Constraint Acquisition

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21-05-19
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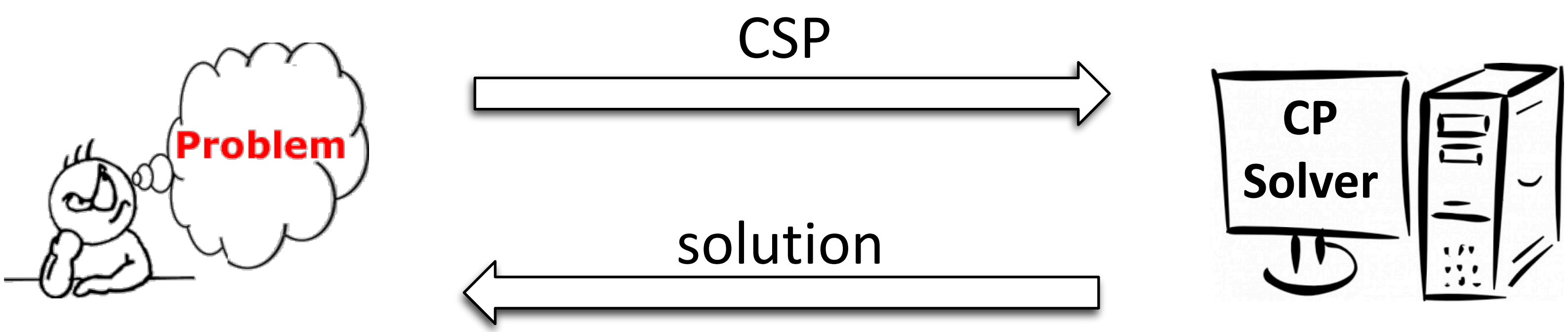
Motivations



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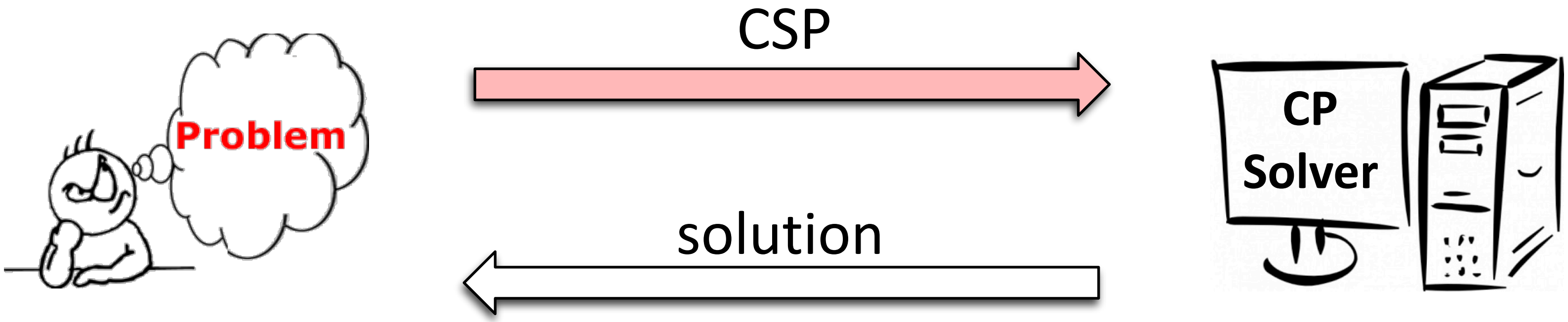

- Question: How does the user write down the constraints of a problem?
- Limitations: modelling constraint networks require a fair expertise

[Freuder99, Frisch et al.05, Smith06]

- Need: Simple way to build constraint model ➔ Modeller-assistant

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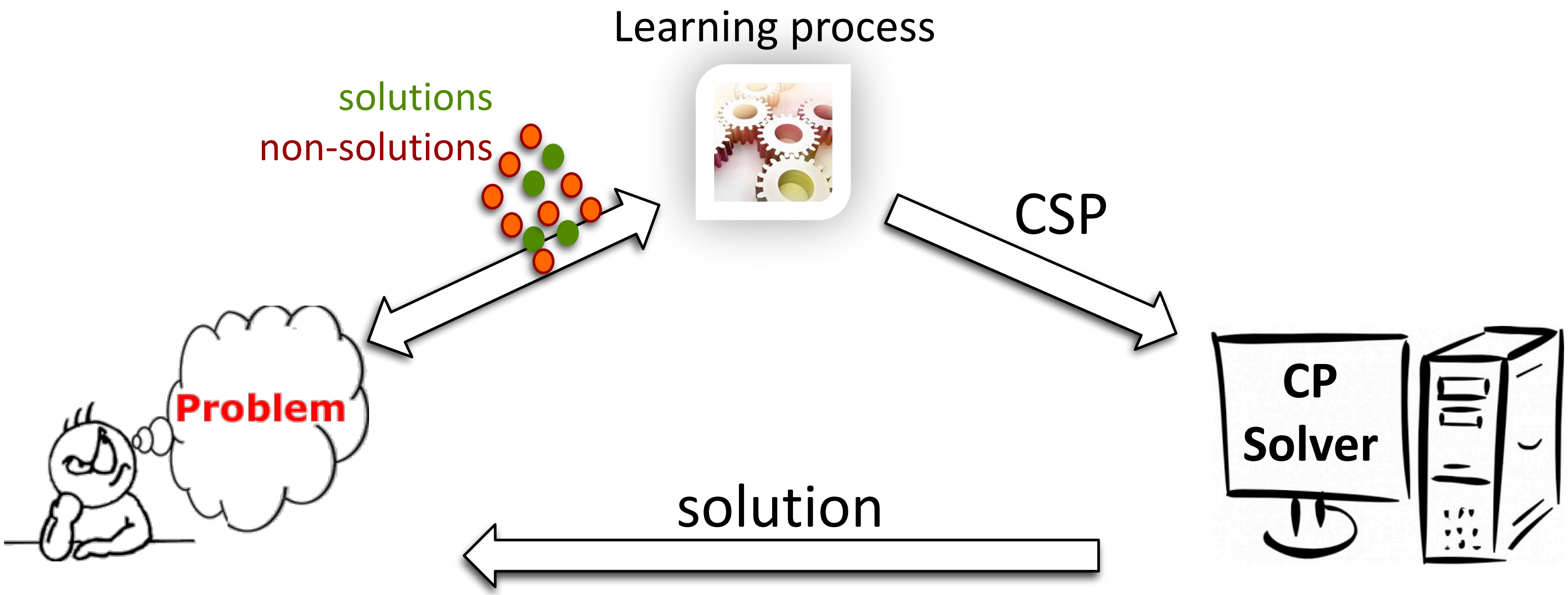

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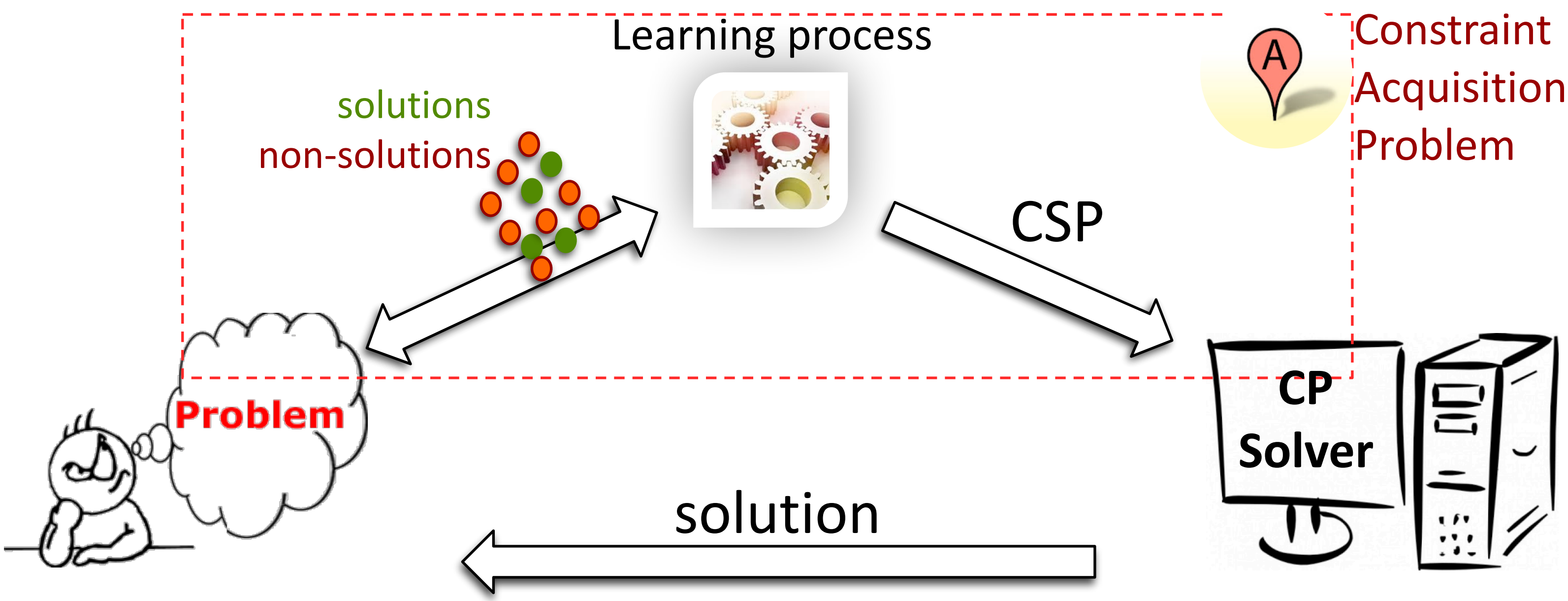

