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Food Track & Trace ontology for helping the food traceability control

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ABSTRACT

This paper describes a food ontology developed for traceability purposes. The Food Track&Trace Ontology (FTTO) is part of a general framework devoted to managing food traceability and it has been developed with the aim of being connected with a Global Track&Trace Information System. The main goal of the proposed FTTO Ontology is to include the most representative food concepts involved in a SC all together in a single ordered hierarchy, able to integrate and connect the main features of the food traceability domain. FTTO is formed by four modules food, service products, processes and actors involved in the supply chain. This paper describes the main features of the FTTO ontology and some examples of application.

1. Introduction

Today the food traceability issue is attracting the attention of public authorities and private companies due to its important impact in society and its relevance in case of food outbreak diseases. The increasing interest in food traceability directly interfaces with customer demands on food quality and security (Trienekens and Zuurbier, 2008). Nowadays, customers are more and more exigent and require the governmental control of the whole food system. In addition, traceability plays an important role in the food industry and it is directly connected with food quality and safety. Safety, in fact, can only be guaranteed by following food products along the entire supply chain, from "farm to fork". Currently, different types of traceability systems are emerging as a result of regulatory interventions at an industry-wide level and as a consequence of competitive strategies adopted at the level of individual supply chain.

The regulatory framework for food traceability is wide and heterogeneous. If the regulatory perspective is considered, companies around the world (UE, Japan, USA, etc.) deal with different implementations of responsibility and liability regulation of products (Mirabelli et al., 2012a). In Europe, the EC Directive 178/2002 (European Commission, 2002) of the European Parliament and of the Council, lays down the general principles and requirements of food law, establishing the European Food Safety. This Directive defines food chain traceability as "the ability to follow a food component intended to be, or expected to be into a food product through all stages of food supply chain" (European Commission, 2002).

The ability of monitoring the whole Supply Chain (SC) is obtained assuring the observation of two primary functions: tracking and tracing. Tracking is the process by which a product is followed by upstream to downstream in the SC. Tracing is the reverse process of tracking by which the history of a product is reconstructed through the information recorded in each step of the SC, identifying the source of a food or group of ingredients and consequently the real origin of a product.

Recently, the need of food quality and security lead to the development of several traceability systems and to their implementation at the industry level. Nevertheless, current traceability systems are characterized by the inability to link food chains records, inaccuracy and errors in records and delays in obtaining essential data, which are fundamental in case of food outbreak disease, and represent the key issues frustrating the job of food safety agents. These deficiencies have been mainly highlighted by the recent food outbreak diseases, which have pointed out the importance of a global traceability system in a global market and have suggested the need of more information to be recorded. In addition to systematically storing information that must be made available for inspection from authorities on demand, a traceability system should take also food safety and quality improvement into account. To take into consideration the current regulated requirements on food quality for health care, additional data that is not strictly

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necessary for traceability must be stored. For instance, for a cooking activity, oven temperature and humidity can be considered important parameters in case of hazard. For a cultivation activity, operations on the parcel are fundamental to identify the possible cause of a contamination due to the use of particular plant protection products or fertilizers.

The information registration is therefore limited by the lack of common standards for information encoding and management (De Cindio et al., 2011a) that represents the main problem related to the development of an efficient traceability system. Standards are consequently required for recording and exchanging information. It is essential to assure a way through any company can connect to a global information system for exchanging information in the SC and, for that it is required to solve the important issues about information system integration and standardization. In order to ensure the system interoperability and communication between the different actors, the use of standards is required for encoding information for all reference operators (De Cindio et al., 2011b).

In order to facilitate the identification of a product responsible for a food borne outbreak disease, information, and the way that it is organized, must be standardized and conceptualized. Under this context, the objective of the presented work is to present a method for facilitating the identification of food borne outbreak disease in a short time window. This research work is part of a doctoral thesis, which aim is to develop a general framework for the traceability of food products able to support quality and safety control (Pizzuti, 2012). A traceability system prototype is proposed as part of the general framework developed to assist the process of information extraction and unification in compliance with legal and quality requirements. In such a context, the development of the Food Track & Trace Ontology (FTTO) ontology has played a relevant because the ontology supports the management of a unique body of knowledge based on natural language and its corresponding synonymous, through the integration of different concepts and terms coming from heterogeneous sources of information and users involved in the SC.

In particular, the main goal of the proposed FTTO Ontology is to include the most representative food concepts involved in a SC all together in a single ordered hierarchy, able to integrate and connect the main features of the food traceability domain. In addition, FTTO have been particularly designed in order to be connected with the Global Traceability Information System proposed by Pizzuti et al. (2012)and obtained through the modeling of a general food SC and data shared among different actors. The sources of information used in the knowledge acquisition phase, consist mainly of thesaurus and food databases, books and the Internet. The food classification tree built in the conceptualization phase refers to the Codex Alimentarius Classification of Food and Animal Feeds (Joint FAO/WHO Food Standards Program CODEX ALIMENTARIUS COMMISSION, 1993).

The knowledge model has been formalized using Protégé (Stanford Center for Biomedical Informatics Research, 2013), which was also used to automatically generate the ontology code. The resulting ontology comprehends four main modules covering the key concepts of the tracking domain: Actor, Food Product, Process, and Service Product.

This paper is structured as follows: Section 2 introduces a brief state of the art of current works carried-out in the development of ontologies in the food domain; Section 3 provides a description of the FTTO ontology, introducing a brief overview of the building process and detailing information for each developed module; Section 4 describes the Global Food Traceability Framework, which is the base of the FTTO Ontology; Section 5 demonstrate the scope and feasibility of the proposed framework and the remaining section address future work and conclusions.

2. State of the art

The increasing need to guarantee the quality and safety required for the food in a global market lead, in recent years, to the introduction of several mechanisms for food traceability. At the same time, important technologies, such as the Internet and the new generation of communication infrastructure, have been developed for supporting new traceability application. The first traceability schemes were based on working papers used to record information on incoming and outgoing products, while more recent systems are based on the use of the new information technologies. New research activities are currently investigating how ontology can be used to set up a traceability semantic model in order to reuse the information resources in the process of tracing and to promote the accuracy and efficiency of the information management. Furthermore, information shared in a general SC is heterogeneous and it is recorded into different data collection. In such a context, ontologies can be used for integrating heterogeneous databases and enabling inter-operability among different systems, since consistent vocabulary is needed for unambiguous querying and unifying information from multiple sources (Jagadish, 1990). The aim of an ontology is to capture knowledge in related field, provide shared understanding to conceptual knowledge, definite common vocabulary in this field and give clear definition to the mutual relationship between these jargons and words from different levels of formal model (Heijst et al., 1995). Ontologies, defined as explicit formal specifications of terms in the domain and relations among them (Kim et al., 1995), have become common in the World-Wide Web.

The need for ontologies has increased in computer science recently due to the need of a common core for heterogeneous agents for communicating and expressing knowledge. This section illustrates the relevant literature on food ontologies and the semantics of food traceability and introduces the main features that should be included in a new ontology for representing the whole knowledge related to the domain of food traceability.

