Generalizing Constraint Models in Constraint Acquisition

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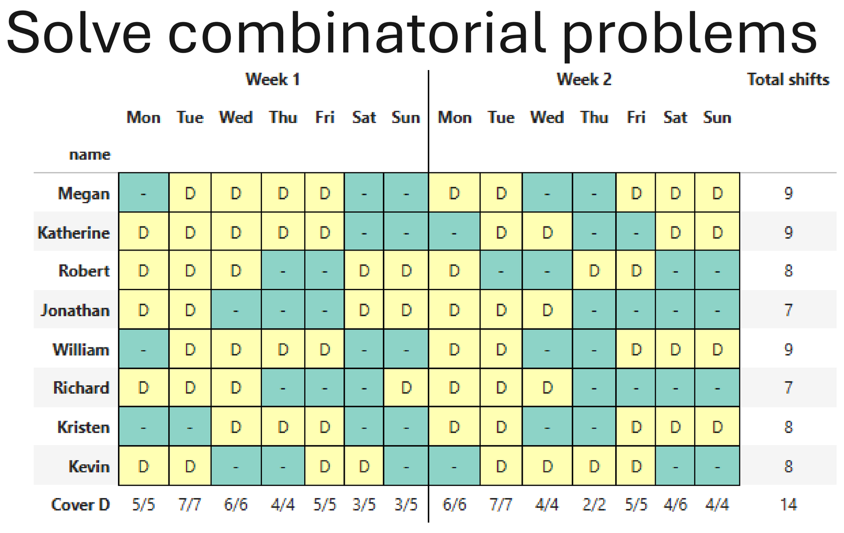
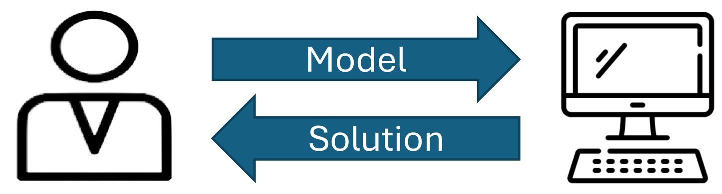
Motivation

Constraint programming (CP)

