The Downgrading Axioms Challenge for Qualitative Composition of Food Ingredients

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Abstract

Qualitatively graded relations provide increased granularity for fine-grain modelling, and achieve qualitative abstraction from quantitative data. We focus on composite dosage for food ingredients in the BAALL Ontology (of considerable size): weight ratios, Alcohol By Volume, etc. To deduce the overall qualitative composition by reasoning, axioms for *downgrading* are introduced. These impose a heavy load on reasoning such that conventional reasoners fail.

Keywords

qualitatively graded relations, downgrading, composite dosage, food ingredients

1. Introduction

The BAALL Ontology, originally motivated by Ambient Assisted Living at DFKI's *Bremen Ambient Assisted Living Lab, BAALL*, now integrates diverse applications with more than 40k OWL axioms [6], covering a foundational, a variety of general, and several application domain ontologies for configuration of service robots, diets, structured food products and dishes, and cooking assistance [1, 2, 3, 4, 5].[1] We plan a harmonisation with the FoodOn initiative [7] that demonstrates the dire need for ontologies in the food domain and related commercial interest. For food products and their composition by ingredients we have introduced *Qualitatively Graded Relations* (Sect. 2) for the deduction of *Composite Dosage* (Sect. 3) with a significant number of *Downgrading Axioms* (Sect. 4), providing a considerable challenge for reasoning. Only advanced reasoners such as Konclude provide an adequate response; conventional reasoners such as HermiT or Pellet easily reach limitations in space or processing time that can only be overcome by reducing the downgrading axioms for "normal" work with Protégé. As examples for the *Semantic Reasoning Evaluation Challenge* we thus provide several reduced versions of the BAALL Ontology (Sect. 5).

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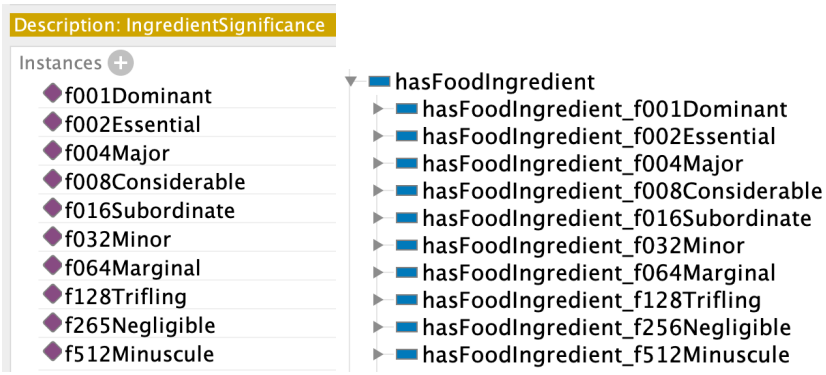

Figure 1: Names in sheaf of relation hasFoodIngredient encode grades from IngredientSignificance

Figure 2: hasFoodIngredient_f001Dominant has range FoodIngredient_f001Dominant, which has IngredientSignificance grade f001Dominant

2. Qualitatively Graded Relations

To achieve a graded valuation according to some qualitative abstraction of a semantic concept, we introduce extra valuation domains (cf. IngredientSignificance in Fig. 1, left) with values such as f001Dominant, f002Essential, ... or some other (arbitrarily fine) qualitative metrics; the number of grades/levels depends on the application.

Such values are used as grades in *qualitatively graded relations* (cf. [2, 1, 3, 4]) to encode the valuations in the names of (a sheaf of) relations, e.g. hasFoodIngredient_f001Dominant, hasFoodIngredient_f002Essential, ... , cf. Fig. 1. The axiomatization defining the relationship between the set of values (grades) in Fig. 1, left, and the ranges of the relations in the sheaf hasFoodIngredient is partially given in Fig. 2: e.g. the relation hasFoodIngredient_f001Dominant has the range FoodIngredient_f001Dominant, defined by hasIngredientSignificance to have as grade value the IngredientSignificance individual f001Dominant. These axioms are partially omitted in the challenge, cf. Sect. 5.

3. Composite Dosage

As a motivating example, these relations refer to the *composite dosage* of food ingredients, i.e. the significance of ingredients in composite ingredients, giving rise to a hierarchy of qualitative composition. Consider the composition of ingredients in ChiliConCarne (Fig. 3).

