Towards Understanding Cognitive Aspects of Configuration Knowledge Formalization

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Overview

- Motivation
- Related Work
- Initial User Study
- Results
- Future Work
- Conclusions

Motivation

- Model-based Knowledge Representations
- Graphical Development Environments
- Automated Testing & Debugging
- Our Goal: Develop a more in-depth understanding of cognitive issues in knowledge base development (organization, representation, formalization)

Constraint Satisfaction Problem (CSP)

Definition (Constraint Satisfaction Problem and Solution – CSP). A CSP is a triple (V, D, C) where V represents a set of variables (V=$\{v_1, v_2, ..., v_n\}$), D describes the corresponding variable domains (D=$\{dom(v_1), dom(v_2), ..., dom(v_n)\}$), and C is a set of constraints (C=$\{c_1, c_2, ..., c_m\}$). A solution for a given CSP is represented by a complete set of variable assignments which is consistent with the set of constraints.

Example Configuration Model (as CSP)

$$V = \{wr, ip, rr\}$$
$$C = \{c_1, c_2, c_3, c_4, c_5\}$$
$$T = \{t_1, t_2, t_3, t_4\}$$
$$dom(wr) = \{low, medium, high\}$$
$$dom(ip) = \{shortterm, mediumterm, longterm\}$$
$$dom(rr) = \{3-6\%, 6-9\%, >9\%\}$$
$$c_1 : wr = medium \rightarrow ip \neq shortterm$$
$$c_2 : wr = high \rightarrow ip = longterm$$
$$c_3 : ip = longterm \rightarrow (rr = 3-6\% \vee rr = 6-9\%)$$
$$c_4 : rr = \; >9\% \rightarrow wr = high$$
$$c_5 : rr = 6-9\% \rightarrow (wr \neq low \wedge wr \neq medium)$$

Related Work: k-means Clustering of Constraints

$c_i \in C$	c_1	c_2	c_3	c_4	c_5	c_6	c_7
c_1	1.0	-	-	-	-	-	-
c_2	0.33	1.0	-	-	-	-	-
c_3	0.16	0.33	1.0	-	-	-	-
c_4	0.16	0.5	0.16	1.0	-	-	-
c_5	0.1	0.25	0.1	0.37	1.0	-	-
c_6	0.0	0.0	0.0	0.0	0.12	1.0	-
c_7	0.0	0.33	0.33	0.16	0.12	0.16	1.0

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iteration	c_1	c_2	c_3	c_4	c_5	c_6	c_7
1	$1(cs)$	1	1	2	$2(cs)$	2	2
2	1	$1(cs)$	1	1	$2(cs)$	2	1

$$sim(c_a, c_b) = \frac{\sum_{v \in V} co\text{–}occurrence(v, c_a, c_b)}{|V|}$$

k groups generated by k-means clustering: each group has a centroid which is the constraint most similar to all others.

Related Work: Understandability and Constraint Grouping Criteria

Grouping approach	kba_1: *SOL*	kba_2: *CON*
Similar variables	21.43%	42.86%
Similar operators	30.77%	53.85%
Random	38.46%	76.92%

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Table 5: Error rates for completing the tasks *find a solution (SOL)* and *find a conflict (CON)* depending on clustering approach (variable-based, operator-based, or random).

The best results were achieved with variable similarity-based clustering (N = 40 subjects).

Related Work: Understandability of Constraint Formalizations

kbb_1: SOL	errors	kbb_2: SOL	errors
$X \rightarrow Y$	21.43%	$X \rightarrow \neg Y$	14.29%
$\neg X \vee Y$	50.0%	$\neg X \vee \neg Y$	34.62%
$\neg Y \rightarrow \neg X$	96.43%	$Y \rightarrow \neg X$	50.0%
$\neg(X \wedge \neg Y)$	73.08%	$\neg(X \wedge Y)$	42.31%
$Y \leftarrow X$	25.0%	$\neg Y \leftarrow X$	16.67%

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- Knowledge bases with different representations of „requires“ and „incompatibility“ relations.
- “Preferred” representations can serve as a basis for recommending constraint refactorings.

User Study

- Goal: develop an understanding of the impact of textual domain specifications on corresponding formalizations.
- Focus: Compatibility & Requires Constraints.
- Study Participants (subjects): 10 subjects, completed studies of Computer Science (2 Universities), 2-5 years of experience in developing constraint-based applications, 50% experiences from industry projects.
- Subjects with industrial background: two companies focusing on configuration and recommendation.