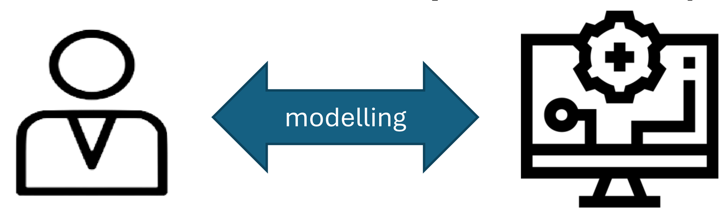
- Solve combinatorial problems



- Model + Solve paradigm

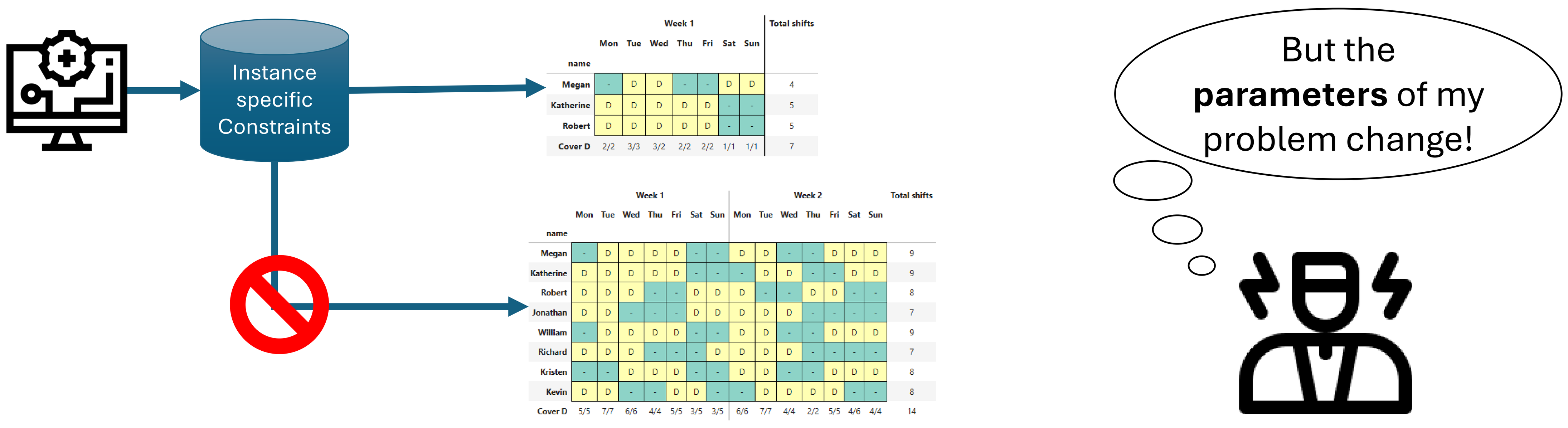


- Constraint Acquisition (CA)



Main challenge

- CA methods learn ground constraints for specific instances/parameters!
- Learned constraints cannot generalize to instances with new parameters.



Background

Parameterized Constraint Problems

An (instance-specific) CSP is a tuple (V,D,C):

- *V*: Variables
- *D*: Their domains
- *C*: Set of constraints

Parameterized Constraint model

- Parameters *P (e.g. number of nurses, days etc)*
- Set of **Constraint specifications**
  - That can generate the constraints for any instance

Constraint specification (CS):

A triple (r, G, S):

- The **relation** r
- **Partitioning** function: $G: V_T \rightarrow P(V_T)$
- Sequence **conditions** *S*

```
Foreach Y ∈ 𝒫(V_T):
  Foreach scope ∈ combinations(Y, arity(r),
                              S):
    c ← (rel(c) = r, var(c) = scope)
```

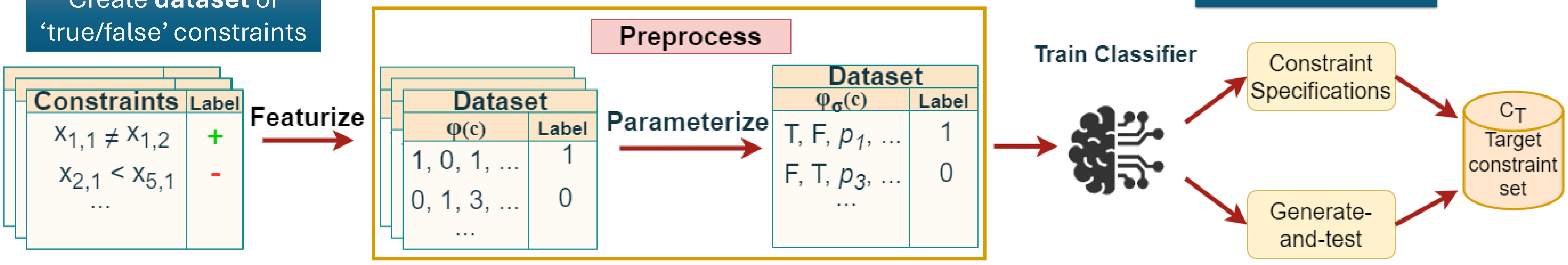
Contributions

Exploiting the power of statistical ML to generalize a ground CSP to different problem instances

Feature Representation of Constraints

Features to capture elements of CSs

- Relations
- Partitioning functions
- Sequence Conditions



Use of Statistical ML to capture the problem structure implicitly.