A systematic literature review approach has been used for identifying the current food supply chain ontological models. The general idea was to classify the scientific literature focusing on the specific domain area of the works published in order to reuse the main concepts for the definition of the FTTO ontology. Three main subsections have been identified. The first subsection describes the current ontological models developed for describing the food world from a top level point of view. Moreover, these ontologies mainly refer to the nutrition, diet and health domain. In the second subsection, a deep analysis has been conducted focusing on the main works carried out for the definition of ontologies devoted at describing the knowledge related to specific food products. The last subsection includes some concepts related to the traceability domain and some works carried out in this area are analyzed. Finally some considerations are provided, highlighting the main features to include in a new ontology for food traceability purpose.

Table 1 presents the main work carried out with a short description on the main topic and the specification of the domain area (Bansal and Malik, 2011; Batista et al., 2006; Cantais et al., 2005; Chifi et al., 2007; Drummond et al., 2007; Easwaran and Thottupuram, 2011; Graça et al., 2005; Heflin, 2000; Kim, 2012; Noy and McGuinness, 2001; Snae and Bruckner, 2008; Yue et al., 2006).

2.1. Food ontologies for the domain of health care, diet and nutrition

The definition of a complete taxonomy for food is fundamental for modeling the domain of food traceability. There are various types of information about food, such as name, ingredients, stuff,

Table 1
Main works carried out in the domain of food.

Authors	Year	Title	Description	Food Area	Context
Cantais et al.	2005	An example of food ontology for diabetes control	The food ontology proposed in PIPS organizes foods in 13 main categories, each one describing either a type of unprocessed aliment, miscellaneous categories or food types determined by the main ingredients.	General	Nutrition and health
Snae and Bruckner	2008	FOODS: A Food-oriented Ontology-Driven System	The ontology contains specifications of ingredients, nutritional facts, recommended daily intakes for different regions, dishes and menu. Food is categorized by nine main concepts: regional cuisine, dishes, ingredients, availability, nutrients, nutrition based diseases, preparation methods, utensils and price.	General	Nutrition and diet
Batista et al.	2006	Ontology construction: cooking domain	The ontology comprehends four main modules covering the key concepts of the cooking domain (actions, food, recipes, and utensils) and three auxiliary modules (units and measures, equivalencies and plate types).	General	Cooking
Eugene Kim	2012	Korean Food Ontology	The ontology organized the Korean food in three main classes: main stample food, side dish and dessert. Information on nutrients, recipes, ingredients and taste are provided.	Food of a specific Country (Korea)	Korean Food
Chifu et al.	2007	Ontology-enhanced description of traceability services	The ontology described the participants involved in the traceability chains, the services and products they offer/use, and the main features of the products. The core ontology defines six generic concepts: Business Actors, Service, Service Input, Service Output, Product and Feature.	Food of animal origin	Traceability in the domain of meat industry
Bansal and Malik	2011	A Framework for Agriculture Ontology Development in Semantic Web	The ontology pointed out the most important classes for modeling the world of crop production such as soil, plant, cultivation method, cultivation stage, fertilizer.	Food of plant origin	Crop production cycle
Yue et al.	2006	Ontology Based Vegetable Supply Chain Knowledge Expressing	To implement vegetable supply chain knowledge searching, authors build three Ontologies: the vegetable supply chain domain Ontology, the user Ontology and the knowledge content Ontology.	Food of Plant Origin, Vegetables	Vegetable supply chain
Heflin	2000	Beer Ontology 1.0 (Draft)	The beer ontology is based on the SHOE (Simple HTML Ontology Extension) framework and it models brewers and types of beer.	Beverage	Beer
Noy and McGuinness	2001	Ontology development 101: A guide to creating your first ontology	The ontology is formed by two main classes: wine and food. The wine class is categorized in White wine, Red wine, Rosé wine. Information on wine refers to their color, body, flavor, sugar content and location of a winery.	Beverage	Wine
Graça et al.	2005	Ontology building process: the wine domain	The ontology for the wine domain id proposed according to several features: (i) maceration; (ii) fermentation process; (iii) grape maturity state; (iv) wine characteristics; (v) classification system according to country; and (vi) region where the wine was produced.	Beverage	Wine
Drummond et al.	2007	Pizza Ontology v1 .5 (2007/02/12)	The ontology models the knowledge related to the pizza domain. The class pizza is dived into Pizza topping and Pizza Base. In addition different type of topping are proposed depending on the main element of the topping (cheese, meat, seafood, vegetable, pepper).	Processed Food	Pizza
Easwaran et al.	2011	Farm-Agro Ontology formation: A black pepper model	The pepper ontology is modeled considering as main categories the cultivation type, the pepper variety, the type of propagation, the disease that can attack the plant, the Farm processing and the Value added products	Food of Plant Origin	Pepper

package, processing condition etc. Currently, some food ontologies are emerging mainly related to nutritional concepts, such as the food ontology proposed by (Snae and Bruckner, 2008) as a part of the Food-Oriented Ontology-Driven Systems (FOODS). FOODS has been mainly devoted to assist customers through an appropriate suggestion of dishes and meal. The ontology contains specifications of ingredients, nutritional facts, recommended daily intakes for different regions, dishes and menu. Food is categorized by nine main concepts: regional cuisine, dishes, ingredients, availability, nutrients, nutrition based diseases, preparation methods, utensils and price.

One more food ontology oriented to the nutritional and health care domain, has been developed by (Cantais et al., 2005) for assisting in sharing the knowledge between the different stakeholders involved in the PIPS (Personalized Information Platform for Health and Life Sciences) project. The food ontology proposed in PIPS organizes foods in 13 main categories, each one describing either a type of unprocessed aliment, miscellaneous categories or food types determined by the main ingredients. It is mainly addressed to provide provision of nutritional advice to diabetic patients.

2.2. Food ontologies for specific area of the food domain

Currently food ontologies have been only designed for specific "County Food", such as the Korean Food Ontology proposed by Kim (2012), and only for representing the knowledge related to specific food area. Several authors, in fact, have focused their attention on the definition of taxonomies and ontologies for particular areas of the food domain such as fruit and vegetables (Wang et al., 2012; Yue et al., 2005), meat (Chifi et al., 2007), pepper

(Easwaran and Thottupuram, 2011), wine (Graça et al., 2005; Noy and McGuinness, 2001), beer (Heflin, 2000), pizza (Drummond et al., 2007). The above mentioned ontologies deal with small area of the food sector and are focused on a specific product or on a particular class of products, such as beverages or food. In addition, several authors tried to model the knowledge related to particular vegetables or animals supply chain.

On one hand, the use of an ontology for knowledge expressing of vegetable SC has been discussed in Yue et al. (2005), in which authors put forward a process to build a vegetable SC Ontology and gave to the vegetable SC a knowledge-expressing frame that was used to express concepts and their relationships in the domain of vegetable supply chain. In addition, a traceability system for fruit and vegetable products based on ontology has been proposed also in Wang et al. (2012) for improving the quality and safety of agriculture products. In their work, authors pay attention on the agricultural chain and define a sematic model for the traceability of fruit and vegetables dividing this domain into a set of sub-systems, each of one is used to model to planting system, the gaining system, the transportation system and the sale system. Nevertheless, in this work there is no a clear expression of how terms are organized in classes and how concepts are related. From the cultivation point of view, an ontology for modeling the domain of crop production (the CROPonto Ontology) have been proposed by Bansal and Malik, 2011. The CROPonto Ontology serves as a building block for an ontology driven by the Agriculture Information System Framework. It has been developed using the AGROVOC thesaurus as base vocabulary. The ontology pointed out the most important classes for modeling the world of crop production such as soil, plant, cultivation method, cultivation stage, fertilizer. Relevant domain concepts (crops, fertilizers, chemicals) within the agriculture domain have been also included in Shoaib and Basharat, 2010 for the definition of the Centralized Agriculture Resource Ontology as part of the Integrated Agriculture Information Framework.

