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## Accepted Manuscript

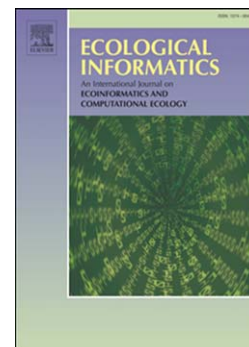
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# Decision Support for Agri-Food Chains: A Reverse Engineering Argumentation-Based Approach

Rallou Thomopoulos<sup>a,b,\*</sup>, Madalina Croitoru<sup>b</sup>, Nouredine Tamani<sup>b</sup>

<sup>a</sup>*IATE Joint Research Unit, UMR1208, CIRAD-INRA-Supagro-Univ. Montpellier II, 2 place P. Viala, F-34060 Montpellier cedex 1, France*

<sup>b</sup>*INRIA GraphIK, LIRMM, 161 rue Ada, F-34392 Montpellier cedex 5, France*

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## Abstract

Evaluating food quality is a complex process since it relies on numerous criteria historically grouped into four main types: nutritional, sensorial, practical and hygienic qualities. They may be completed by other emerging preoccupations such as the environmental impact, economic phenomena, etc. However, all these aspects of quality and their various components are not always compatible and their simultaneous improvement is a problem that sometimes has no obvious solution, which corresponds to a real issue for decision making. This paper proposes a decision support method guided by the objectives defined for the end products of an agrifood chain. It is materialized by a backward chaining approach based on argumentation.

*Keywords:* decision support, knowledge representation, argumentation, reverse engineering, backward chaining, agrifood chain control, goal, viewpoint

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\*Corresponding author

*Email addresses:* [rallou.thomopoulos@supagro.inra.fr](mailto:rallou.thomopoulos@supagro.inra.fr) (Rallou Thomopoulos), [madalina.croitoru@lirmm.fr](mailto:madalina.croitoru@lirmm.fr) (Madalina Croitoru), [nouredine.tamani@lirmm.fr](mailto:nouredine.tamani@lirmm.fr) (Nouredine Tamani)

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## 1. Introduction

In agrifood chains, the products traditionally go through the intermediate stages of processing, storage, transport, packaging and reach the consumer (the demand) from the producer (the supply). More recently, due to an increase in quality constraints, several parties are involved in production process, such as consumers, industrials, health and sanitary authorities, etc. expressing their requirements on the final product as different point of views which could be conflicting. The notion of reverse engineering control, in which the demand (and not the supply) sets the specifications of desired products and it is up to the supply to adapt and find its ways to respond, can be considered in this case.

In this article, we discuss two aspects of this problem. First, we accept the idea that specifications cannot be established and several complementary points of view - possibly contradictory - can be expressed (nutritional, environmental, taste, etc.). We then need to assess their compatibility (or incompatibility) and identify solutions satisfying a maximum set of viewpoints. To this end we propose a logical framework based on argumentation and introduce a method of decision making based on backward chaining for the bread industry.

Since a joint argumentation - decision support approach is highly relevant to the food sector (Thomopoulos et al., 2009), the contribution of the paper is twofold. First we present a real use case of an argumentation process in the agrifood domain. Second we introduce the notion of viewpoint / goal in this setting based on the notion of backwards chaining reasoning and show how to use those techniques in a concrete application.

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5 The main alternative method to deal with the problem is the multicri-  
6 teria decision approach. However multicriteria decision aims at evaluating  
7 several alternative options, whereas argumentation-based decision focuses on  
8 whether several options make sense together, which is a different perspective,  
9 addressed in this paper. Moreover, multicriteria decision is not connected to  
10 the backward chaining procedure as the argumentative approach is, by con-  
11 struction of the arguments, as will be explained in Section 5.2.  
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18 In Section 2, we introduce the real scenario considered in the application.  
19 In Section 3, we motivate our technical and modeling choices. In Section 4,  
20 the developed approach is introduced. It relies on an instantiation of a logic  
21 based argumentation framework based on a specific fragment of first order  
22 logic. In Section 5, we explain the technical results that ensure the soundness  
23 and completeness of our agronomy application method. In Section 6, some  
24 evaluation results are presented. Finally, Section 7 concludes the paper.  
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## 32 33 **2. Scenario**

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35 The case of study considered in this paper relates to the debate around the  
36 change of ash content in flour used for common French bread. Various actors  
37 of the agronomy sector are concerned, in particular the Ministry for Health  
38 through its recommendations within the framework of the PNNS (“National  
39 Program for Nutrition and Health”), the millers, the bakers, the nutritionists  
40 and the consumers.  
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47 The PNNS recommends to privilege the whole-grain cereal products and  
48 in particular to pass to a common bread of T80 type, i.e made with flour  
49 containing an ash content (mineral matter rate) of 0.8%, instead of the type  
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5 T65 (0.65% of mineral matter) currently used. Increasing the ash content  
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7 comes down to using a more complete flour, since mineral matter is concen-  
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9 trated in the peripheral layers of the wheat grain, as well as a good amount  
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11 of components of nutritional interest (vitamins, fibers). However, the pe-  
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13 ripheral layers of the grain are also exposed to the phytosanitary products,  
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15 which does not make them advisable from a health point of view, unless one  
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17 uses organic flour.

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19 Other arguments (and of various nature) are in favour or discredit whole-  
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21 grain bread. From an organoleptic point of view for example, the bread loses  
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23 out in its “being crusty”. From a nutritional point of view, the argument  
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25 according to which the fibers are beneficial for health is discussed, some  
26  
27 fibers could irritate the digestive system. From an economic point of view,  
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29 the bakers fear selling less bread, because whole-grain bread increases satiety  
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31 – which is beneficial from a nutritional point of view, for the regulation of  
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33 the appetite and the fight against food imbalances and pathologies. However  
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35 whole-grain bread requires also less flour and more water for its production,  
36  
37 thus reducing the cost. The millers also fear a decrease in the quality of the  
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39 technical methods used in the flour production.

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41 Beyond the polemic on the choice between two alternatives (T65 or T80),  
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43 one can take the debate further by distinguishing the various points of view  
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45 concerned, identifying the desirable target characteristics, estimating the  
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47 means of reaching that point. The contribution of this paper is showing  
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49 how using argumentation can help towards such practical goals.  
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### 3. Motivation

In this paper we will elicit the points of view and the desirable target characteristics by the means of interviews with agronomy experts. Once the target characteristics identified, finding the means of reaching them will be done automatically by a combination of reverse engineering and argumentation. The reverse engineering will be used in order to find the complete set of actions to take towards a given characteristic, for all characteristics. In certain cases the actions to take will be inconsistent. Argumentation will then be employed in order to identify actions that can be accepted together.

#### 3.1. Reverse Engineering

While reverse engineering has been widely employed in other Computer Science domains such as multi agent systems or requirements engineering (e.g. Brunelière et al. (2014)), it is quite a novel methodology when applied in agronomy. In agrifood chains, the products traditionally go through the intermediate stages of processing, storage, transport, packaging and reach the consumer (the demand) from the producer (the supply). It is only recently, due to an increase in quality constraints, that the notion of reverse engineering control has emerged (Perrot et al., 2011). In this case the demand (and not the supply) sets the specifications of desired products and it is up to the supply to adapt and find its ways to respond. In what follows, starting from the desired target criteria for the final product, the methods allowing one to identify ways to achieve these criteria (by intervention on the various stages of the supply chain) are named “reverse engineering”.