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Acquisition using standard ML

- Empirical Model Learning [Lombardi and Milano, AIJ17]
  - Extracting an Empirical Model using Neural Networks and Decision Trees
  - Empirical Model in terms of variables/constraints
- Model Agnostic Solution of CSPs via Deep Learning: A preliminary [Galassi et al., CPAIOR18]
- Study Boundary estimation for constraint optimization problem [Spieker and Gotlieb, ISMP18]
  - Learning boundaries for objective variables
  - Based on supervised learning (data curation, regression models)

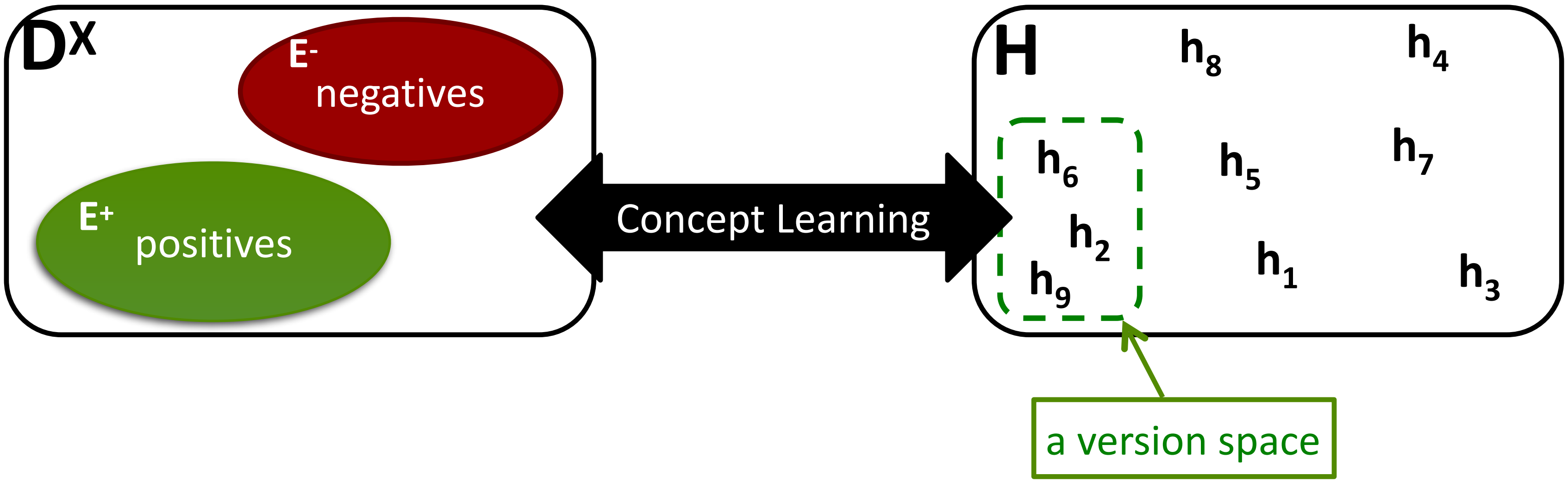
Version Space Learning (Overview) [Mitchell82]

- Let $X = x_1,..,x_n$ a set of attributes of domains $D = D_1,..,D_n$
- A concept is a Boolean function $f : X \to \{0, 1\}$
  - *$f(x_i)=0$* => *x_i* is a negative instance
  - *$f(x_j)=1$* => *x_j* is a positive instance

Given a set of hypothesis **H**, any subset of **H** represents **a version space**

- A concept **to learn** is the set of **positive instances** that can be represented by **a version space**

Version Space Learning (Overview) [Mitchell82]

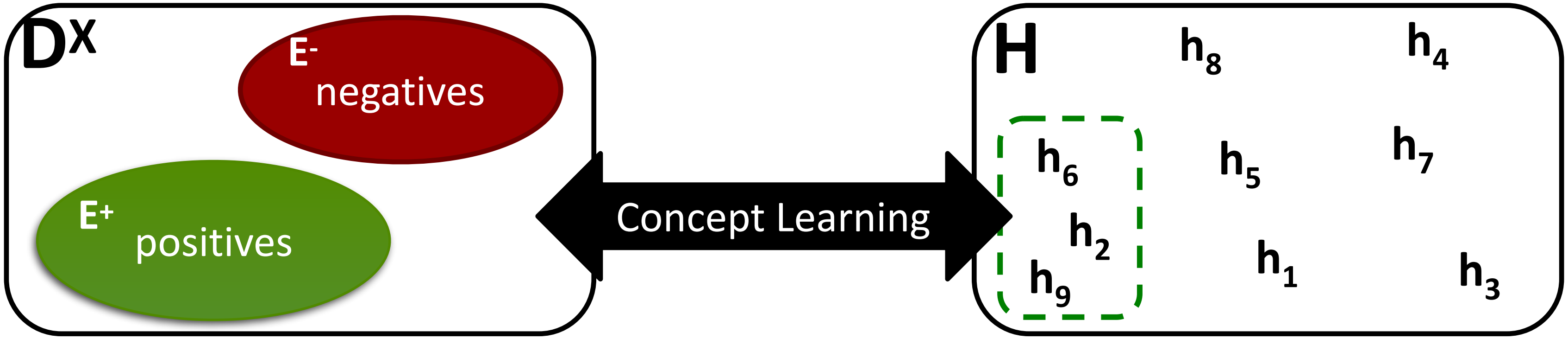


- Most specific concept to learn:

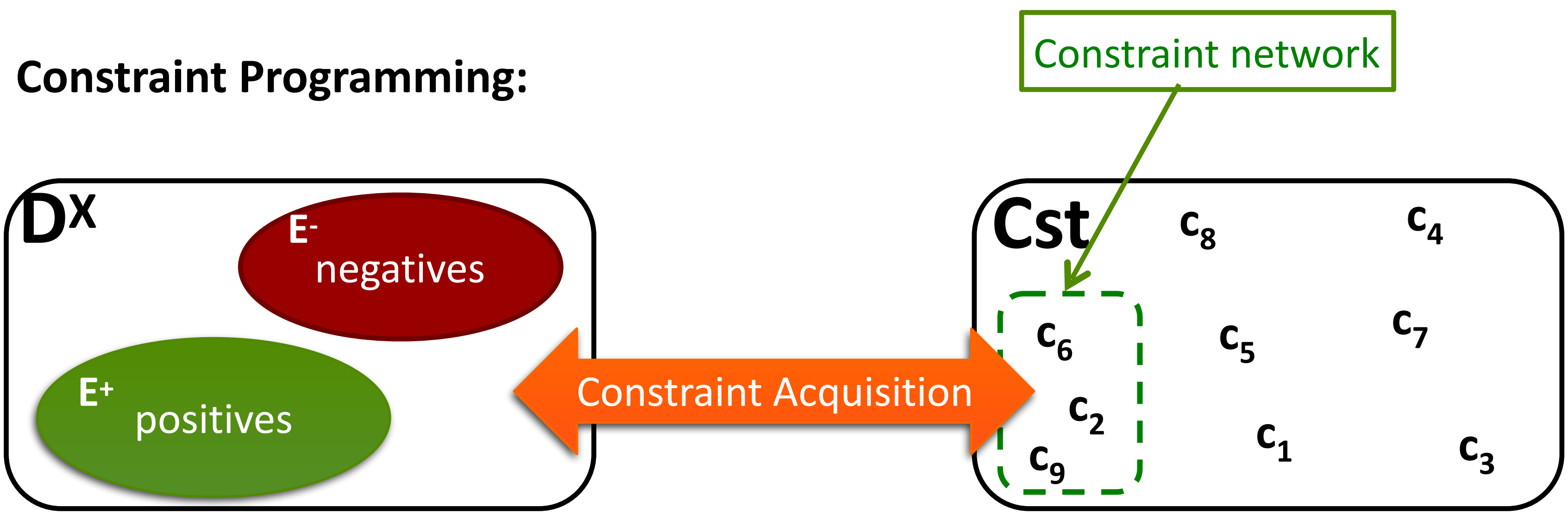
$$f: \quad (\forall x_i \in E^+ : f(x_i) = 1) \wedge (\forall x_i \in E^- : f(x_i) = 0)$$

$$\boxed{f \equiv h_2 \wedge h_6 \wedge h_9}$$

Constraint Acquisition as Version Space Learning

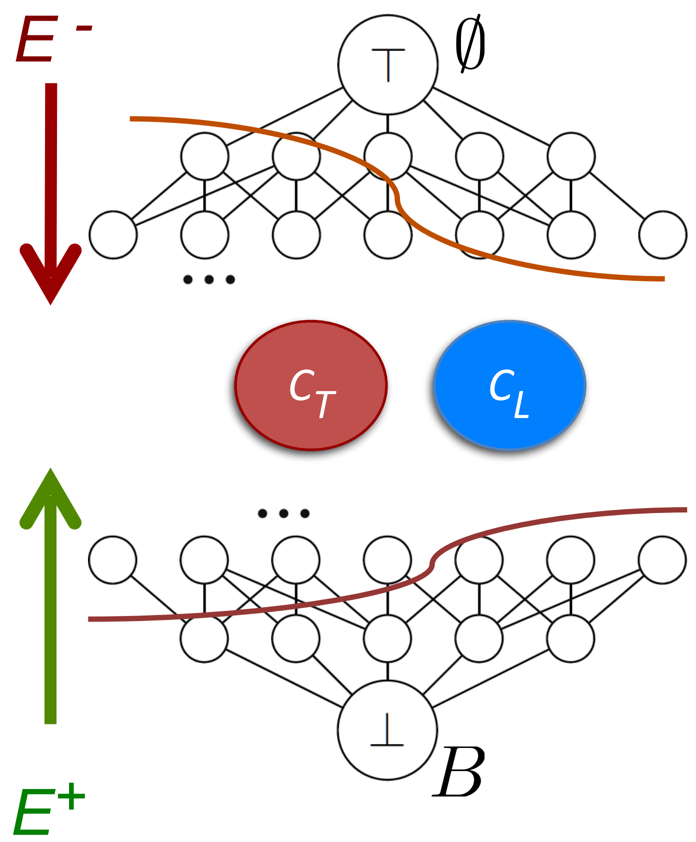


Constraint Programming:



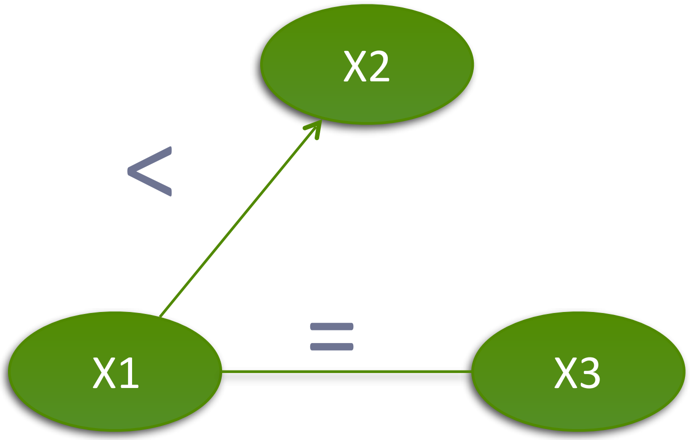
Constraint Acquisition Problem

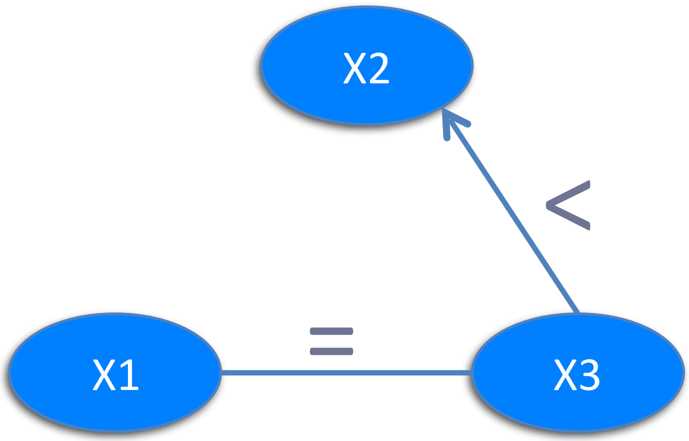
- Inputs:
  - (X,D): Vocabulary
  - Γ: Constraint language
    - → B: Bias (constraints/hypothesis)
  - C_T: Target Network (concept to learn)
  - (E^+,E^-): training set
- Output:
- C_L: Learned network such that:



Example

- $\Gamma = \{<, =\}$
- $B = \{x_i < x_j, x_i = x_j, \forall i, j\}$
- $C_T = \{x_1 = x_3, x_1 < x_2\}$
- $C_L = \{x_1 = x_3, x_3 < x_2\}$



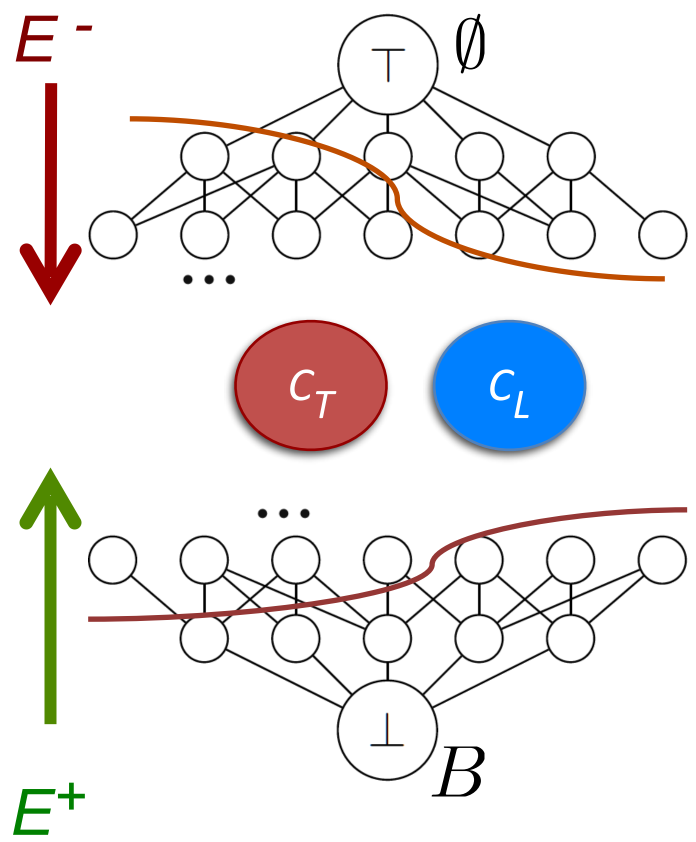


Constraint Acquisition Problem

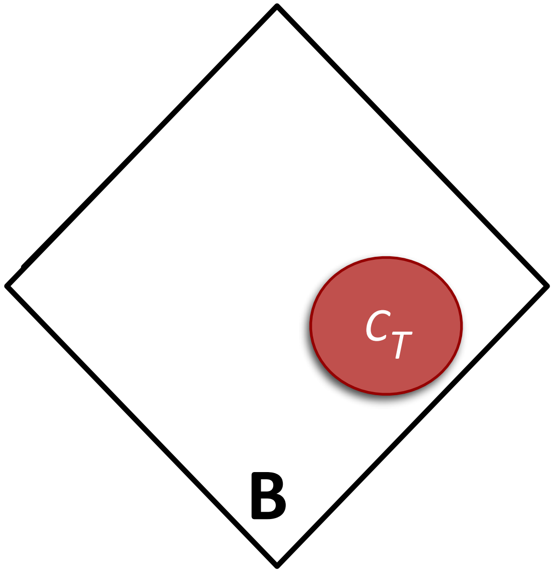
- Convergence Problem:
  - C_L agrees with E
  - For any other network' $C' \subseteq B$ agreeing with E, we have:

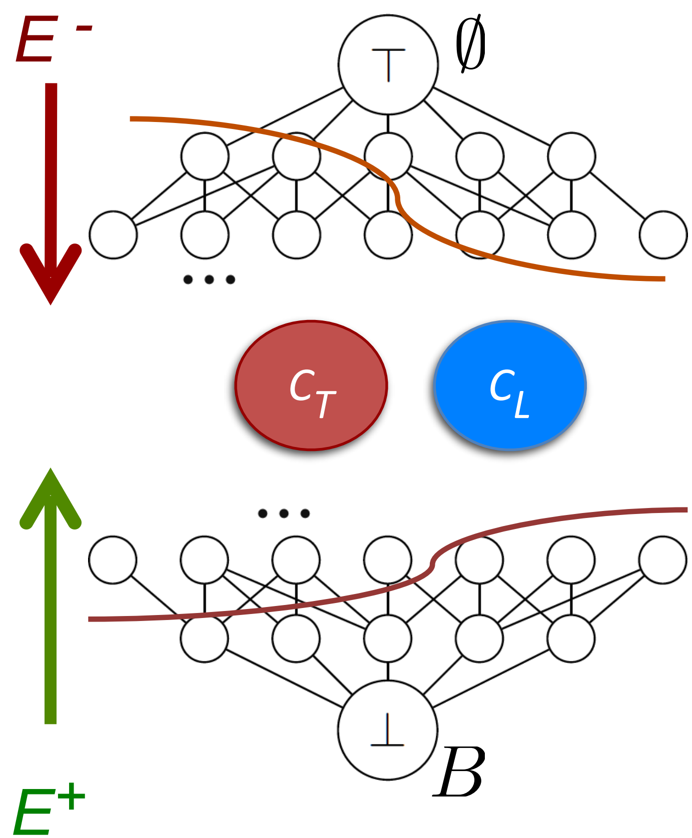
$$sol(C') = sol(C_L)$$

coNP-complete [Constraint Acquisition, AIJ17]