Example Task: Formalization of Requires Constraints

Natural Language Statement (s)	*Appropriate Formalization?*
A shortterm investment period as well as a high expected return rate require a high willingness to take risks.	1) ip=shortterm $\rightarrow$ wr = high. rr=high $\rightarrow$ wr = high.
	2) ip=shortterm $\vee$ rr=high $\rightarrow$ wr = high.
	3) (ip = shortterm $\rightarrow$ wr = high) $\vee$ (rr = high $\rightarrow$ wr = high).

☞100% correct formalizations.

Task: Redundancy Detection

Variables and Domains	*Redundant Constraints?*
$V = \{v_1, ..., v_{10}\}$ $dom(v_i = \{1,2,3\})$	$c_0 : v_8 \neq v_9.$
	$c_1 : v_9 \neq v_{10}.$
	$c_2 : v_2 \neq v_9.$
	$c_3 : v_3 = 1.$
	$c_4 : v_{10} \neq v_8.$
	$c_5 : v_9 \neq v_8.$
	$c_6 : v_4 > v_2.$
	$c_7 : v_2 \neq v_{10}.$
	$c_8 : v_8 \geq v_7.$
	$c_9 : v_9 > v_8.$
	$c_{10} : v_2 \neq v_8.$

Redundant constraint $c_i \in C$: $C - \{c_i\} \models c_i$

☞ 40% faulty responses, i.e., redundancy detection is a complex task even for simple settings.

Task: Formalization of Compatibility Constraints

Natural Language Statement (s)	*Appropriate Formalization?*
A high expected return rate is only compatible with a high willingness to take risks.	1) $rr = high \leftrightarrow wr = high.$
	2) $rr = high \wedge wr = high.$
	3) $rr = wr.$
	4) $rr = high \rightarrow wr = high.$

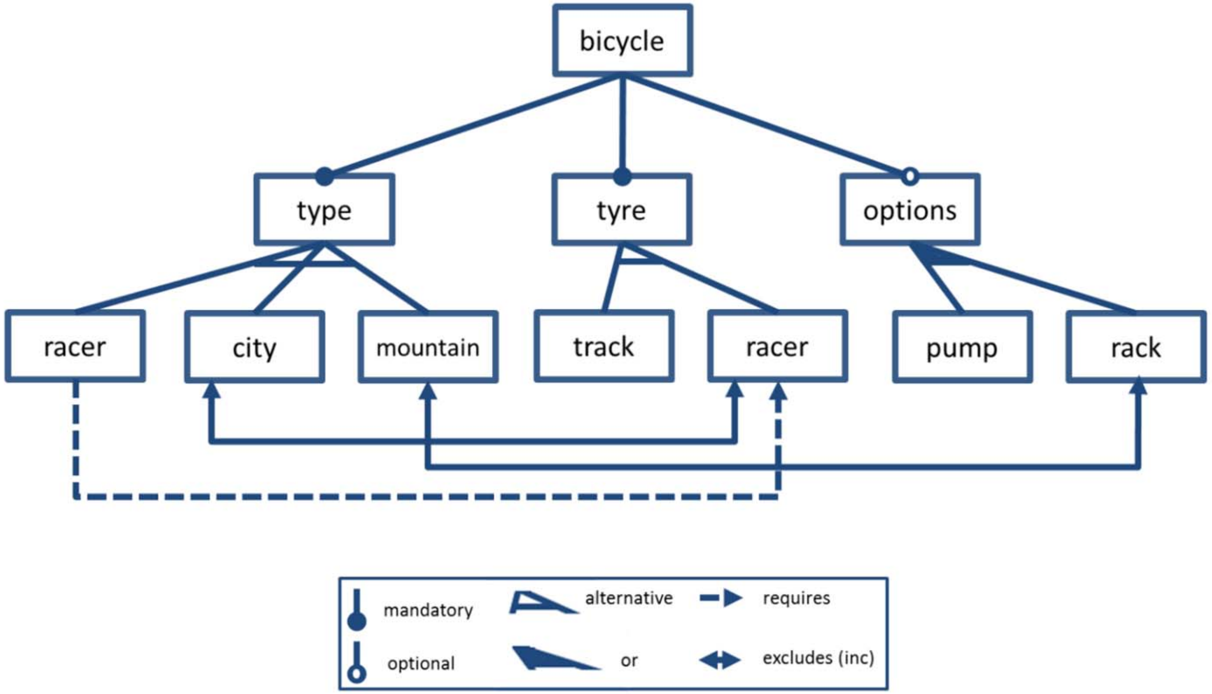
☞80% faulty formalizations. Potential assumption behind "only compatible": A with B and B with A.

