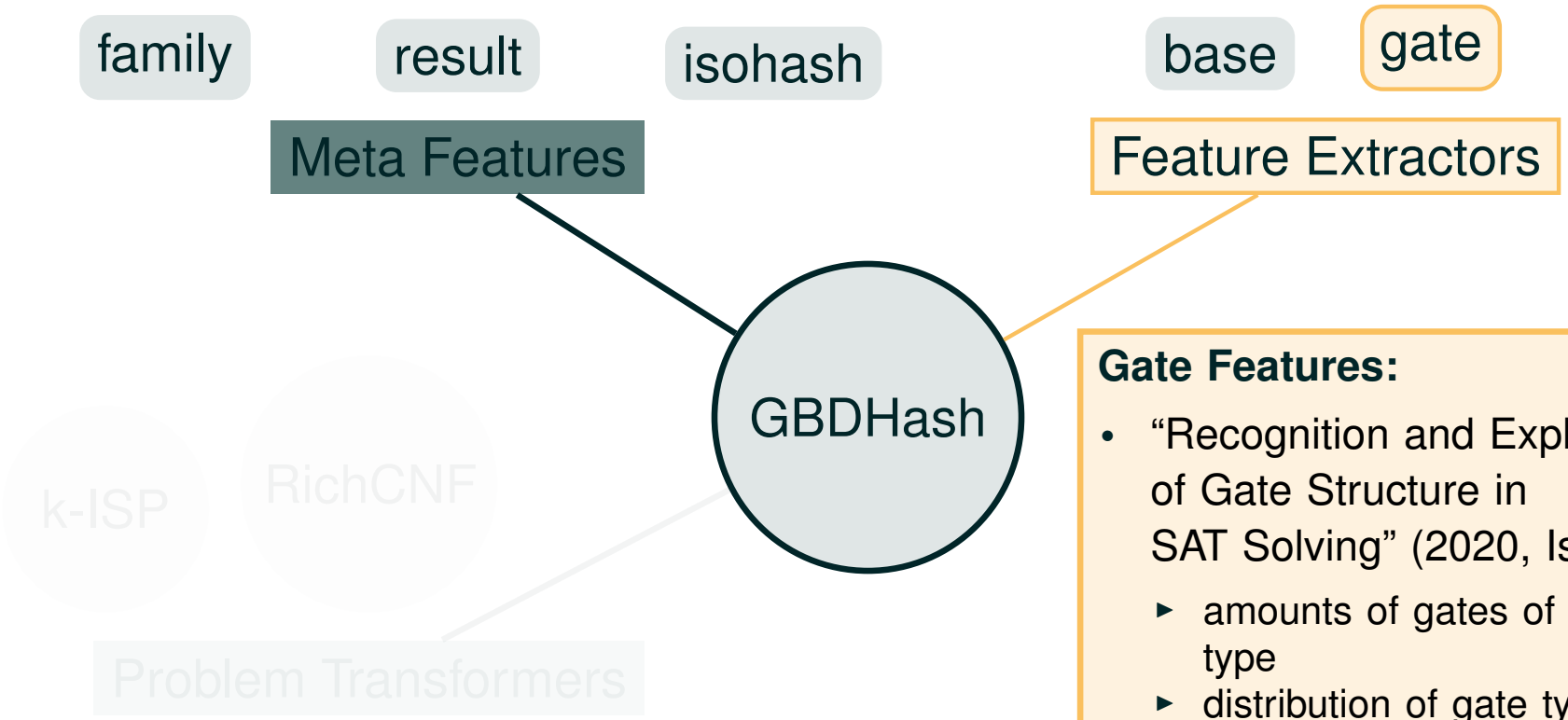
GBD Benchmark Database



Base Features:

- Similar to SATzilla base features
  - amounts of clauses of specific size or type
  - balance of positiv to negative literals (global and local)
  - node degree distributions of various graph representations
  - ...