Convergence / Collapse states





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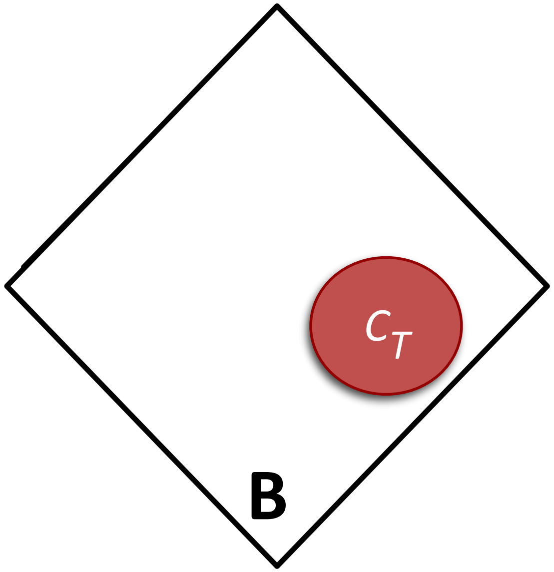
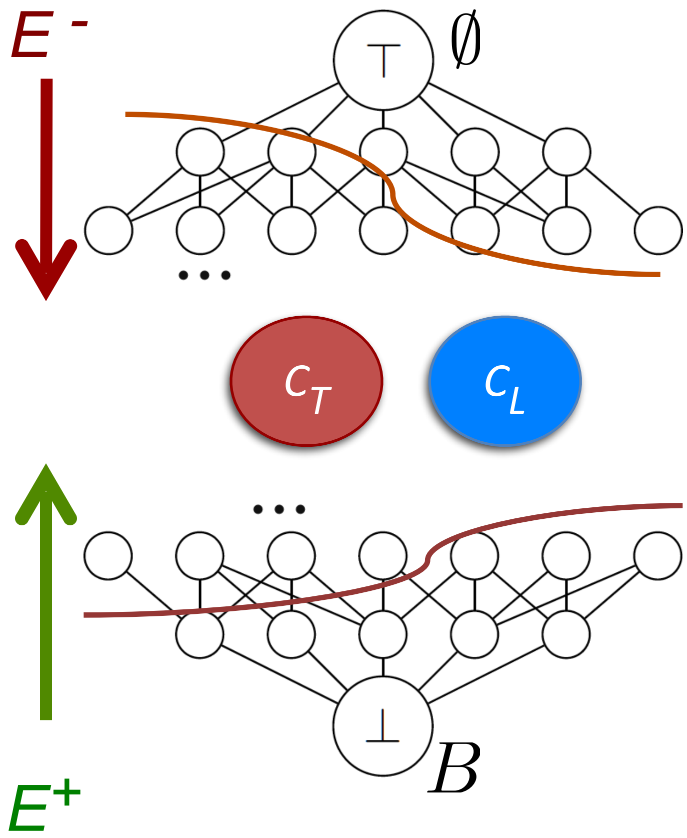


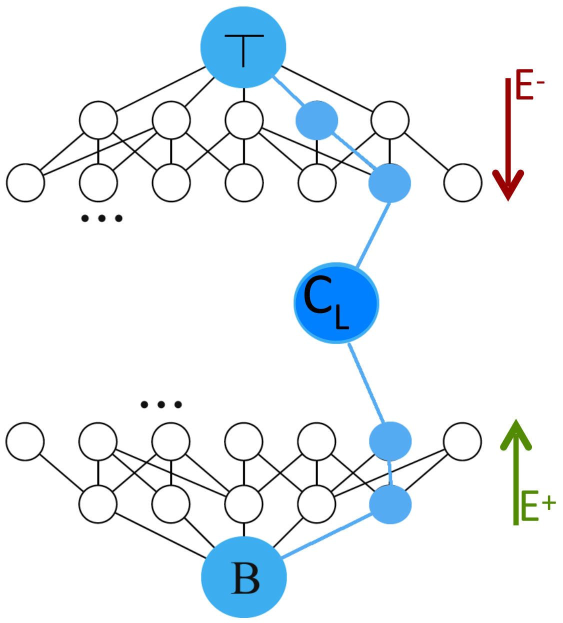
Collapse state



Acquisition using membership queries

- CONACQ [Bessiere et al. AIJ17]
  - SAT-Based constraint acquisition
  - Bidirectional search using Membership queries
  - Conacq1.0 (passive learning)
  - Conacq2.0 (active learning)

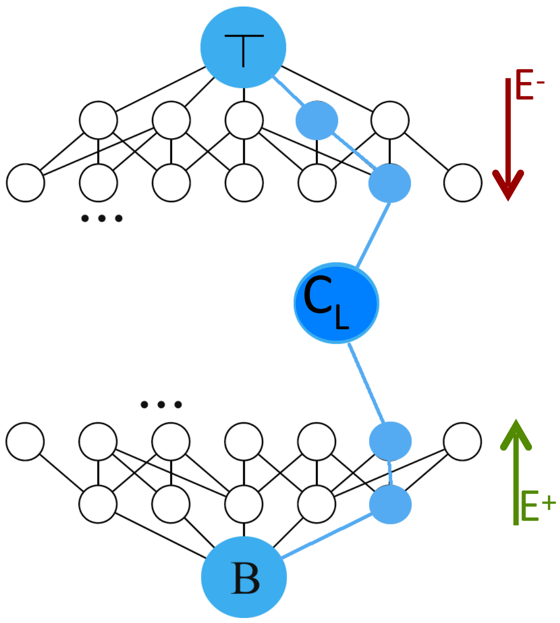
$$\mathcal{K} = \underbrace{(\neg x_1 \wedge \neg x_2 \wedge \neg x_3)}_{e^+} \bigwedge \underbrace{(x_4 \vee x_5 \vee x_6 \vee x_7)}_{e^-} \ldots$$



Non-learnability using Membership queries [Constraint Acquisition, AIJ17]

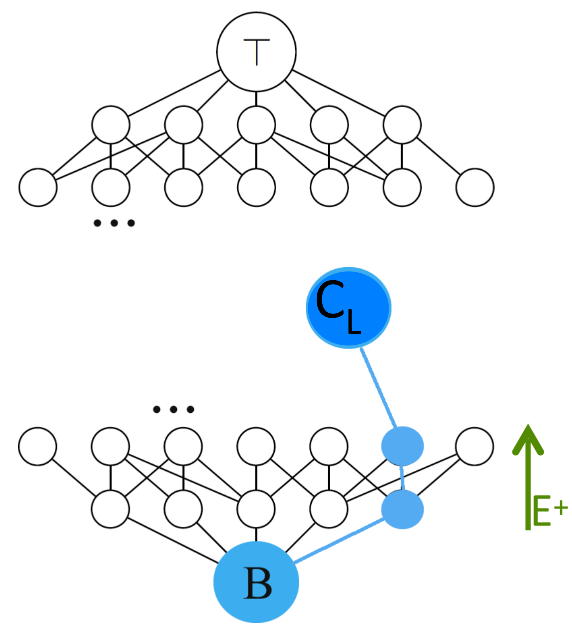
Acquisition using complex queries

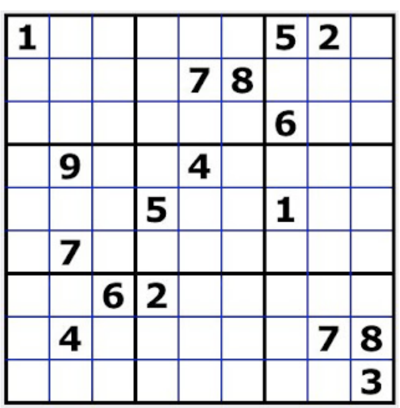
- Matchmaker agents [Freuder and Wallace wAAAI97]
- Argument-Based CONACQ [Friedrich et al.09]
- ILP-Based Acquisition [Lallouet et al. 10]

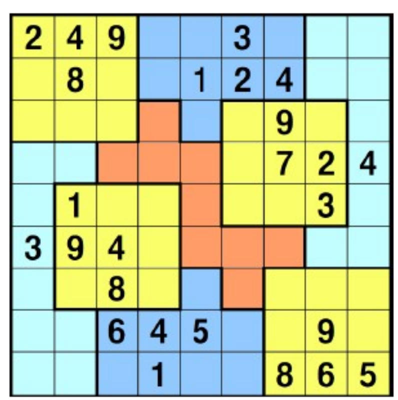


Structured problem acquisition

- ModelSeeker [Beldiceanu and Simonis, CP11'12]
  - A passive learning
  - Based on global constraint catalogue (≈1000)
  - Buttom-up search
  - ModelSeeker learns constraints underlying the scheduling of the Bundesliga (the German Football Liga) from a single example schedule.