On the other hand, from the point of view of traceability of food from animal origin, the ontological model proposed by Chifi et al. (2007) for maintaining the traceability in the meat industry can been used as a base for the successive modeling of the agricultural domain for livestock production. In particular, the core ontology implemented by Chifi et al. (2007) in the framework of the Food Trace Project describes participants involved in the traceability chains, services and products they offer/uses and the main features of the products. The Food-Trace system represents a solution to assure the traceability in the domain of food industry even if it refers to the meat processing industry only. Nevertheless it represents a good reference for the implementation of a traceability ontological model for the meat industry. Detailed analysis must be carried out for modeling the different subsystems which are at the base of the meat processing industry, such as for the livestock production.

2.3. Food ontologies for the traceability domain

There are various sources of knowledge and concepts on the food domain like the AGROVOC thesaurus , the USDA National Nutrient Database for Standard Reference, or the LanguaL thesaurus which comprise thousands of food items. These terms and these concepts can be integrated and combined taking into account the above mentioned food ontologies for defining a complete Food ontology for traceability purposes. The obtained ontology can be used for solving the main traceability issues and, at the same time, for solving nutritional and healthcare problems. Salampasis et al., 2008 tried to solve the problem of developing traceability systems from a Semantic Web (SW) perspective and present a traceability solution that consider food traceability as a complex integration of a business process problem which demands information sharing. They propose a generic framework for traceability applications which consists of three basic components: (i) an ontology management component based on OWL; (ii) an annotation component for "connecting" a traceable unit with traceability information using RDF; (iii) Traceability core services & applications. In Salampasis et al., 2012 the authors describe the TraceALL framework and provide a set of core services for storing, processing and retrieving traceability information in a scalable way. In addition, they uniquely identify a Traceability Resource Unit (TRU) using a Uniform Resource Locator (URL) code.

The fundamental concepts that should be considered during the formulation of an ontology for traceability of products, have been defined for the first time by Kim et al., 1995 and they consist in Traceable Resource Unit (TRU) and primitive activity. A TRU is the representation of a resource that must be traceable. In the batch processes, a TRU represents a unique unit, meaning that no other unit can have exactly the same, or comparable, characteristics from the point of view of traceability. On the other hand, a primitive activity is the representation of the activity that must be traceable; a primitive activity is not formed by sub-activities, and it is also not an abstraction of other activity-like entities. Unique identification and the size of the TRU are the keys for a successful traceability system implementation.

2.4. Methodologies for representing the knowledge related to food traceability domains

In a typical supply chain mass information and knowledge spread out in various format among different enterprise systems. In addition, especially in Small and Medium Enterprises, data are generally stored in relational databases and actors normally use the same terms with different meanings. Current enterprise informative systems usually do not contain information about the meaning of concepts and about the relations existing between different terms and these conditions lead to semantic interoperability issues. In such a context a new ontology should be developed for providing a structure for developing knowledge and unifying the metadata model of the current systems.

The need of a global ontology is supported by the analysis of the state of the art developed. This highlights that ontologies are one of the main focus of attention in systems oriented to the food traceability.

The food ontologies which are at the base of the Food-Oriented Ontology-Driven Systems (FOODS) (Snae and Bruckner, 2008) and of the PIPS project (Cantais et al., 2005) should be considered as guide for the development of a more completed ontology for the traceability of food products. The new ontology, considering the main elements defined by Kim et al., 1995 and looking at the traceability as a complex integration of a business process problem which demands information sharing, as defined by Salampasis et al., 2008, should include not only products and activities as most important elements, but should consider all the actor involved in the food supply chain, from the raw ingredient producer to the final retailer, passing through transporters, wholesalers, manufacturing companies, and company involved in the distribution channel. For the detailed definition of the food taxonomy important consideration can be provided by the contemplation of the main works carried out for the definition of particular ontologies devoted to the modeling of specific food domain (Chifi et al., 2007; Drummond et al., 2007; Easwaran and Thottupuram, 2011; Graça et al., 2005; Heflin, 2000; Noy and McGuinness, 2001; Wang et al., 2012; Yue et al., 2005). While the afore mentioned ontologies deal with some smaller area of the food sector, these ontologies could be integrated and combined with each other with the main aim of defining a new complete food taxonomy, which includes food and beverages under the same main class. For the definition of the beverage taxonomy, the beer ontology (Heflin, 2000) and the wine ontology (Graça et al., 2005; Noy and McGuinness, 2001) can be reused. On the other hand, the taxonomy of food can be defined classifying aliments on the base of their origin. Food, in fact, may originate from plants or from animals. In addition, the cooking ontology presented in Batista et al. (2006) and in Ribeiro et al., 2006 can be useful for the definition of the taxonomy for processed food, since recipes concepts introduced in the ontology interconnect food concepts with each other.

Some ontologies have been proposed in the food domain, moreover there is no ontology that connect food products with the elements involved in their transformation process. There is the need of new ontology in the domain of food traceability in which information on ingredients, receipts, food processes and actors involved in the supply chain are combined all together to facilitate the knowledge sharing.

The above mentioned ontologies can be reused and correctly implemented for the definition of the Global Food Track&Trace (FTTO) Ontology for traceability purposes. The new ontology should combine the main elements of the previous works and should include the main elements fundamentals for representing the knowledge related to the food world with the main goal of modeling the domain of food traceability. Additional information to represent in the new ontology, in a simple and understandable way, are data related to products, actors and processes involved in the food supply chain.

3. Ontology description

This section describes how a new ontology for the food traceability domain, called Food Track&Trace Ontology (FTTO), has been defined to set up a traceability semantic model in order to reuse the available information resources involved in the process of tracing and promoting the accuracy, reliability and efficiency of the information management system.

The main aim of containing all the information related to the food traceability domain in a unique ontology is directly related with the need of enabling information sharing along the food supply chain. Food traceability can be seen, in fact, as part of a complex system in which different business processes collaborates in sharing information on products and actors. To enable information sharing, data and the way they are organized should be standardized. Each company of the supply chain should adopt the same language for describing the same entities and this language should be agreed by all the agents involved in the system. In fact, when agents collaborate in a supply chain they should agree on the same use of world and adopt the same standard and notation. The need of a new ontology for traceability purposes is directly related with the main goal of ensuring that all the terms used for encoding products and activities operated by different actors are agreed by all the users of the food SC.

A typical food supply chain is a complex system in which different actors collaborates with each other in order to share information on products and processes. Products include raw ingredients and service products involved in a particular process, such as packaging. Processes are atomic system in different actors execute particular activities that leads to the production of specific food elements. Consequently, the output of a process is a final food product that have undergone some operation, has been manipulated or only moved. In such a context, the importance of mapping and connecting information is stressed by the particular aspects of food: different products, in fact, can be obtained through the use of the same raw ingredients; in addition, specific processes can be used for the obtaining different food products or different service products can be used for the production of the same final product.