Reverse engineering is known to be challenging from a methodological

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5 viewpoint. This is due to two main aspects. First, the difficulty of defining  
6 the specifications for the expected finished product. The desired quality cri-  
7 teria are multiple, questionable, and not necessarily compatible. The second  
8 difficulty lies in the fact that the impact of different steps of food process-  
9 ing and their order is not completely known. Some steps are more studied  
10 than others, several successive steps can have opposite effects (or unknown  
11 effects), the target criteria may be outside of the characteristics of products.  
12 Second, reconciling different viewpoints involved in the food sector still raises  
13 unaddressed questions. The problem does not simply consist in addressing  
14 a multi-criteria optimisation problem (Bouyssou et al., 2009): the domain  
15 experts would need to be able to justify why a certain decision (or set of  
16 possible decisions) is taken.  
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### 29 *3.2. Argumentation*

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31 Argumentation is a reasoning model based on the construction and the  
32 evaluation of interacting arguments. It has been applied to nonmonotonic  
33 reasoning, decision making, or for modeling different types of dialogues in-  
34 cluding negotiation. Most of the models developed for these applications are  
35 grounded on the abstract argumentation framework proposed by Dung in  
36 Dung (1995). This framework consists of a set of arguments and a binary  
37 relation on that set, expressing conflicts among arguments. An argument  
38 gives a reason for believing a claim, for doing an action.  
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46 Argumentation theory in general (Dung, 1995; Besnard and Hunter, 2008;  
47 Rahwan and Simari, 2009) is actively pursued in the literature. Some ap-  
48 proaches combine argumentation and multi criteria decision making (Am-  
49 goud and Prade, 2009).  
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5 Value based Argumentation Frameworks (Bench-Capon, 2003a) have been  
6 proposed, where the strength of an argument corresponds to the values it pro-  
7 motes. What we call viewpoint later on in this paper would then correspond  
8 to the notion of audience in such setting. Although intuitive, this approach  
9 is not adapted in the case of the considered application. Here a value can be  
10 “split” into several audiences: there could be contradictory goals even from  
11 the same viewpoint. The notion of viewpoint and goals introduced in this  
12 setting also remind those proposed by (Assaghir et al., 2011).  
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### 21 *3.2.1. Logic-based Argumentation*

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23 In this paper we present a methodology combining reverse engineering  
24 and logical based argumentation for selecting the actions to take towards the  
25 agronomy application at hand. The logical instantiation language is a subset  
26 of first order logic denoted in this paper *SRC* equivalent to Datalog+- (Cali  
27 et al., 2010), Conceptual Graphs or Description Logics (more precisely the  $\mathcal{EL}$   
28 fragment (Baader et al., 2005) and DL-Lite families (Calvanese et al., 2007)).  
29 All above mentioned languages are logically equivalent in terms of representa-  
30 tion or reasoning power. The reason why this application is using *SRC* is the  
31 graph based representation proper to *SRC* (and not to the other languages).  
32 This graph based representation (implemented in the Cogui tool (Chein and  
33 Mugnier, 2009; Chein et al., 2013)) makes the language suitable for interact-  
34 ing with non computing experts (Chein et al., 2013).  
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46 Here we use the instantiation of (Croitoru and Vesic, 2013) for defining  
47 what an argument and an attack are. While other approaches such as (García  
48 and Simari, 2004), (Besnard and Hunter, 2005), (Muller and Hunter, 2012)  
49 etc. address first order logic based argumentation, the work of (Croitoru and  
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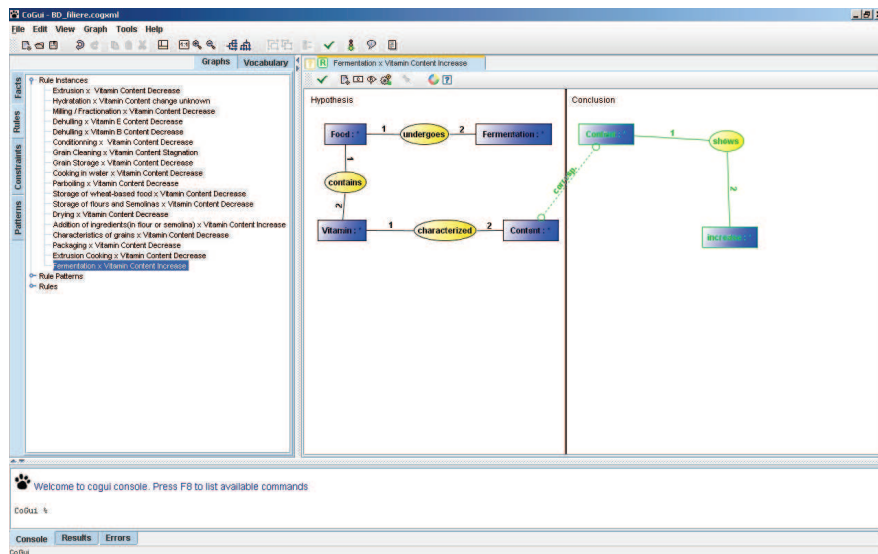


Figure 1: The Cogui visual graph based interface

Vesic, 2013) uses the same  $SRG$  syntax and graph reasoning foundations. In Figure 1 the visual interface of Cogui is depicted: knowledge is represented as graph which is enriched dynamically by rule application. More on the visual appeal of Cogui for knowledge representation and reasoning can be found in (Chein et al., 2013).

#### 4. Approach

As mentioned above, in this paper we use an instantiation of logic based argumentation based on a specific fragment of first order logic. This subset is equivalent to Datalog+- (Cali et al., 2010), Conceptual Graphs or Description Logics (the  $\mathcal{EL}$  fragment (Baader et al., 2005) and the DL-Lite families (Calvanese et al., 2007)). The reason for which our application required this

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5 specific logic fragment is related to the information capitalisation needs of  
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7 the food sector. The long term aim is to enrich ontologies and data sources  
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9 based on these ontologies and join the Open Data movement. This entails  
10  
11 that the language used by the food applications needs to be compatible with  
12  
13 the Semantic Web equivalent languages as mentioned before.

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15 The choice of the *SRC* syntax and graph reasoning mechanism is justified  
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17 by the visual appeal of this language for non computing experts.

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19 In a nutshell our methodology is as follows. The set of goals, viewpoints  
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21 as well as the knowledge associated with the goals / viewpoints is elicited  
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23 either by the means of interviews with the domain experts or manually from  
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25 different scientific papers. This step of the application is the most time con-  
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27 suming but the most important. If the knowledge elicited is not complete,  
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29 sound or precise the outcome of the system is compromised. Then, based on  
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31 the knowledge elicited from the knowledge experts and the goals of the ex-  
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33 perts, we enrich the knowledge bases using reverse engineering (implemented  
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35 using backwards chaining algorithms). Putting together the enriched knowl-  
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37 edge bases obtained by backwards chaining from the different goals will lead  
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39 to inconsistencies. The argumentation process is used at this step and the  
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41 extensions yield by the applications computed. Based on the extensions and  
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43 the associated viewpoints we can use voting functions to determine the ap-  
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45 plication choice of viewpoints.