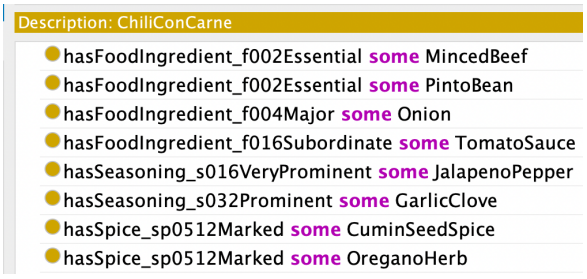

Figure 3: Recipe prototype for ChiliConCarne with qualitative characterization of ingredients

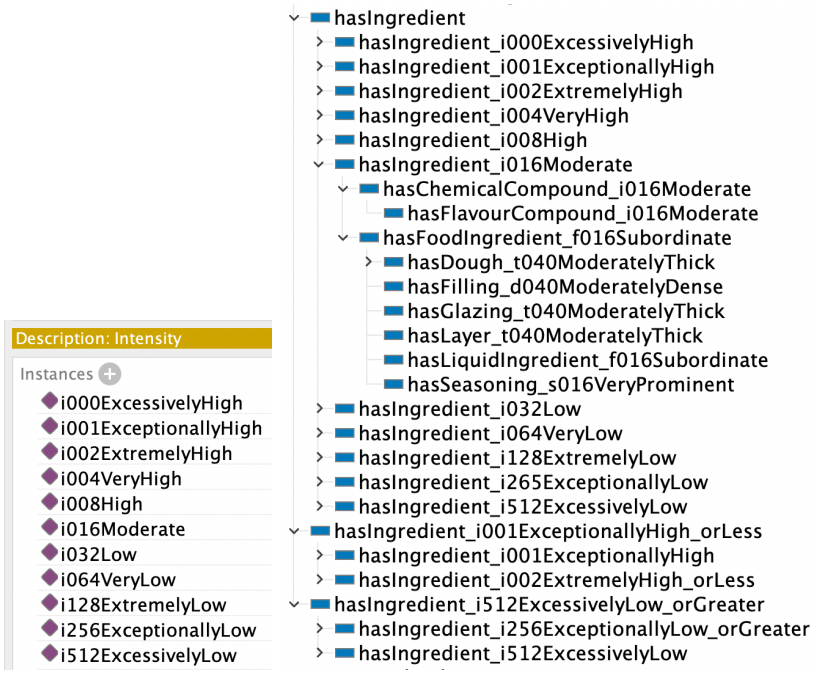

Figure 4: Grading of Intensity in hasIngredient, embedding graded notions for bakery etc.

The names are suggestive, leading to the qualitative characterization of a food product in terms of its ingredients, in effect a kind of *recipe prototype* sufficient for an experienced cook to derive precise measures for a personal recipe at her/his discretion (cf. quantitative vs. qualitative scales in Sects. 3.1, 3.2 below). TomatoSauce refers to a sub-recipe.

Qualitative grading for different kinds of food ingredients is embedded in a general grading scheme for ingredients based on Intensity (Fig. 4). Consider hasIngredient_i016Moderate: it embeds hasChemicalCompound_f016Subordinate and hasFoodIngredient_f016Subordinate, etc.; note that different notions/scales are used for bakery, seasoning, or (hot) spices, and related to the grading of weight proportions in Intensity, on which we will focus here.

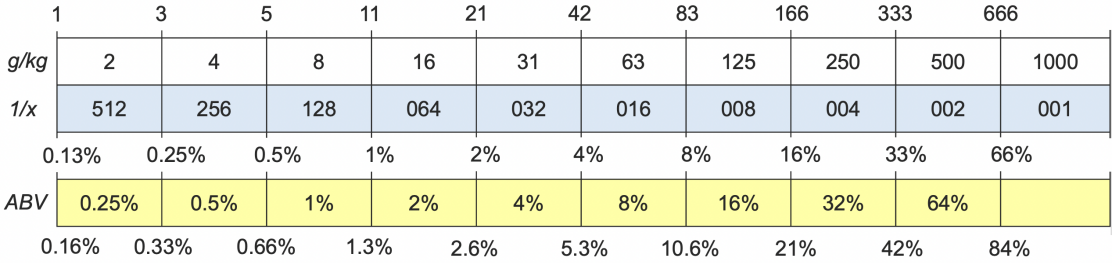

Figure 5: Qualitative scale with doubling proportions (blue), and ABV scale (yellow)