Since consistent vocabulary is needed for unifying information manipulated by different actors, the FTTO ontology can be defined as a standard mainly devoted to the maintenance of food traceability, capable of enabling interoperability among different systems and integrating the heterogeneous databases adopted by each actor of the food supply chain. It is important to point out that FTTO is a prototype developed for defining a standard and unify the meaning of the terms used on the Food General Framework proposed by Pizzuti et al. (2012) and discussed in the next section.

In the first part of this section the development process of the ontology prototype is explained. Then, additional information on the conceptualization phase is provided. Finally, a description of the main features of the developed ontology is introduced .The ontology is proposed as a combination of separated modules covering the key concepts of the traceability domain. Both food and processes are key components or core entities of the developed ontology. Additional information is provided on the different features of the FTTO ontology, focusing on the different modules generated. Each module has been developed considering the main elements involved in a general food supply chain. These elements or, key components, are required for keeping the traceability.

3.1. FTTO Building process

In the recent past a growing number of methodologies that specifically address the issue of development and maintenance of ontologies have been defined in the recent past. As an example, Methontology (Fernández-López et al., 1997) represents a general methodology that can be used as guide in the phase of ontology development. Methontology is quite general and includes a life cycle based on the continuous evolution of prototypes in which are involved the following activities:

– *Specification*. In this step the purpose of the ontology is identified along with its scope including the set of terms to be represented, their characteristics and the required granularity.
– *Knowledge acquisition*. This activity generally occurs in parallel with the specification phase. Knowledge acquisition is a long process of working with domain experts. It comprises the use of various knowledge acquisition techniques, in order to create a preliminary version of the ontology specification document, as well as all of the intermediate representations resulting from the conceptualization phase.
– *Conceptualization*. In this phase, domain terms are identified as concepts, instances, verbs relations or properties and each one is represented using an applicable informal representation.
– *Integration*. In order to obtain some uniformity across ontologies, definitions from other ontologies should be incorporated.
– *Implementation*. The ontology is formally represented in a language, such as OWL, generally obtained using an ontology development environment.
– *Evaluation*. In this activity a series of techniques are used to evaluate incompleteness, inconsistencies and redundancies.
– *Documentation*. A set of documents is collected resulting from other activities.

Following this life cycle, an ontology goes through a series of states, which correspond to some of the activities above identified, that are respectively specification, conceptualization, formalization, integration and implementation. Finally, the ontology enters into the maintenance state where knowledge acquisition, evaluation and documentation are carried during the entire life cycle (Fernández-López et al., 1997). Because of the general approach adopted by Methontology, the ontology development process for FTTO has been extended and integrated also being inspired by the ontology building process proposed by (Noy and McGuinness, 2001).

The FTTO building process is presented in Table 2.

The FFTO building process was supported by the use of Protégé (SCBIR, 2013), a popular tool able to edit and save the terms of an ontology, providing also a graphical representation of it. Protégé was developed at the Stanford University and has already been through a number of versions and modifications. It facilitates the definition of concepts or classes, properties, taxonomies, and restrictions, as well as class instances. Protégé supports several ontology representation languages, including OWL and RDF (S), and provides translation functionalities for graphical ontology. The Web Ontology Language (OWL) (Smith et al., 2004) is used as the reference representation language for the FTTO. An important feature of the OWL vocabulary is its extreme richness for describing relations among classes, properties, and individuals. For example, it is possible to specify in OWL that a property is Symmetric, the Inverse of another one, an equivalent property of another one, and Transitive; that a certain property has some specific cardinality, or minCardinality, or maxCardinality; and that a class is defined to be an intersectionOf or a unionOf some other classes, and that it is a complement of another class.

Similarly, a class instance can be the same individual as another instance, or it can be required to be different from some other instance.

The FTTO evaluation phase has been supported by the Pellet reasoner (Cuenca Grau, 2007) included as external plug-in in Protégé. Pellet is an open-source Java based OWL-DL (Description Logic) reasoner. Pellet API provides functionalities to verify the species validation, check consistency of ontology, classify the taxonomy, check entailments and answer a subset of queries. The core of the system is the tableaux reasoner that checks the consistency of a knowledge base. The datatype reasoner is responsible for checking if the intersection of datatypes is consistent or not.

The different elements of the ontology and the related properties are described in Section 3.3.

3.2. FTTO conceptualization

The representation of a body of knowledge is based on the specification of its conceptualization. A conceptualization is a simplified view of the world to be represented for some purpose. The main activities of the conceptualization required for the development of each module were:

(1) Identification of class and their classification.
(2) Identification and description of data properties.
(3) Identification and description of object properties.
(4) Identification of instances and their description.
(5) Validation of the previous step.

Table 2
FTTO Building process.

Step1	Analysis of the existing ontology in the food domain for reusing.
Step2	Extraction of the relevant information for the food traceability domain.
Step3	Collection of the nouns related to the food and to the agro-food processes (Identification of concepts).
Step4	Definition of modules.
Step5	Definition of classes' hierarchy.
Step6	Definition of Data Properties to describe classes.
Step7	Definition of Object Properties to describe the internal structure of concepts.
Step8	Definition of Individuals.
Step9	Definition of cardinality constraints and values restrictions.
Step10	*Connection of the different modules to the top-level ontology.*
Step11	*Performing of the reasoning.*
Step12	*Translation of the ontology schema in OWL language.*

The concept identification phase was a prerequisite for the definition of the FTTO in the OWL language. At this step, a large list of nouns of the food and agro-food processes domain was identified and classified in hierarchical form. The representation of things in a hierarchical form is the backbone of an ontology and it is known as taxonomy.

Moore deeply, the main components of OWL ontology are Classes, Individuals, and Properties. OWL classes are interpreted as sets that contain individuals. Individuals represent objects in the domain of interest. Individuals are also known as instances and can be referred to as being "instances of classes". Properties are binary relations on individuals. A taxonomy of properties can be defined as well. The basic elements of the FTTO are described in the Section 3.2, along with a description of some type terms used, type of relationship used and examples.

The need to cover the whole traceability domain, for a general food supply chain, led the authors to define the FTTO ontology as combination of four separated modules covering the key concepts of the traceability domain (actors, food, process, and traceability elements). The FTTO ontology consists of the following main classes:

- *Agent*. An agent represents an entity (or actor) involved in the process of food manipulation. This class includes companies and actors operating at each company.
- *Food Product*. This class includes ingredients such as salt, sugar, oil, and vinegar and food products in the form of raw material or manipulated products.
- *Service Product*. It includes products used during the manipulation of raw material or unprocessed food, such as phitosanitary products used in the agricultural phase, or during the transformation phase, such as food coloring or food additives. It includes also material for packaging and container of products.
- *Process*. It includes business processes and agro-food processes.

Another class has been used in order to define parameter and measurement unit for processes and products.

Several datatype properties were defined to describe relationships between individuals and data values. In addition, numerous object properties have been introduced for defining the relationships between two objects, well known as individuals. However, the need to add knowledge about the world, not limiting ontology to simple definitions of taxonomic hierarchies of classes and terminologies, led to the introduction of several axioms that constraint the possible interpretations for the defined terms. As consequence, a series of restriction were introduced to describe class of individuals on the base of the relationships that members of the class participate in.

3.3. Ontology basic elements

As mentioned before, four different types of classes have been and combined in the design of the FTTO. A short description for each module is provided in the following paragraphs.

3.3.1. Agent module

The Agent Module has to represent the information included in the definition of the actors modeled in the BPMN Model of the food supply chain. The main actors involved in the food supply chain are:

– Primary producer. It represents the roles of seeder, nursery and cultivator.
– Processor, which manipulate food products.