#### 46 47 *4.1. Use Case Real Data*

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49 Expressing the target characteristics – or goals – according to various  
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51 points of view consists of identifying the facets involved in the construction  
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53 of product quality: points of view, topics of concern such as nutrition, envi-  
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5 ronment, technology, etc. In addition, such viewpoints have to be addressed  
6 according to their various components (fibers, minerals, vitamins, etc). De-  
7 sirable directions need to be laid down, and in a first step we consider them  
8 independent one from another.  
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12 The considered sources of information include, from most formal to less  
13 formal: (1) peer reviewed scientific papers; (2) technical reports or infor-  
14 mation posted on websites; (3) conferences and scientific meetings around  
15 research projects; (4) expert knowledge obtained through interviews. The sci-  
16 entific articles we have analysed – with the supervision of experts in agrifood  
17 – include: (Bourre et al., 2008; Slavin and Green, 2007; Dubuisson-Quellier,  
18 2006; Ginon et al., 2009; Layat, 2011). (Bourre et al., 2008) compares the  
19 different types of flour from a nutritional point of view. (Slavin and Green,  
20 2007) explores the link between fiber and satiety. (Dubuisson-Quellier, 2006;  
21 Ginon et al., 2009) deal with consumer behaviour and willingness to pay.  
22 They focus on French baguette when information concerning the level of  
23 fibers is provided, and they base their results on statistical studies of con-  
24 sumer panels. (Layat, 2011) provides a summary of the nutritional aspects  
25 of consumption of bread and the link with technological aspects.  
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39 We also reviewed technical reports available on official websites on health  
40 policy: the public PNNS (National Program for Nutrition and Health, [www.mangerbouger.fr/pnns](http://www.mangerbouger.fr/pnns)) (PNNS (documents statutaires), 2010), the Euro-  
41 pean project Healthgrain (looking at improving nutrition and health through  
42 grains) (Dean et al., 2007; HEALTHGRAIN, 2009), as well as projects and  
43 symposia on sanitary measures regarding the nutritional, technological and  
44 organoleptic properties of breads (DINABIO, 2008; CADINNO, 2008; AQUA-  
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5 NUP, 2009; FCN, 2009). Finally, several interviews were conducted to collect  
6 domain expert knowledge, in particular for technology specialists in our lab-  
7 oratory.  
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10 A summary of the results obtained in the baking industry is synthesised in  
11 Figure 2 regarding nutritional and organoleptic aspects. Figure 2(a) shows  
12 the main identified goals to reach for a nutritionally optimised bread (for  
13 instance, containing a high level of soluble fibers, vitamins and minerals, low  
14 salt, etc.), whereas Figure 2(b) sums up the main goals to achieve for an  
15 enjoyable bread regarding sensorial concerns (for example, crusty, etc.).  
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## 22 23 **5. Technical Soundness**

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25 In this section we explain the technical results that ensure the soundness  
26 and completeness of our agronomy application method. The section is com-  
27 posed of three parts. A first subsection explains the logical subset of first  
28 order logic language employed in the paper. The second subsection shows  
29 how to construct arguments and attacks in order to obtain extensions when  
30 a knowledge base expressed under this language is inconsistent. Last, the  
31 third section shows how we used reverse engineering to complete the knowl-  
32 edge base with all possible actions and how argumentation can be used in  
33 order to select consistent subsets of knowledge which support given actions.  
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### 44 *5.1. The Logical Language*

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46 In the following, we give the general setting knowledge representation  
47 language used throughout the paper.  
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50 A knowledge base is a 3-tuple  $\mathcal{K} = (\mathcal{F}, \mathcal{R}, \mathcal{N})$  composed of three finite  
51 sets of formulae: a set  $\mathcal{F}$  of facts, a set  $\mathcal{R}$  of rules and a set  $\mathcal{N}$  of constraints.  
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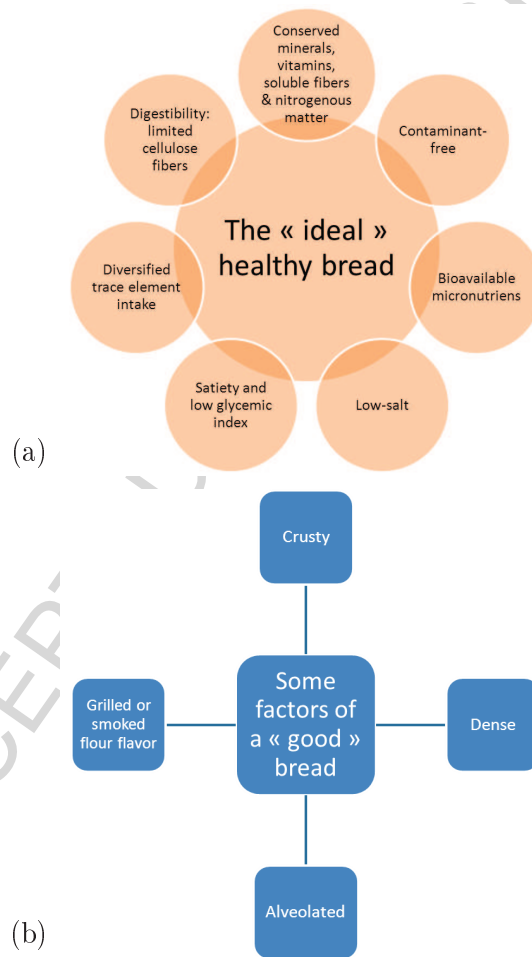


Figure 2: Nutritional (a) and organoleptic (b) goals

Let us formally define what we accept as  $\mathcal{F}$ ,  $\mathcal{R}$  and  $\mathcal{N}$ .

**Facts Syntax.** Let  $\mathbf{C}$  be a set of constants and  $\mathbf{P} = P_1 \cup P_2 \dots \cup P_n$  a set of predicates of the corresponding arity  $i = 1, \dots, n$ . Let  $\mathbf{V}$  be a countably infinite set of *variables*. We define the set of *terms* by  $\mathbf{T} = \mathbf{V} \cup \mathbf{C}$ . As usual, given  $i \in \{1 \dots n\}$ ,  $p \in P_i$  and  $t_1, \dots, t_i \in \mathbf{T}$  we call  $p(t_1, \dots, t_i)$  an *atom*. A *fact* is the existential closure of an atom or an existential closure of a conjunction of atoms. (Note that there is no negation or disjunction in the facts and that we consider a generalised notion of facts that can contain several atoms.)

- *Bread, Cereal, LowSalt, ContaminantFree* are examples of unary predicates (arity 1) and *IsIngredientOf* is a binary predicate (arity 2).

- *Wheat, oats, rye, barley* are constant examples.

- *Cereal (wheat)* is an atom.

- $\exists x (Bread(x) \wedge IsIngredientOf(wheat, x))$  is a fact.

Due to lack of space we do not show the full semantic definitions of facts (or rules and constraints in the following section). For a complete semantic depiction of this language please check (Chein and Mugnier, 2009; Chein et al., 2013; Croitoru and Vesic, 2013). It is well known that  $F' \models F$  (read the fact  $F'$  entails the fact  $F$ ) if and only if there is a homomorphism from  $F$  to  $F'$  (Chein and Mugnier, 2009).