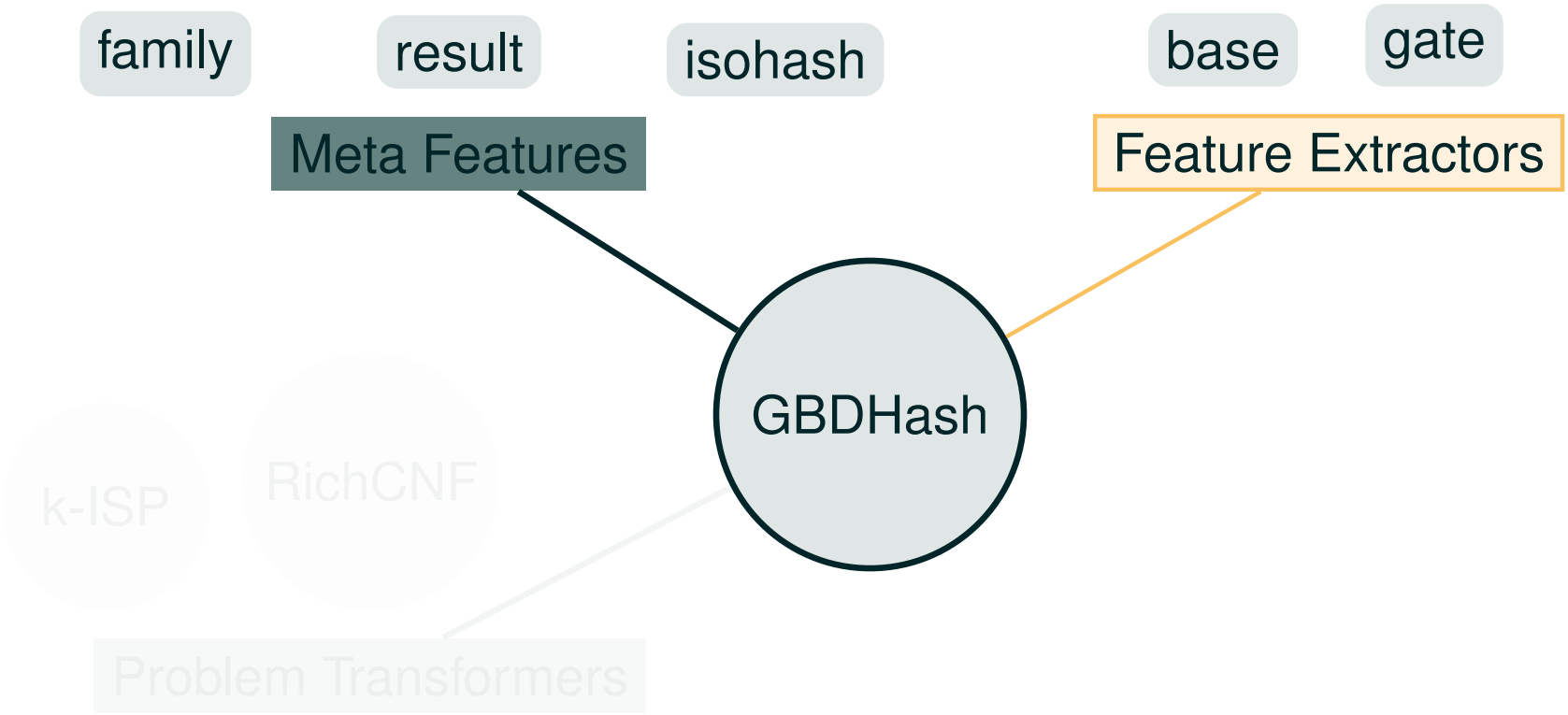
GBD Benchmark Database



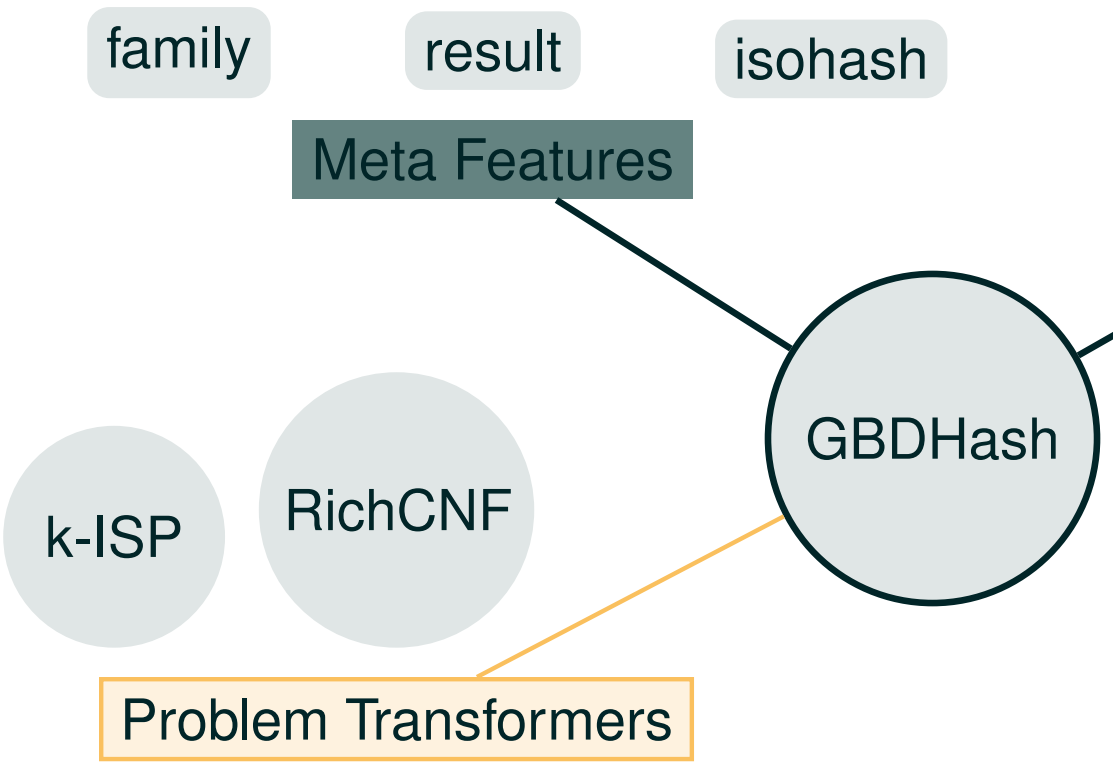
Gate Features:

- "Recognition and Exploitation of Gate Structure in SAT Solving" (2020, Iser)