Task: Formalization of Compatibility Constraints

Natural Language Statement (s)	*Appropriate Formalization?*
A shortterm investment period is only compatible with a low willingness to take risks (and vice-versa).	1) $ip = shortterm \leftrightarrow wr = low.$
	2) $ip = shortterm \land wr = low.$
	3) $ip = shortterm \rightarrow wr = low.$

☞90% correct formalizations due to a complete specification: both directions are taken into account.

Task: Model Description in Natural Language Text



☞Tendency of under-specifications of “or/alternative” relationships could be observed (90% of the cases).

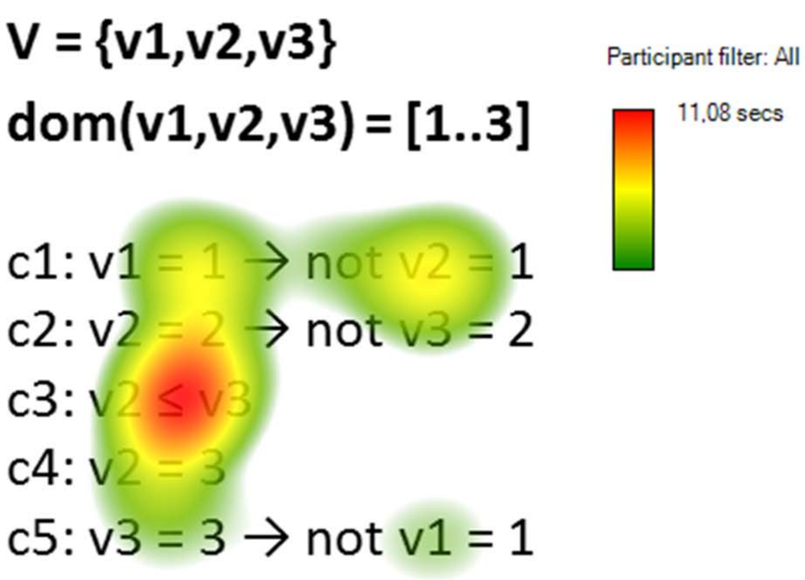
Preliminary Results (Summary)

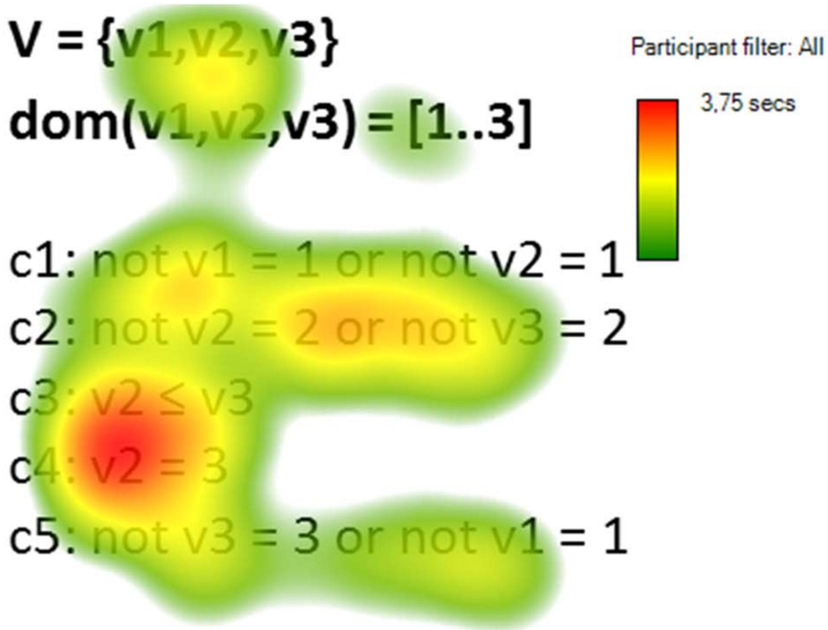
- Directed incompatibilities misunderstood („standard“ incompatibility assumed)
- Redundancy detection is a complex task even for low-complexity knowledge bases
- Similar results could be observed when study participants had to identify minimal diagnoses
- Underspecified „or/alternative“ semantics in domain descriptions
- „Direct“ translations (without further logical transformations) make constraints more maintainable

Future Work

- More in-depth analysis of industrial domain descriptions
- In-depth field study how domain experts specify variability knowledge (presented study limited)
- Empirical studies with larger user communities
- Extended set of knowledge types (e.g., generalization hierarchies, partonomies, resource constraints)
- Analyze in more detail existing work, for example, in Software Requirements Engineering