**Rules.** A rule  $R$  is a formula of the form

$$\forall x_1, \dots, \forall x_n \forall y_1, \dots, \forall y_m (H(x_1, \dots, x_n, y_1, \dots, y_m) \rightarrow \exists z_1, \dots, \exists z_k C(y_1, \dots, y_m, z_1, \dots, z_k))$$

where  $H$ , the hypothesis, and  $C$ , the conclusion, are atoms or conjunctions of atoms,  $n, m, k \in \{0, 1, \dots\}$ ,  $x_1, \dots, x_n$  are the variables appearing in  $H$ ,

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5  $y_1, \dots, y_m$  are the variables appearing in both  $H$  and  $C$  and  $z_1, \dots, z_k$  the new  
6 variables introduced in the conclusion. An example of a rule is the following:  
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8  $\forall x (Bread(x) \wedge PesticideFree(x) \wedge MycotoxinFree(x))$   
9  $\rightarrow ContaminantFree(x)$ .

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12 In the following we will consider rules without new existential variables  
13 in the conclusion.  
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15 Reasoning consists of applying rules on the set  $\mathcal{F}$  and thus inferring new  
16 knowledge. A rule  $R = (H, C)$  is *applicable* to set  $\mathcal{F}$  if and only if there  
17 exists  $\mathcal{F}' \subseteq \mathcal{F}$  such that there is a homomorphism  $\sigma$  from the hypothesis  
18 of  $R$  to the conjunction of elements of  $\mathcal{F}'$ . A rule  $R = (H, C)$  is inversely  
19 applicable to a fact  $F$  if there is a homomorphism  $\pi$  from  $C$  to  $F$ . In this  
20 case, the inverse application of  $R$  to  $F$  according to  $\pi$  produces a new fact  
21  $F'$  such that  $R(F') = F$ . We then say that the new fact is an immediate  
22 inverse derivation of  $F$  by  $R$ , abusively denoted  $R^{-1}(F)$ .  
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31 Note that this technique is commonly used, for example, for backward  
32 chaining query answering (Baget and Salvat, 2006; Konig et al., 2012) where  
33 a query is rewritten according to the rules. The same mechanism is also  
34 discussed by abductive reasoning algorithms (Klarman et al., 2011) where  
35 minimal sets of facts (in the set inclusion sense) are added to the knowledge  
36 base in order to be able to deduct a query.  
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43 Let  $F = Bread(bleurette) \wedge PesticideFree(bleurette) \wedge MycotoxinFree(bleu-$   
44  $ette)$  and  $R$  the rule  $\forall x (Bread(x) \wedge PesticideFree(x) \wedge MycotoxinFree(x) \rightarrow$   
45  $ContaminantFree(x))$ .  
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48  $R$  is applicable to  $F$  and produces by derivation the following fact:  $Bread$   
49  $(bleurette) \wedge PesticideFree(bleurette) \wedge MycotoxinFree(bleurette) \wedge Contaminant-$   
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$Free(bleurette)$ .

Let  $F = Bread(bleurette) \wedge ContaminantFree(bleurette)$  and  $R$  the rule  $\forall x (Bread(x) \wedge PesticideFree(x) \wedge MycotoxinFree(x) \rightarrow ContaminantFree(x))$ .

$R$  inversely applicable to  $F$  and produces by inverse derivation the fact:  $F' = Bread(bleurette) \wedge PesticideFree(bleurette) \wedge MycotoxinFree(bleurette)$ .

Let  $F$  be a subset of  $\mathcal{F}$  and let  $\mathcal{R}$  be a set of rules. A set  $F_n$  is called an  $\mathcal{R}$ -derivation of  $F$  if there is a sequence of sets (called a *derivation sequence*)  $(F_0, F_1, \dots, F_n)$  such that  $F_0 \subseteq F$ ,  $F_0$  is  $\mathcal{R}$ -consistent, for every  $i \in \{1, \dots, n-1\}$ , it holds that  $F_i$  is an immediate derivation of  $F_{i-1}$ .

Given a set  $\{F_0, \dots, F_k\} \subseteq \mathcal{F}$  and a set of rules  $\mathcal{R}$ , the closure of  $\{F_0, \dots, F_k\}$  w.r.t.  $\mathcal{R}$ , denoted  $Cl_{\mathcal{R}}(\{F_0, \dots, F_k\})$ , is defined as the smallest set (with respect to  $\subseteq$ ) which contains  $\{F_0, \dots, F_k\}$ , and is closed for  $\mathcal{R}$ -derivation (that is, for every  $\mathcal{R}$ -derivation  $F_n$  of  $\{F_0, \dots, F_k\}$ , we have  $F_n \subseteq Cl_{\mathcal{R}}(\{F_0, \dots, F_k\})$ ). Finally, we say that a set  $\mathcal{F}$  and a set of rules  $\mathcal{R}$  entail a fact  $G$  (and we write  $\mathcal{F}, \mathcal{R} \models G$ ) iff the closure of the facts by all the rules entails  $F$  (i.e. if  $Cl_{\mathcal{R}}(\mathcal{F}) \models G$ ).

**Constraints.** A constraint is a formula  $\forall x_1 \dots \forall x_n (H(x_1, \dots, x_n) \rightarrow \perp)$ , where  $H$  is an atom or a conjunction of atoms and  $n \in \{0, 1, 2, \dots\}$ . Equivalently, a constraint can be written as  $\neg(\exists x_1, \dots, \exists x_n H(x_1, \dots, x_n))$ . As an example of a constraint, consider  $N = \neg(\exists x (Growth(x) \wedge Decrease(x)))$ .

Given a knowledge base  $\mathcal{K} = (\mathcal{F}, \mathcal{R}, \mathcal{N})$ , a set  $\{F_1, \dots, F_k\} \subseteq \mathcal{F}$  is said to be *inconsistent* if and only if there exists a constraint  $N \in \mathcal{N}$  such that  $\{F_1, \dots, F_k\} \models H_N$ , where  $H_N$  denotes the existential closure of the hypothesis of  $N$ . A set is consistent if and only if it is not inconsistent. A set  $\{F_1, \dots, F_k\} \subseteq \mathcal{F}$  is  $\mathcal{R}$ -inconsistent if and only if there exists a constraint

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5  $N \in \mathcal{N}$  such that  $\text{Cl}_{\mathcal{R}}(\{F_1, \dots, F_k\}) \models H_N$ , where  $H_N$  denotes the existential  
6  
7 closure of the hypothesis of  $N$ .

