Context-Aware Clause Selection Using Symbol Name Meanings in Theorem Proving

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HOCHSCHULE TRIER

Automated Reasoning

$subclass(bed, furniture)$
$subclass(doublebed, bed)$
$subclass(pillow, artifact)$
$subclass(blanket, fabric)$
$\ldots$

$\forall x(instance(x, hammock) \rightarrow$
$(material(x, fabric) \wedge \ldots$

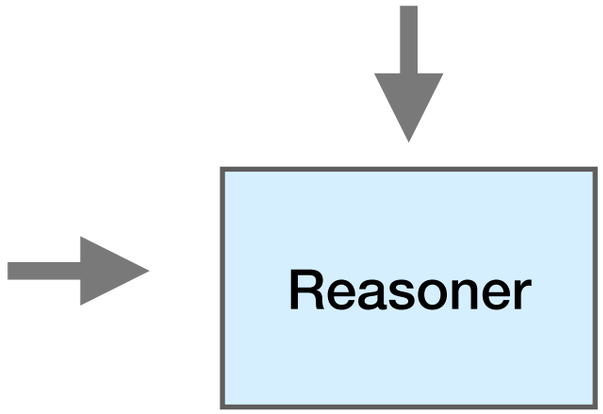
$\ldots$

$\forall x, y, z$
$((subclass(x, y) \wedge subclass(y, z)) \rightarrow$
$subclass(x, z))$

$subclass(weapon, device)$
$subclass(device, artifact)$

Knowledge Base

Goal:
Are hammocks beds?
$\forall x(instance(x, hammock) \rightarrow instance(x, bed))$



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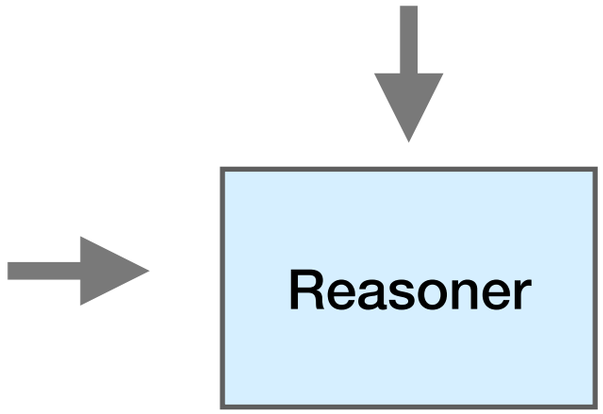

Computes inferences!

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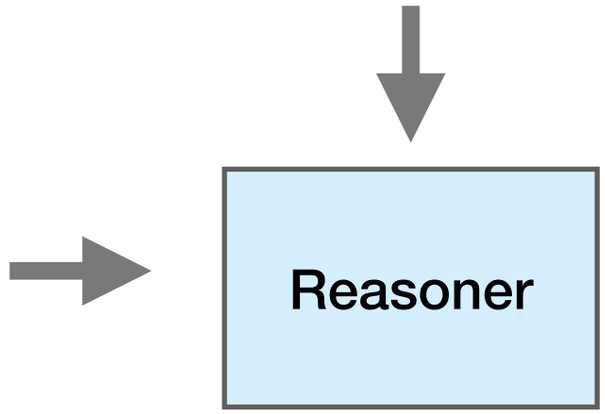


Computes inferences!

Does not take the meaning of symbols into account!

Automated Reasoning

$s(b, f)$
$s(db, b)$
$s(p, a)$
$s(bl, fa)$
$\ldots$

$\forall x(in(x, h) \rightarrow$
$(m(x, fa) \wedge \ldots$

$\ldots$

$\forall x, y, z$
$((s(x, y) \wedge s(y, z)) \rightarrow$
$s(x, z))$

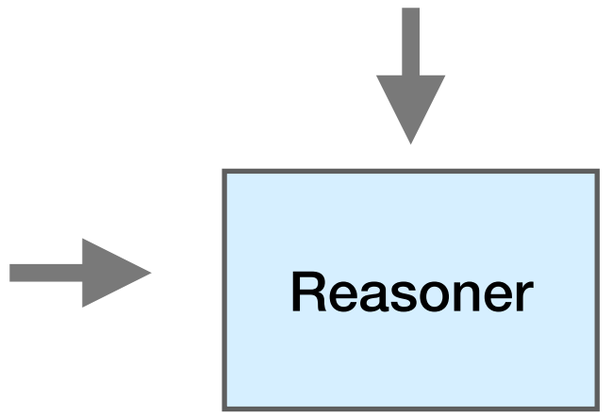
$s(w, de)$
$s(de, a)$

Knowledge Base

For the prover, the proof task looks like this:

Goal:

$\forall x(in(x, h) \rightarrow in(x, b))$



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Automated Reasoning: Are Hammocks Beds?

Reasoner: PyRes

Wortwolken.com. (2024). Word cloud generator. Available at: https://www.wortwolken.com [Accessed: 2024-08-29].

Automated Reasoning: Are Hammocks Beds?

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PyRes computes 538 resolvents!

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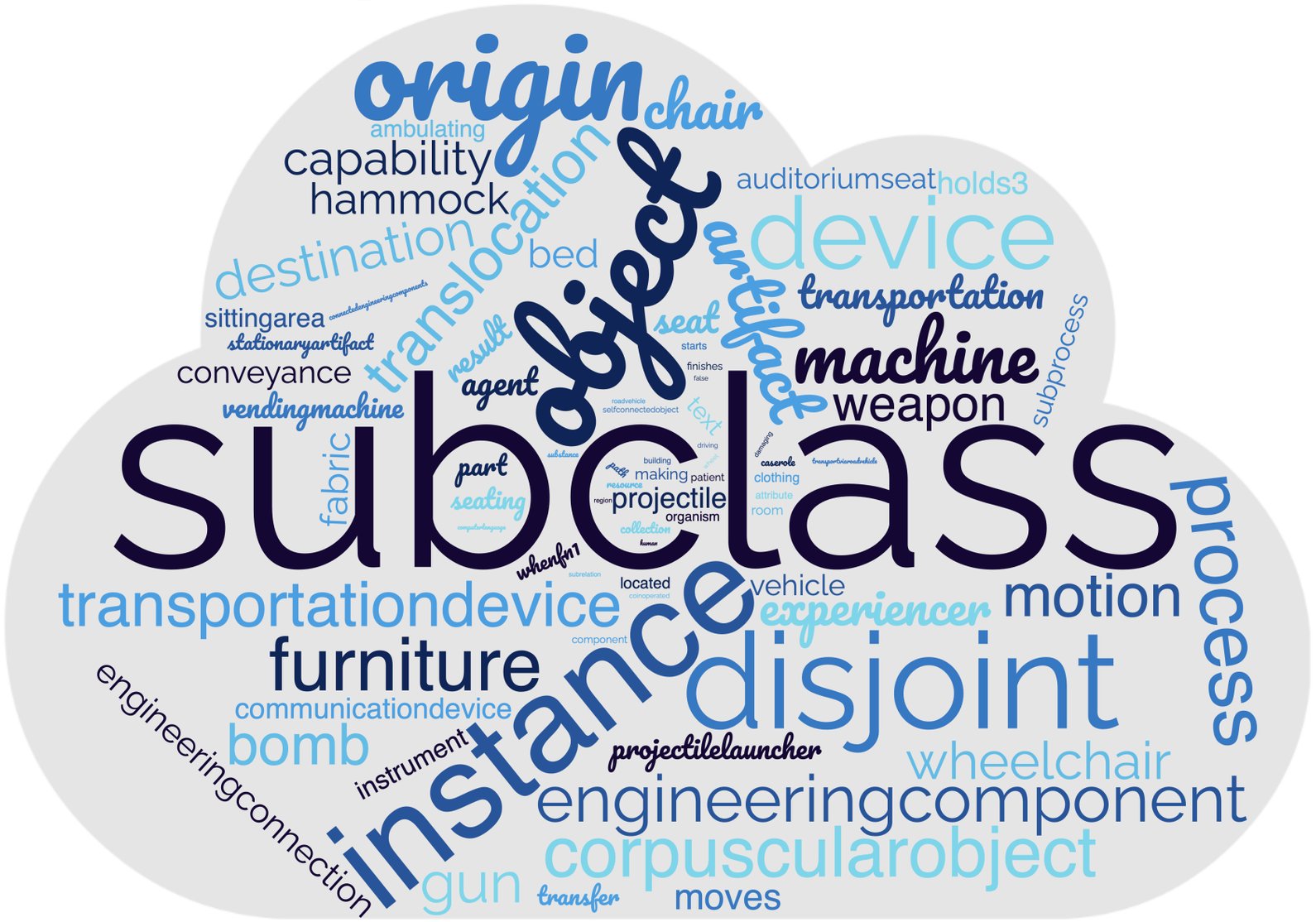

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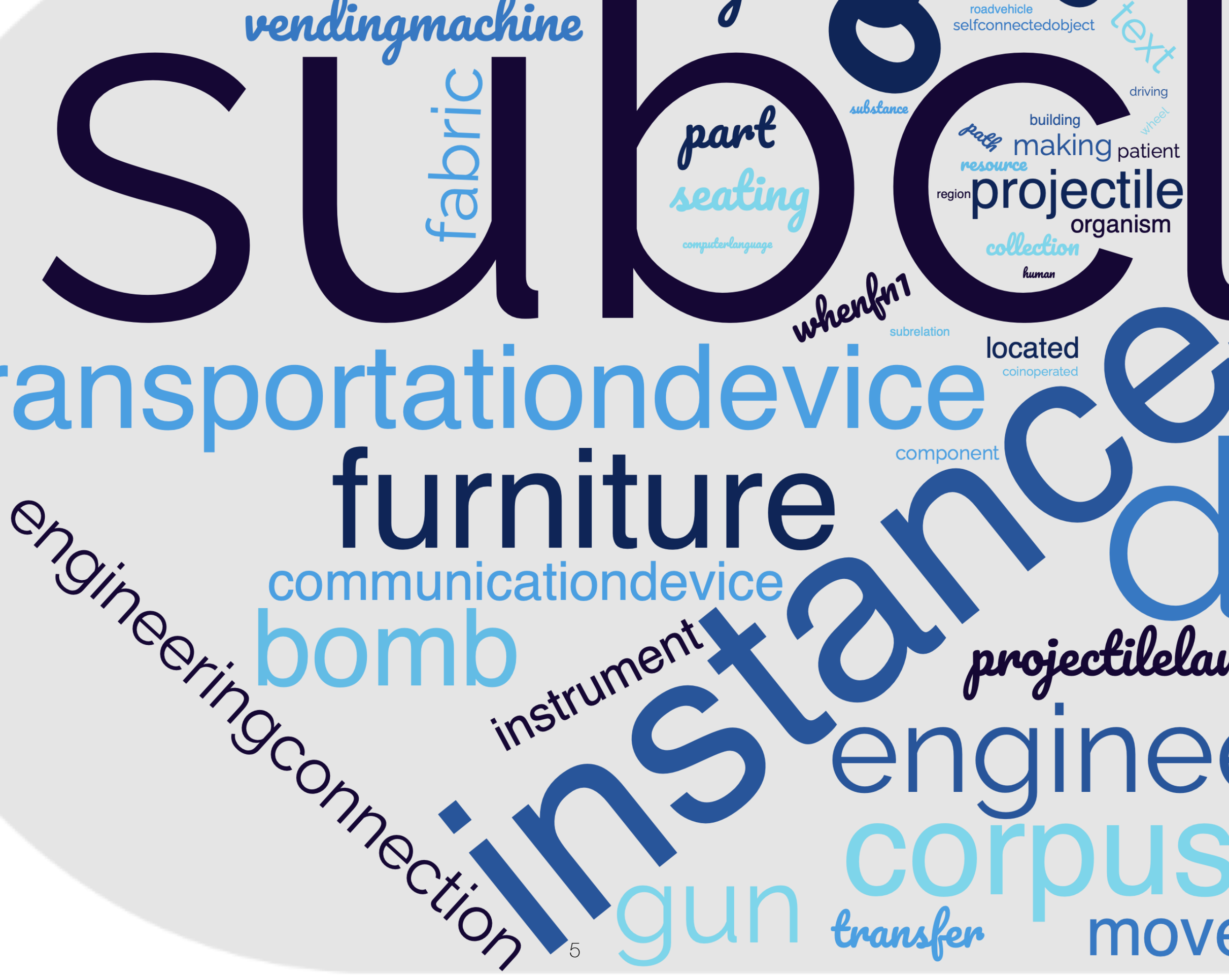
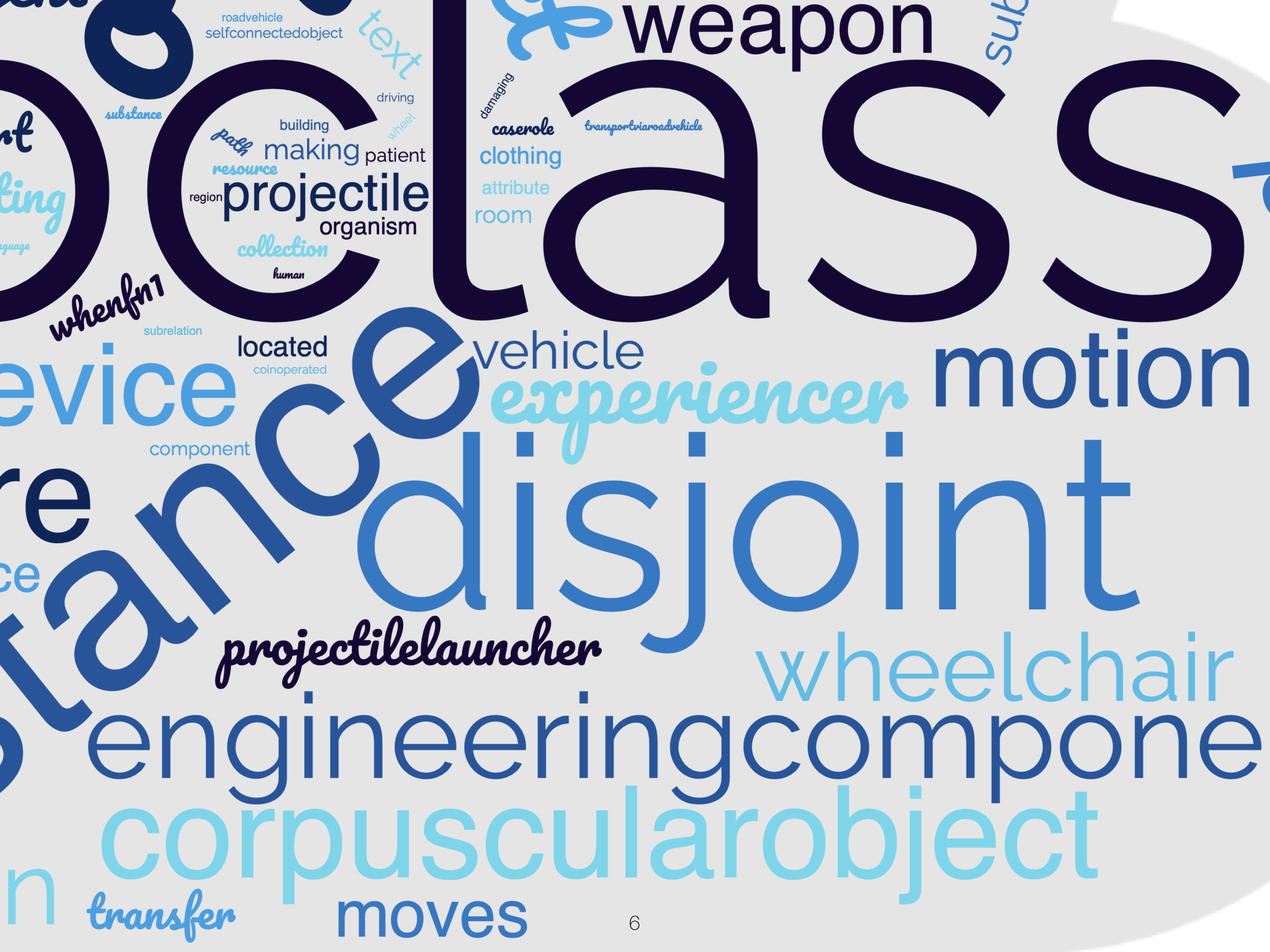
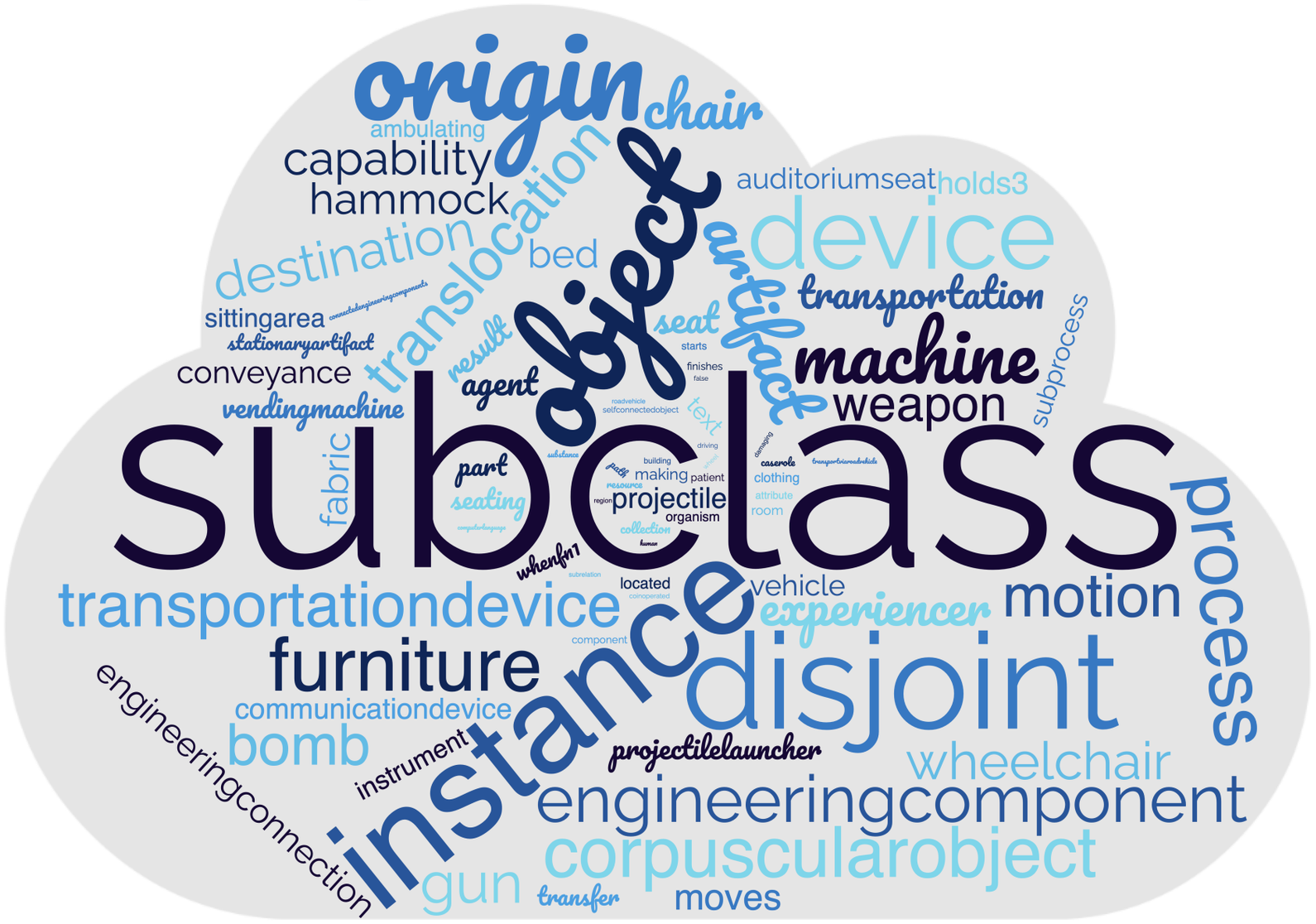