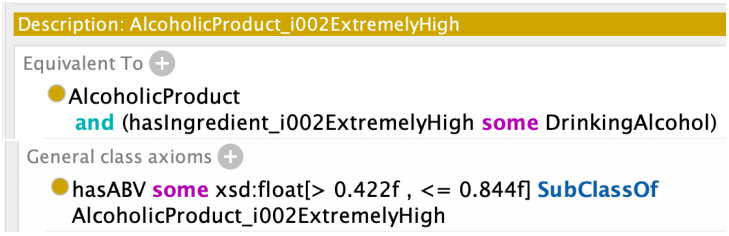

Figure 6: Quantitative intervals for hasABV yielding qualitative classification

3.1. Qualitative Scales

The governing principle for the qualitative scaling of intensity is the doubling, or conversely halving, of proportions, see Fig. 5: level 001 (see blue row), corresponding to hasFoodIngredient_f001Dominant, refers to *that* ingredient, which is dominant in the composite food, i.e. it has the ratio 1/1, while an ingredient at level 002 is comprised with ratio 1/2, and so on; thus the level names x correspond to the ratio 1/x. This gives rise to an exponential scale of (ordered) qualitative levels based on powers of 2.

Each level corresponds to an interval. For example level 002 corresponds to the interval 33% .. 66%, thus 1/3 .. 2/3 of the total, or, if we assume a total weight of 1kg, to 333 g/kg .. 666 g/kg. The notions of doubling/halving seem appropriate (cognitively adequate) for the application. Note that the governing proportion resides in the middle of each interval (e.g. 1/002 in the middle of 33% .. 66%). As a consequence, level 001 is in the middle of 66% .. 133%; this takes a little getting used to, but, after some reflection, makes a lot of sense. In practice, it means that the "whole" may actually be a little more than 1kg; taking the analogy of recipe prototypes, the "whole" is identified with an amount of 666g .. 1.33kg, appropriate for a meal for 4 persons.

3.2. Quantitative vs. Qualitative Dosage

The qualitative intervals may thus be related to quantitative intervals. As a further example take the definition of AlcoholicProducts (cf. Fig. 5, yellow row): the scale for mass (kg) is related to the ABV (Alcohol by Volume) scale based on the relative density

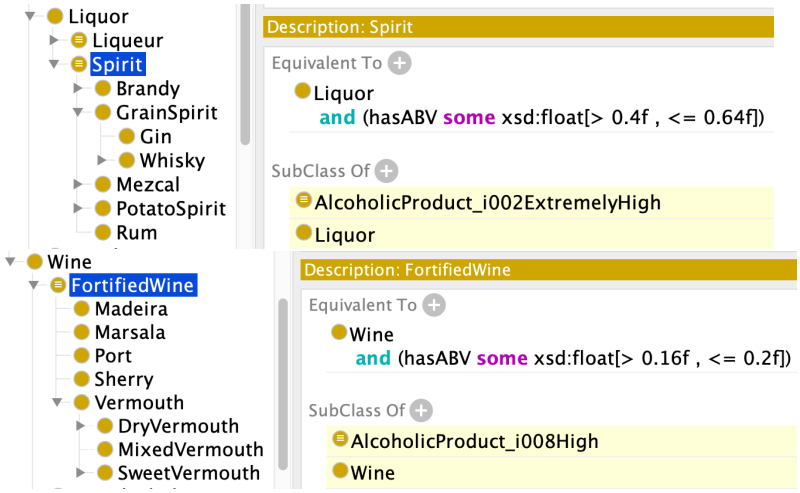

Figure 7: Deduced qualitative classification as AlcoholicProduct of Spirit and Fortified Wine

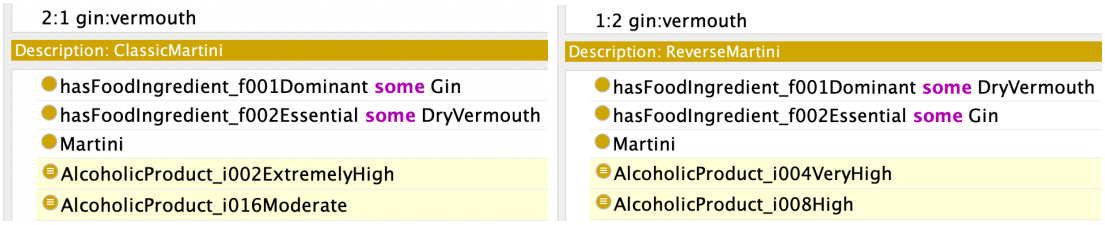

Figure 8: Qualitative dosage for Classic Martini and Reverse Martini deduced by downgrading