8 Let  $\mathcal{K} = (\mathcal{F}, \mathcal{R}, \mathcal{N})$  where:  
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- 10  
11 •  $\mathcal{F}$  contains the following facts:  
12  
13 –  $F_1 = \text{Bread}(\text{bleuette}) \wedge \text{ContaminantFree}(\text{bleuette})$   
14  
15 –  $F_2 = \exists e \text{ExtractionRate}(e, \text{bleuette})$   
16  
17 –  $F_3 = \exists f (\text{FiberContent}(f, \text{bleuette}) \wedge \text{High}(f))$   
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21 •  $\mathcal{R}$  consists of the following rules:  
22  
23 –  $R_1 = \forall x, y (\text{Bread}(x) \wedge \text{ExtractionRate}(y, x) \wedge \text{PesticideFree}(x)$   
24  
25  $\rightarrow \text{Decrease}(y))$   
26  
27 –  $R_2 = \forall x, y, z (\text{Bread}(x) \wedge \text{ExtractionRate}(y, x) \wedge \text{FiberContent}(z, x) \wedge$   
28  
29  $\text{High}(z) \rightarrow \text{Growth}(y))$   
30  
31 –  $R_3 = \forall x (\text{Bread}(x) \wedge \text{ContaminantFree}(x)$   
32  
33  $\rightarrow \text{PesticideFree}(x) \wedge \text{MycotoxinFree}(x))$   
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38 •  $\mathcal{N}$  contains the following negative constraint:  
39  
40 –  $N = \neg(\exists x (\text{Growth}(x) \wedge \text{Decrease}(x)))$   
41  
42  
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44  $\mathcal{K}$  is inconsistent since  $(\mathcal{F}, \mathcal{R}) \models N$ . Indeed,  $F_1$  and  $R_3$  allow to deduce  
45  $\text{PesticideFree}(\text{bleuette})$ . Combined to  $F_2$  and  $R_1$  we obtain  $\text{Decrease}(e)$ .  $F_3$   
46  
47 and  $R_2$  deduce  $\text{Growth}(e)$ , violating the negative constraint  $N$ .  
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49 Given a knowledge base, one can ask a conjunctive query in order to  
50 know whether something holds or not. Without loss of generality we consider  
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5 boolean conjunctive queries (which are facts). As an example of a query, take  
6  $\exists x_1 \text{cat}(x_1)$ . The answer to query  $\alpha$  is positive if and only if  $\mathcal{F}, \mathcal{R} \models \alpha$ .  
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8 Answering  $Q$ , traditionally, has two different algorithmic approaches: ei-  
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either forward chaining or backwards chaining. The two approaches come to either (1) finding an answer of  $Q$  in the  $\mathcal{R}$ -derivations of the facts in the knowledge base or (2) computing the inverse  $\mathcal{R}$ -derivations of the query and finding if there is a match in the facts. We will focus on the latter approach in the following.

## 5.2. Arguments and Attacks

This section shows that it is possible to define an instantiation of Dung's abstract argumentation theory (Dung, 1995) that can be used to reason with an inconsistent ontological KB.

We first define the notion of an argument. For a set of formulae  $\mathcal{G} = \{G_1, \dots, G_n\}$ , notation  $\bigwedge G$  is used as an abbreviation for  $G_1 \wedge \dots \wedge G_n$ .

**Definition 1.** *Given a knowledge base  $\mathcal{K} = (\mathcal{F}, \mathcal{R}, \mathcal{N})$ , an argument  $a$  is a tuple  $a = (F_0, F_1, \dots, F_n)$  where:*

- $(F_0, \dots, F_{n-1})$  is a derivation sequence with respect to  $\mathcal{K}$
- $F_n$  is an atom, a conjunction of atoms, the existential closure of an atom or the existential closure of a conjunction of atoms such that  $F_{n-1} \models F_n$ .

This definition, following the definition of (Croitoru and Vesic, 2013) is a straightforward way to define an argument, since an *argument* corresponds to a *derivation*.

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5 To simplify the notation, from now on, we suppose that we are given a  
6 fixed knowledge base  $\mathcal{K} = (\mathcal{F}, \mathcal{R}, \mathcal{N})$  and do not explicitly mention  $\mathcal{F}$ ,  $\mathcal{R}$  nor  
7  $\mathcal{N}$  if not necessary. Let  $a = (F_0, \dots, F_n)$  be an argument. Then, we denote  
8  $\text{Supp}(a) = F_0$  and  $\text{Conc}(a) = F_n$ .  
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12 Arguments may attack each other, which is captured by a binary attack  
13 relation  $\text{Att} \subseteq \text{Arg}(\mathcal{F}) \times \text{Arg}(\mathcal{F})$ .  
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17 **Definition 2.** Let  $\mathcal{K} = (\mathcal{F}, \mathcal{R}, \mathcal{N})$  be a knowledge base and let  $a$  and  $b$  be  
18 two arguments. The argument  $a$  attacks argument  $b$ , denoted  $(a, b) \in \text{Att}$ ,  
19 if and only if there exists  $\varphi \in \text{Supp}(b)$  such that the set  $\{\text{Conc}(a), \varphi\}$  is  
20  $\mathcal{R}$ -inconsistent.  
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26 This attack relation is not symmetric. To see why, consider the following  
27 example. Let  $\mathcal{F} = \{p(m), q(m), r(m)\}$ ,  $\mathcal{R} = \emptyset$ ,  $\mathcal{N} = \{\forall x_1(p(x_1) \wedge q(x_1) \wedge$   
28  $r(x_1) \rightarrow \perp)\}$ . Let  $a = (\{p(m), q(m)\}, p(m) \wedge q(m))$ ,  $b = (\{r(m)\}, r(m))$ . We  
29 have  $(a, b) \in \text{Att}$  and  $(b, a) \notin \text{Att}$ . This will ensure that the naive extension  
30 is different, at least in theory, from the preferred, stable, etc. semantics.  
31 However, in our application they all entail the same information as shown  
32 later on.  
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41 **Definition 3.** Given a knowledge base  $\mathcal{K} = (\mathcal{F}, \mathcal{R}, \mathcal{N})$ , the corresponding  
42 argumentation framework  $\mathcal{AF}_{\mathcal{K}}$  is a pair  $(\mathcal{A} = \text{Arg}(\mathcal{F}), \text{Att})$  where  $\text{Arg}(\mathcal{F})$   
43 is the set of all arguments that can be constructed from  $\mathcal{F}$  and  $\text{Att}$  is the  
44 corresponding attack relation as specified in Definition 2.  
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48 Let  $\mathcal{E} \subseteq \mathcal{A}$  and  $a \in \mathcal{A}$ . We say that  $\mathcal{E}$  is conflict free iff there exists no  
49 arguments  $a, b \in \mathcal{E}$  such that  $(a, b) \in \text{Att}$ .  $\mathcal{E}$  defends  $a$  iff for every argument  
50  $b \in \mathcal{A}$ , if we have  $(b, a) \in \text{Att}$  then there exists  $c \in \mathcal{E}$  such that  $(c, b) \in \text{Att}$ .  
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5  $\mathcal{E}$  is admissible iff it is conflict free and defends all its arguments.  $\mathcal{E}$  is a  
6 complete extension iff  $\mathcal{E}$  is an admissible set which contains all the arguments  
7 it defends.  $\mathcal{E}$  is a preferred extension iff it is maximal (with respect to set  
8 inclusion) admissible set.  $\mathcal{E}$  is a stable extension iff it is conflict-free and for  
9 all  $a \in \mathcal{A} \setminus \mathcal{E}$ , there exists an argument  $b \in \mathcal{E}$  such that  $(b, a) \in \text{Att}$ .

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14  $\mathcal{E}$  is a grounded extension iff  $\mathcal{E}$  is a minimal (for set inclusion) complete  
15 extension.