Future Work

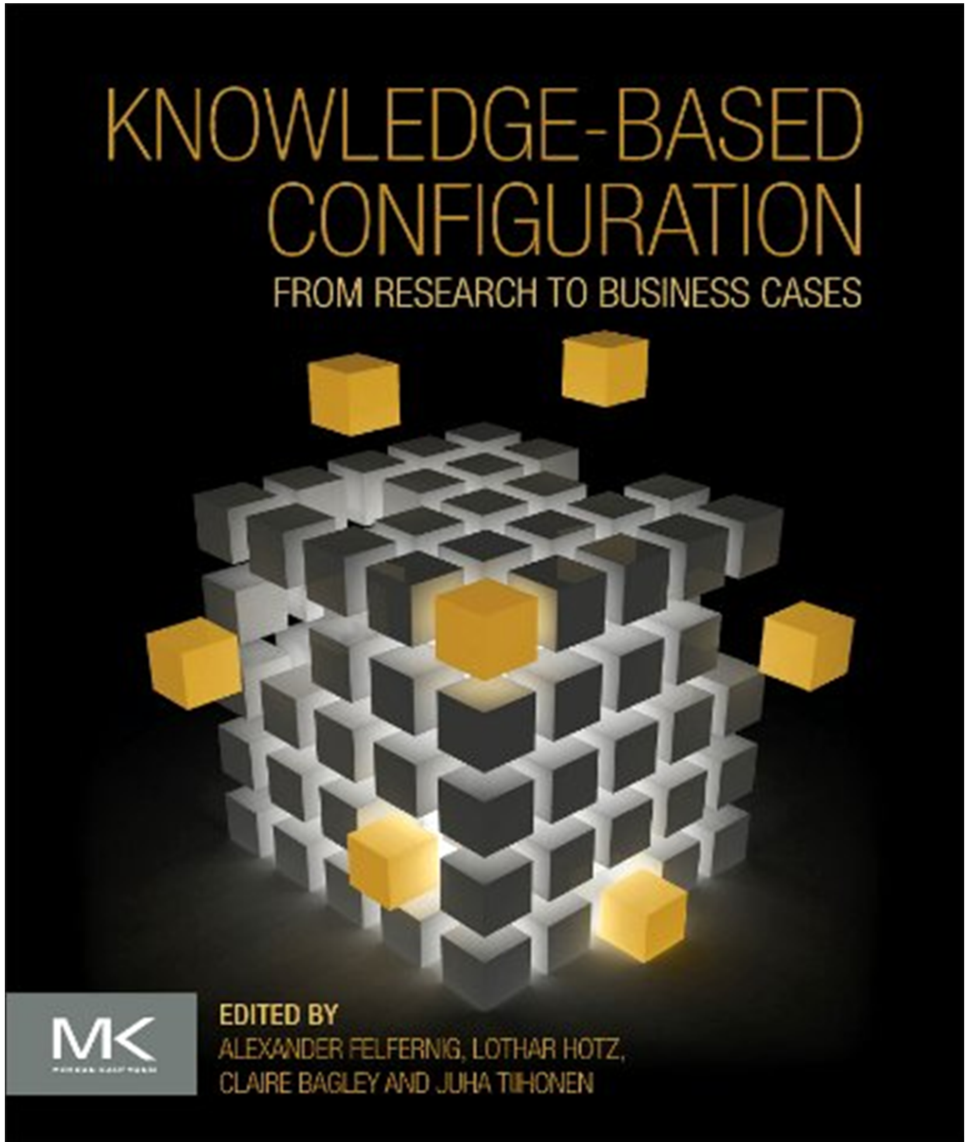




- Overview of areas, knowledge engineers looked at.
- Can be used, for example, for constraint ranking.

Conclusions

- Understanding cognitive processes in configuration knowledge engineering important
- Compact knowledge organization (e.g., clustering), understandable formalizations, no underspecified domain descriptions, …
- Focus of preliminary study: typical ways of formalizing domain knowledge
- Many open issues, for example, detailed analysis of industrial domain descriptions



Knowledge-Based Configuration by: *A. Felfernig*, *L. Hotz*, *C. Bagley*, and *J. Tiihonen*.

The purpose of this book is to expose the reader to a field of Artificial Intelligence that has been successfully integrated and used in the industry for more than 30 years. It provides configuration-related material for interested readers from the fields of industry, education, and research.

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Thank You!