vendingmachine
fabric
roadvehicle
selfconnectedobject
text
substance
driving
wheel
part
building
path
making
patient
seating
resource
region
projectile
organism
computerlanguage
collection
human
whenfn1
subrelation
located
coinoperated
transportationdevice
component
furniture
engineeringconnection
communicationdevice
bomb
instrument
gun
transfer


weapon
text
roadvehicle
selfconnectedobject
driving
substance
building
path
making
patient
wheel
resource
region
projectile
organism
collection
human
damaging
caserole
transportviaroadvehicle
clothing
attribute
room
whenfn1
subrelation
located
coinoperated
vehicle
motion
experiencer
component
disjoint
projectilelauncher
wheelchair
engineeringcompone
corpuscularobject
transfer
moves

Automated Reasoning: Are Hammocks Beds?



Reasoner: PyRes

PyRes computes 538 resolvents!

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Why should we draw unrelated inferences in automated reasoning?

Given-Clause Algorithmus

Task: proof that $h \rightarrow b$ follows from clause set S

$\neg w \vee d$

$\neg d \vee a$

$\neg h \vee f$

$\neg h \vee s$

$\ldots$

Clause set S

Given-Clause Algorithmus

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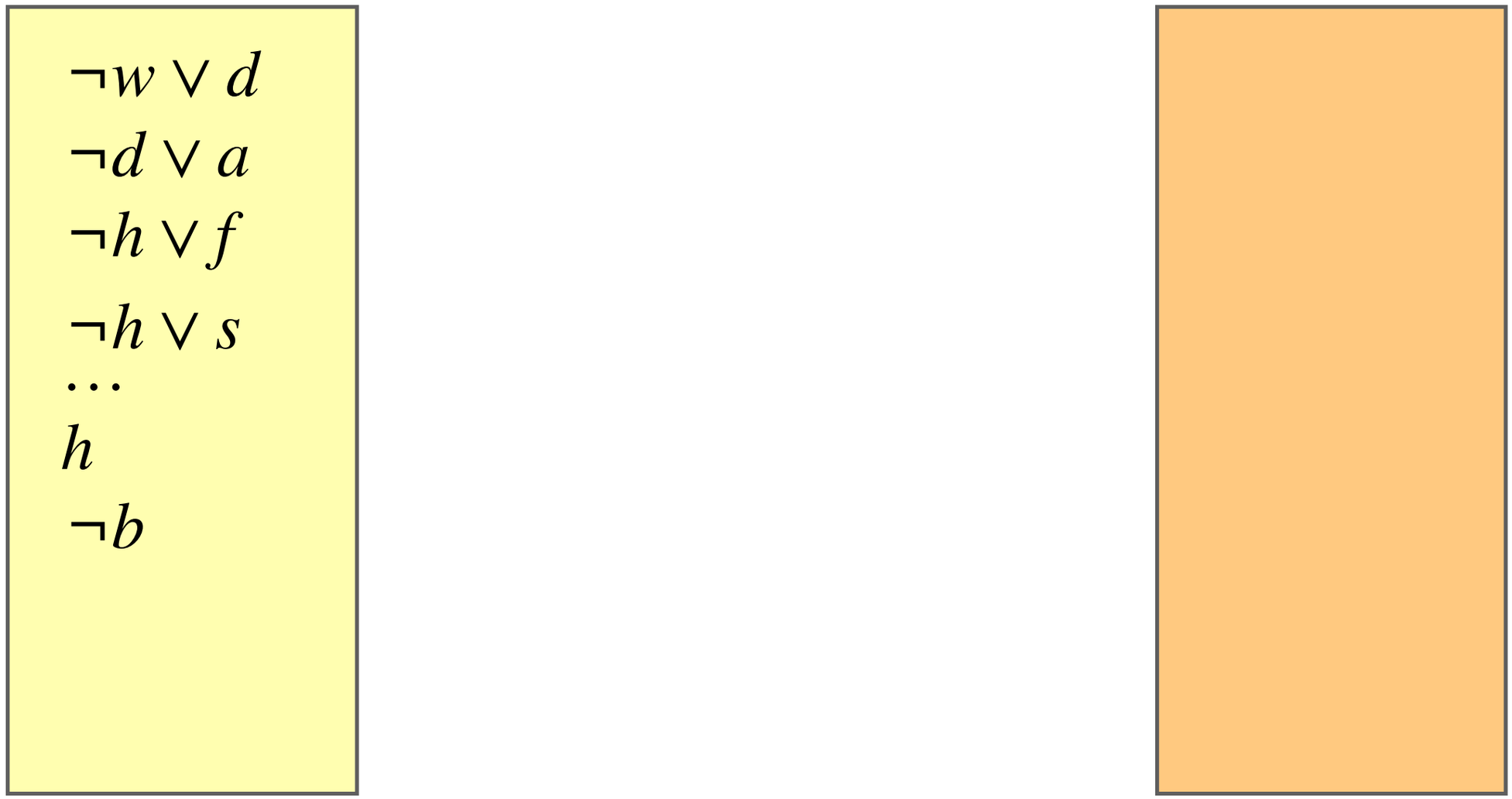

U: set of unprocessed clauses

P: set of processed clauses

Given-Clause Algorithmus

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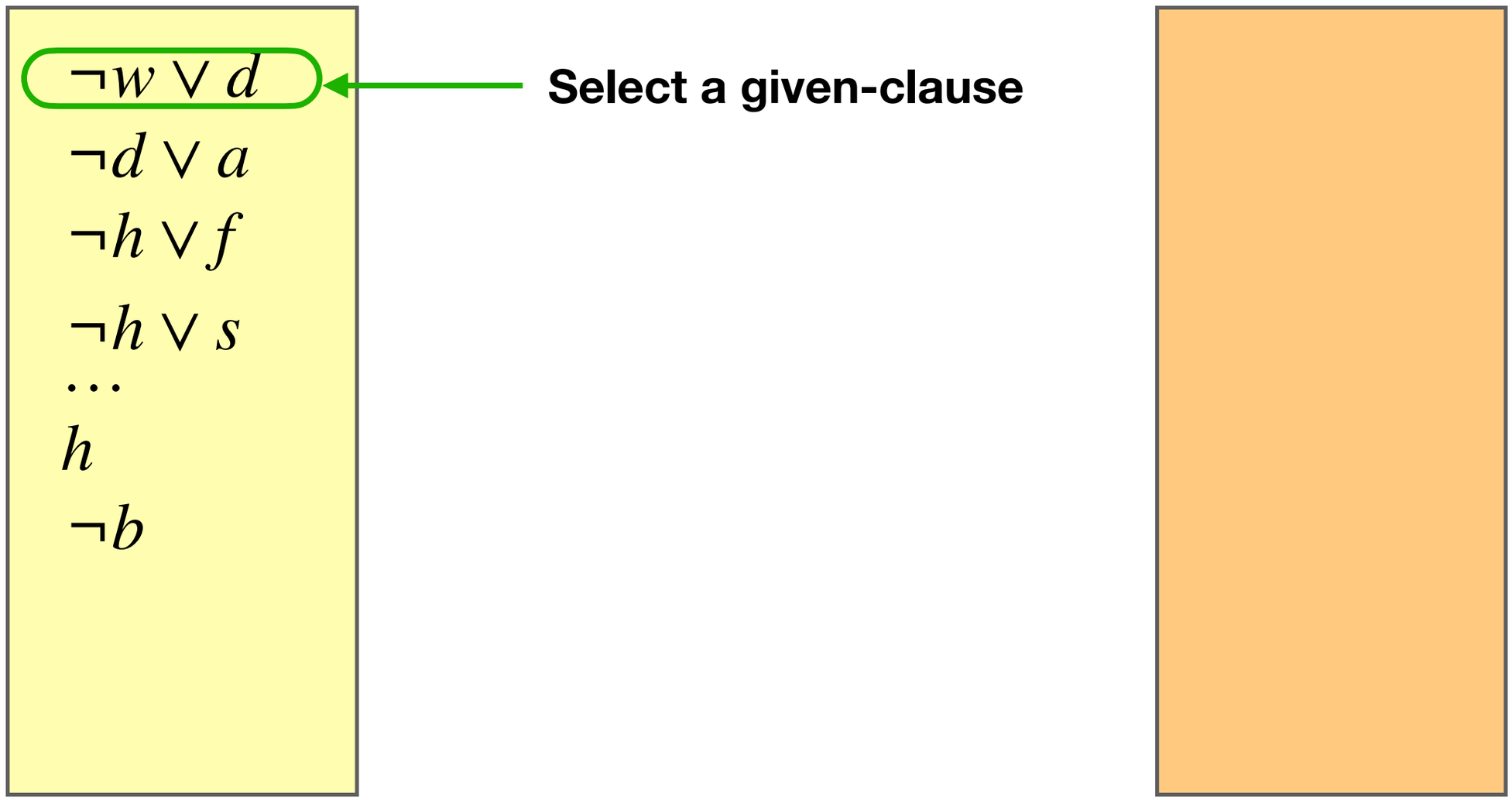