(specific weight) of alcohol; level 002, corresponding to hasFoodIngredient_f002Essential, or hasIngredient_i002ExtremelyHigh, refers to the interval 42% .. 84% ABV. We can formally state this correspondence by a general class axiom as in Fig. 6, thus relating the qualitative definition to quantitative measures. Moreover, an alcoholic beverage stating its ABV by an assertion with the data property hasABV will be classified automatically by an OWL-DL reasoner. As examples, take Spirit and FortifiedWine in Fig. 7.

4. Downgrading

We would like to automatically derive the ABV of a composite dosage as in e.g. ClassicMartini or ReverseMartini in Fig. 8. Note that the 2:1 (i.e. $1/3 : 2/3$ or 66%:33%) mass proportion of Gin vs. DryVermouth in ClassicMartini just fits above the lower bounds of the intervals for f001Dominant and f002Essential, resp.

This is achieved by axioms downgrading the dosage composition such as those for hasIngredient_i004VeryHigh in Fig. 9; they may be generated according to the downgrading table in Fig. 9 by Generic Ontology Design Patterns (GODPs, cf. [3, 4, 6]): for example,

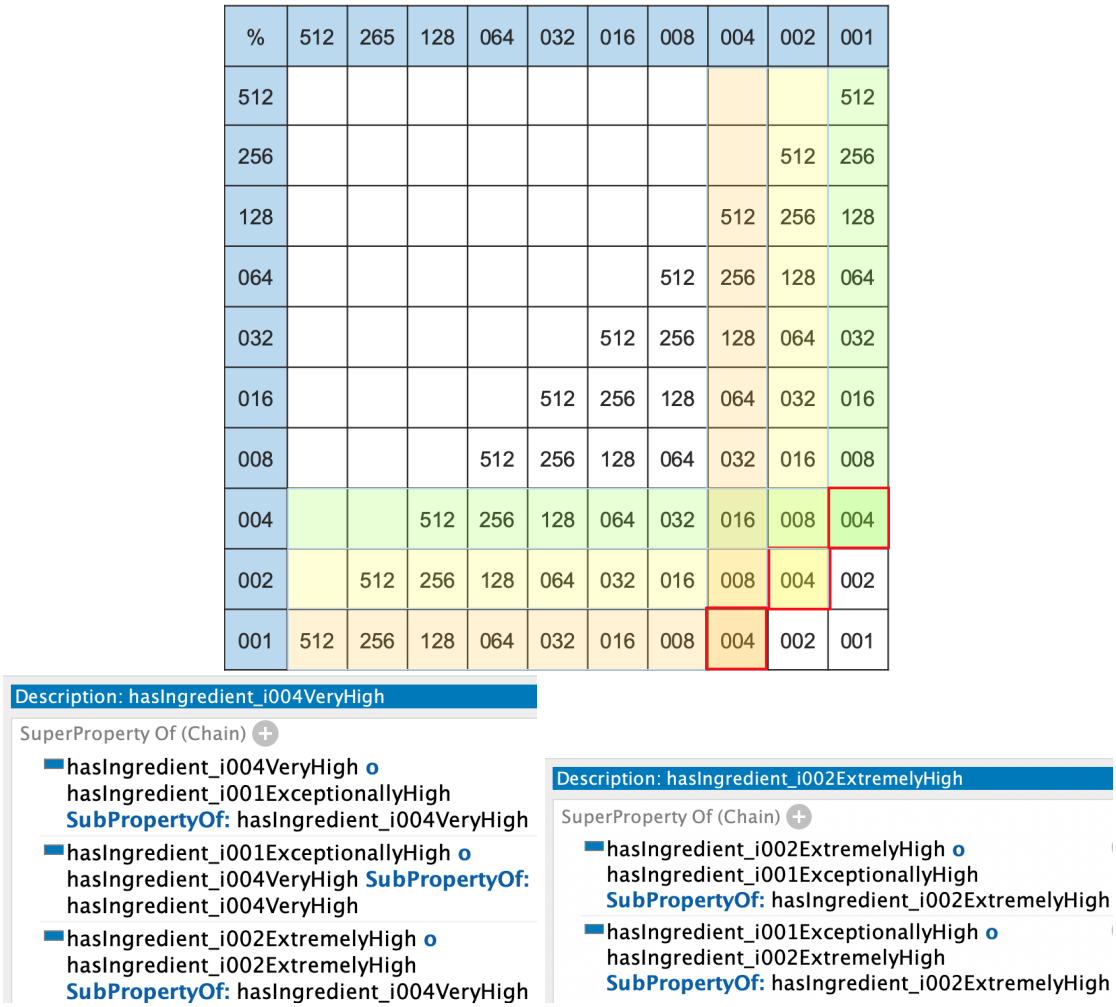

Figure 9: Downgrading Table and Downgrading Axioms

the composition of hasIngredient_i002ExtremelyHigh and hasIngredient_i002ExtremelyHigh leads to hasIngredient_i004VeryHigh at the next lower level, and so on. Downgrading is symmetric here (but cf. other composition patterns in [3]).

For the ClassicMartini example, we note that Spirit is classified as an AlcoholicProduct_i002ExtremelyHigh, while FortifiedWine is classified as an AlcoholicProduct_i008High, cf. Fig. 7. For the composite dosage hasFoodIngredient_i001Dominant **some** Gin we deduce an AlcoholicProduct_i002ExtremelyHigh, similarly for hasFoodIngredient_f002Essential **some** DryVermouth we deduce an AlcoholicProduct_i016Moderate, cf. Fig. 8, Fig. 9.

Fig. 10 shows the derived subsumption hierarchy for AlcoholicProduct_i001ExceptionallyHigh_orLess where the derivations AlcoholicProduct_i002ExtremelyHigh and AlcoholicProduct_i016Moderate for ClassicMartini combine into AlcoholicProduct_i002Extremely-

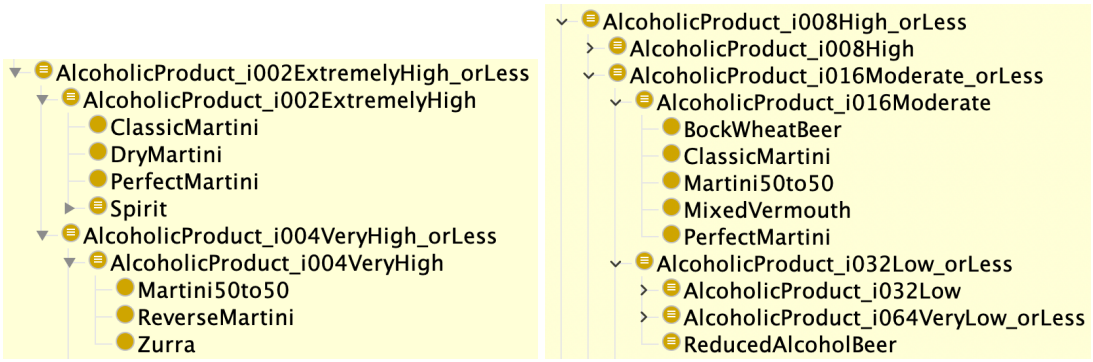

Figure 10: Derived Subsumption Hierarchy for AlcoholicProduct_i002ExtremelyHigh_orLess