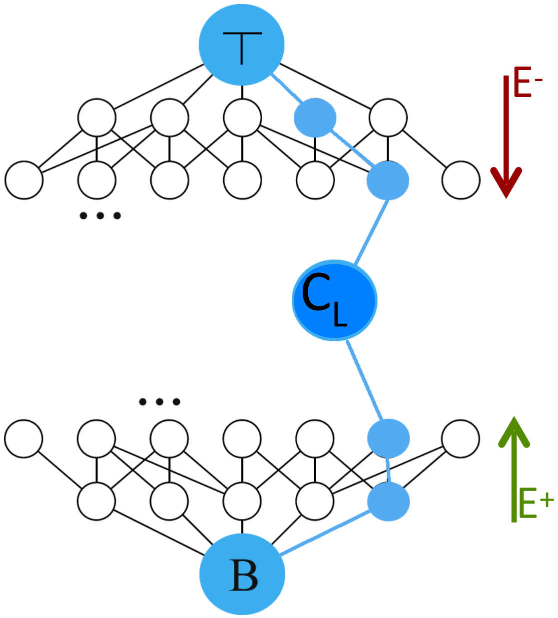


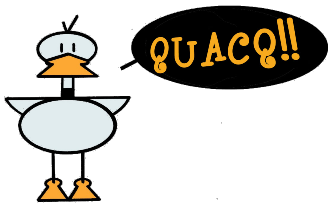




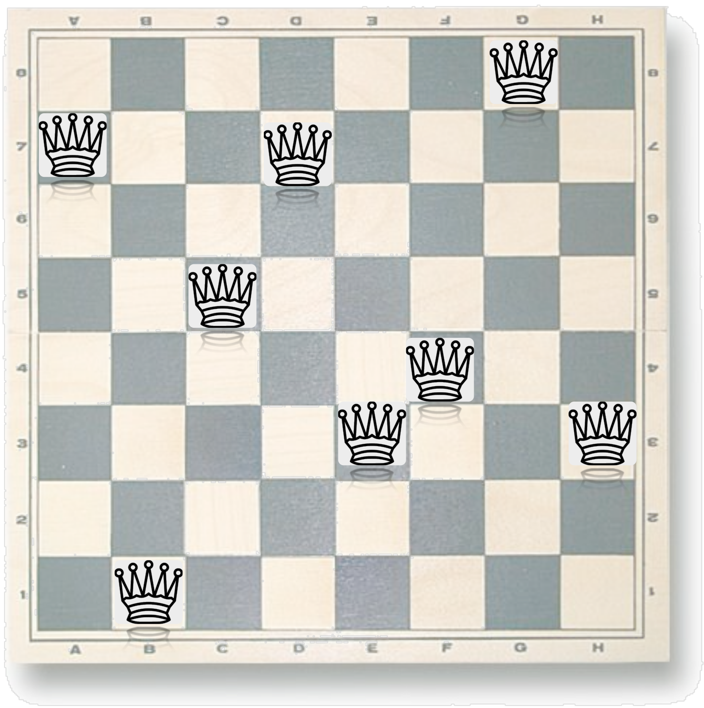
QUACQ: Quick Acquisition

- QUACQ [Bessiere et al. IJCAI13]
  - Active learning approach
  - Bidirectional search
    - But it can be top-down search if no positive example
  - Based on partial queries to elucidate the scope of the constraint to learn
  - Learnability using partial queries



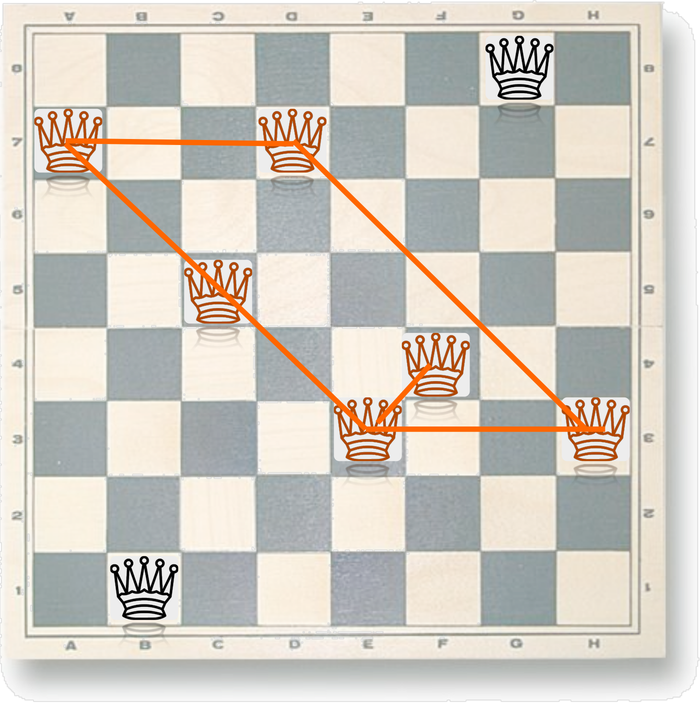


Membership Queries



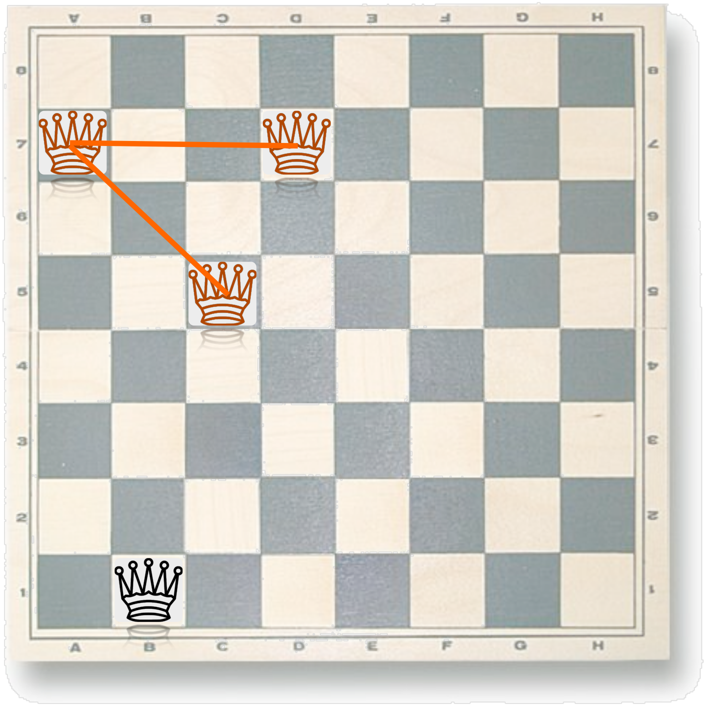
ask(2, 8, 4, 2, 6, 5, 1, 6)