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18 For an argumentation framework  $AS = (\mathcal{A}, \text{Att})$  we denote by  $\text{Ext}_x(AS)$   
19 (or by  $\text{Ext}_x(\mathcal{A}, \text{Att})$ ) the set of its extensions with respect to semantics  $x$ .  
20 We use the abbreviations  $c$ ,  $p$ ,  $s$ , and  $g$  for respectively complete, preferred,  
21 stable and grounded semantics.  
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26 An argument is sceptically accepted if it is in all extensions, credulously  
27 accepted if it is in at least one extension and rejected if it is not in any  
28 extension.  
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32 Based on this definition of arguments and attacks in (Croitoru and Vesic,  
33 2013) was also shown that the rationality postulates of (Caminada and Am-  
34 goud, 2007) are respected. This instantiation respects the direct, indirect  
35 consistency as well as the closure.  
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### 39 5.3. Formalising the use case

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41 In this subsection we formalise the notions presented in section 4.

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43 Let  $\mathcal{K} = (\mathcal{F}, \mathcal{R}, \mathcal{N})$  be a consistent knowledge base. This is the knowledge  
44 base that all actors share and agree upon. In this paper we assume that the  
45 rules and negative constraints are common to everybody.  
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50 The goals of the different actors can be seen as a set of existentially closed  
51 conjuncts. We denote them by  $G_1, G_2, \dots, G_n$ .  
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5 Let  $G_i$  be a goal and  $\mathcal{K}$  the knowledge base.  $\mathcal{K}$  is consistent and  $\mathcal{K}$  does  
6 not entail  $G_i$ . We compute the inverse  $\mathcal{R}$ -derivations of  $G_i$  (where  $\mathcal{R}$  is the  
7 set of rules of the knowledge base). We add all of the  $\mathcal{R}^{-1}(G_i)$  to the facts.  
8 We thus obtain a new knowledge base  $\mathcal{K}_i$  which differs from  $\mathcal{K}$  solely by its  
9 facts set (which now also includes  $\mathcal{R}^{-1}(G_i)$ ):  $\mathcal{K} = (\mathcal{F} \cup \mathcal{R}^{-1}(G_i), \mathcal{R}, \mathcal{N})$ . We  
10 also impose that  $\mathcal{K}_i$  is consistent.  
11

12 Given  $\mathcal{G} = \{G_1, G_2, \dots, G_n\}$ , the goals correspond to a set of viewpoints  $\mathcal{V}$   
13 (there exists a function  $\kappa : \mathcal{G} \rightarrow 2^{\mathcal{V}}$ ). This function can assign a goal to one  
14 or more viewpoints and each viewpoint can be associated with one or more  
15 goals. Given a goal  $G_i$ , the (set of) viewpoint(s) associated with this goal is  
16 denoted by  $\kappa(G_i)$ . Similarly, given a viewpoint  $v_i$ , the set of goals associated  
17 with it is denoted by  $\kappa^{-1}(v_i)$ .  
18

19 **Example 1.** Let the set of viewpoints  $\mathcal{V} = \{\text{nutrition}, \text{sanitary}, \text{organoleptic}\}$   
20 and  $\mathcal{G}$  consisting of the following goals:  $G_1 = \exists x (\text{Bread}(x) \wedge \text{LowSalt}(x))$ ,  
21  $G_2 = \exists x (\text{Bread}(x) \wedge \text{ContaminantFree}(x))$ ,  $G_3 = \exists x (\text{Bread}(x) \wedge \text{Crusty}(x))$ ,  
22  $G_4 = \exists x (\text{Bread}(x) \wedge \text{TraceElementRich}(x))$ .  
23

24 We have  $\kappa(G_1) = \kappa(G_4) = \text{nutrition}$ ,  $\kappa(G_2) = \text{sanitary}$  and  $\kappa(G_3) =$   
25  $\text{organoleptic}$ . Conversely  $\kappa^{-1}(\text{nutrition}) = \{G_1, G_4\}$ ,  $\kappa^{-1}(\text{sanitary}) = \{G_2\}$   
26 and  $\kappa^{-1}(\text{organoleptic}) = \{G_3\}$ .  
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28 The rules will correspond to the set of sufficient conditions needed for  
29 the goal  $G_i$ . In the context of our practical application this is illustrated in  
30 Figure 3 (with respect to nutrition goals).  
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32 **Example 2.** To reach the goal  $G_1 = \exists x (\text{Bread}(x) \wedge \text{LowSalt}(x))$ , the  
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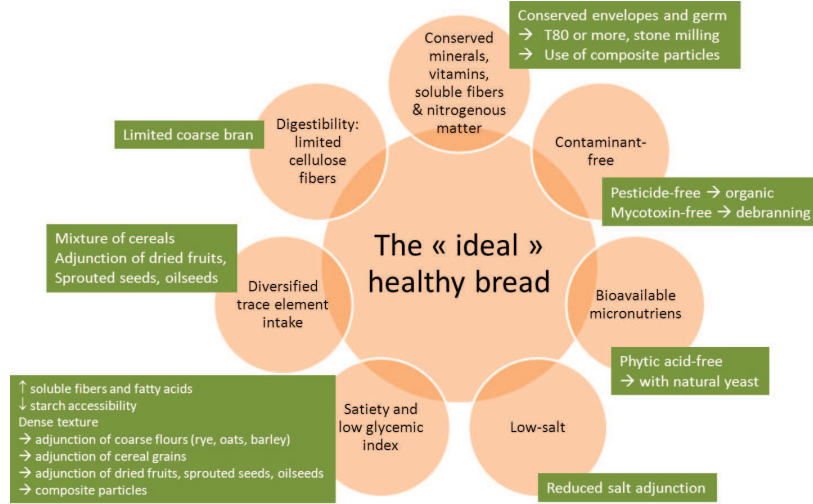


Figure 3: Ways to reach nutritional goals

knowledge base  $\mathcal{K}$  contains the following rule:  $\forall x,y (Bread(x) \wedge SaltAdjunction(y,x) \wedge Decrease(y) \rightarrow LowSalt(x))$

Let us now consider the set of goals  $\mathcal{G} = \{G_1, G_2, \dots, G_n\}$  and the initial knowledge base  $\mathcal{K} = (\mathcal{F}, \mathcal{R}, \mathcal{N})$ . As described above we compute the  $n$  knowledge bases, corresponding to each goal:  $\mathcal{K}_i = (\mathcal{F} \cup \mathcal{R}^{-1}(G_i), \mathcal{R}, \mathcal{N})$  for each  $i = 1, \dots, n$ . We consider the union of all these knowledge bases:

$$\mathcal{K}_{agg} = (\mathcal{F} \cup \bigcup_{i=1, \dots, n} \mathcal{R}^{-1}(G_i), \mathcal{R}, \mathcal{N})$$

**Example 3.** Let  $\mathcal{K} = (\mathcal{F}, \mathcal{R}, \mathcal{N})$  where :

- $\mathcal{F} = \{F_1\} = \{CurrentExtractionRate(T65)\}$
- $\mathcal{R}$  contains the following rules:

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- $R_1 = \forall x, y (Bread(x) \wedge ExtractionRate(y, x) \wedge Decrease(y) \rightarrow Digestible(x))$
  - $R_2 = \forall x, z (Bread(x) \wedge SaltAdjunction(z, x) \wedge Decrease(z) \rightarrow LowSalt(x))$
  - $R_3 = \forall x, y (Bread(x) \wedge ExtractionRate(y, x) \wedge Growth(y) \rightarrow TraceElementRich(x))$
  - $R_4 = \forall x, y (Bread(x) \wedge ExtractionRate(y, x) \wedge Decrease(y) \rightarrow PesticideFree(x))$

24 •  $\mathcal{N}$  contains the following negative constraint:

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- $N = \neg(\exists x (Growth(x) \wedge Decrease(x)))$

29 Let the goal set  $\mathcal{G}$  as follows:

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- $G_1 = \exists p (Bread(p) \wedge Digestible(p))$ , where  $\kappa(G_1) = nutrition$
  - $G_2 = \exists p (Bread(p) \wedge LowSalt(p))$ , where  $\kappa(G_2) = nutrition$
  - $G_3 = \exists p (Bread(p) \wedge TraceElementRich(p))$ , where  $\kappa(G_3) = nutrition$
  - $G_4 = \exists p (Bread(p) \wedge PesticideFree(p))$ , where  $\kappa(G_4) = sanitary$ .

40 Then:

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- $\mathcal{K}_1 = (\mathcal{F}_1, \mathcal{R}, \mathcal{N})$  where  $\mathcal{F}_1 = \mathcal{F} \cup \mathcal{R}^{-1}(G_1)$  contains the following facts:
    - $F_1 = CurrentExtractionRate(T65)$
    - $F_2 = Bread(p) \wedge ExtractionRate(\tau, p) \wedge Decrease(\tau)$
  - $\mathcal{K}_2 = (\mathcal{F}_2, \mathcal{R}, \mathcal{N})$  where  $\mathcal{F}_2 = \mathcal{F} \cup \mathcal{R}^{-1}(G_2)$  contains the following facts:
    - $F_1 = CurrentExtractionRate(T65)$
    - $F_3 = Bread(p) \wedge SaltAdjunction(s, p) \wedge Decrease(s)$
  - $\mathcal{K}_3 = (\mathcal{F}_3, \mathcal{R}, \mathcal{N})$  where  $\mathcal{F}_3 = \mathcal{F} \cup \mathcal{R}^{-1}(G_3)$  contains the following facts:



$$- F_1 = \text{CurrentExtractionRate}(T65)$$

$$- F_4 = \text{Bread}(p) \wedge \text{ExtractionRate}(\tau, p) \wedge \text{Growth}(\tau)$$

•  $\mathcal{K}_4 = (\mathcal{F}_4, \mathcal{R}, \mathcal{N})$  where  $\mathcal{F}_4 = \mathcal{F} \cup \mathcal{R}^{-1}(G_4)$  contains the following facts:

$$- F_1 = \text{CurrentExtractionRate}(T65)$$

$$- F_2 = \text{Bread}(p) \wedge \text{ExtractionRate}(\tau, p) \wedge \text{Decrease}(\tau)$$

Finally  $\mathcal{K}_{agg} = (\mathcal{F} \cup_{i=1, \dots, n} \mathcal{R}^{-1}(G_i), \mathcal{R}, \mathcal{N})$  where

$$\mathcal{F} \cup_{i=1, \dots, n} \mathcal{R}^{-1}(G_i) = \{F_1, F_2, F_3, F_4\}.$$

As observed in the previous example, it may happen that  $\mathcal{K}_{agg}$  is inconsistent (and it does so even for goals belonging to the same viewpoint). We then use argumentation, which, by the means of extensions will isolate subsets of facts we can accept together (called extensions). Furthermore, the extensions will allow us to see which are the viewpoints associated to each maximal consistent subset of knowledge (by the means of the function  $\kappa$ ). A choice procedure then has to be used (see example below).

The argument framework we can construct from the above knowledge base is  $(\mathcal{A}, \text{Att})$  where  $\mathcal{A}$  contains the following:

•  $a = (\{F_2\}, F_2, R_1(F_2))$  where  $R_1(F_2) = \text{Bread}(p) \wedge \text{ExtractionRate}(\tau, p) \wedge \text{Decrease}(\tau) \wedge \text{Digestible}(p)$ .

•  $b = (\{F_4\}, F_4, R_3(F_4))$  where  $R_3(F_4) = \text{Bread}(p) \wedge \text{ExtractionRate}(\tau, p) \wedge \text{Growth}(\tau) \wedge \text{TraceElementRich}(p)$ .

•  $c = (\{F_2\}, F_2, R_4(F_2))$  where  $R_4(F_2) = \text{Bread}(p) \wedge \text{ExtractionRate}(\tau, p) \wedge \text{Decrease}(\tau) \wedge \text{PesticideFree}(p)$ .

•  $d = (\{F_3\}, F_3, R_2(F_3))$  where  $R_2(F_3) = \text{Bread}(p) \wedge \text{SaltAdjunction}(s, p) \wedge \text{Decrease}(s) \wedge \text{LowSalt}(p)$  and

$\text{Att} = \{(a, b), (b, a), (b, c), (c, b)\}$ .

In this argumentation system defined we now obtain:

$$\bullet \text{Ext}_{stable}(\mathcal{A}, Att) = \text{Ext}_{semi-stable}(\mathcal{A}, Att) = \text{Ext}_{preferred}(\mathcal{A}, Att) = \{\{a, c, d\}, \{b, d\}\}.$$

Starting from the extensions  $\text{Ext}_x(\mathcal{A}, Att)$ , the proposed decision support system functions as follows: for every extension  $\varepsilon \in \text{Ext}_x(\mathcal{A}, Att)$  :

- Consider the facts occurring in the arguments of  $\varepsilon$  ;
- Identify the knowledge bases  $\mathcal{K}_i$  where these facts occur;
- Obtain the goals  $G_i$  which are satisfied by the extension;
- Using the  $\kappa$  function to obtain the viewpoints corresponding to these goals;
- Show domain experts the set of goals, and compatible viewpoints corresponding to the given extension.

This method allows us to obtain a set of options equal to the cardinality of  $\text{Ext}_x(\mathcal{A}, Att)$ . For taking a final decision several possibilities can be considered and presented to the experts:

- Maximise the number of goals satisfied;
- Maximise the number of viewpoints satisfied;
- Use preference relations of experts on goals and / or viewpoints.

In the previous example (please recall that the goals  $G_1$  and  $G_2$  are associated with the nutritional viewpoint while  $G_4$  is associated with the sanitary viewpoint) we have:

- The first extension  $\{a, c, d\}$  is based on the facts  $F_2$  and  $F_3$  obtained from  $\mathcal{K}_1$ ,  $\mathcal{K}_2$  and  $\mathcal{K}_4$  that satisfy the goals  $G_1$ ,  $G_2$  and  $G_4$ .
- The second extension  $\{b, d\}$  is based on  $F_3$  and  $F_4$  obtained from  $\mathcal{K}_2$  and  $\mathcal{K}_3$  satisfying  $G_2$  and  $G_3$  both associated with the nutritional viewpoint.