– Distribution channel. It represents the roles of wholesaler, retailer and distributor.
– Transporter, which physically moves products among different actors.

Along the food supply chain these actors can be present in the role of Client or Supplier. In case health problems due to food contamination or degradation, a key role in the supply chain management is covered the additional actor Observatory, which is responsible for the management of the traceability system and the recall activities. Each agent communicates with the rest of the SC providing to the Observatory actor, the information required for the traceability management. The Agent Module is presented in Fig. 1.

Fig. 1 shows that each actor is uniquely identified by the datatype *idActor*, present in the Keys section, and that it is characterized by a *codeActor* datatype that specifies its role in the supply chain. In particular, in the proposed figure, the *codeActor* with value *S* correspond to the seeder. In addition, general information on processes operated is provided as restriction. These means that the seeder can involve different persons in the role of sales responsible, warehouse responsible, operator or manager.

Each agent of the model represent a company in which are involved different persons who have been assigned a specific role in a specific department. The connection among persons of the class agent is obtained through the definition of the object property *hasMember*, which connect the domain Actor with the range Person. The list of object properties used to define connections among persons, departments and actors are showed in Fig. 2.

Each actor is characterized by some data properties such as *fiscalCode*, *codeActor* and *nameActor*.

Furthermore, information on actor's location is modeled through the use of the object *property hasLocation*, which connect the Actor domain with the Location range.

3.3.2. Food module

The aim of the Food class is to represent an abstract model of the different types of foods available to the users, together with the information about its ingredients. There are a huge number of existing coding systems that have been used in order to classify food and several databases developed with the same purpose. However, very few ontological resources that describe food exist.

The food taxonomy used in the Food class is based on the Codex Classification of Foods and Animal Feeds (Joint FAO/WHO Food Standards Program CODEX ALIMENTARIUS COMMISSION, 1993). Other taxonomies were considered an used in order to complete the food hierarchy such as Eurocode2 food Categories (Unwin and Møller, 1999) and CIAA Food Categorization (Confederation of the Food and Drink Industries of the EEC, 1995).

The terms modeled in the Codex Classification of Foods and Animal Feeds, the Eurocode2 and the CIAA Food Categorization have been integrated with several food databases. More specifically, the vocabulary of food products, used for referring the terms for food traceability, come from the integration of information contained in the AGROVOC metathesaurus (Liang et al., 2006), the LangualL Thesaurus (Møller and Ireland, 2008) and other databases, such as the USDA National Nutrient Database for Standard Reference (U.S. Department of Agriculture, 2012), the Food Composition database of EUROFIR (Church, 2009), the Molecular Biology Database of the TRACE project ("TRACE – Molecular Biology Database") and the Italian Food Composition Database for Epidemiological Studies in Italy (Food Composition Database for Epidemiological Studies in Italy, 1998).

AGROVOC is a multi-lingual thesaurus developed by the Food and Agriculture Organization of the United Nations (FAO) in 1982 that includes about 17,000 concepts and 3 types of relations (FAO, 2012). The USDA National Nutrient Database for Standard Reference is a database developed by the United Stated Department of Agriculture to be the major source of food composition data in the United States. Its eighteenth release (SR18) comprehends 7146 food items and up to 136 food components (U.S. Department of Agriculture, Agricultural Research Service, Food Surveys Research Group, 2010).

Fig. 3 shows the taxonomy of the Food class in which food products are classified according to their origin and on the base of processes executed on them. According to their origin, food products

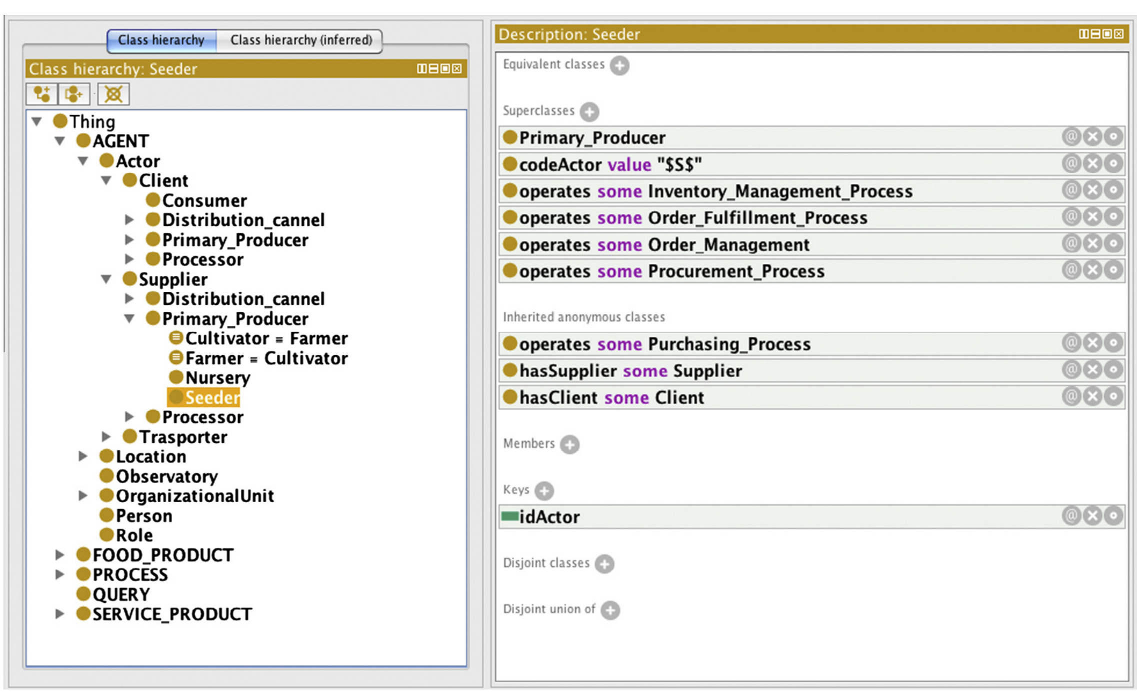

Fig. 1. Agent Module.

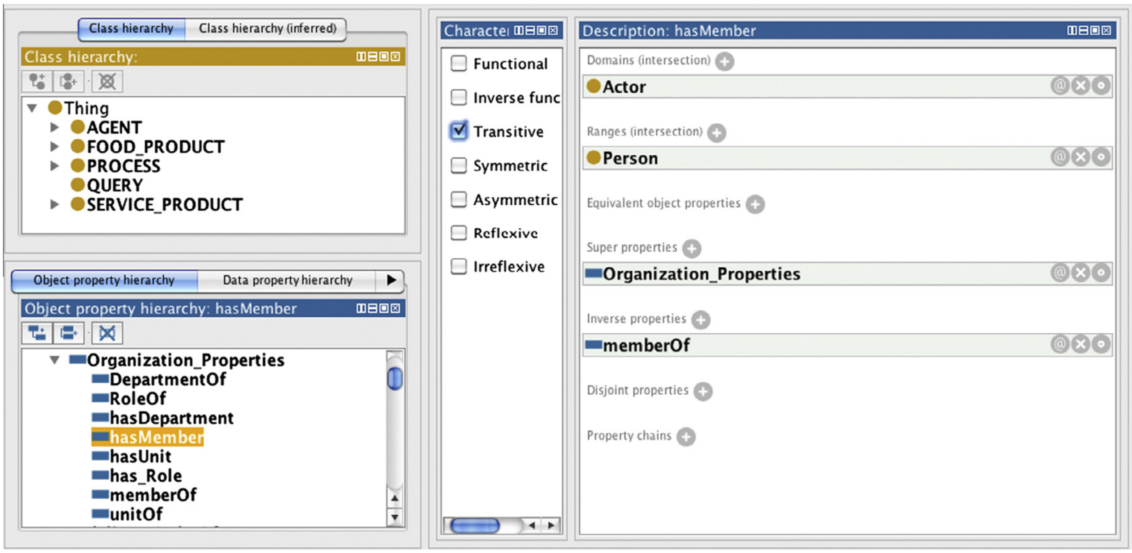

Fig. 2. Organizational data properties.