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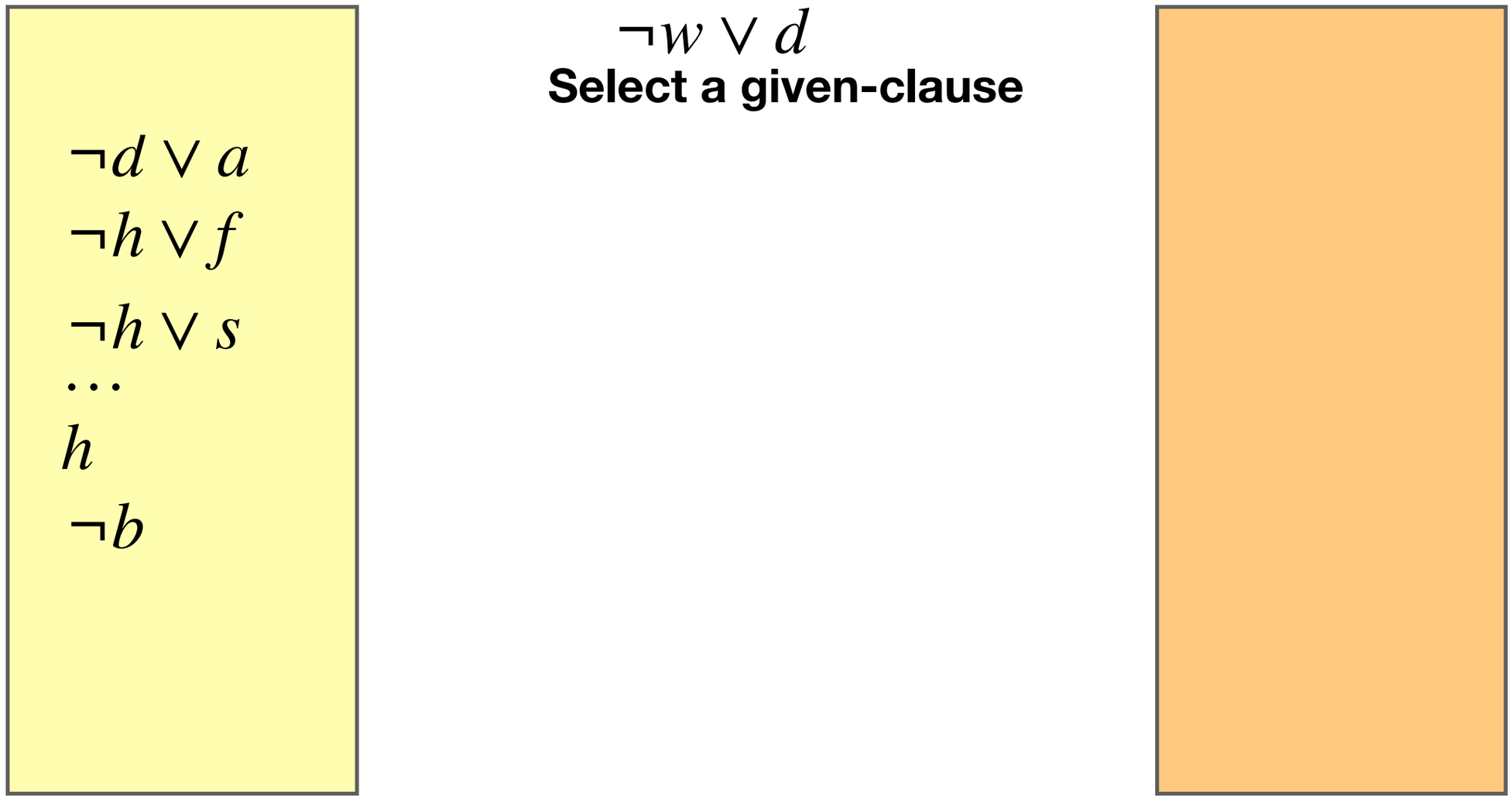

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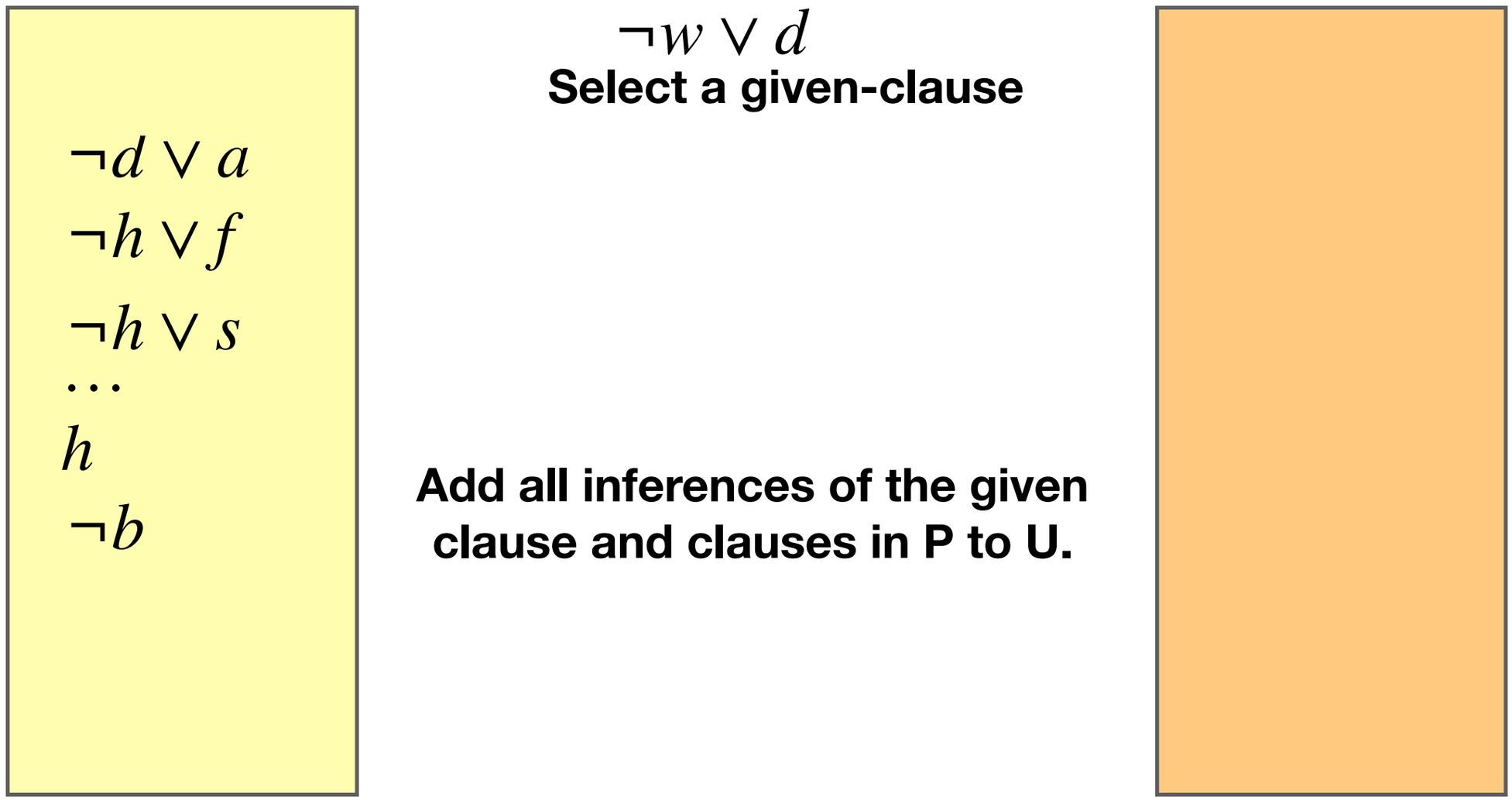

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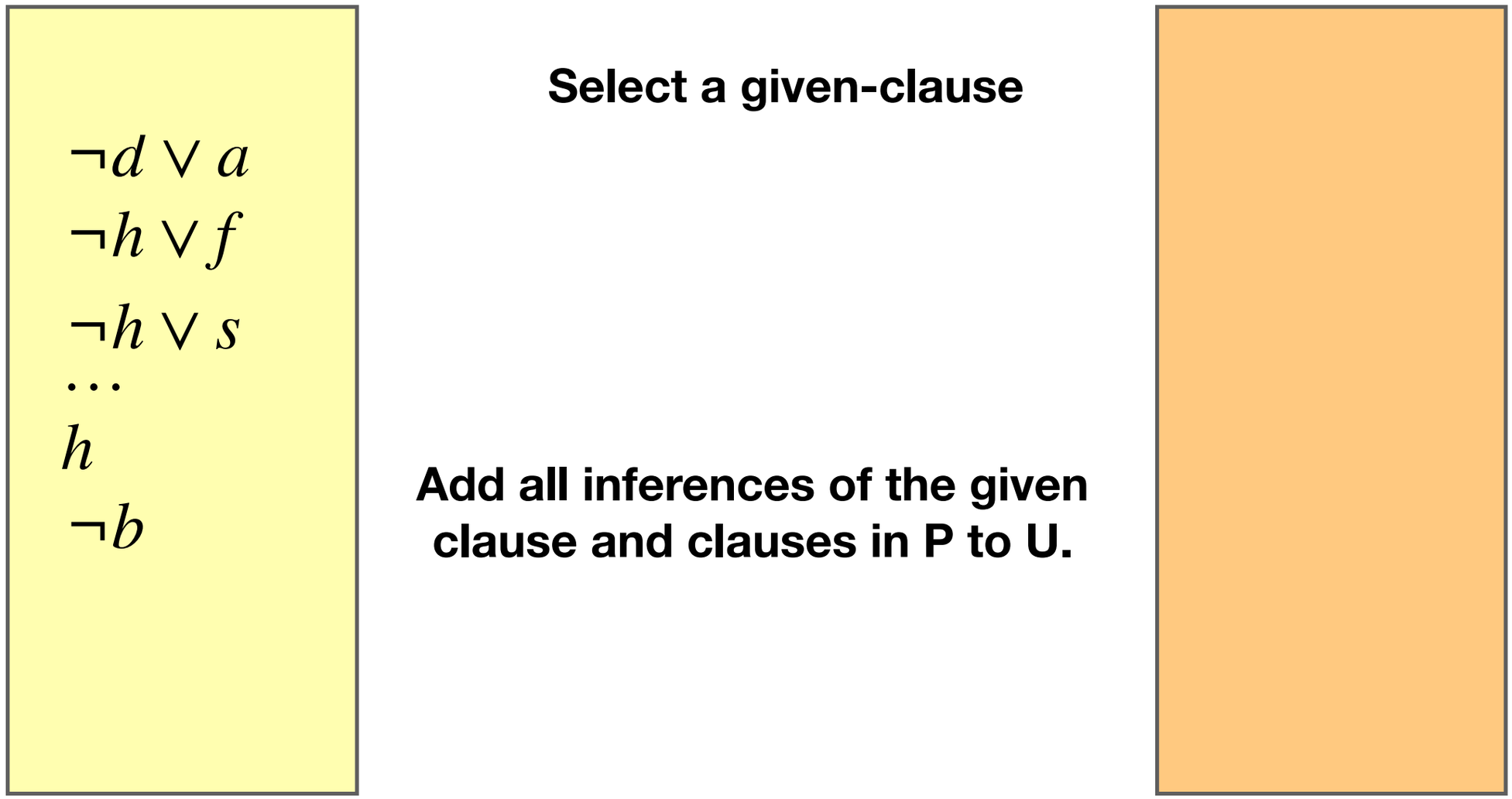

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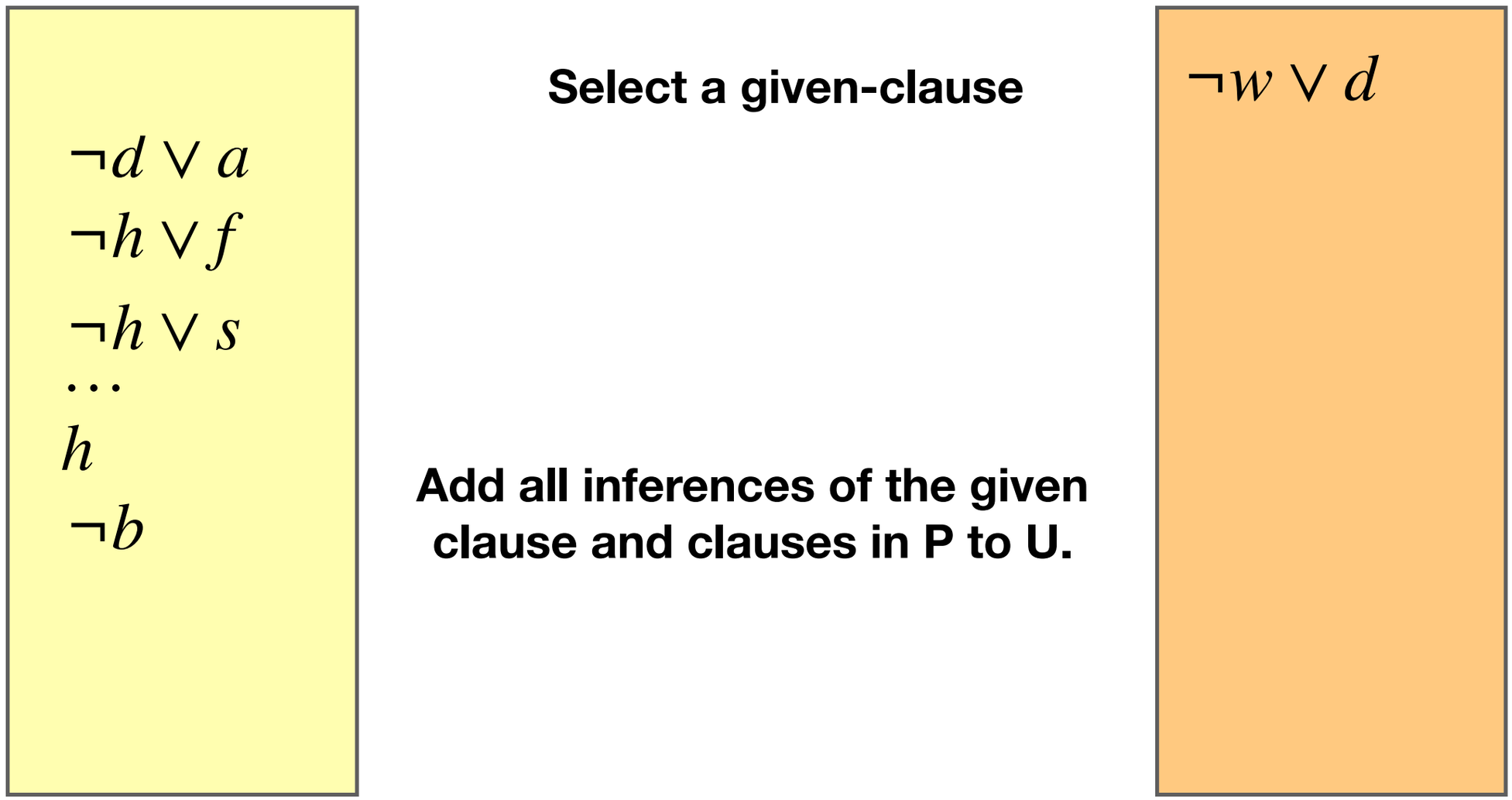