Partial Queries



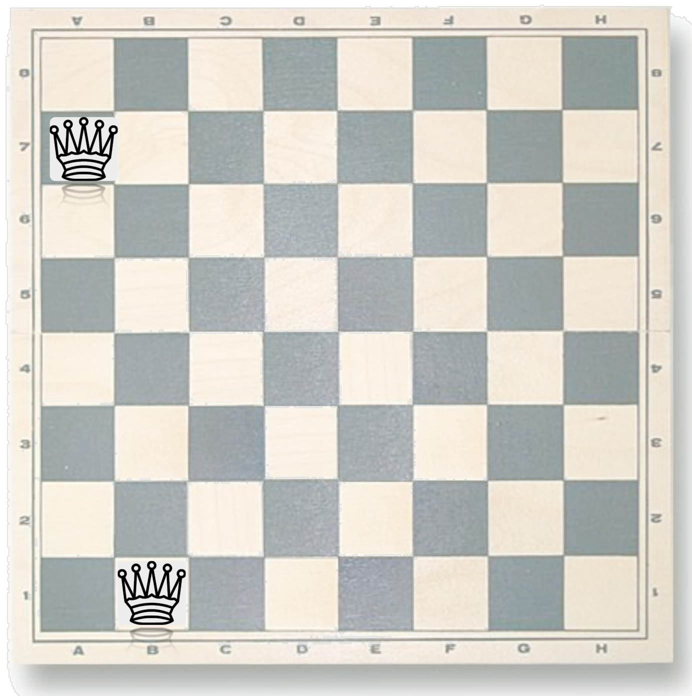
ask(2, 8, 4, 2, 6, 5, 1, 6) = No

Partial Queries



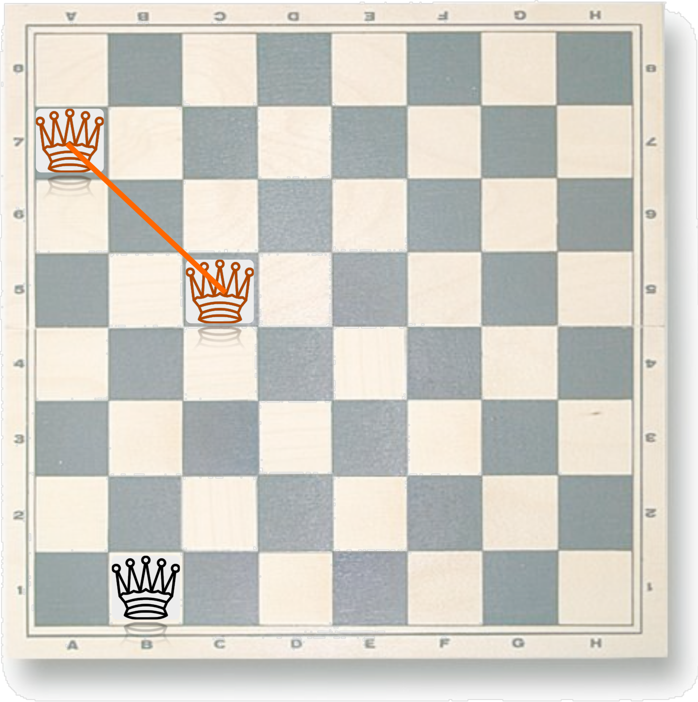
ask(2, 8, 4, 2, -, -, -, -) = No

Partial Queries



ask(2, 8, -, -, -, -, -, -) = Yes

Partial Queries



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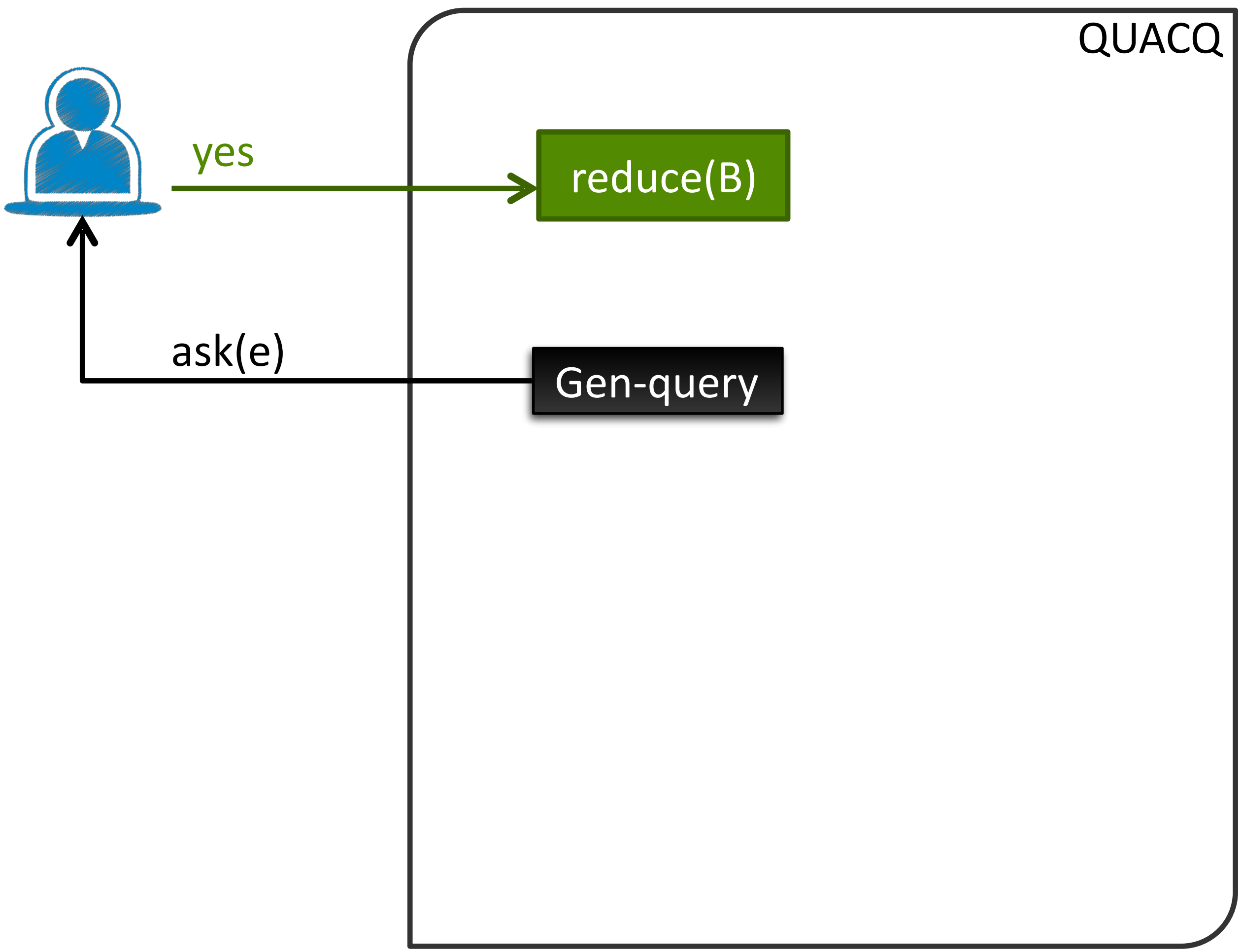

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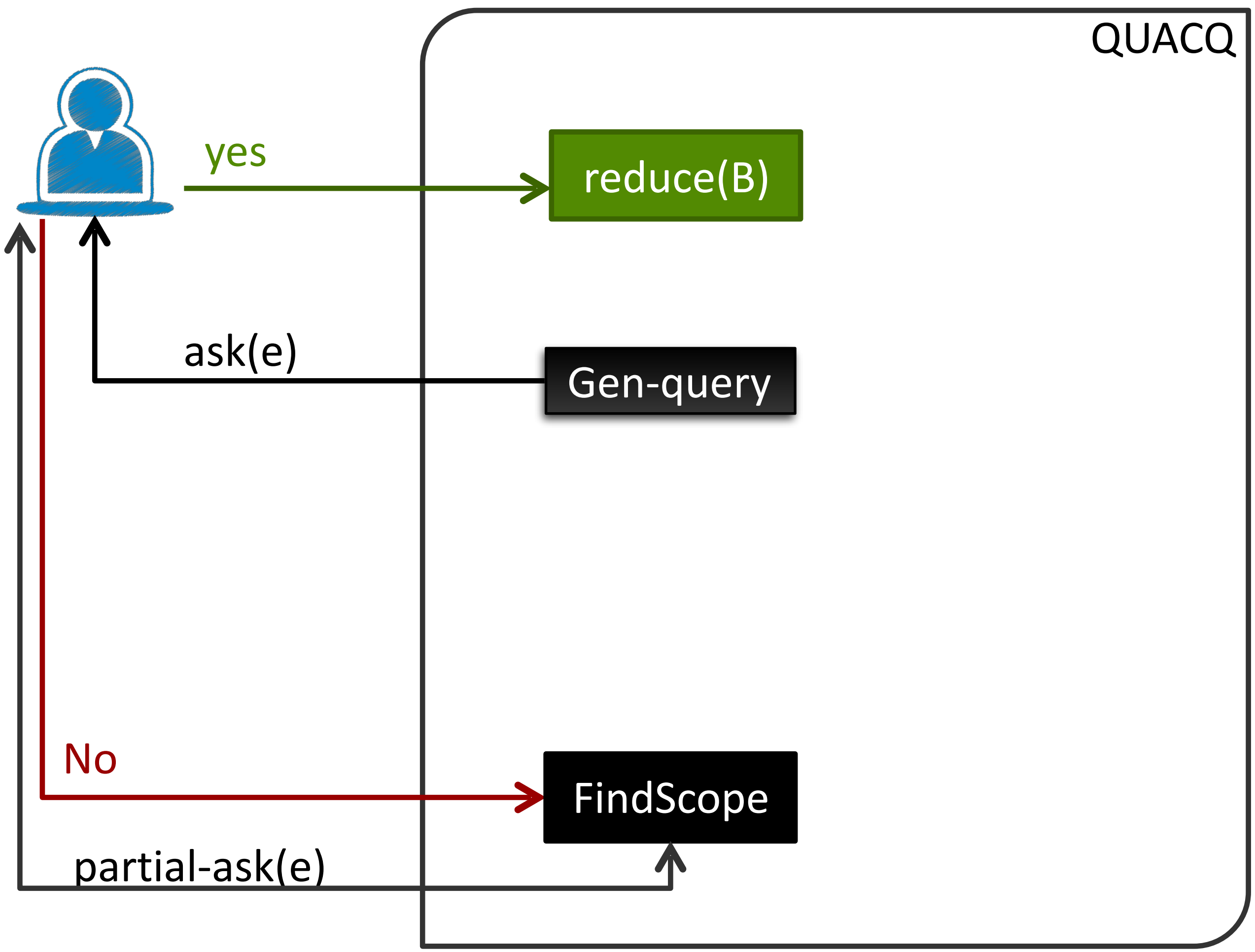