One first possibility (corresponding to the extension  $\{a, c, d\}$ ) consists of accomplishing  $F_2$  and  $F_3$  and allows to satisfy the biggest number of goals and viewpoints.

The second possibility (corresponding to the extension  $\{b, d\}$ ) consists of accomplishing  $F_3$  and  $F_4$ . It would satisfy two goals and one viewpoint. It could be considered though if the goal  $G_3$  (not satisfied by the first option) is preferred to the others.

## 6. Evaluation

The evaluation of the implemented system was done via a series of interviews with domain experts. The above knowledge and reasoning procedures were implemented using the Cogui knowledge representation tool (Chein et al., 2013), with an extension of 2000 lines of supplemental code. Three experts have validated our approach: two researchers in food science and cereal technologies of the French national institute of agronomic research, specialists respectively of the grain-to-flour transformation process and of the breadmaking process, and one industrial expert - the Director of the French National Institute of Bread and Pastry.

The first meeting dealt with the delimitation of the project objectives and addressed fundamental questions such as: Is it possible to uniquely define a

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5 “good” bread? Which scenarii of “good bread” should be considered? How  
6 could they be defined from a nutritional, sanitary, sensorial and economic  
7 point of view? Which are the main known ways to achieve them?  
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10 Then a series of individual interviews constituted the elicitation phase.  
11 Each expert gave more arguments which were complementing one each other.  
12 In parallel, the writing of specifications for the demonstrator and the defini-  
13 tion of the knowledge base structure were conducted.  
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18 In the following plenary meeting the real potential of the approach was  
19 shown. The experts were formulating goals and viewpoints they were inter-  
20 ested in and the Cogui system together with the argumentation extension was  
21 yielding the associated possible propositions. Figure 6 shows a screenshot of  
22 the demonstrator answers for a two-goal query: a nutritional goal (high fiber  
23 content) and an organoleptic goal (crusty bread). Two sets of compatible  
24 actions are proposed, some choices (such as increasing or decreasing the ex-  
25 traction rate) being incompatible for both goals, and thus separated in the  
26 two alternative sets.  
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35 Four scenarii were more specifically evaluated. These scenarii concern  
36 four kinds of consumers: obeses (fiber preference), people with iron deficiency  
37 (micronutrient preference), people with cardiovascular disease (decreased salt  
38 preference) and vegetarians (limited phytic acid), which produces different  
39 sets of goals. For each scenario, the system proposes several outputted rec-  
40 ommendations. The audience for decreasing salt tips the balance in favour  
41 of a recommendation for the T80 bread, while the audience for decreasing  
42 phytic acid pushes to specify recommendations towards a natural sourdough  
43 bread or a conservative T65 bread. Other audiences are in favor of a status  
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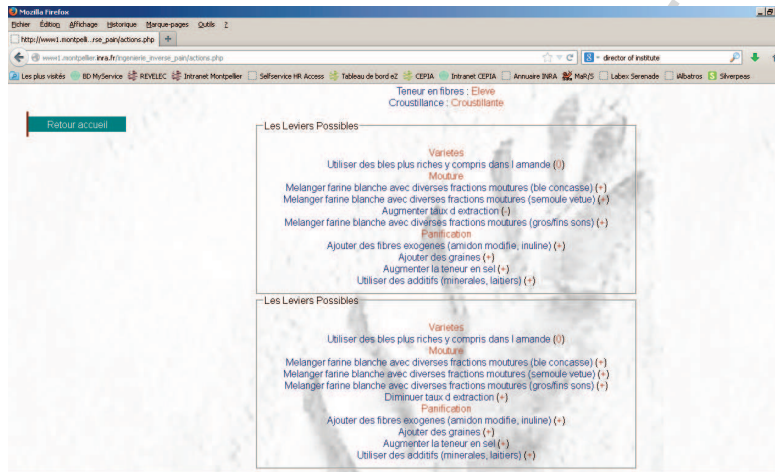


Figure 4: Demonstrator screenshot showing two sets of possible actions

quo. The results were considered as explainable by experts, but not obvious, since many considerations had to be taken into account.

Two interests of the approach were more particularly highlighted. They concern cognitive considerations. Firstly, experts were conscious that the elicitation procedure was done according to their thought processes, that is, in a forward way which is more natural and intuitive. The system was thus able to reconstitute the knowledge in a different manner than the experts usually do. Secondly, from a problem that could initially seem simple, the experts realized that it covered a huge complexity that a human mind could hardly address alone. The tool is currently available to them under restricted access.

The knowledge modeling task can be a very time-consuming step. As presented in Section 4.1, several sources of information were used, from peer reviewed scientific papers and technical reports, to conference meetings and expert interviews. On the one hand, expert interviews appeared to be the

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5 least expensive ones in terms of time. A one-day period allows both eliciting  
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7 knowledge through an interview and formalizing it in the software system –  
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9 which constitutes the longest part of the work. However, this relatively short  
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11 time hides a strong prerequisite: having already a clear view of the case study,  
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13 a synopsis of the questions to ask the expert and an implemented knowledge  
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15 model. On the other hand, websites, technical reports and scientific articles  
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17 are more costly to analyze. For instance, the critical reading a scientific  
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19 paper of the domain may require a one-day period on its own, for a discerning  
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21 reader. However they allow one to to grasp the ins and outs of the question.

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23 During the evaluation step, the experts raised the question of the impor-  
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25 tance attached to the different pieces of knowledge modeled in the system.  
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27 Moreover, in some cases experts may hesitate on the relevance of some facts  
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29 or rules. A possibility would thus be to adopt a preference-based argumen-  
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31 tation system, as proposed in several works such as (Amgoud and Cayrol,  
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33 2002; Bench-Capon, 2003b; Kaci and van der Torre, 2008; Amgoud et al.,  
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35 2000; Bourguet et al., 2013a), able to take into account different levels of  
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37 importance among arguments.

## 38 39 **7. Conclusion**

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42 Even if argumentation based decision making methods applied to the food  
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44 industry were also proposed by (Bourguet, 2010; Bourguet et al., 2013b),  
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46 this paper addresses a key point in the context of current techniques used  
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48 by the food sector and namely addressing reverse engineering. Also, in this  
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50 approach, an argument is used here as a method computing compatible ob-  
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52 jectives in the sector. This case study represents an original application and  
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5 an introspective approach in the agronomy field by providing an argumenta-  
6 tion based decision-support system for the various food sectors. It requires  
7 nevertheless the very expensive task of knowledge modeling. Such task, in  
8 its current state cannot be automated. It strongly depends on the quality of  
9 expert opinion and elicitation (exhaustiveness, certainty, etc). The current  
10 trend for decision-making tools includes more and more methods of argu-  
11 mentation as means of including experts in the task of modeling and the  
12 decision-making processes. Another element to take into account, not dis-  
13 cussed in this paper, is the difficulty of technologically (from an agronomy  
14 viewpoint) putting in place the facts of each option. Modeling this aspect in  
15 the formalism is still to be studied.  
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**Highlights**

- We present a real use case study of an argumentation process in the agrifood domain, in the wheat to bread chain.
- We introduce the notions of viewpoint and goal in a backward chaining reasoning procedure.
- We provide a logical framework in first order logic.
- Specific recommended actions are computed depending on the considered concerns.
- We present the case study evaluation process.