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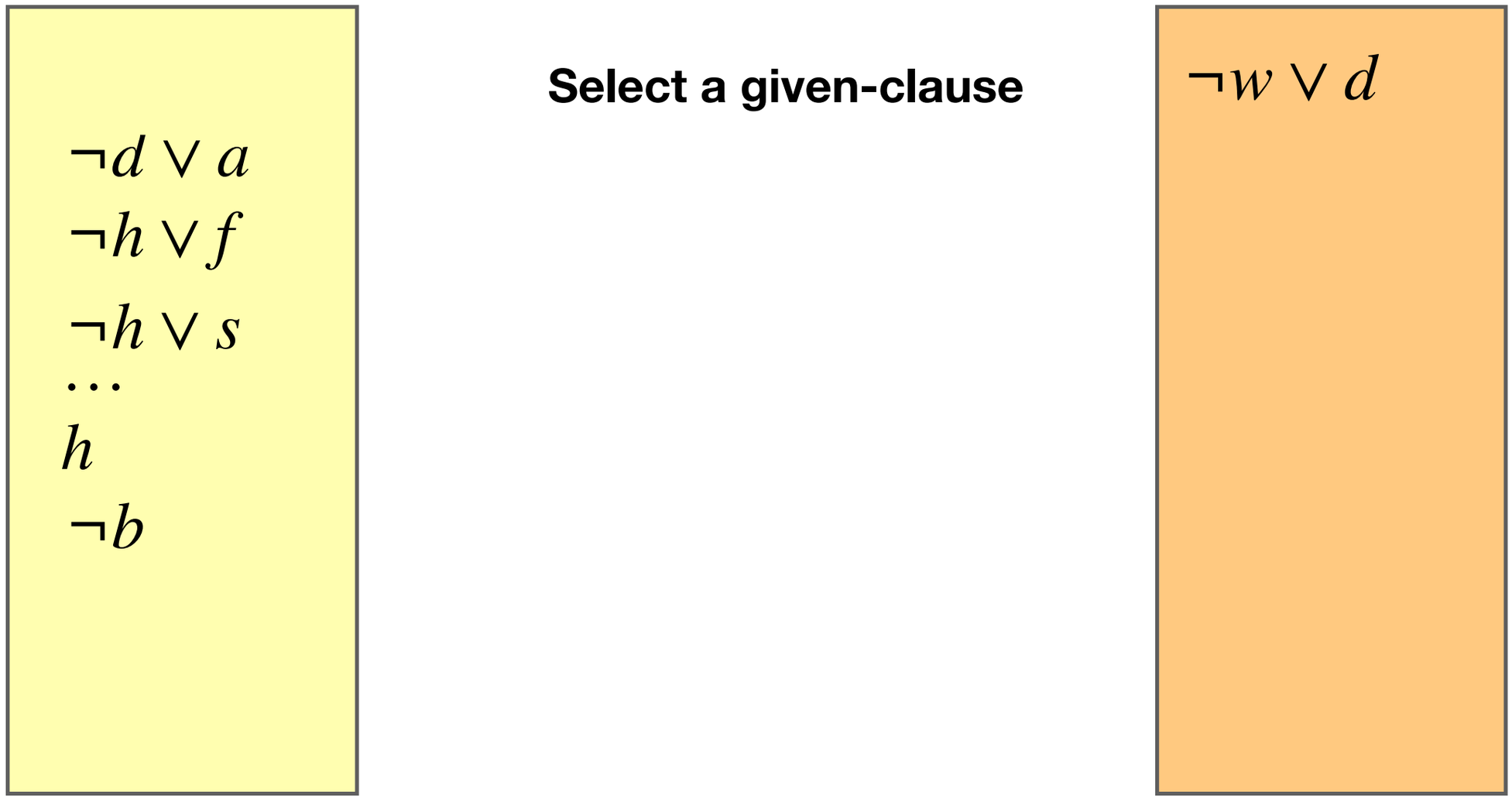

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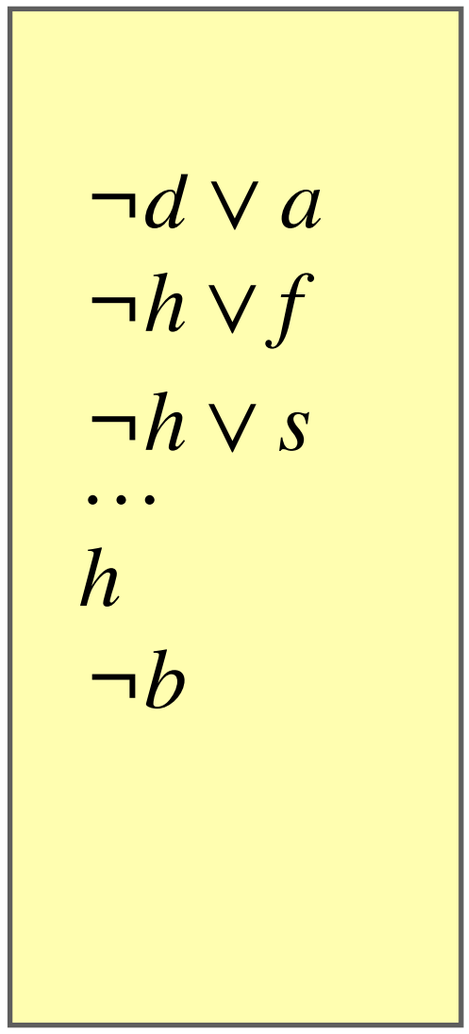

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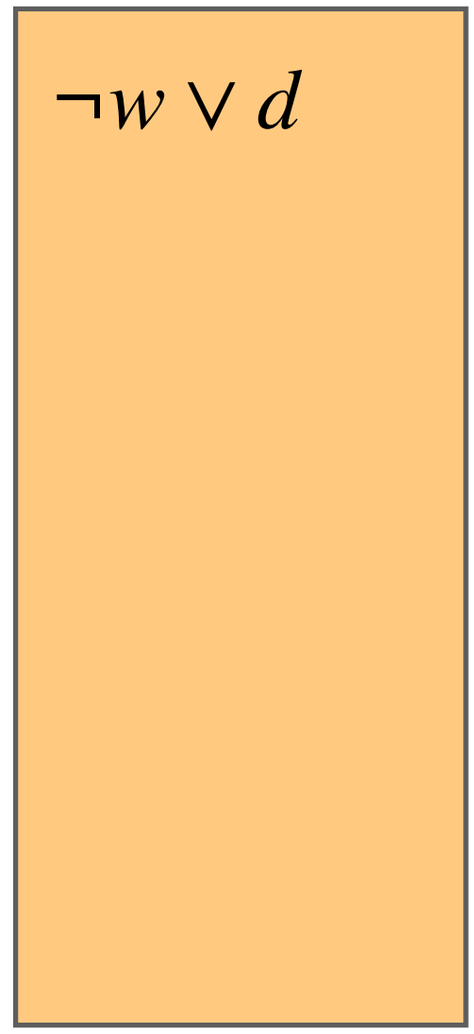

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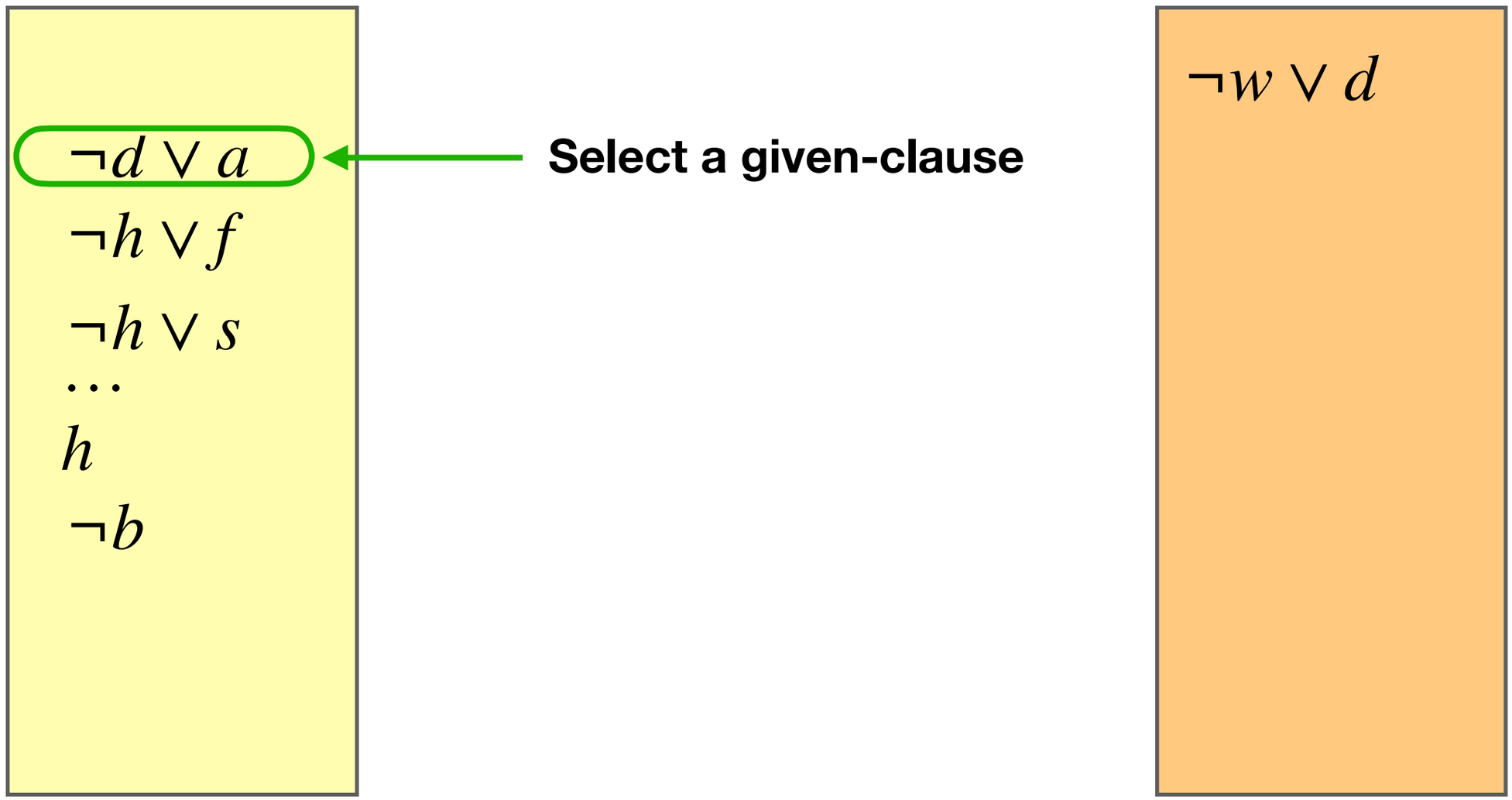

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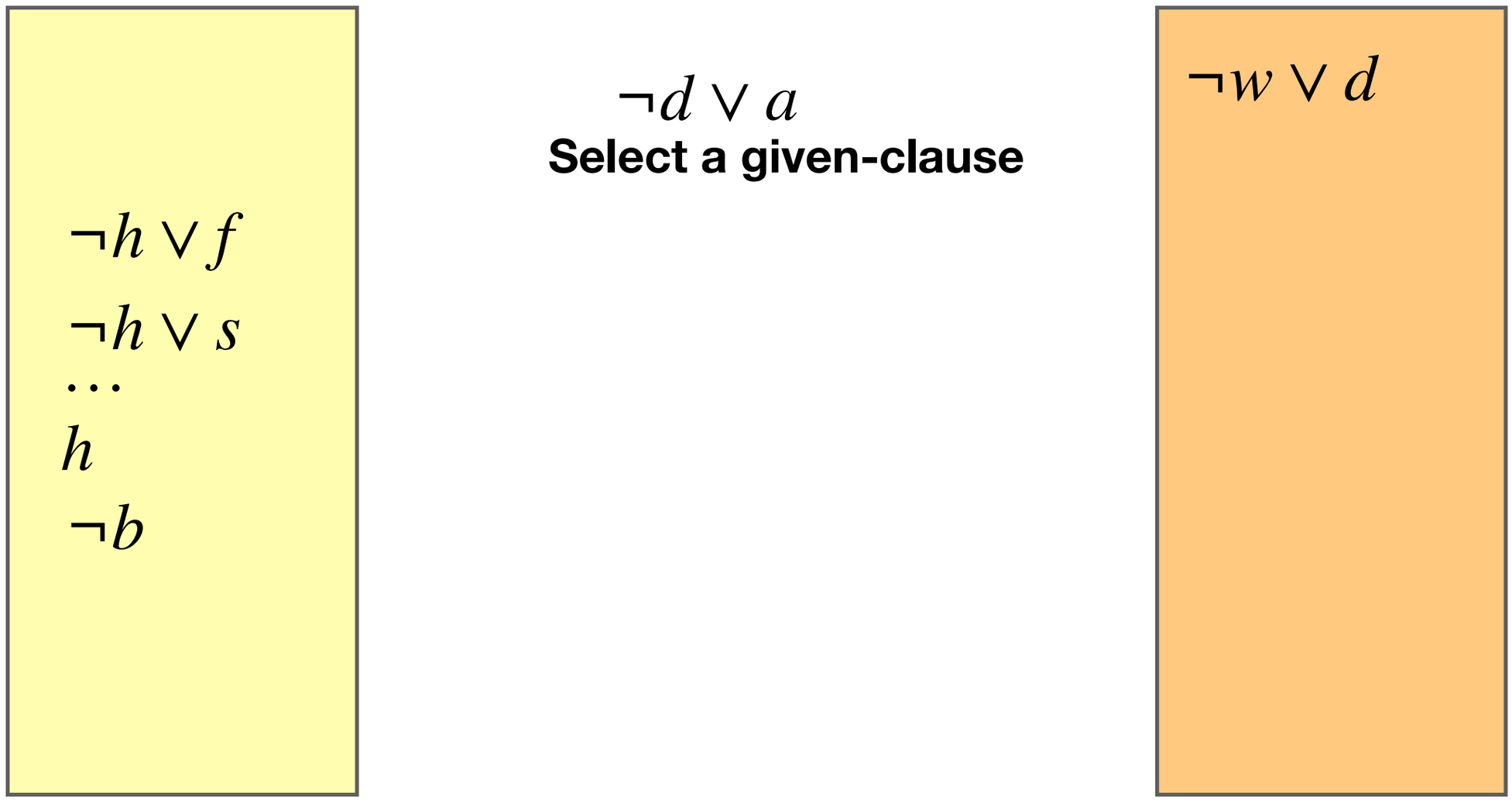