  - amounts of gates of specific type
  - distribution of gate type over levels in hierarchical gate structure

GBD Benchmark Database



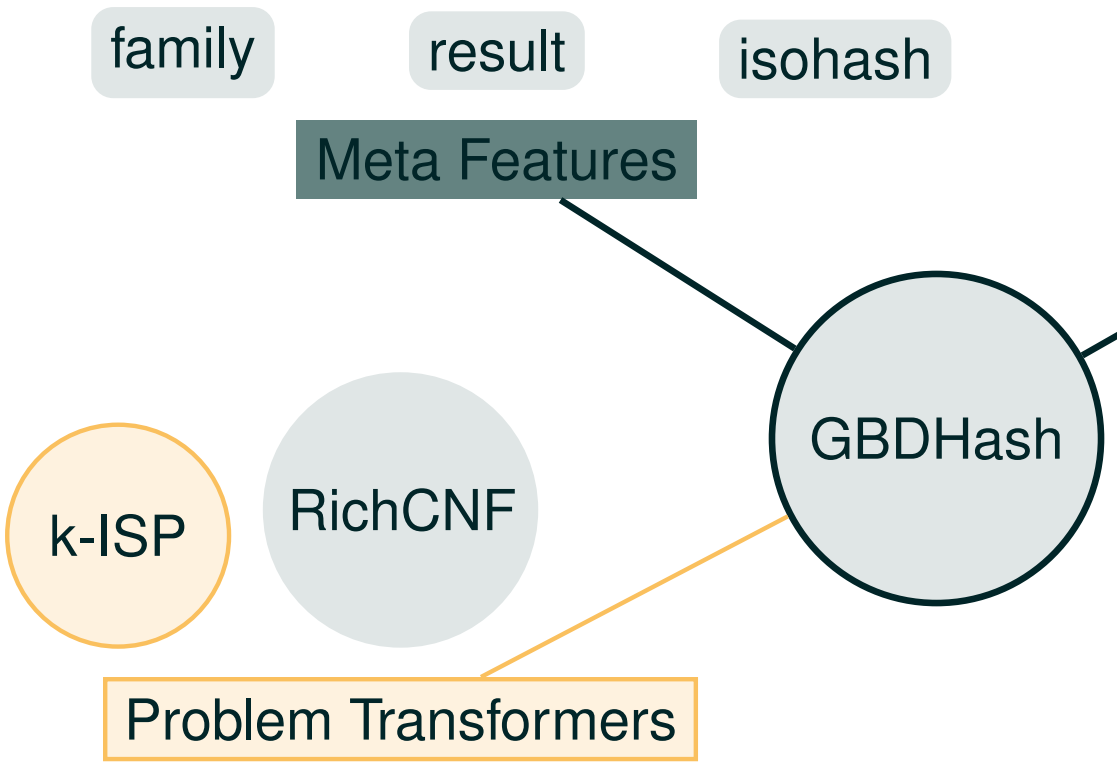
GBD Benchmark Database



Problem Transformers:

- handle instances of other domains
- handle relations between instance of several domains
- scale tool-chain to other domains

GBD Benchmark Database



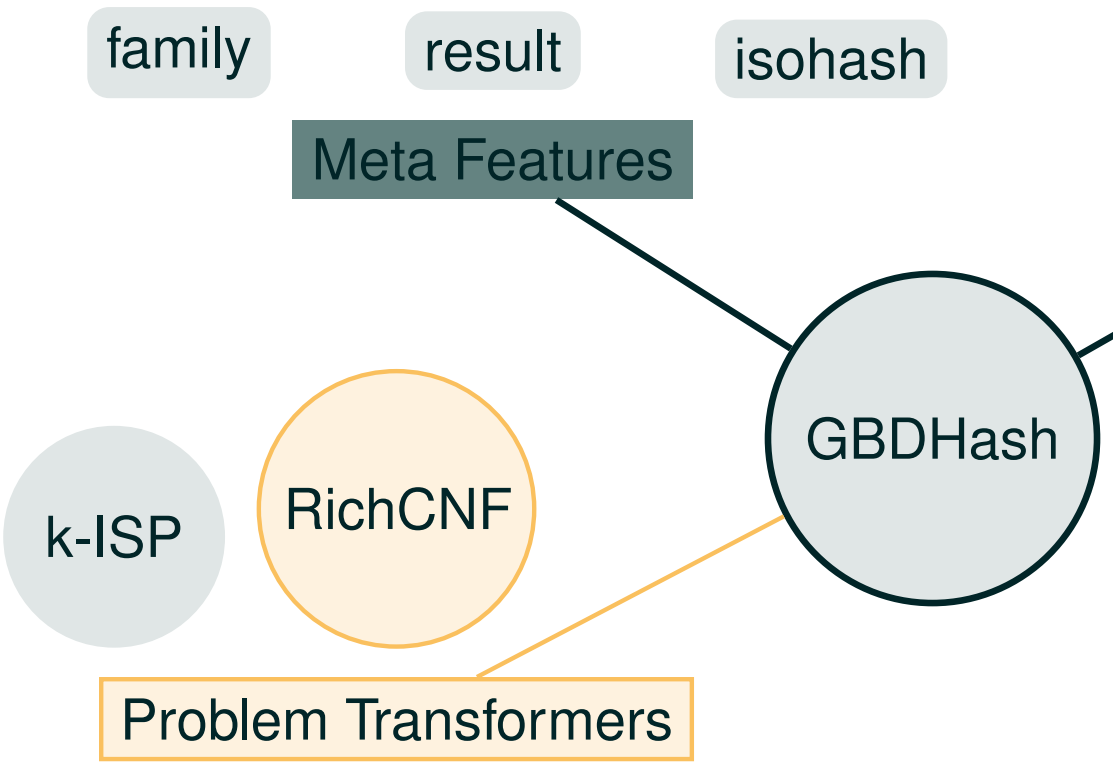
Independent Set Problem:

Given graph (V, E) and $k \in \mathbb{N}$

Decision Problem: Existence of independent set $I \subseteq V$ of size k

Indepentent Set is set of mutually non-adjacent nodes, i.e, $\nexists (v, w) \in E, \{v, w\} \subseteq I$