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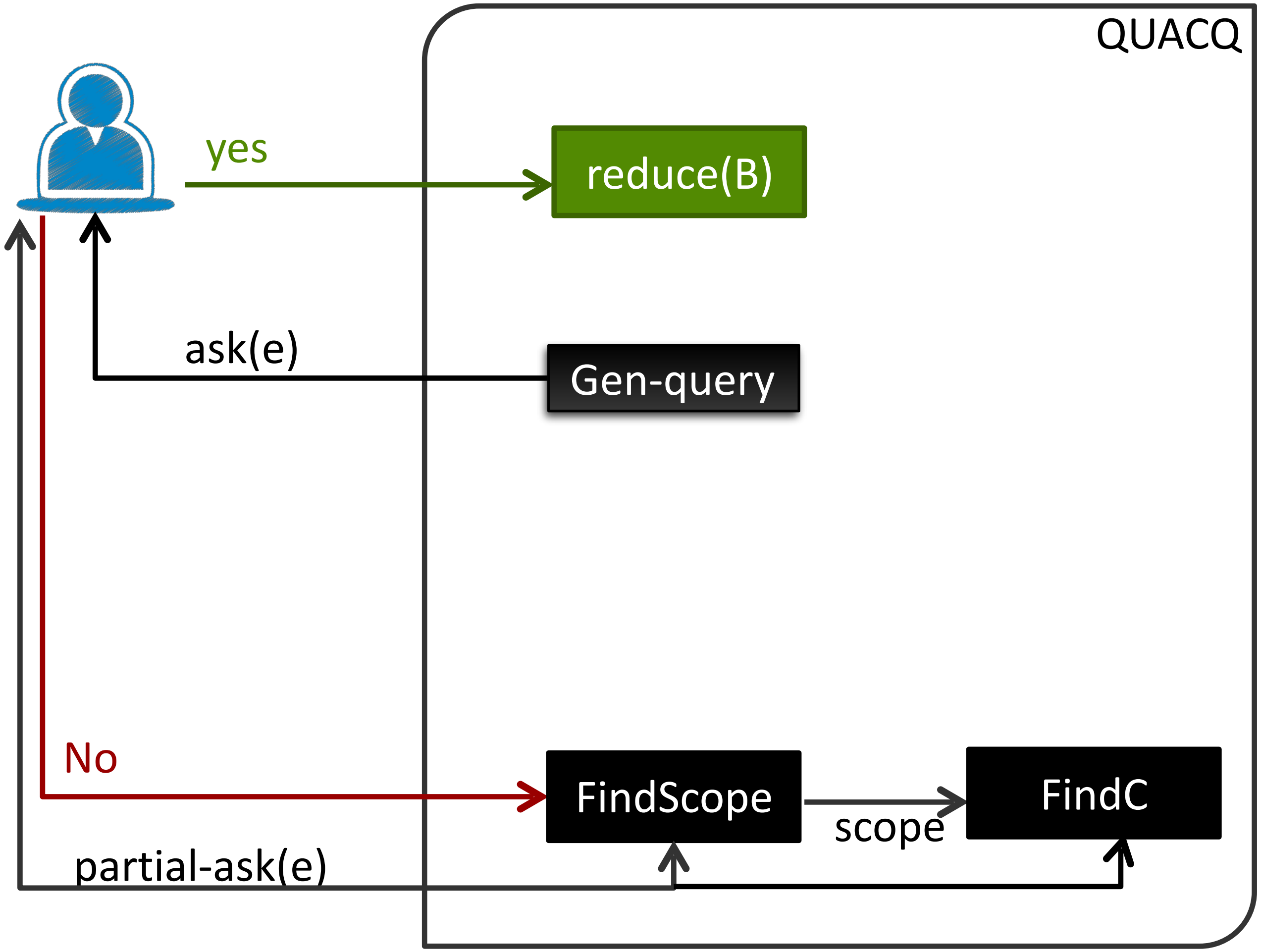

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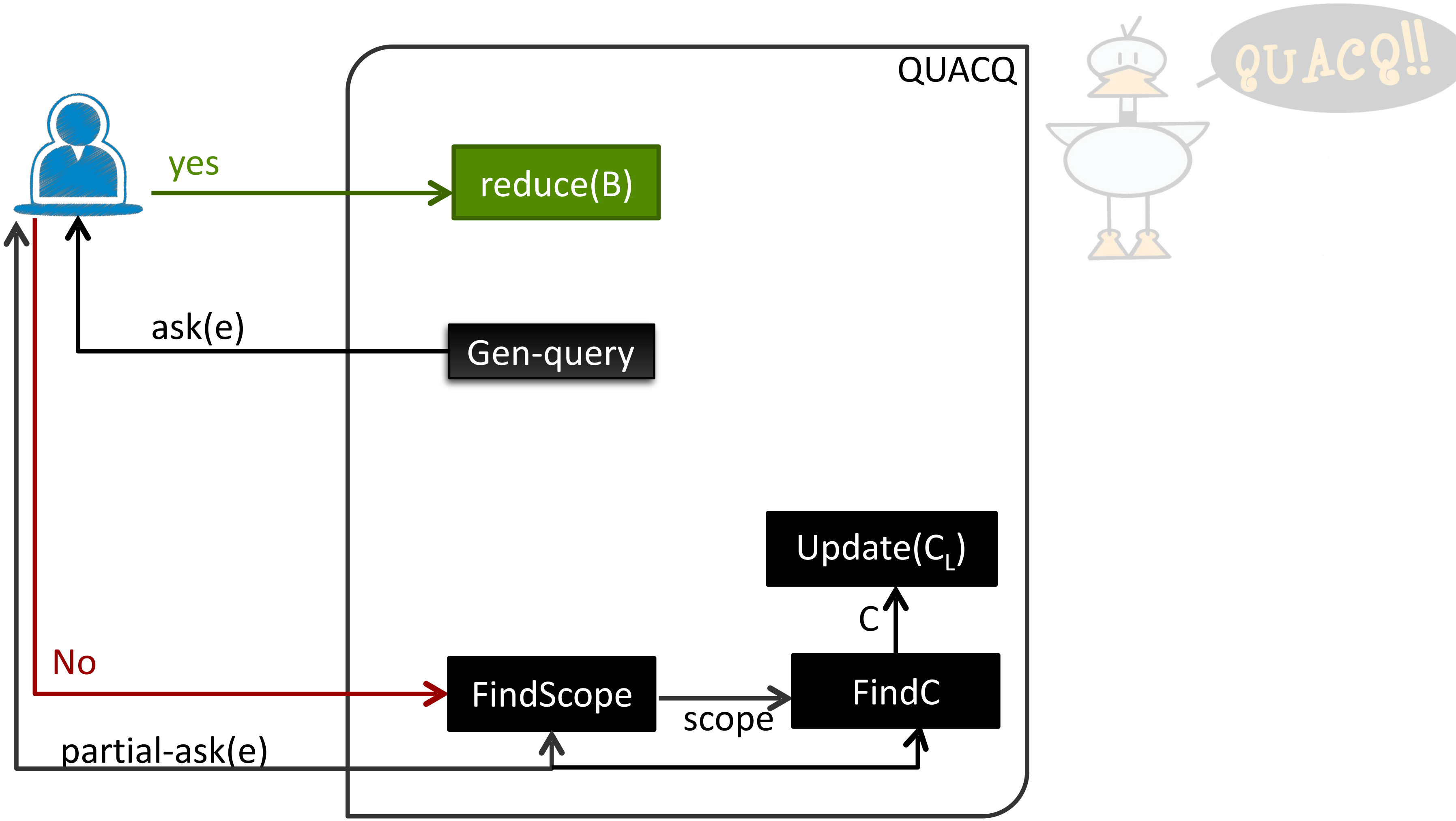

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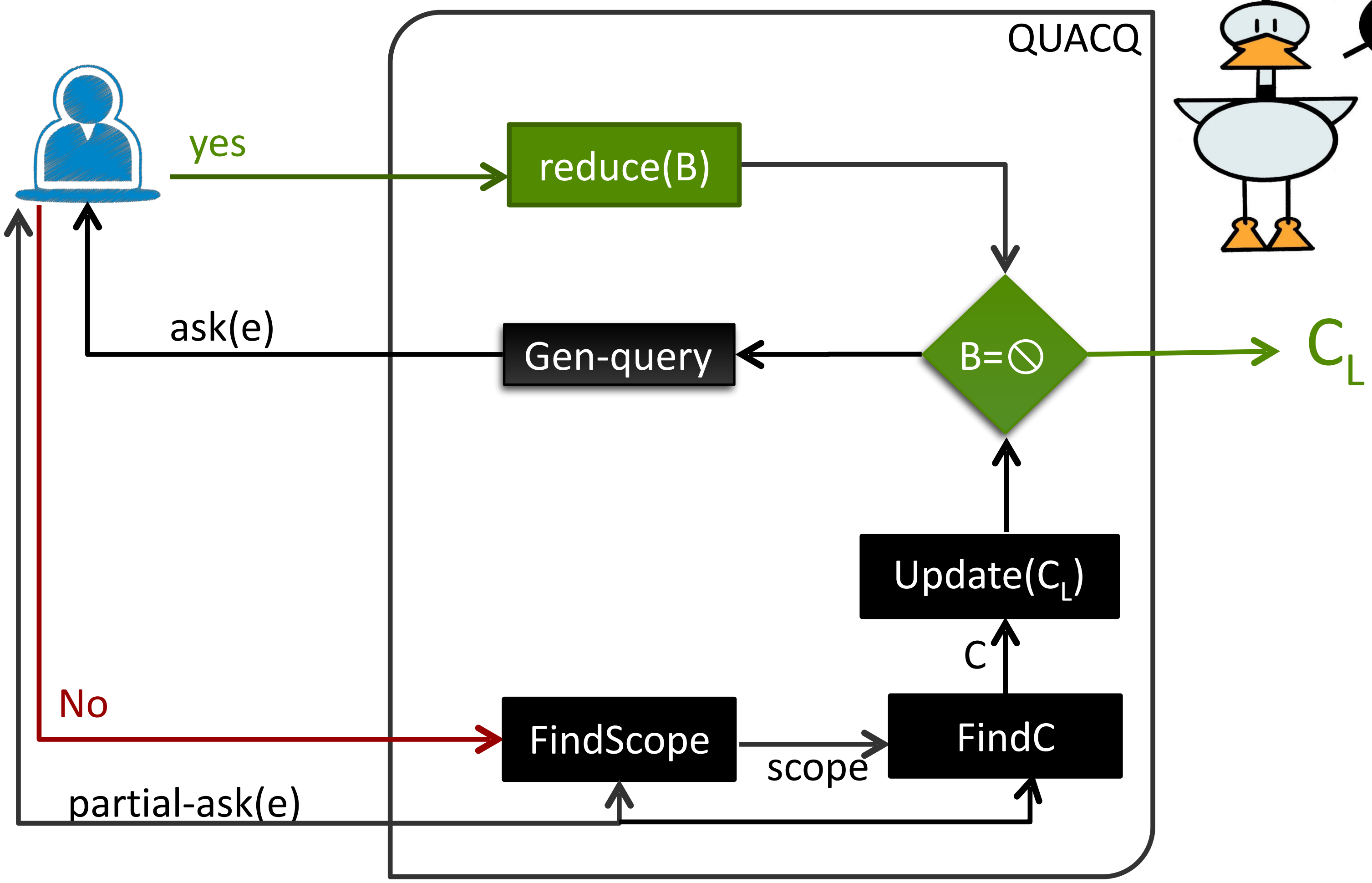
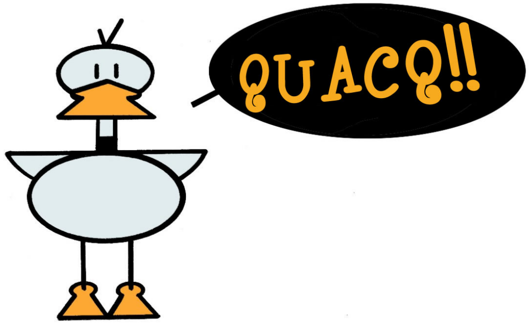