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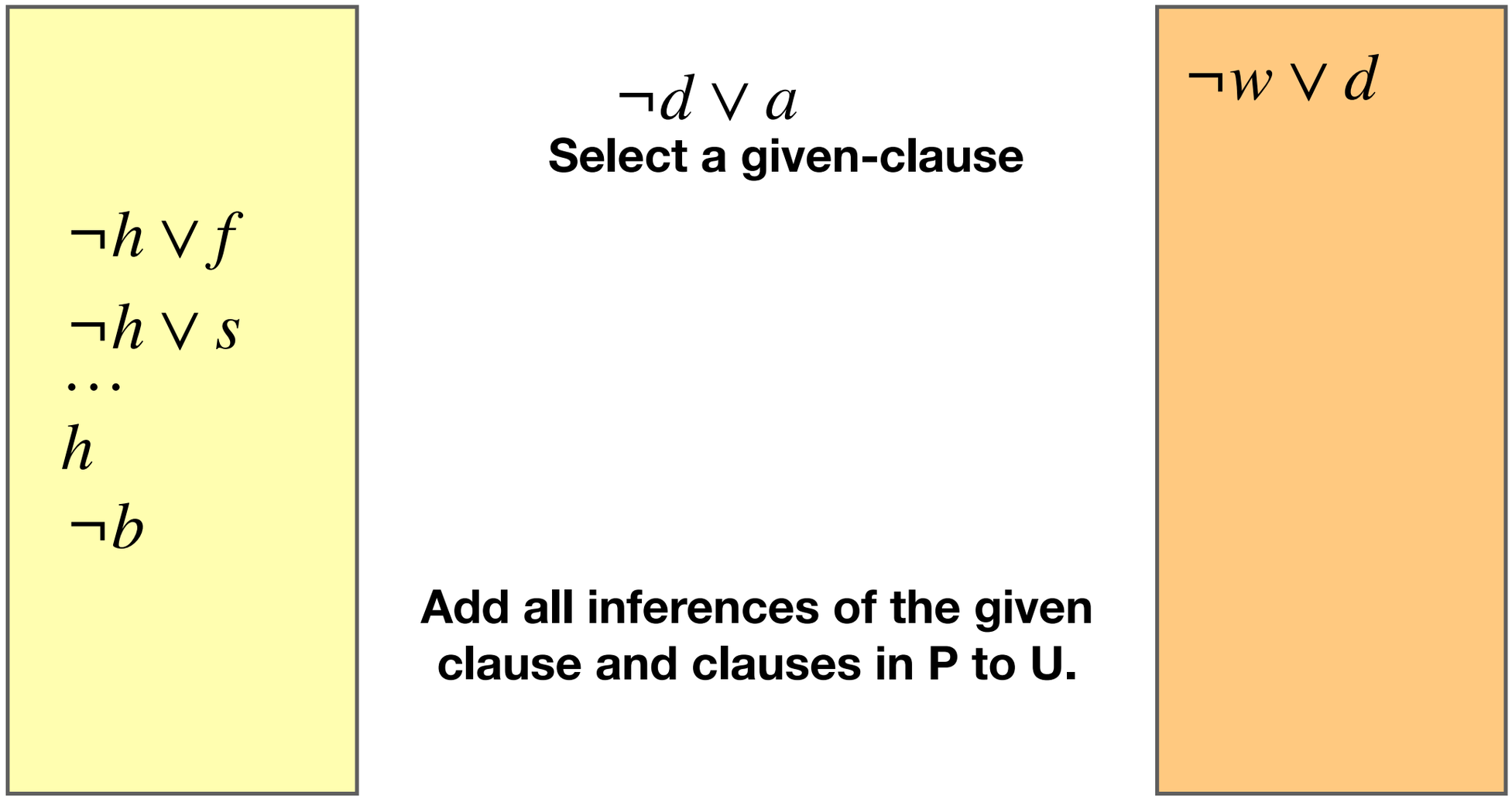

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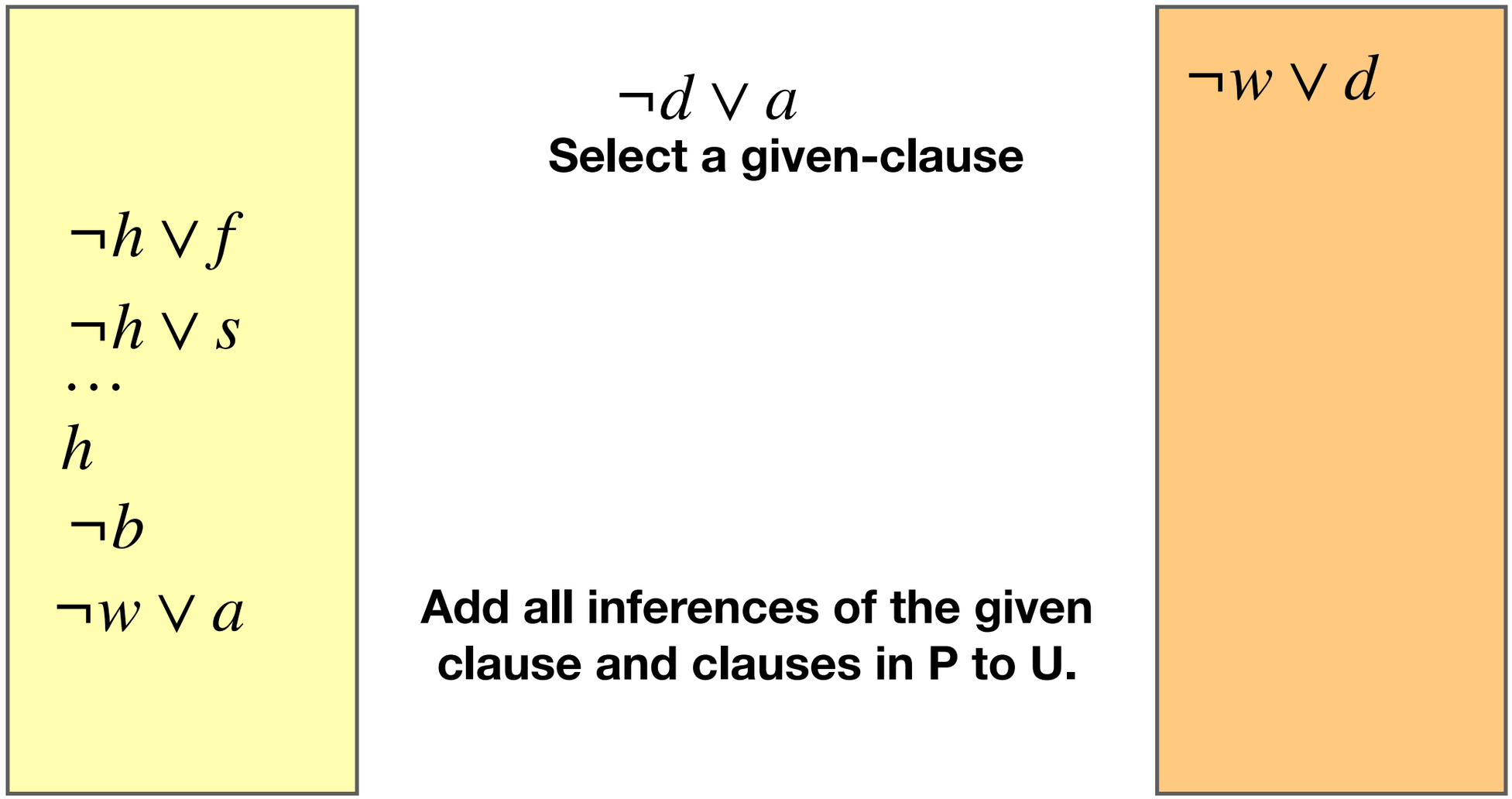

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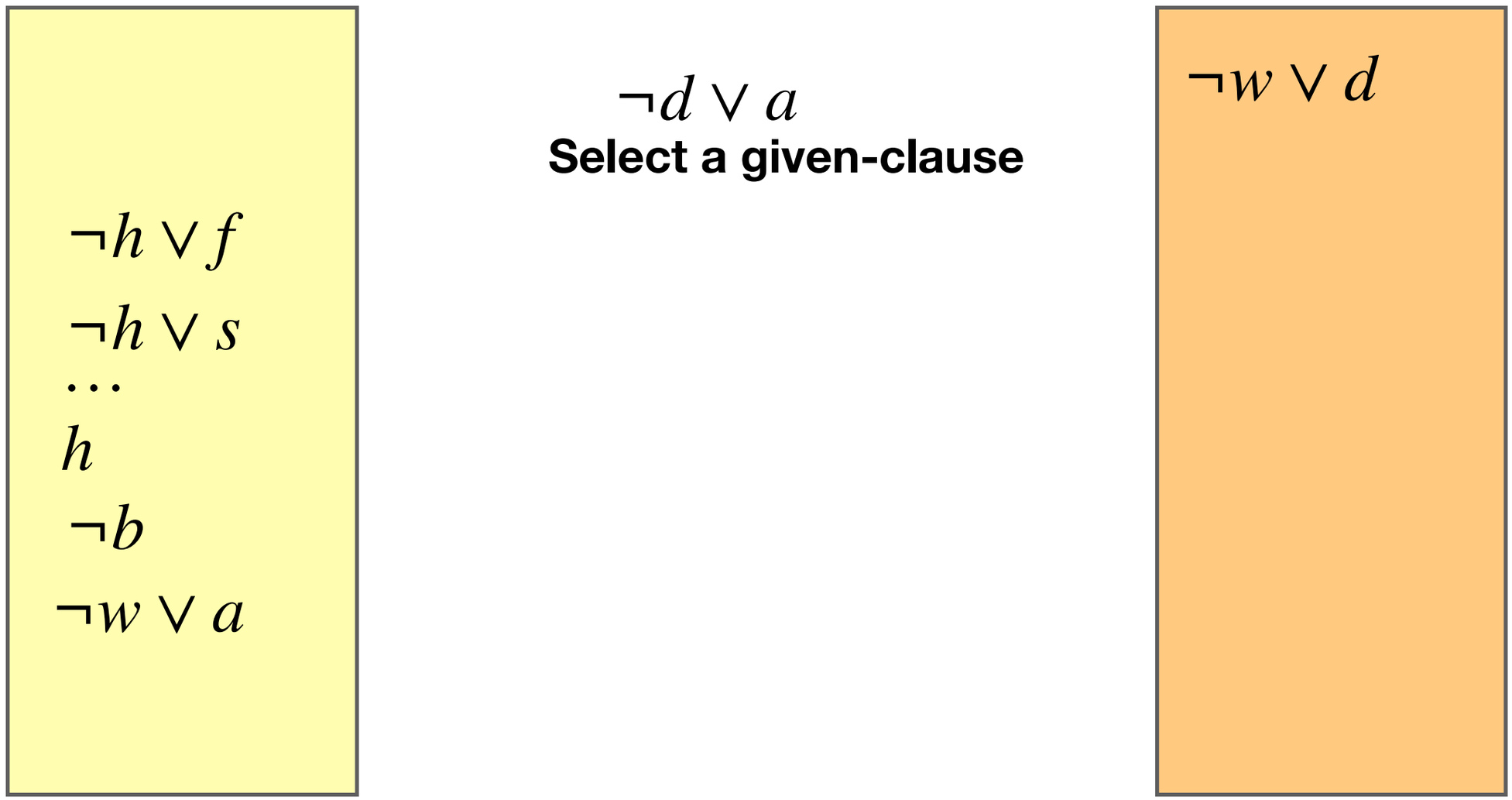

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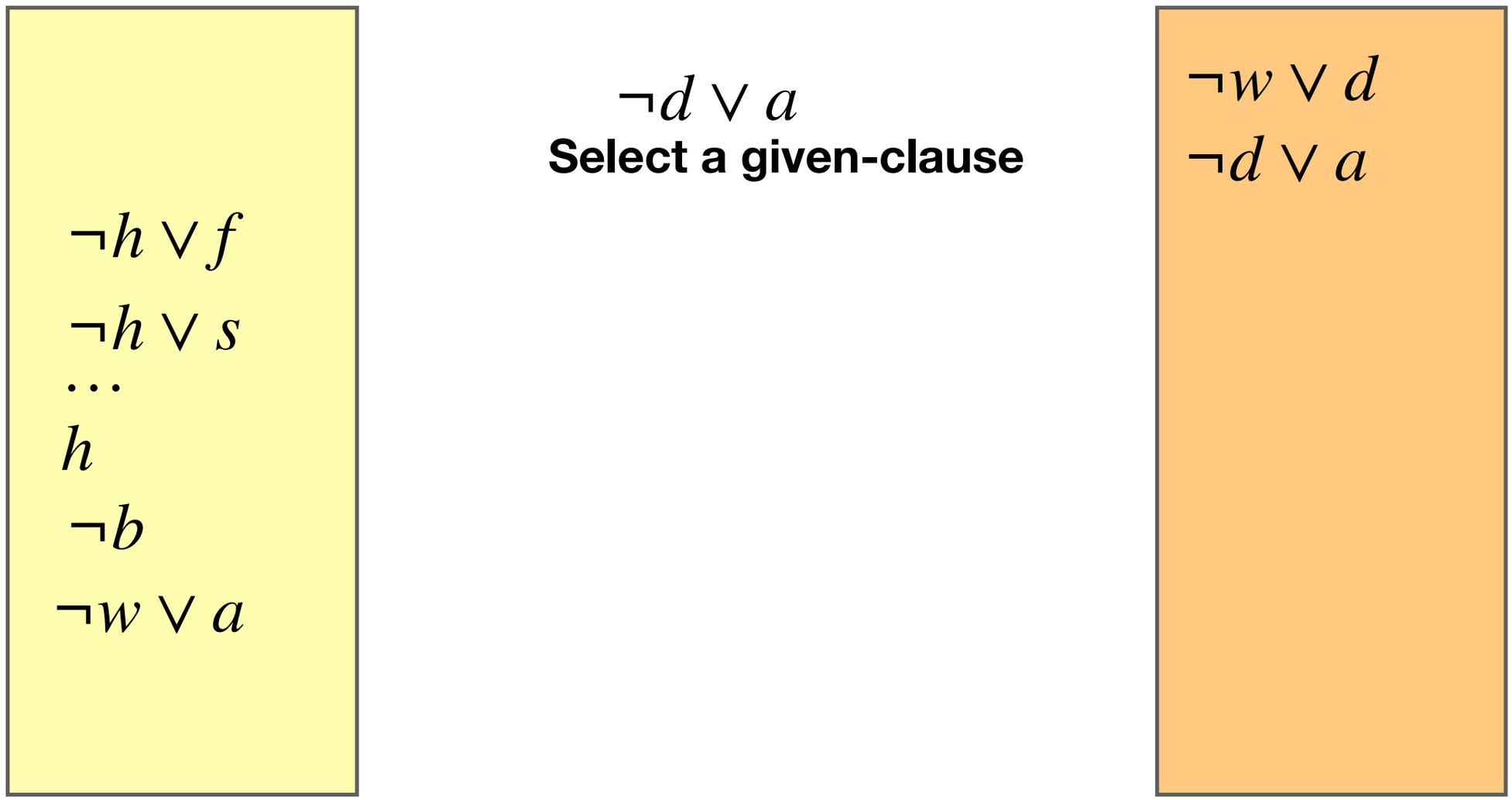

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Given-Clause Algorithmus

Task: proof that $h \rightarrow b$ follows from clause set S

$\neg h \vee f$

$\neg h \vee s$

$\cdots$

h

$\neg b$

$\neg w \vee a$

$\neg d \vee a$

Select a given-clause

$\neg w \vee d$

$\neg d \vee a$

U: set of unprocessed clauses

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Selection of given clause using heuristics.
Does not take the meaning of symbol names into account.