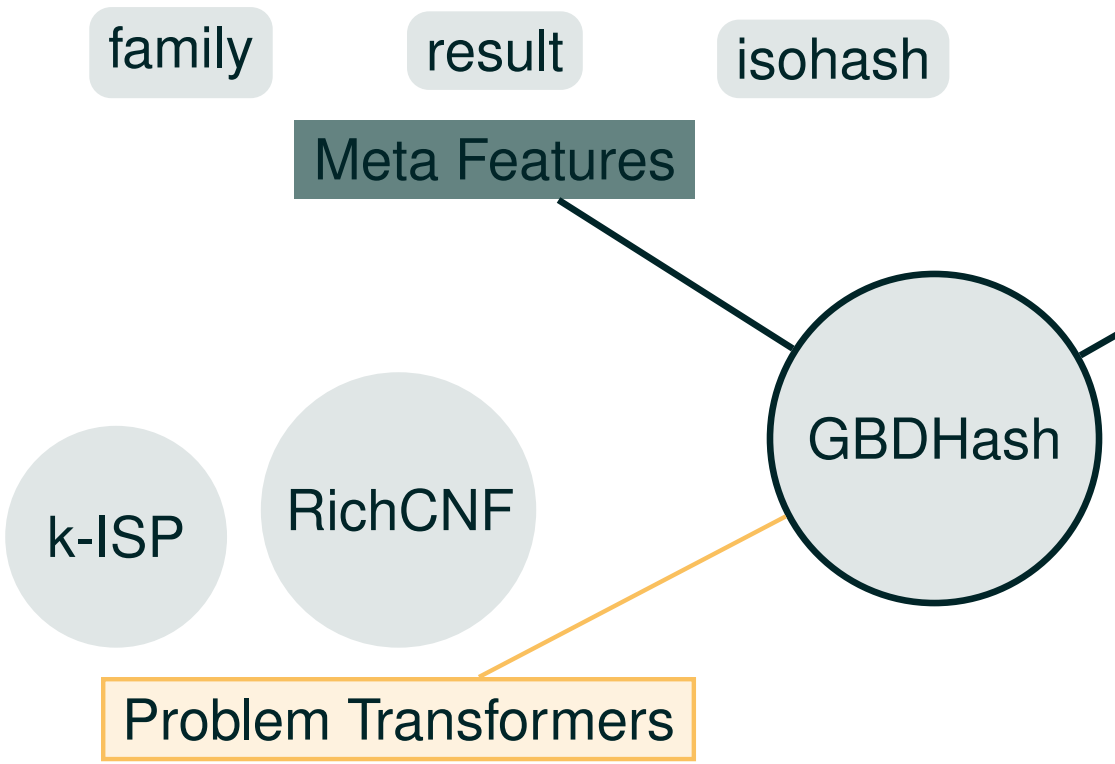
GBD Benchmark Database



RichCNF:

- conjunction of general constraints
- constraints can be:
  - cardinality constraints
  - DNF
  - BDD
  - ...