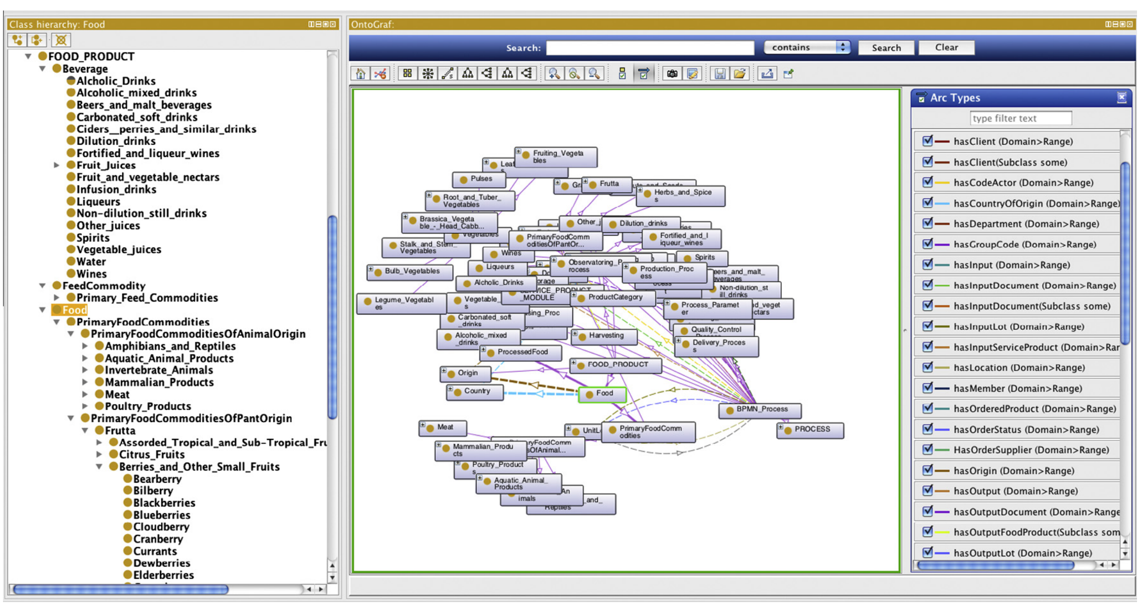

Fig. 3. Food Product Ontology.

can have animal or plant origin, even though most food has its origin in plants. Food taxonomy initially identifies the categories of "primary food commodities" and "processed foods". The term "primary food commodity" means the product in or nearly its natural state. The category of primary food commodities of animal origin includes irradiated primary food commodities and products after removal of certain parts of the animal tissue, e.g. bones. Food commodities of animal origin are parts of domesticated or wild animals, including their eggs and mammary secretions. The category of "processed foods" includes products that have been handled and transformed by the execution of some unit operation of food processing. These products have been classified in "derived products", "manufactured foods" and "secondary food commodities". The term "secondary food commodity" means a "primary food commodity" which has undergone simple processing, such as removal of certain portions, drying, and combination, which do not basically alter the composition or identity of the commodity. "Secondary food commodities" may be processed further or used as ingredients in the manufacture of food or sold directly to the consumer. "Processed foods" prepared from these primary food commodities are again separated into those of plant origin and of animal origin. Multi-ingredient "manufactured foods" containing ingredients of both plant and animal origin are listed as plant or animal origin depending upon the main ingredients.

During the development phase of the FTTO ontology, the main difficulty found in the conceptualization of the food class was to consider and model the concept that a food item may be part of another one (Ribeiro et al., 2006) in case of processed foods. This issue was solved specifying the objet property *hasIngredient*, which links each food item with the primary commodities and the processed food used to obtain it, and that has as inverse property the relationship *isIngredientOf*. As example, the food item "minestrone", is an individual of the class *Vegetables Mix*, which is a sub-class of *Manufactured Foods of Plant Origin*, that contains has ingredients carrot, tomato, onion, bean, potato, spinach (Fig. 4)

3.3.3. Process module

The Process Module conceptualizes the knowledge related to the process domain in the field of the food processes. The need to connect the FTTO ontology to the General Track&Trace framework introduces a taxonomy of the all processes modeled in the BPMN model of the food supply chain in the Process Module. The classification of the processes operated in the food supply chain us particularly important to standardize the internal traceability systems of each company involve di in the SC and to reuse the same terms in order to specify or refer to particular activity operated on food, independently by the actor who manipulated the product.

A detailed analysis of a generic food supply chain have been initially carried-out in order to identify the main terms and concepts to be included in the FTTO ontology. The supply chain analysis lead to the development of the supply chain model presented in Pizzuti et al. (2012) and described in detail in Section 4. Taking into account the modeled food supply chain, a classification of the processes has been obtained. As shown in Fig. 5, the Process class includes a classification of business processes, agro-food processes and food transformation processes operated by the different agents involved in the supply chain.

The class of Business processes includes processes related to traceability, such as distribution, labeling, purchasing, order fulfillment, storage, packaging and labeling. For the definition of the taxonomy of the business process class, important consideration have been done taking into account the Supply Chain Operations Reference (SCOR) model proposed by the Supply Chain Council (Supply Chain Council, 2010). Business processes, in fact, have been classified considering their main goals. Moreover, as mentioned before, the business processes classification has been mainly defined considering the business process models proposed by Pizzuti et al. (2012).

The class of Agro-food processes includes crop cultivation processes, livestock production processes and aquafarming processes. In order to maintain internal traceability, important information must be recorded for each process depending on the specific activity operated on food. To this end, for each process, the most important activities have been classified. For example, the crop cultivation process includes the activities of sowing or transplanting, irrigation, fertilization, weeding, plant protection treatments and harvesting. On the other hand, the livestock and poultry production process includes feeding processes and watering, along with the pharmacological treatments processes. Further considerations can be done also for the aquafarming process.

The taxonomy for the processes of food transformation was collected based on the unit operation of food processing (Earle, 1983). Food processing refers to the transformation of raw ingredients into food or food into other forms. The main processes operated for food transformation have been defined under the class Food Transformation processes. As previously defined, the processes used by the food industry can be divided into common operations, called unit operation. Examples of common operations to many food products include cleaning, drying, separation, material handling, heating and cooling. Unit operation operations may include different types of activities (Potter and Hotchkiss, 1998). The unit operation of mixing, for example, includes the activities of emulsifying, blending, agitating or stirring.