Given-Clause Algorithmus

Task: proof that $hammock \rightarrow bed$ follows from the set of clauses

$\neg weapon \vee device$
$\neg device \vee artifact$
$\neg hammock \vee fabric$
$\neg hammock \vee sleep$
…
$hammock$
$\neg bed$

U: set of unprocessed clauses

P: set of processed clauses

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$\ldots$

$hammock$

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$\neg weapon \vee device$

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…

$hammock$

$\neg bed$

$\neg weapon \vee device$

Select a given-clause

Add all inferences of the given clause and clauses in P to U.

U: set of unprocessed clauses

P: set of processed clauses

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$\neg weapon \vee device$

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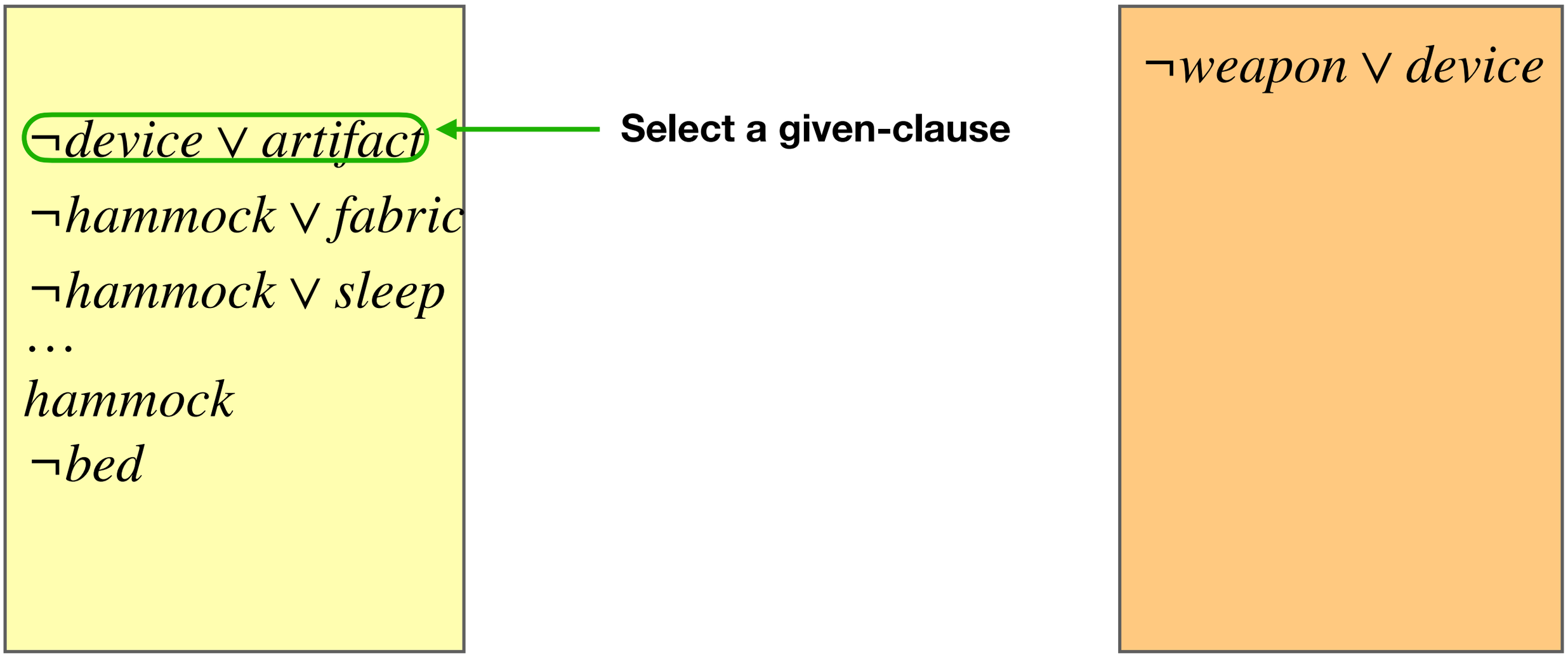

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$\neg weapon \vee artifact$

$\neg device \vee artifact$

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Idea: Use clauses with symbols similar to the proof task as given clause!

Symbol Name Heuristics

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How to determine similarity?

Symbol Name Heuristics

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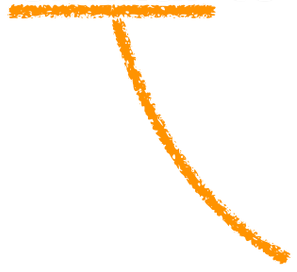

How to determine similarity?

We use Word Embeddings!

Meaning of Symbol Names using Word Embeddings

“a word is characterized by the company it keeps” (Firth, 1957)

Word embedding: a function $f : Voc \rightarrow \mathbb{R}^n$

Measuring Similarities

Let $u, v \in \mathbb{R}^n$. The cosine similarity of u and v is defined as

$$cosine\_similarity(u, v) = \frac{u \cdot v}{||u|| \quad ||v||}$$

assuming that both u and v are non-zero.

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$$cosine\_similarity(u, v) = \frac{u \cdot v}{||u|| \ \ ||v||} = \frac{\sum_{i=1}^{n} u_i \cdot v_i}{\sqrt{\sum_{i=1}^{n} (u_i)^2} \cdot \sqrt{\sum_{i=1}^{n} (v_i)^2}} = \cos(\phi)$$

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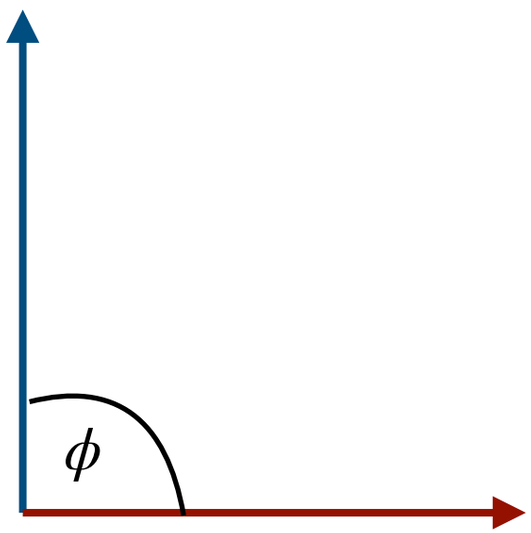

$\cos(\phi) = 0$

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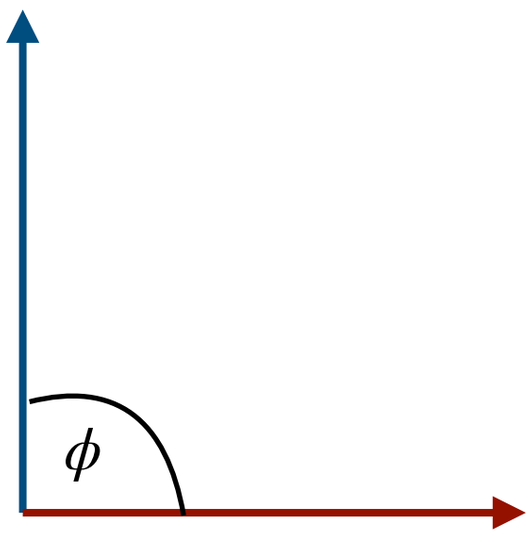
assuming that both u and v are non-zero.



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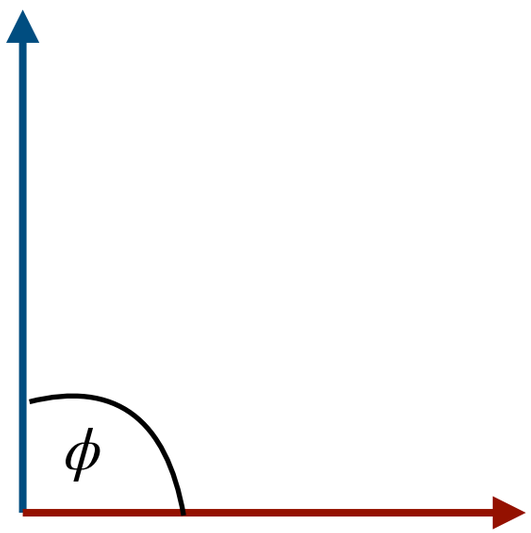

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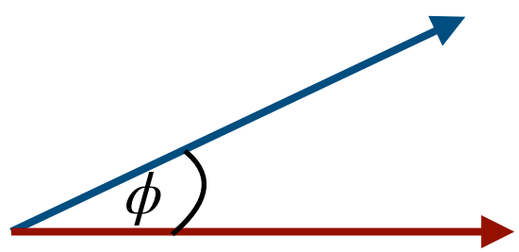

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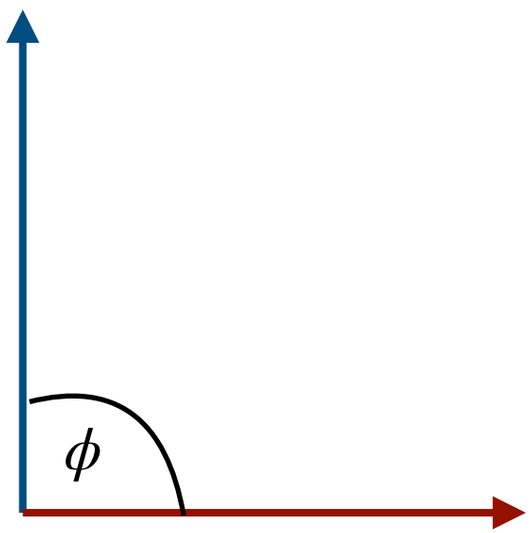

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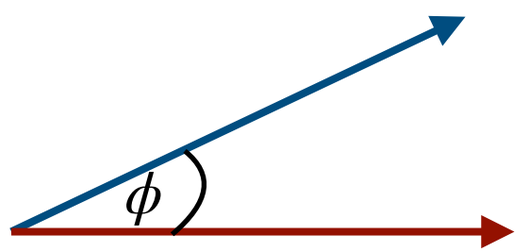

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Word Embeddings: Similar Words

Comparing words to the word *bed* in the Numberbatch word embedding:

Word	Cosine Similarity to *bed*
bed	1.0000
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We use these similarities to select the given clause!

Symbol Name Heuristic

goal G

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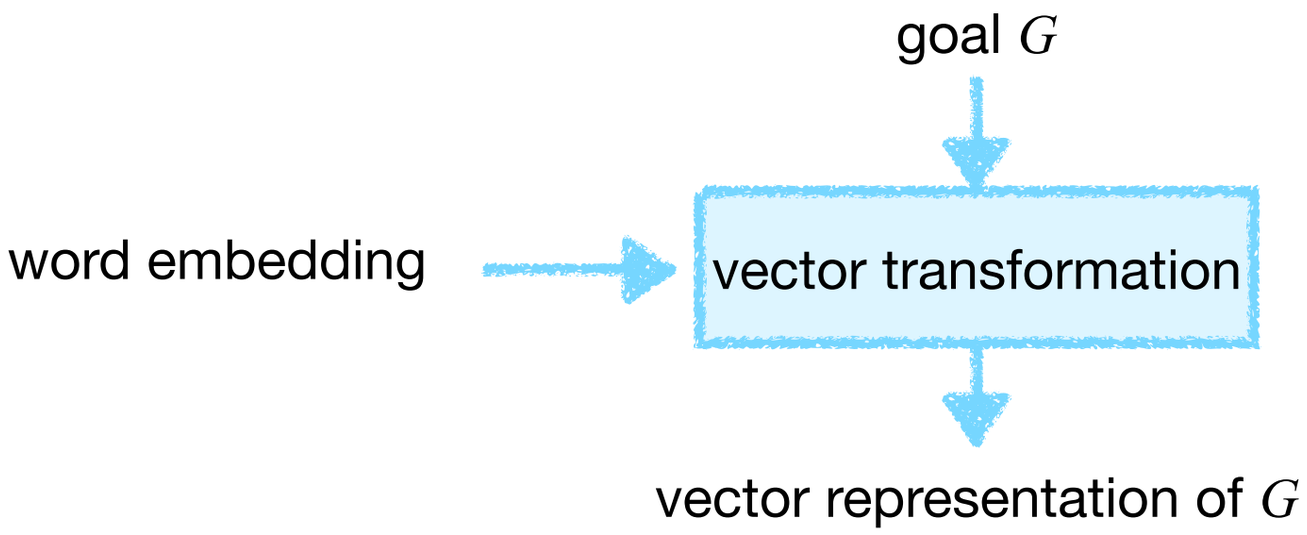

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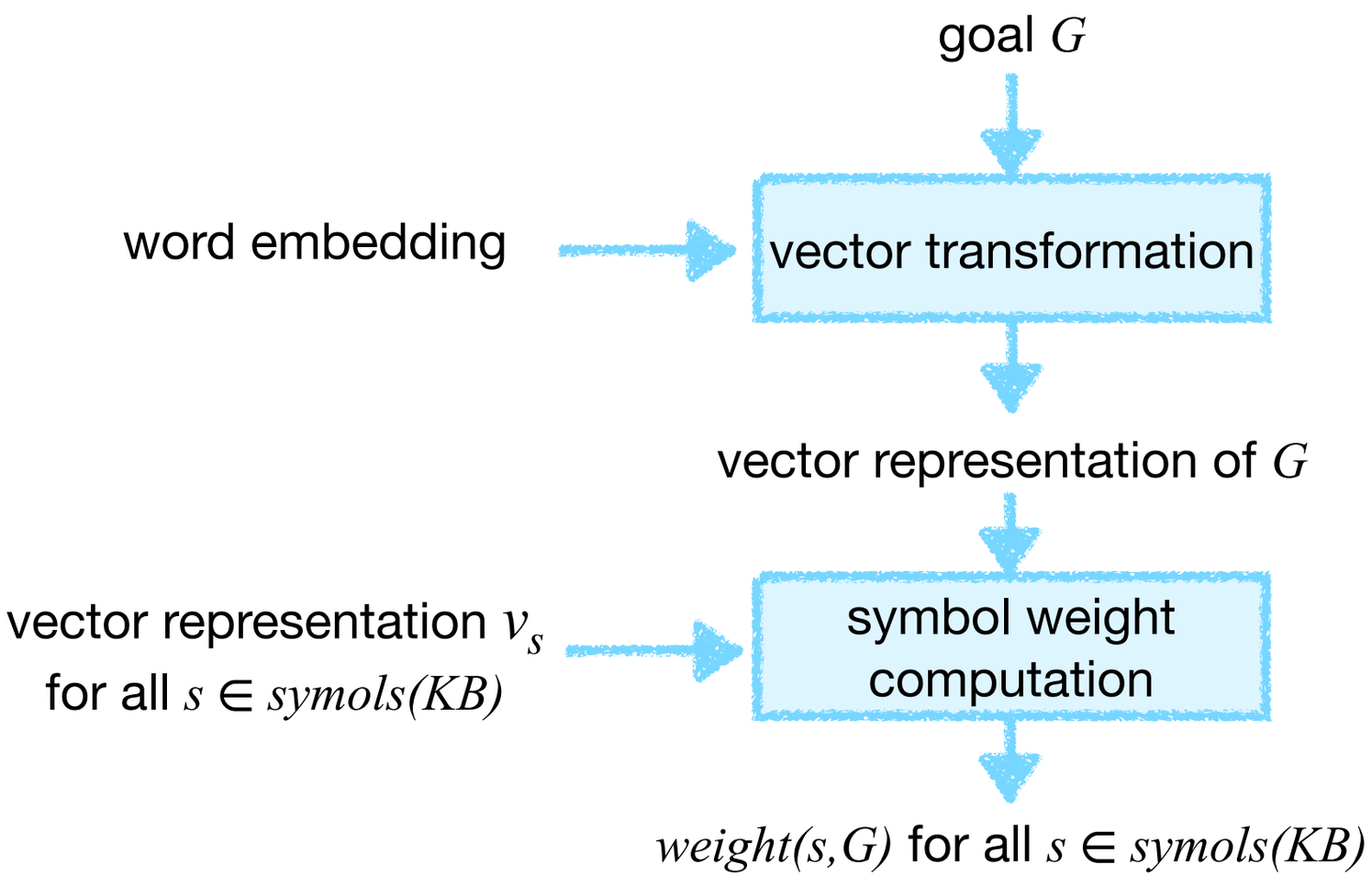