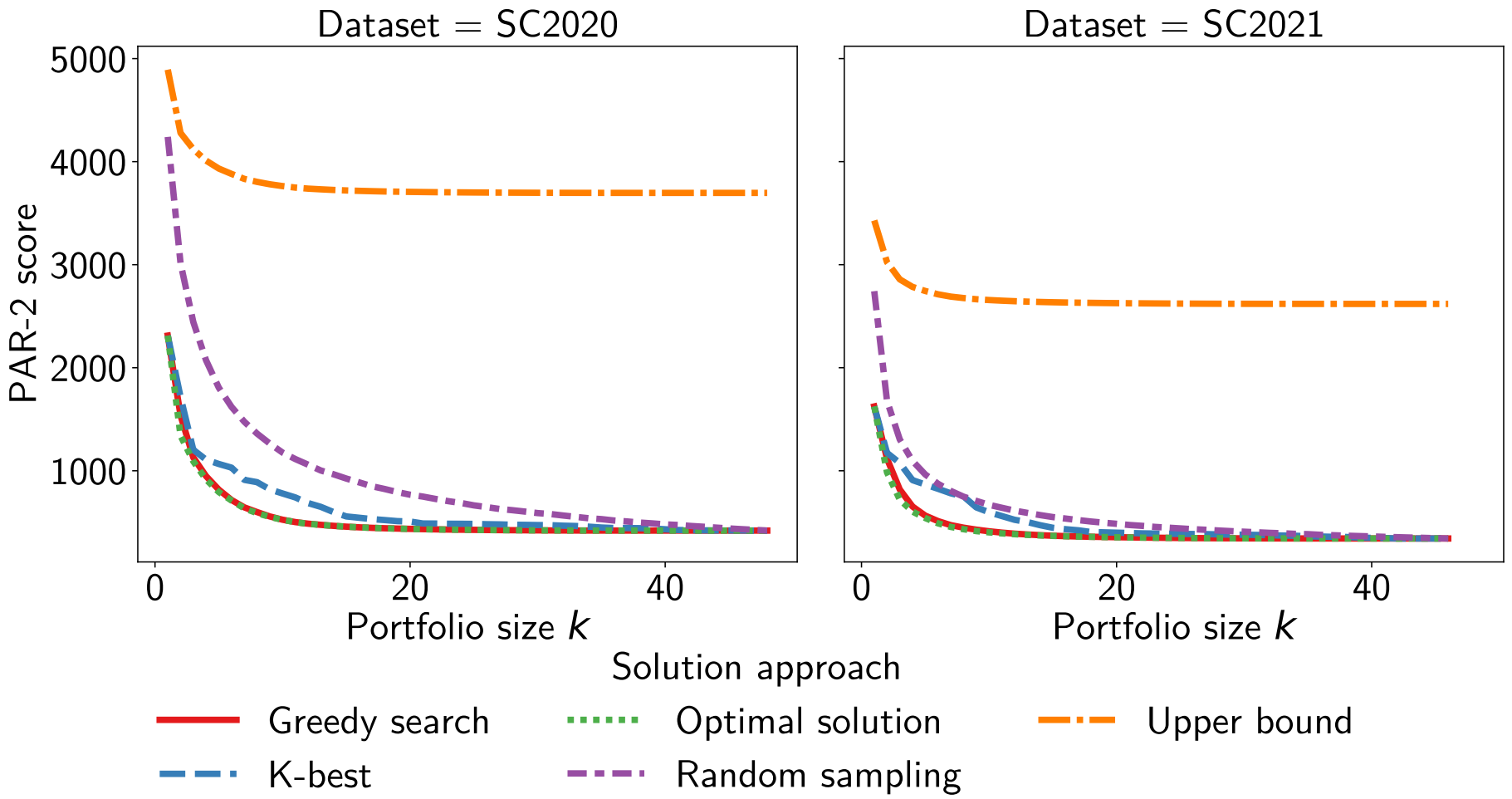
GBD Benchmark Database



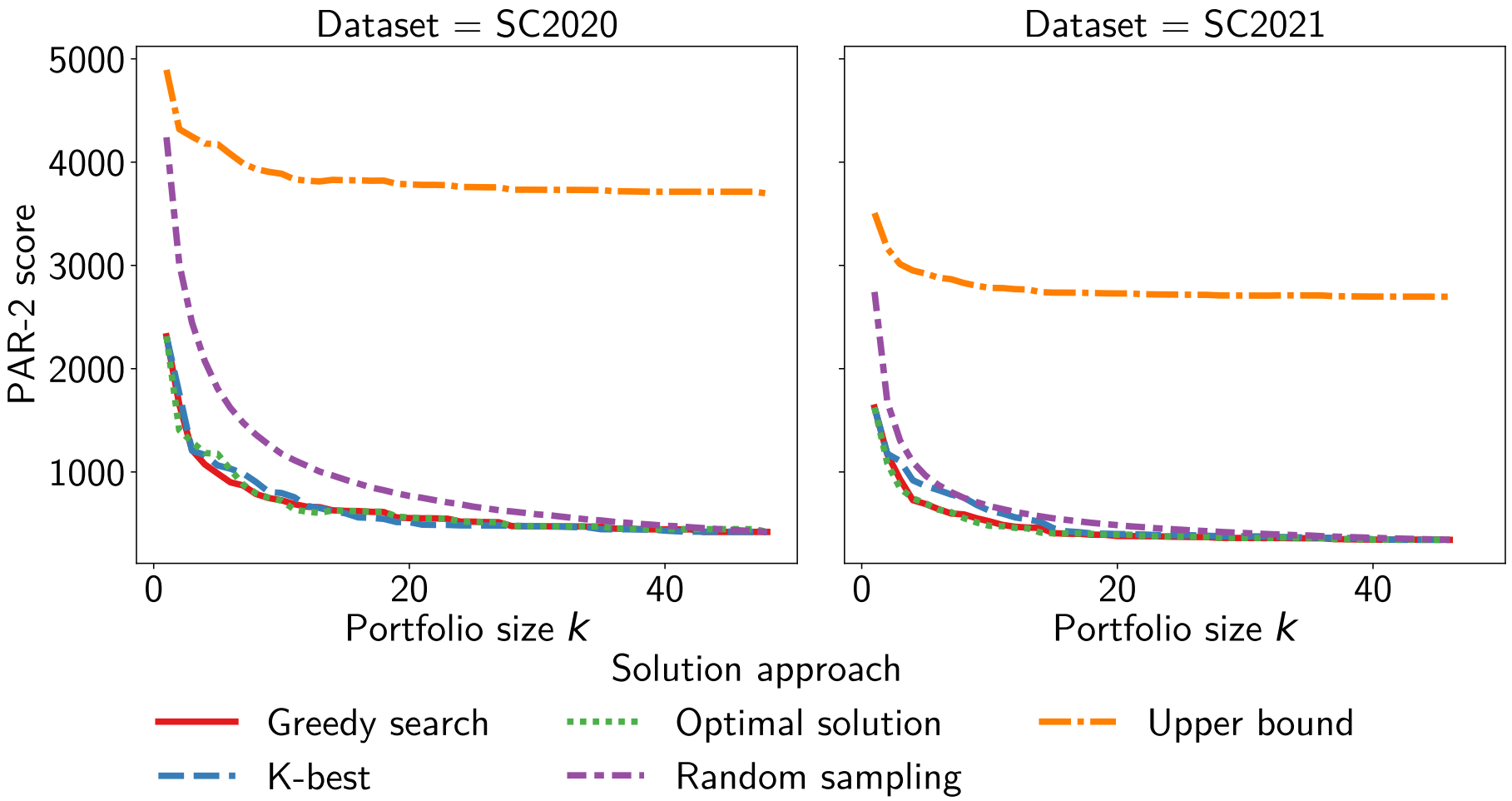
Future Domains:

- MaxSAT
- QBF
- PB
- Graphs
- DRAT Proofs
- ...

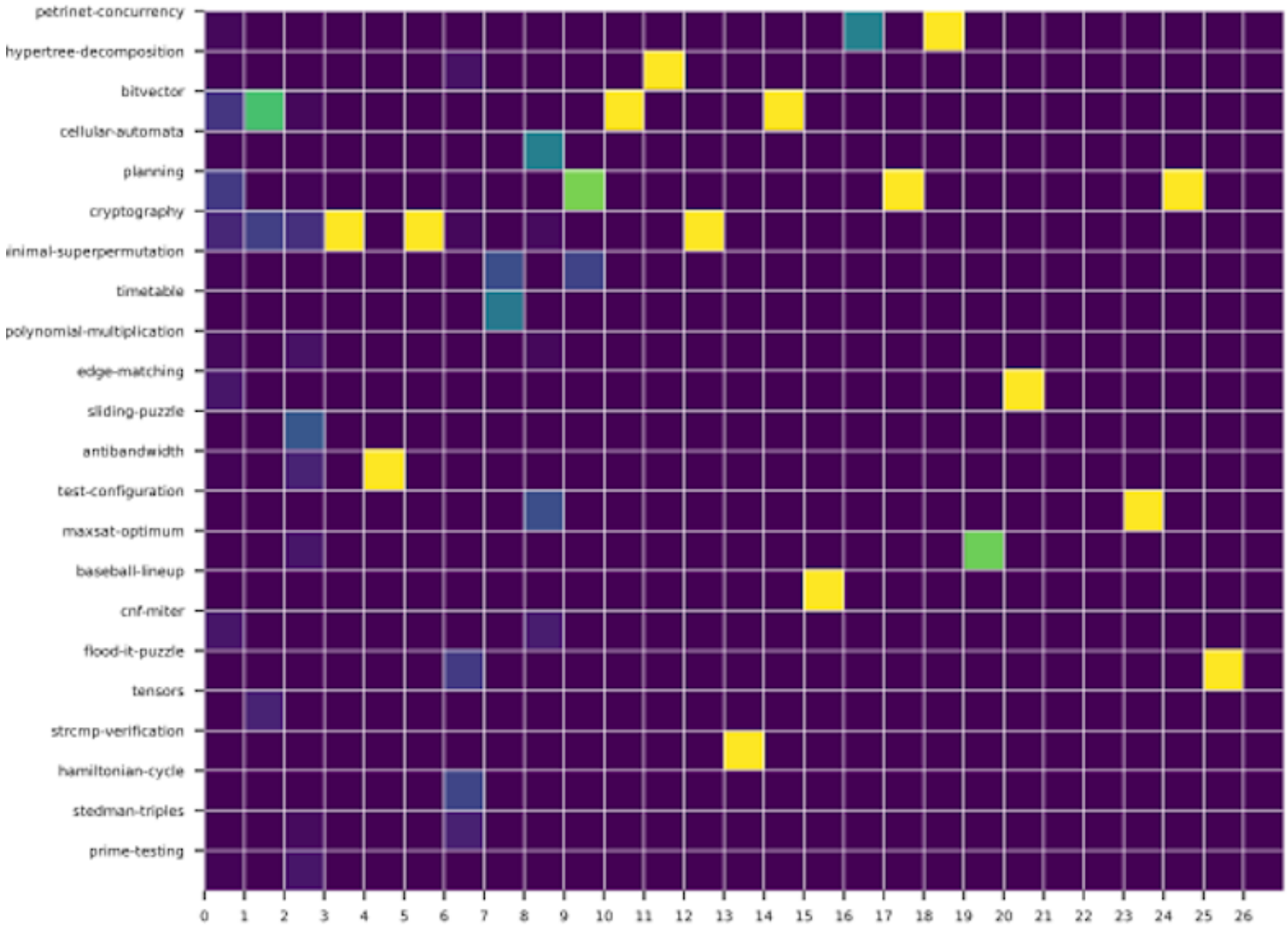
k-Portfolios



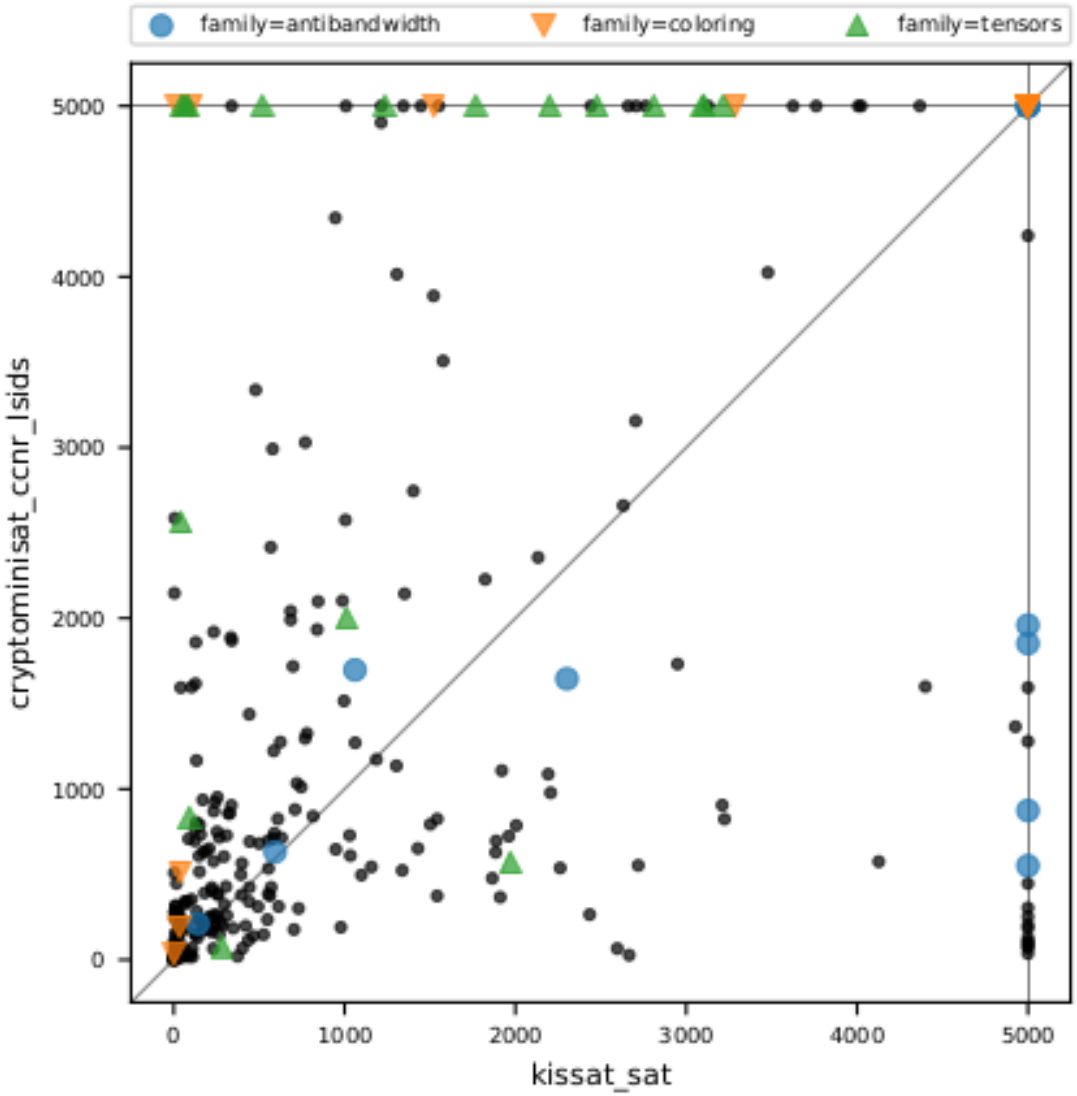
k-Portfolios (test)



Cluster Composition (dbscan)



Families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