QUACQ: Quick Acquisition

Algorithm 1: QUACQ: Acquiring a constraint network C_T with partial queries

$C_L \leftarrow \varnothing$;
while *true* **do**
    if $sol(C_L) = \varnothing$ **then return** "collapse";
    choose e in D^X accepted by C_L and rejected by B;
    if $e = nil$ **then return** "convergence on C_L";
    if $ASK(e) = yes$ **then** $B \leftarrow B \setminus \kappa_B(e)$;
    else
        $c \leftarrow \texttt{FindC}(e, \texttt{FindScope}(e, \varnothing, X, \textbf{false}))$;
        if $c = nil$ **then return** "collapse";
        else $C_L \leftarrow C_L \cup \{c\}$;

Complexity of QUACQ

- The number of queries required to find the target concept is in:

$$O(|C_T| \cdot (\log |X| + |\Gamma|))$$

- The number of queries required to converge is in:

$$O(|B|)$$

E^{-}

E^{+}

In practice?

Limitations:

- QUACQ needs more than **8000** queries to learn the Sudoku model
- Generating a query can be time-consuming

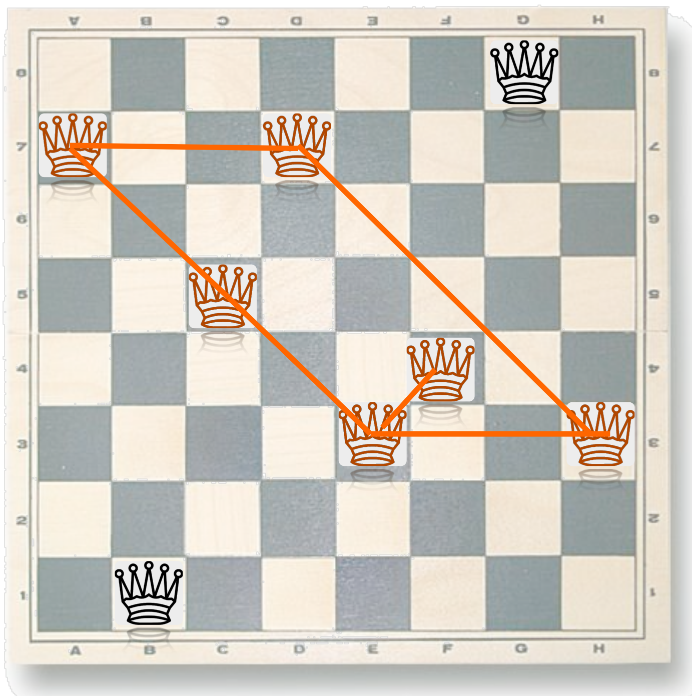
Need:

- Reduce the dialogue with the user and the waiting time

How:

- **Eliciting more information on why a complete instantiation is classified as negative by the user [MultiAcq, IJCAI16]**
- Eliciting more information by asking complex queries to the user [ECAI14, ICTAI15, IJCAI16]
- Time-bounded query generator [T-QUACQ, CPAIOR'18]

Partial Queries



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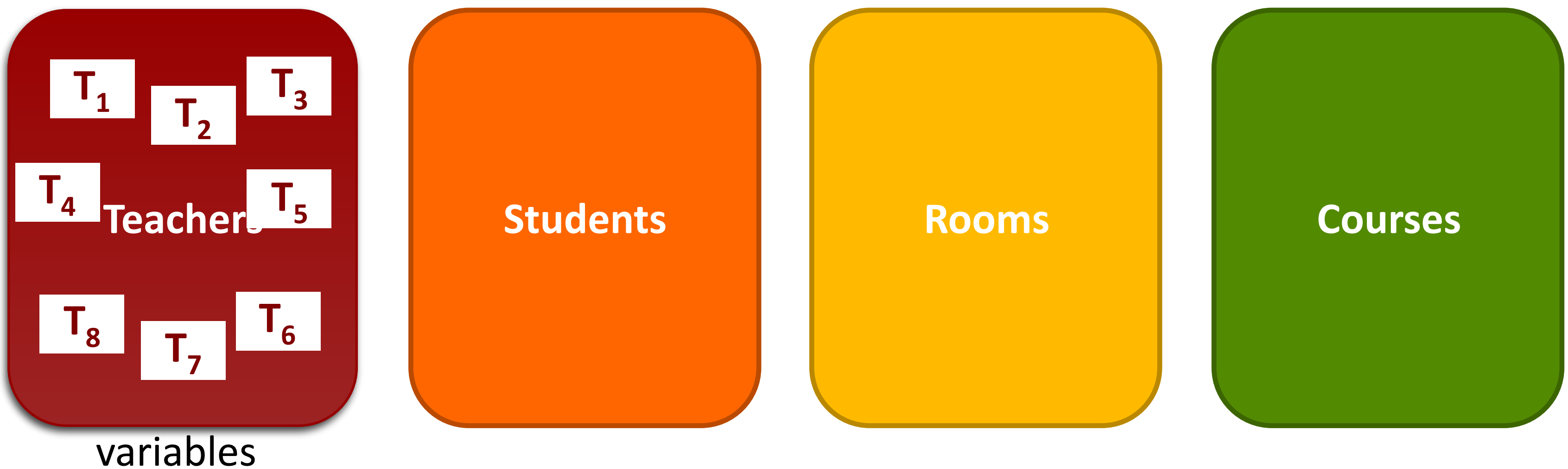
Variables and Types

- A type is a subset of variables defined by the user as having a common property
- Example (School Timetabling Problem)



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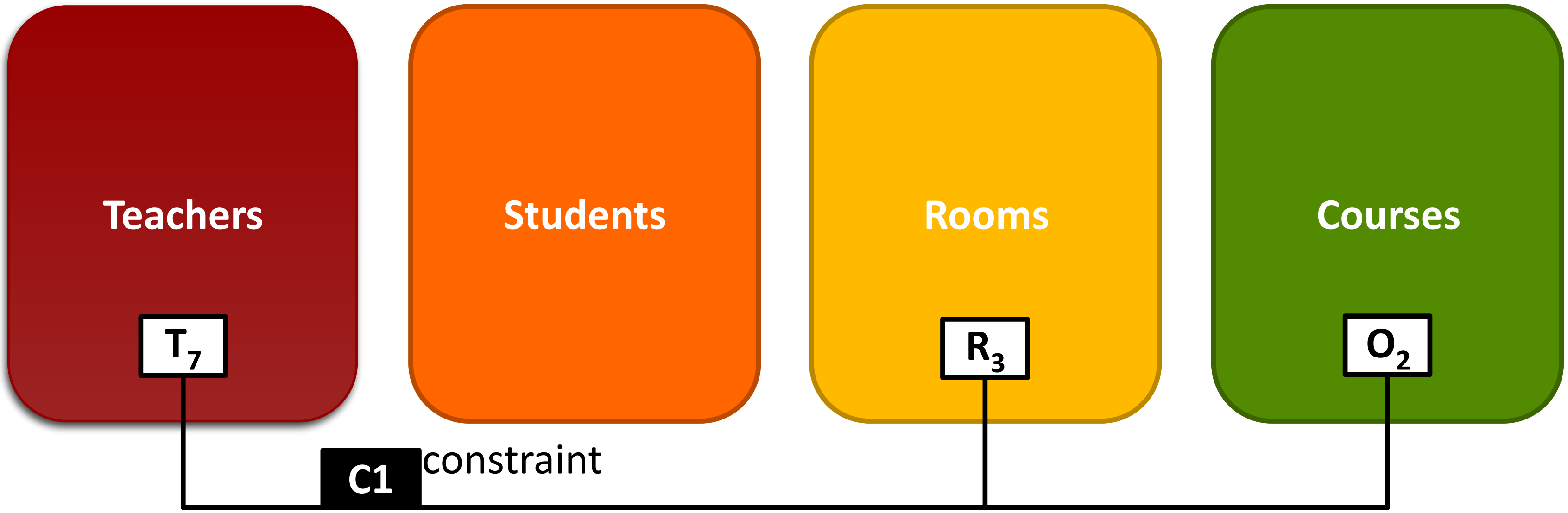

Can C1 be generalized to all Teachers, Rooms and Courses?

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Conclusions

- Formal definition of Constraint Acquisition Problem
- Architectures for acquiring constraint networks
- Future works:
  - Taxonomy of queries
  - Constraint Acquisition toolbox

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