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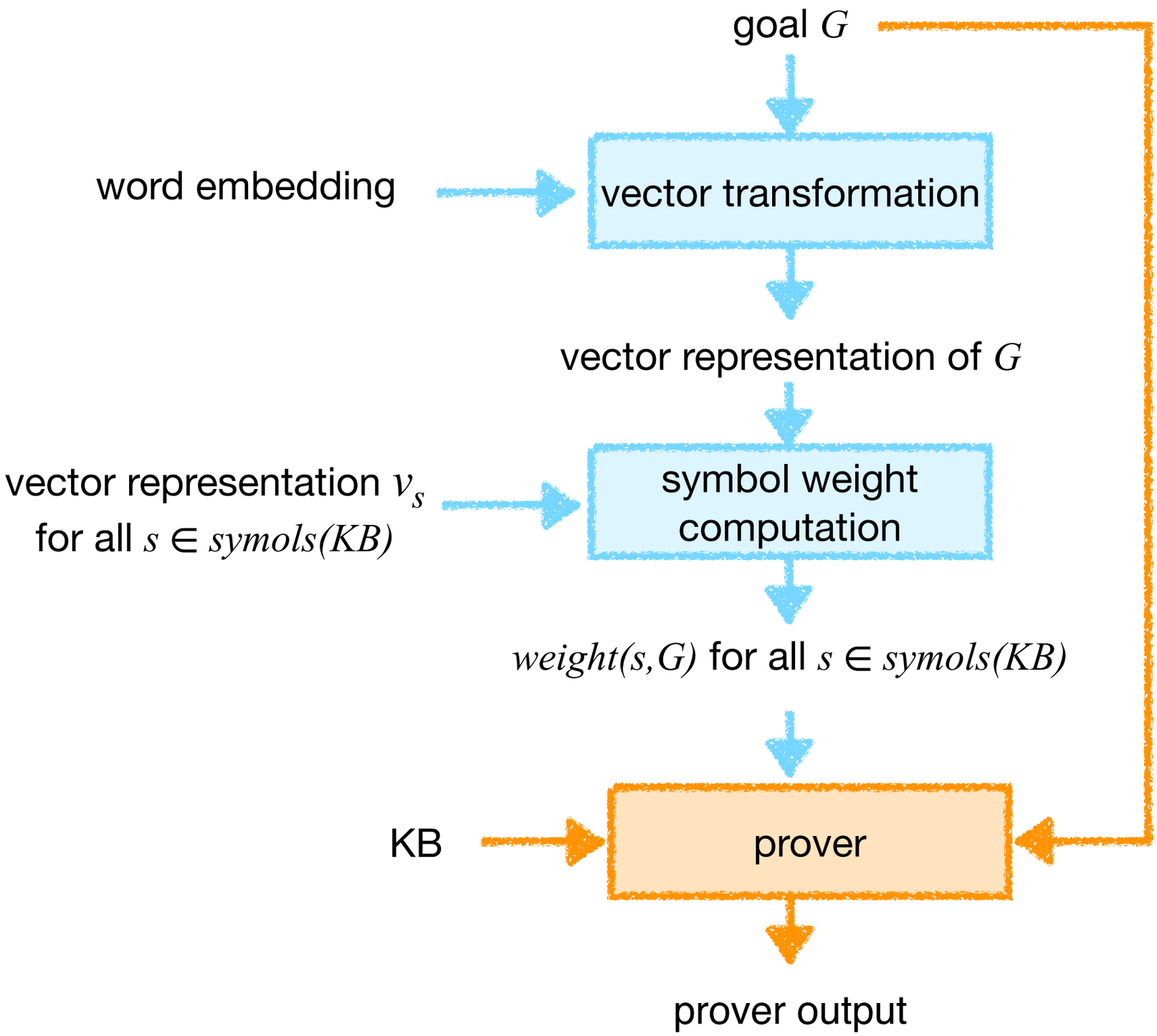

Representing Symbols and Formulae by Vectors

$symbols(F)$: the set of predicate and function symbols in formula F

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The vector representation of a formula F is

$$v_F = \frac{\sum_{s \in symbols(F)} v_s}{|symbols(F)|}$$

Symbol Weight Computation

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We use default weights of 1000 for all symbols.

Selection of Given-Clause

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Goal:
Are hammocks beds?
$\forall x(instance(x, hammock) \rightarrow instance(x, bed))$

Clauses:

$subClass(weapon, device)$

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Symbol weight:

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0.1232	0.0422	0.1933	0.1232	0.7261	0.3323
876.8	957.8	806.7	876.8	273.9	

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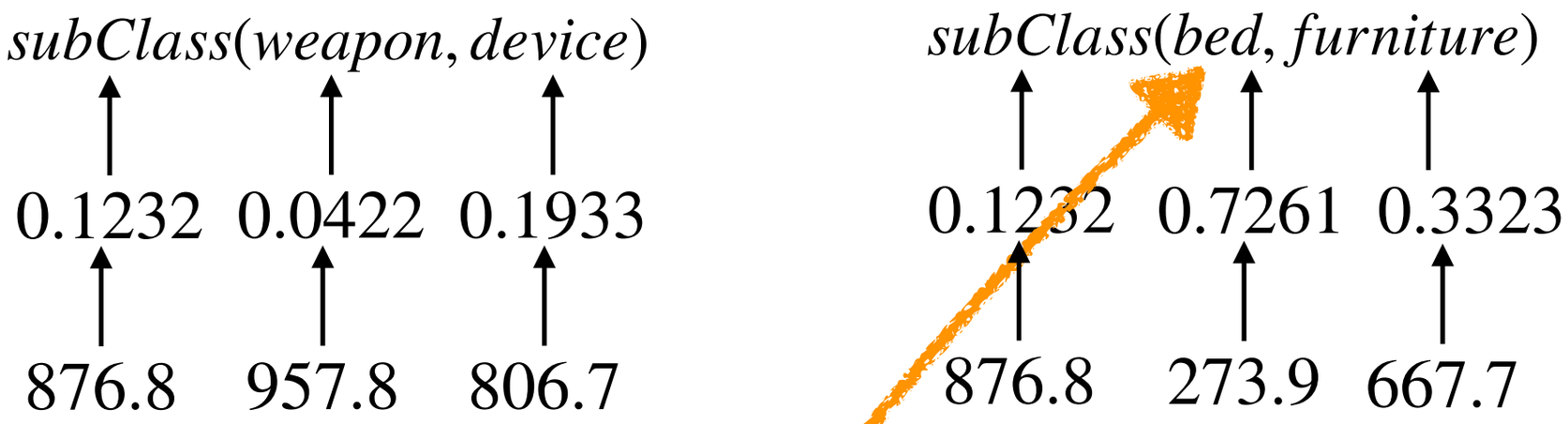

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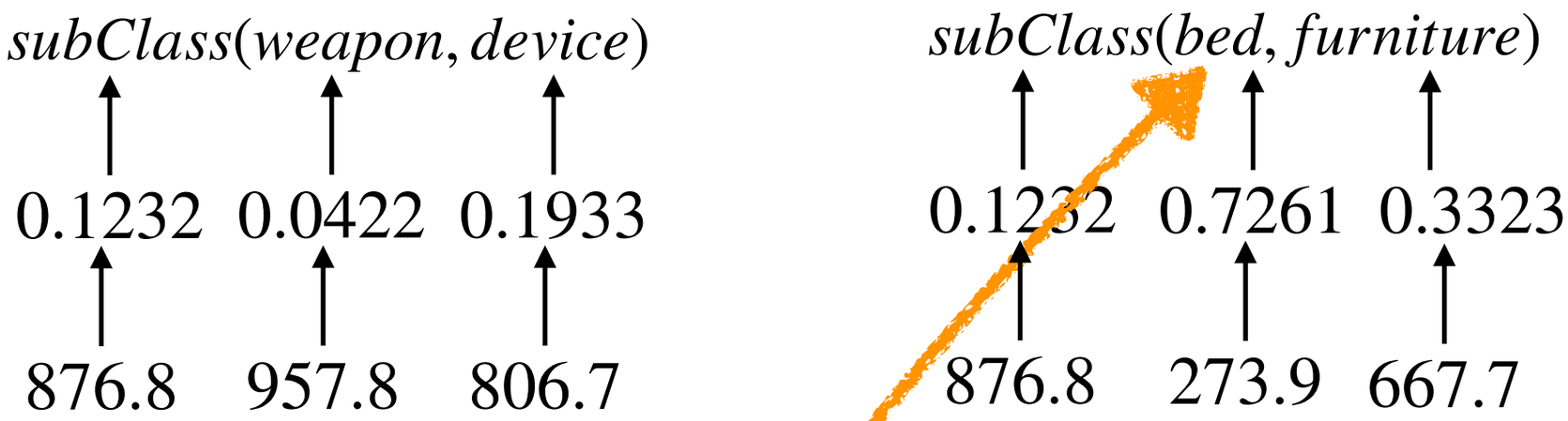

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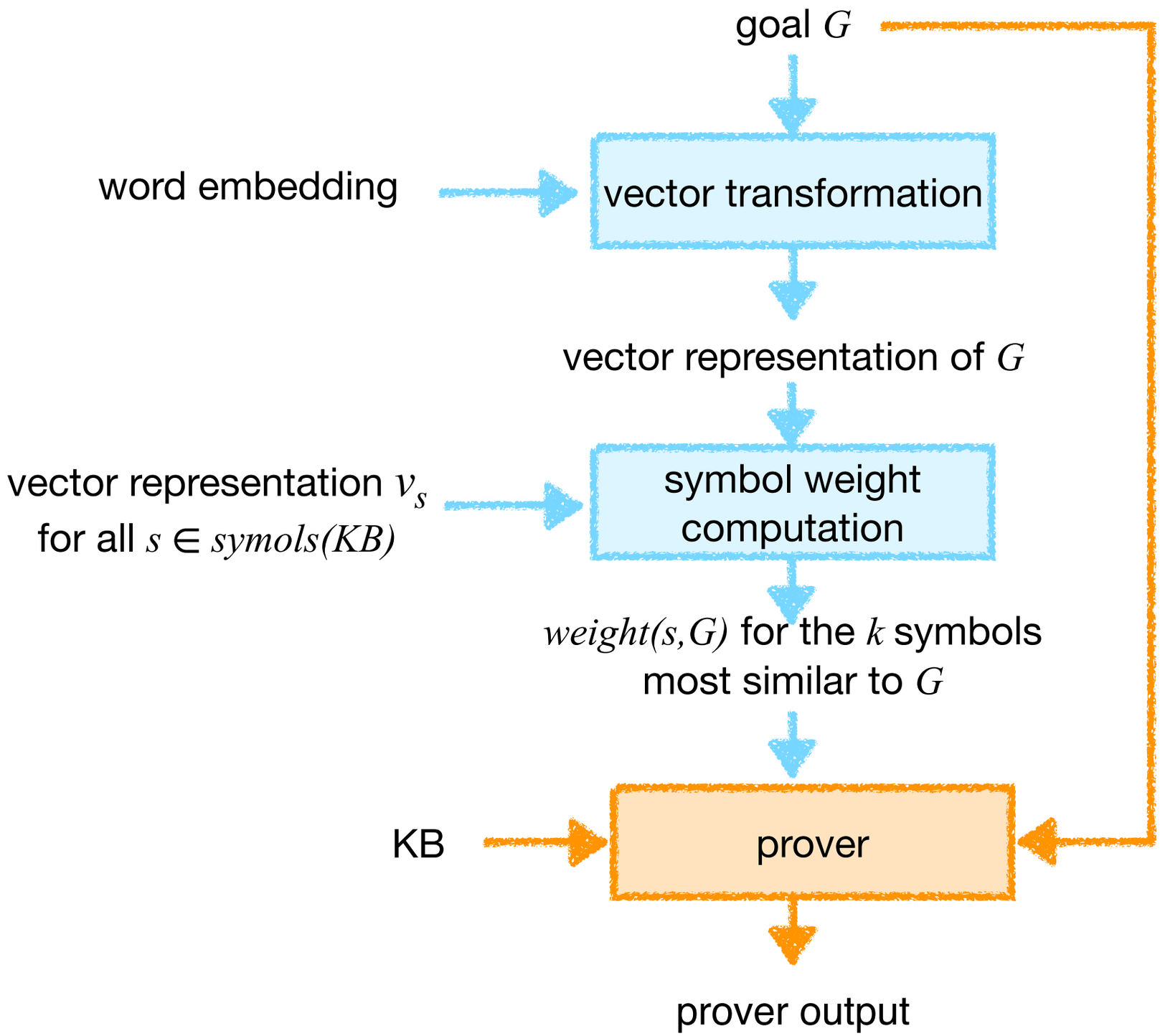
Given clause = clause with smallest similarity-clause-weight

We interleave the selection of the given clause by similarity-clause-weight with the selection of the oldest clause.