Some object properties have been introduced for representing the knowledge related to the processes operated in a food SC. Important information to store for each activity operated in a unit operation is information on process parameters, such as environmental parameters like temperature, humidity and pressure, or technical parameters like speed, capacity or processing time. Process parameters are defined for each process using the objects properties of *hasProcessPameter*, which connect the Process class with the Parameter class.

Furthermore, the starting time for each process is defined by the relationship *hasStartTime*. The information on the date and the time in which a process is operated is fundamental for traceability purposes because it permits to identify critical control points to keep in consideration in case of food crises or food outbreak diseases.

Process classification has been defined specifying the product flow along the food supply chain.

3.3.4. Service product module

The Service Produce Module models the knowledge of the products related with the production processes. The Service Product class includes products for packaging and for food treatments at

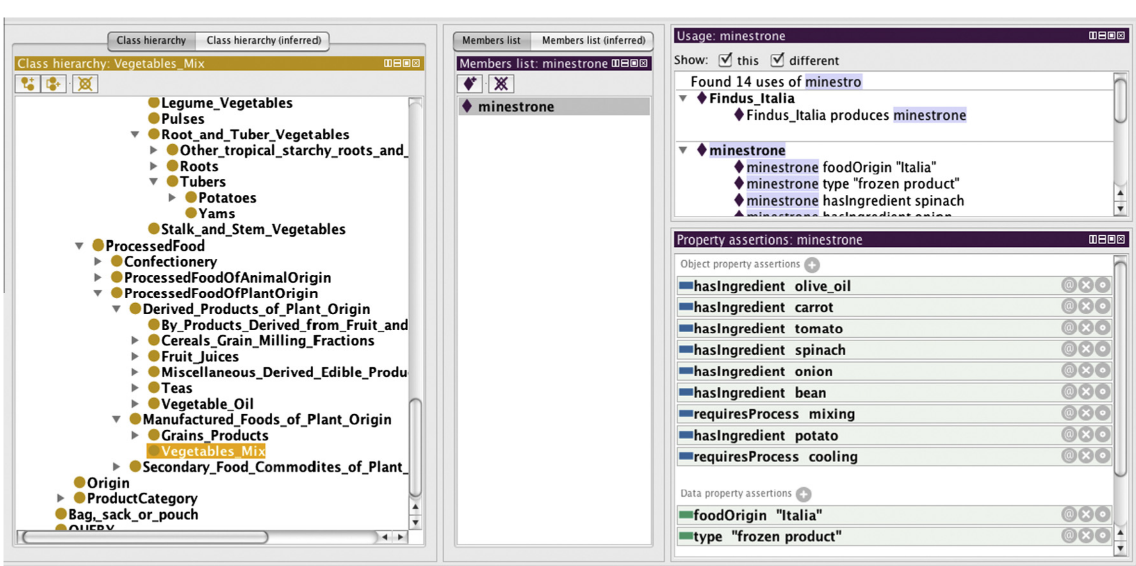

Fig. 4. An example of individual.

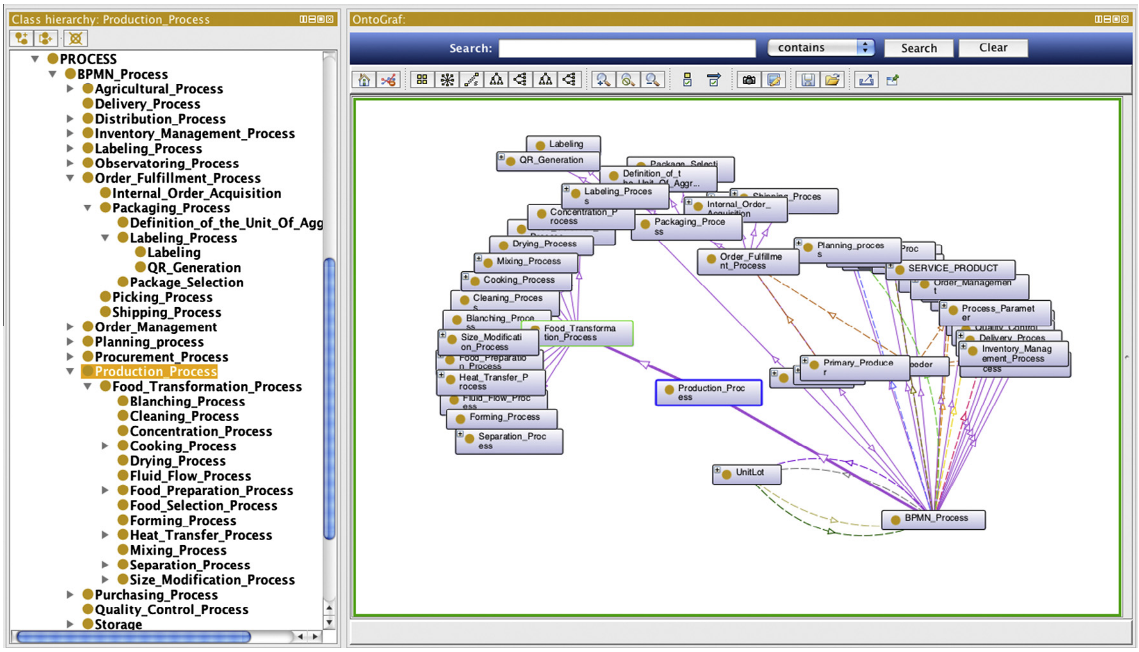

Fig. 5. Representation of the Process class hierarchy.

Fig. 6. Service Product Class Hierarchy.

each stage of the supply chain. For e.g., phytosanitary product are involved in the agricultural processes operated by the nursery and cultivator (farmer). Food additives, however, are substances used in the food industry during the phases of preparation, storage and marketing of foodstuffs. Another sub-class includes machineries and utensil used in each stage of the supply chain. The class hierarchy is showed in Fig. 6.

The importance of the Service Product Class in the FTTO ontology is a consequence of the legal requirements on materials and products used for managing food. In particular the sub-class of the Packaging Products is fundamental for the traceability of materials used to package food, as these can contaminate food or lead to their deterioration.

4. Global food traceability framework

This section describes the Global Food Traceability Framework, which is the framework where the FTTO will be developed. As mentioned before in the Introduction section, the FTTO is part of a general project in which the food supply chain has been previously modeled using as standard the Business Process Modeling and Notation (BPMN) (De Cindio et al., 2012; Mirabelli et al., 2012b; Pizzuti, 2012; Pizzuti et al., 2012). BPMN is a new notation that has been specifically designed to coordinate the sequence of processes and the messages that flow between different process participants in a related set of activities (Object Management Group, 2010).

The analysis of a generic supply chain underlines that since a product moves from the primary producer to the final customer, that product goes through a number of transformations. Each transformation will involve different agents. Every agent must collect, keep and share information in order to enable food traceability. Recording and management of the information is facilitated by the use of an information system generated from the BPMN model of the SC, whereas the information for sharing is facilitated by the FTTO presented in the next section.

Because of the immense variety and differences that exist among food supply chains, in this context the Global Food Traceability Framework is presented to highlights the main features and processes of this particular supply chain.