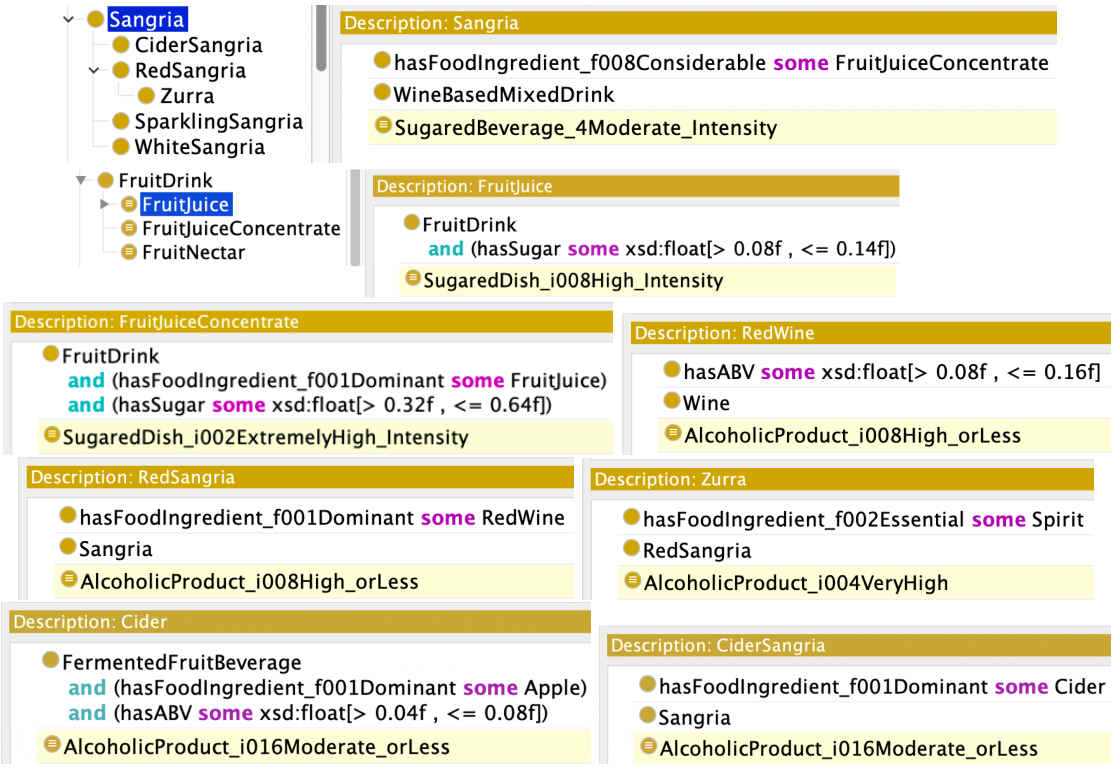

Figure 11: Alcohol and Sugar Dosage of Variants of Sangria

High_orLess, while the derivations AlcoholicProduct_i004VeryHigh and AlcoholicProduct_-i008High for ReverseMartini combine into AlcoholicProduct_i004VeryHigh_orLess, resp.

Fig. 11 shows another example: different kinds of sangría, where not only the dosage of alcohol but also of sugar is derived, clearly dominated by FruitjuiceConcentrate.

	Ontology	#Axioms	#Logical Axioms	Expressive-ness	HermiT	Pellet	Fact++	Konclude
A	FOD_Dish_down	35407	13339	SROIF(D)	heap error	timeout	timeout	2,304.4s
B	FOD_Product_i064to001	29421	10908	SRIF(D)	timeout	timeout	timeout	2.0s
C	FOD_Product_i016to001	29370	10879	SRIF(D)	597s	timeout	timeout	0.6s
D	FOD_Small_i032to001	20118	6609	SRIF(D)	*3,240s	error**	timeout	0.9s
E	FOD_Small_i016to001	20108	6602	SRIF(D)	147s	error**	error***	0.6s
F	IngredientSignificance_down	535	241	SROI	heap error	363.9s	79ms	0.2s
G	IngredientSignificance_i016to001	415	201	SROI	11s	0.6s	67ms	10ms

Figure 12: Performance Table [*standalone, otherwise heap error inside Protégé; **NullPointer-Exception; ***ReasonerInternalException]

5. The Downgrading Axioms Challenge

The downgrading axioms provide a considerable challenge for reasoning. Only advanced reasoners such as Konclude provide an adequate response. For the *Semantic Reasoning Evaluation Challenge* we provide several reduced versions of the BAALL Ontology, all of them with most imports expanded[2]:

A *FOD_Dish_down*: the Food part, with all downgrading axioms (cf. Sect. 4);
B *FOD_Product_i064to001*: smaller version, axioms reduced to grades i064 ... i001;
C *FOD_Product_i016to001*: downgrading axioms reduced to grades i016 ... i001;
D *FOD_Small_i032to001*: yet smaller, axioms reduced to grades i032 ... i001;
E *FOD_Small_i016to001*: downgrading axioms reduced to grades i016 ... i001;
F *IngredientSignificance_down*: the minimal core of the downgrading axioms;
G *IngredientSignificance_i016to001*: axioms reduced to grades i016 ... i001.