Symbol Name Heuristic



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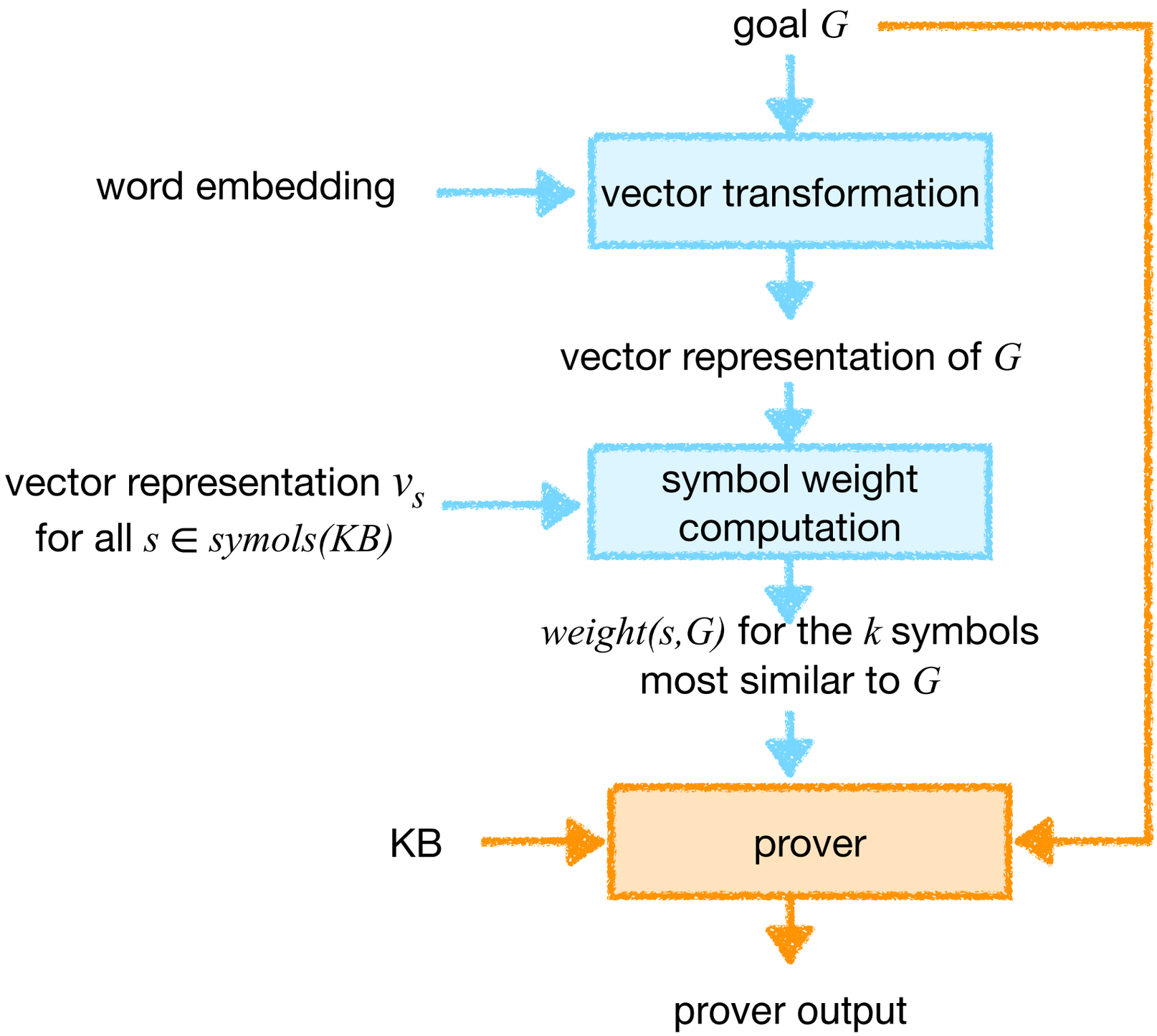

***k* is a parameter**

Experimental Results

- Adimen SUMO WhiteBoxTruthTests:

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  - We randomly chose two disjoint sets of 1,000 of these proof tasks
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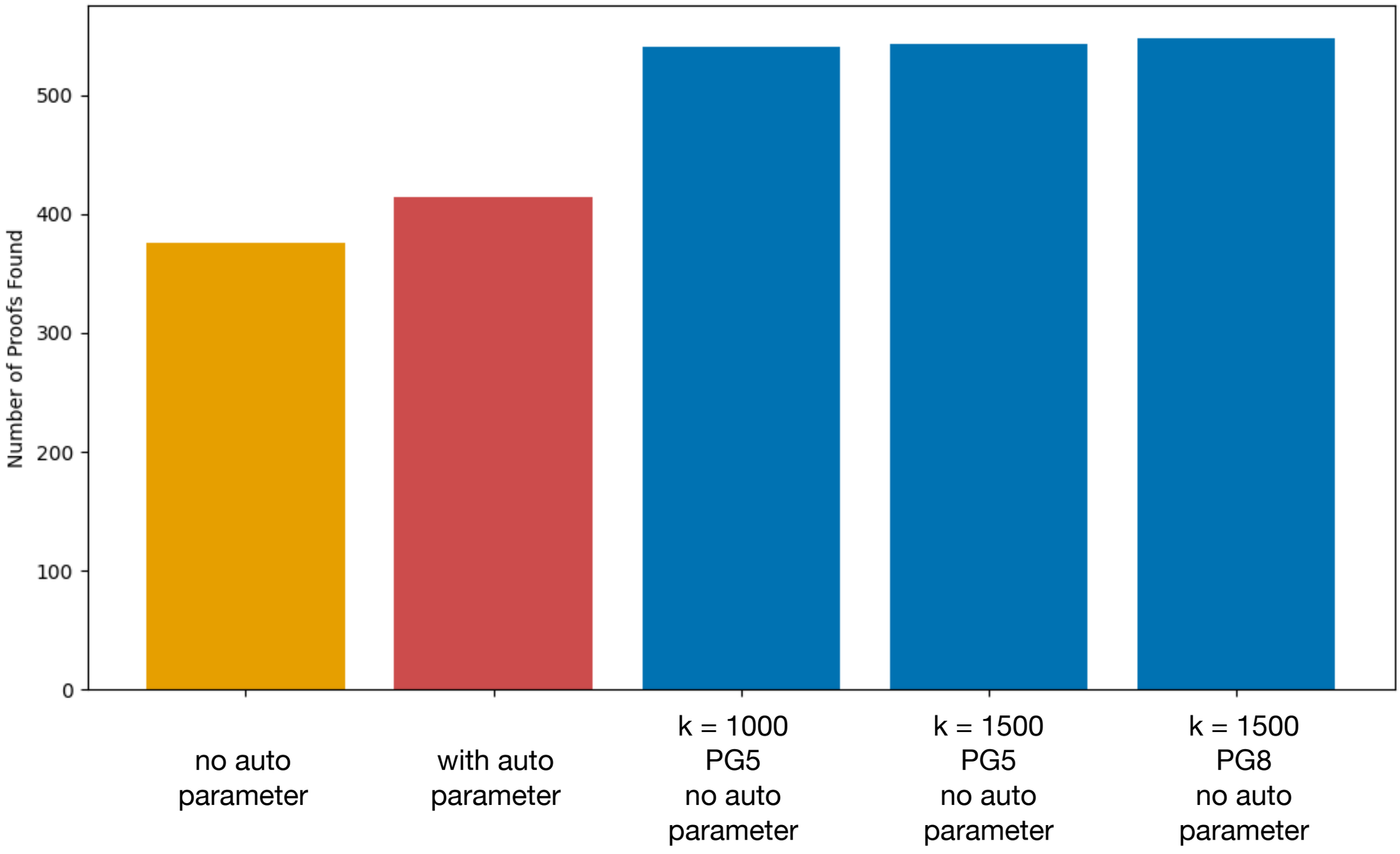
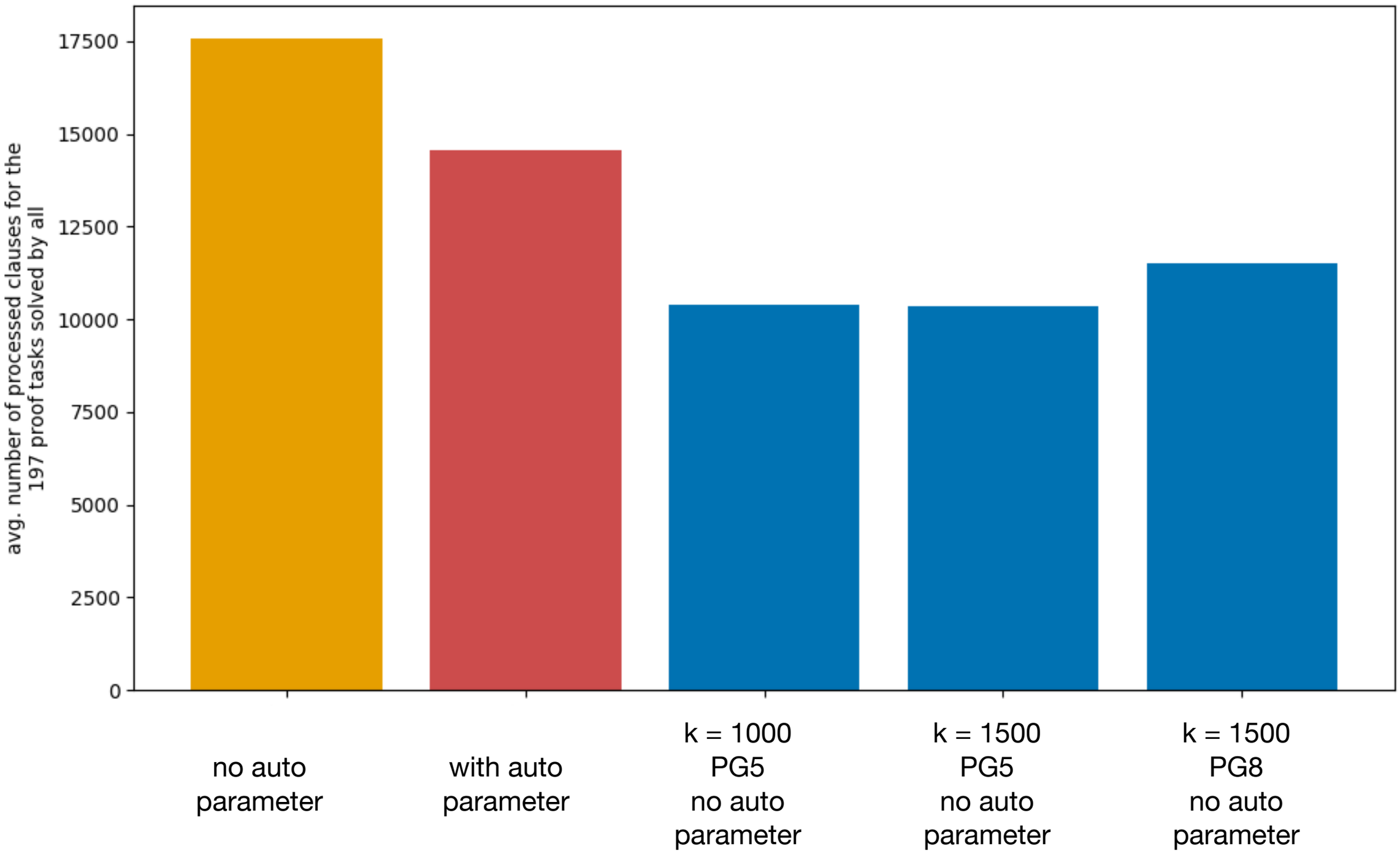
    - Second set: evaluation set
- We use the theorem prover E (timeout 10 sec.)

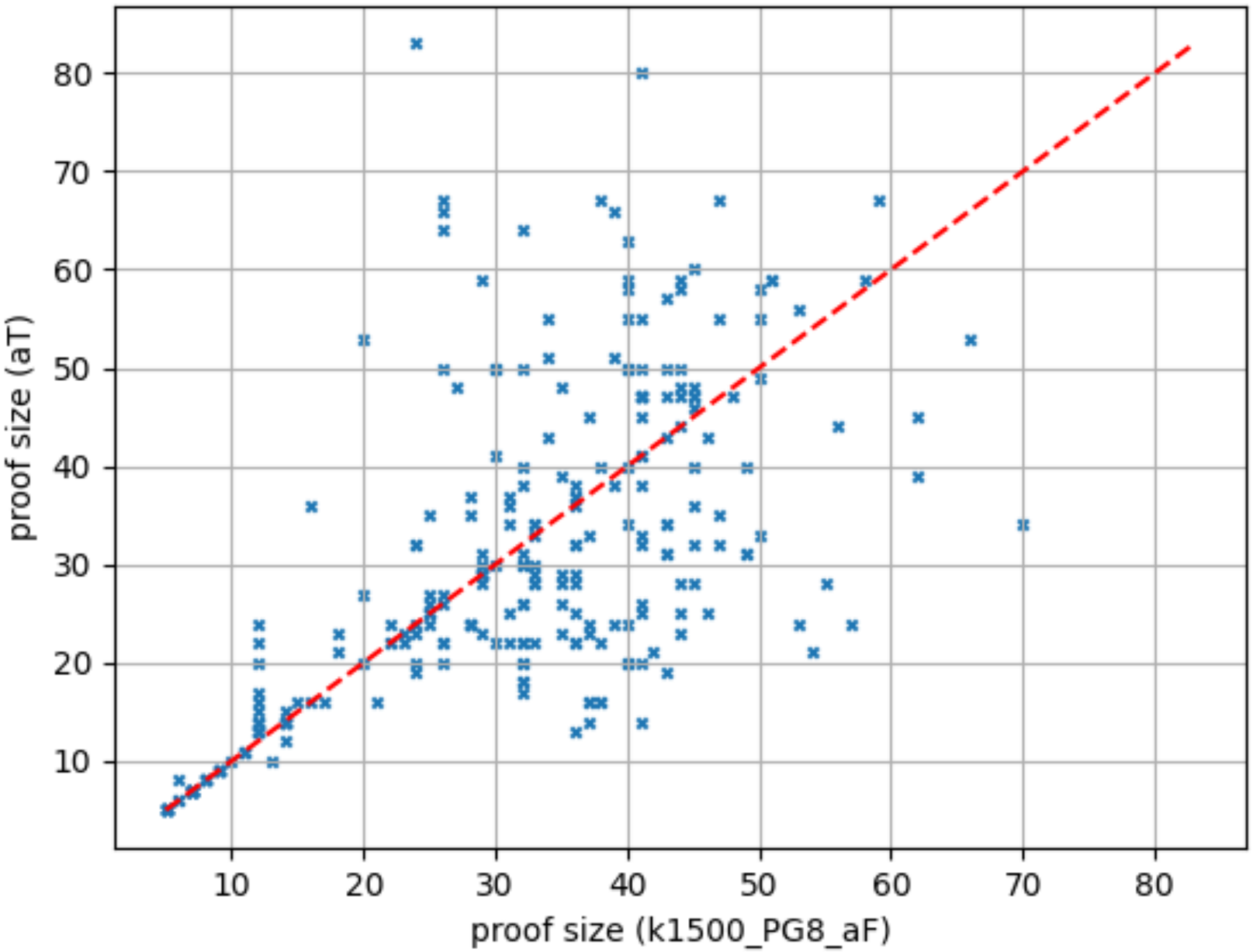
Evaluation Set: Number of Proofs Found



Evaluation Set: Average Number of Clauses Processed



Evaluation Set: Comparison of Proof Sizes



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