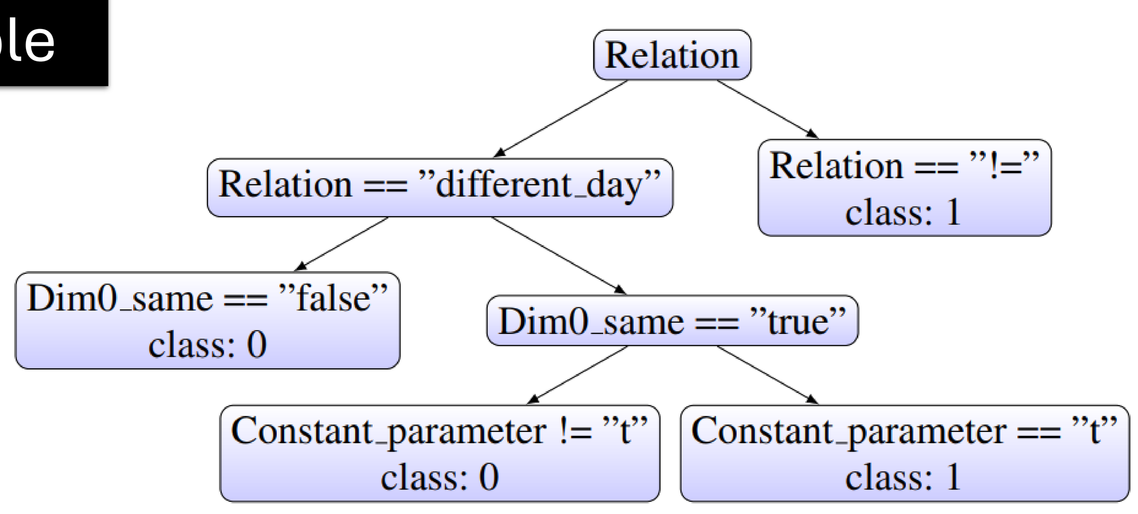
Extract interpretable Constraint specifications from learned decision rules

Extracting Constraint Specifications - Example

Exam Timetabling:

- **"all courses must be scheduled in different timeslots"**
- **"Same semester courses must be scheduled on different days'"**

Decision Tree learned



Decision Rules

```
r1: Relation == "different_day"
& Dim0_same == "false"
then 0
r2: Relation == "different_day"
& Dim0_same == "true"
& Constant_parameter != "t"
then 0
r3: Relation == "different_day"
& Dim0_same == "true"
& Constant_parameter == "t"
then 1
r4: Relation == "!=" then 1
```

Extracted Constraint Specifications

```
Foreach row ∈ all_rows:
  Foreach scope ∈ all_pairs(row):
    c ← (rel(c) = "different_day(t)",
                   var(c) = scope)
```

```
Foreach scope ∈ all_pairs(V):
  c ← (rel(c) = "!=", var(c) = scope)
```

Evaluation

Benchmarks:

- Sudoku
- Golomb
- Exam Timetabling
- Nurse Rostering

10 instances from each

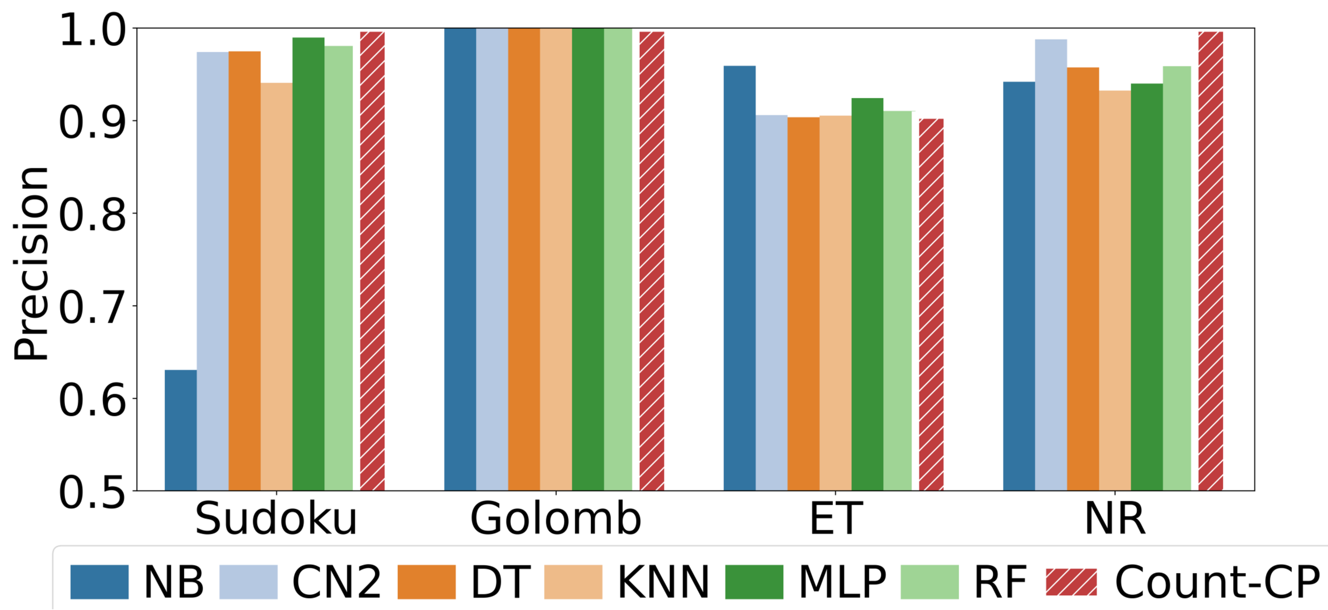
Leave-one in Cross Validation

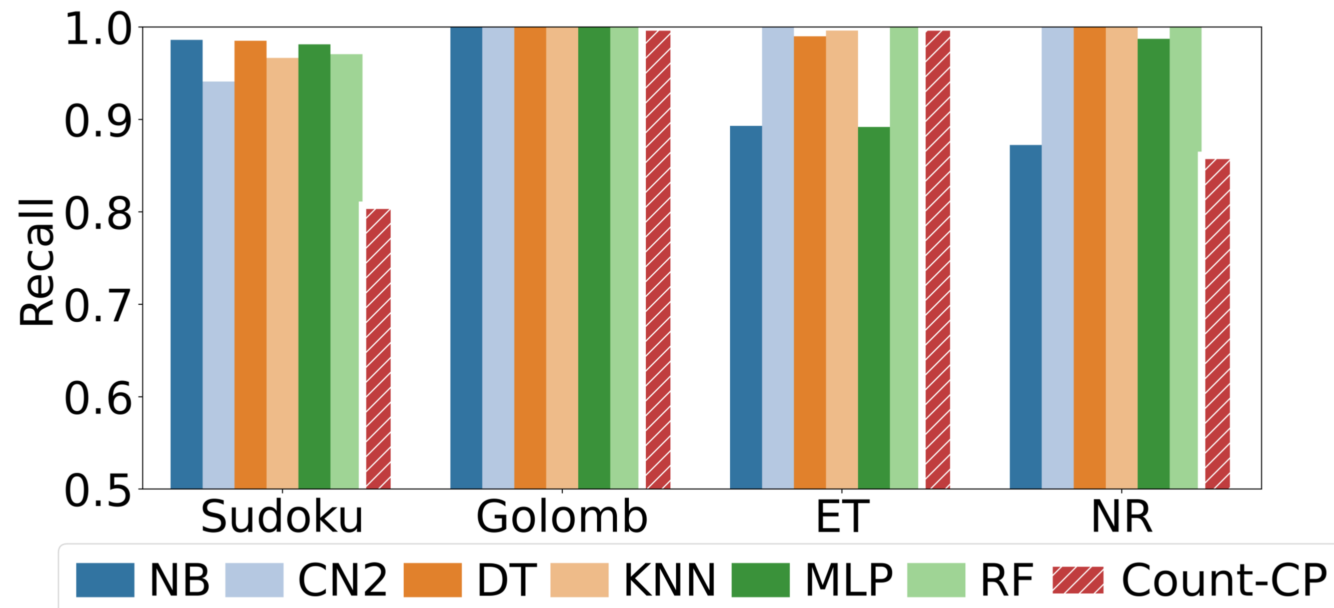
Classifiers:

- Random Forests (RF)
- Naïve Bayes (NB)
- Multilayer Perceptron (MLP)
- Support Vector Machines (SVM)
- Decision Trees (DT)
- CN2 rule learner (CN2)

Comparing against:

- Count-CP Generalization





Conclusions

- **Statistical ML can detect patterns in ground constraint models and effectively generalize them.**
- **Even when the models learned are noisy!**
- **Interpretable CSs can be directly extracted from decision rules.**
- **Generate-and-test approach can be used to generalize with non-interpretable classifiers.**

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