All experiments have been performed on a MacBook Pro with an M1 Max chip with a 10Core CPU and 64GB RAM (Java heap space set to 50 GB). Fig. 12 gives a summary of the performance. All versions perform with Konclude. However, Konclude is not integrated with Protégé; handling is cumbersome as imported ontologies have to be merged before submitting to Konclude, separately from Protégé; explanations of the deduction chain leading to an inconsistency are not provided (as they would in Protégé).

Versions [C,E] are considered to be the limit for reasonable performance with HermiT from Protégé; it is quite irritating that some versions produce (heap) errors or timeouts in HermiT/Pellet/Fact++ so that it is unclear whether they are perhaps indeed erroneous. Versions [A,B,D] are beyond reasonable space limits (leading to Java heap space exceptions) and time requirements (whether executed inside Protégé or separately); even the minimal core version [F] with the complete set of downgrading axioms is out of scope for HermiT.[3]

[2]The versions at http://ontologies.baall.de/2022SemREC/ may be configured with a variety of ranges for the downgrading axioms, or the definitional axioms for qualitatively graded relations (Sect. 2).

[3]Interestingly, although HermiT classified Version [D] rather quickly as a standalone reasoner, we had to disable the reasoning for individual inferences in Protégé; otherwise, HermiT takes 40h, terminating with a heap error (although derivations are usable). This issue merits further investigation.

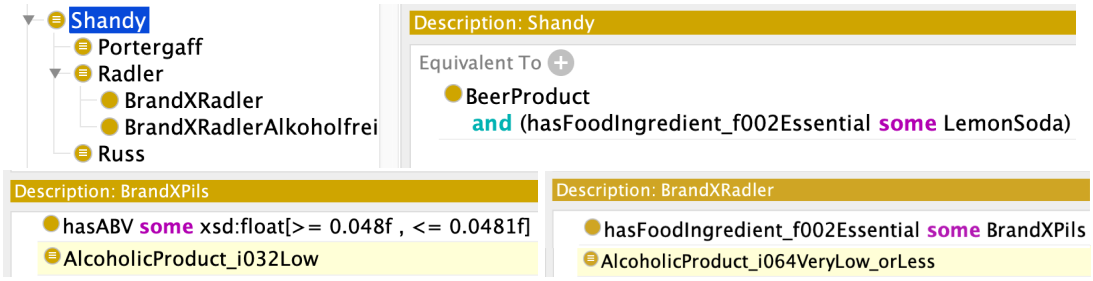

Figure 13: Shandy, Pils and Radler

Note that if Konclude is set up to preserve its initial data structure for a given ontology, it provides a rather immediate response for subsequent DL queries, while HermiT essentially requires a complete re-classification with unacceptable time requirements.

6. Conclusion

For standard reasoners in Protégé such as HermiT, the dosage of CiderSangria (Fig. 11) is already at the limit (cf. versions [B, E] in Fig. 12, Sect. 1). In contrast, the shandy BrandXRadler (Fig. 13) is beyond the limit, since it requires the grade i064VeryLow.

Similarly, when we consider the dosage of spices (cf. Fig. 3) we easily reach very low overall proportions. For chemical aroma compounds (cf. Fig. 4) (and the deduction of aroma compositions in qualitative "virtual cooking" as a perspective) we will even be obliged to go beyond grade i512ExcessivelyLow in the future. Pungency, as an example, is quite important for the modeling of diets related to food related impairments with qualitative grading [1, 2, 5], which we intend to pursue further.

The reduced versions of the performance table in Fig. 12 do not include the definitional axioms for qualitatively graded relations (Sect. 2, Fig. 1, 2), since these significantly burden the deduction[4], nor do they include other constituents (such as sugar, etc.) or the modelling of e.g. bakery products; only the full version [A] does.

Moreover, we are working on a harmonisation of the BAALL Ontology with the FoodOn initiative [7], as an extension regarding qualitative prototype recipes with composite dosage and its derivation. GODPs [3, 4, 6] will be applied in a systematic fashion. Inclusion of a reasonable set of composite products with recipes will lead to substantial size and considerable additional stress on the faculties of reasoning engines. Other applications of Graded Relations or patterns for composition [3] are likely to impose additional challenges.

As a response to the Semantic Reasoning Evaluation Challenge we hope for significant improvement of reasoning capabilities, preferably integrated with Protégé.

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[4] by a factor of 500 for Version [E] on an older laptop.

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