The food supply chain can assume different configuration according with the number of actors which collaborate for the definition of the final product and of the number of processes operated on primary food commodities and processes food before they are introduced into the market. Two actors are always present in the food supply chain: the primary producer and the consumer. When the activities of production, processing and sales are carried out directly from the farm, it refers to the so-called short chain. Typical examples are the co-operatives of farmers cultivating fruits and vegetables that they directly sell them to the final customer in bulk or packaged without any commercial intermediary. Long food supply chains refer to complex agro-industrial systems in which the food, before reaching the consumer, passes through different stages of processing, transportation and distribution that are usually managed and controlled by different actors. A short description of the processes operated by each actor is provided.

Depending on the raw materials produced, the agricultural processes operated by a Primary Producer can be distinguished in crop cultivation processes, aquaculture, livestock or poultry production processes. These processes refer to the agricultural processes. Agriculture, in fact, is the science of producing animals, plants and fungi for food.

Important operation modeled in the cultivation stage are seed selection, land or soil preparation, crop establishment (including seedling and transplanting), irrigation or water management, nutrient management and pest management (or crop health management), harvesting and post harvesting. In order to facilitate good record keeping during the crop cultivation phase, growers must fill a logbook in which annotate, for each lot of cultivation, pre-planting actions and in-crop activities such as herbicide and nutrients applications, with a clear definition of the service product utilized, the explanation or motivation of the cause which led to its usage, the amount of service product utilized and the date of the application along with information of the person responsible for the different operations.

Similarly to its application in the cultivation phase, the logbook can be also used for keeping records on aquaculture and livestock or poultry activities.

Farming practices for growing animals are different depending on the type of animals and breading farm. Livestock, in fact, can be kept in an enclosure and fed by human-provided food, or can be not kept in an enclosure and fed by access to natural food, or are allowed to breed frees or any combination of thereof. On the other hand, aquaculture, also known as aquafarming, is the farming of aquatic organisms such as fish, crustaceans, mollusks and aquatic plants.

For the phase of livestock management and aquaculture, fundamental information to track refers to the establishment of the location where a specific animal has been kept in each phase of its lifecycle. Important information to record are the location and date at which animal were born, raised, transported, information of feed used for its alimentation or on treatment done with pharmacological substances or medicated feed. The logbook management can be facilitated by the use of such informative system.

Beside the operational processes operated on food, a series of business processes not directly related with traceability requirements, but able to support the main traceability activities, must be considered and modeled. Especially for ingredients and raw materials, important information to record is information on suppliers, inventory conditions, material used for contain the products during their stay in the company and during the transportation phase.

A food product can be sold in the form of fresh products or can be manipulated and transformed into a complex or derived product. Food that can be eaten right after harvesting or that do not need any manipulation are defined primary food commodities and, before to be sell, they require just some process of cleaning and/or packaging. For example, food such as fruit and vegetable or even meat are only minimally processed. Generally food goes through different processes before to reach the tables of the consumers. Some of the processes used in food processing change the way food looks, feels and tastes. Food processes may seem bewildering in their diversity, but careful analysis has showed that these complicated and different processes can be broken down into a small number of unit operations. Food unit operations are governed by specific conditions and are characterized by different environmental and process parameters. Important unit operations in the food industry are fluid flow, heat transfer, drying, evaporation, contact equilibrium processes (which include distillation, extraction, gas absorption, crystallization, and membrane processes), mechanical separations (which include filtration, centrifugation, sedimentation and sieving), size reduction and mixing.

The processes operated by an industry for obtaining derived or manufactured products are specified for the actor Processor (or Factory). These processes, which are related also to the processes of Order Management, Inventory Management, and Delivery Process, are mainly devoted to the food transformation and they refer to the operation of food processing. Food processing refers to the transformation of raw ingredients or primary food commodities into food or of processed food into other forms. On the other hand, processed food is made by using lots of different ingredients. All these ingredients are stored and transported to the food manufacturing factories or food processor. Later, manufactured food has to be stored again and transported to the retailers.

Transportation activities play an important role in the food supply chain management. Food products are extremely time critical and, by their nature, they are characterized by a short shelf. Their shelf life can be conditioned by the harvesting means, the transformation processes, the way of transportation, and the storage and handling conditions. Transportation can be done in different ways and using several means of transportation. To this end, the actor Transporter play an important role in the general framework, due to his responsibility in moving food through the different actors involved in the FSC. The main processes operated by the Transporter are Process of Taking Delivery, Transportation Management and Delivery.

A central role is played also by the distribution channel, that includes retailer, wholesalers and the distributors that buys large quantity of goods from various producers or vendors, warehouses them, and resells to retailers. The main processes operated by these actors are Buying, Warehousing and Selling. During the storage phase, in the warehouse some operations such as mixing, cleaning or packaging can be executed. Transformations and logistics operation such as procurement and delivery have been considered for each actor.

The modeling of the food supply chain using the BPMN standard led to the generation of an information system for food traceability that can be used to keep and share mandatory and optional information considering the requirement of specific sectors.

The BPMN model has been developed in order to define a general food supply chain from farm to fork. In addition, the terms and concepts used for defining the food supply chain model have been introduced according with the ontological terms proposed in the FTTO ontology. This condition is much more expressive in order to locate any food in a process and to identify any process that can be associated with a food, along with any food related, as raw ingredient, with a processed food.

In addition, the terms and concepts modeled in the FTTO ontology represent a reference, a standard for introducing data in the correct form in the BPMN model. The terms of the FTTO ontology, in fact, have been used for implementing the BPMN model.

5. Results and discussions

Every agent has its own knowledge base, and only information that can be expressed using ontology can be stored and used in the knowledge base. When an agent wants to communicate to another agent in the food supply chain, he uses the construct from the FTTO ontology. The Global Food Track&Trace Systems, which is at the base of the FTTO ontology, can be configured as a multi-agent system in which agents cooperate and communicate delivering and receiving messages. In this context, the FTTO ontology is used as a standard reference for communication. However, the final aim of the FTTO is to help authorities and food agents to solve problems in case of food crises, when analysis and elaboration of common data available in the food supply chain is required.

To demonstrate the FTTO validity, different scenarios have been studied and analyzed. This paragraph provides a short description of one of this scenario. When a food crisis occurs, authorities or government agencies elaborate data available querying the FTTO ontology and make a series of assertions in a consistent way. In the proposed scenario a series of persons present symptoms food poisoning. For each person, information on food eaten is available.

Due to the complexity of food composition and to the huge number of information on products, the problem of identifying the source of a food outbreak disease is a complex problem. In the analyzed scenario patients have eaten different food. Different foods can be obtained combining several primary food commodities or processed foods that can have some ingredients in common. Through the ontology querying, information on common ingredients can be easily obtained. For example, patients can have eaten different products such as vegetable mixes, tomato sausage, and lasagna. All these products have a common ingredient that is the tomato and that can be the source of the food outbreak disease. Fig. 7 shows the result of a query expressed in Description Language, which requires the selection of all foods that contains tomato as an ingredient. In particular tomato is contained in juices or sauces that are used for the production of complex foods such as ready meals and pizzas. In addition, tomatoes can be dried and pickled in oil or cut and used in vegetable mixes.

The querying of the FTTO ontology permits to elaborate information and to return information of ingredients, processes or service products that are common for elements for the different foods under analysis.

Different food products can be characterized not only by the presence of the same ingredients but also by the use of similar processes operated along the food supply chain, which can requires the same service product. In addition the same actor can manipulate different food products using the same service product and materials. On the base of these statements, another possible scenario to analyze can be characterized by the presence of patients who ate different products that do not share any ingredients, but that can be characterized by the use of some service product in a

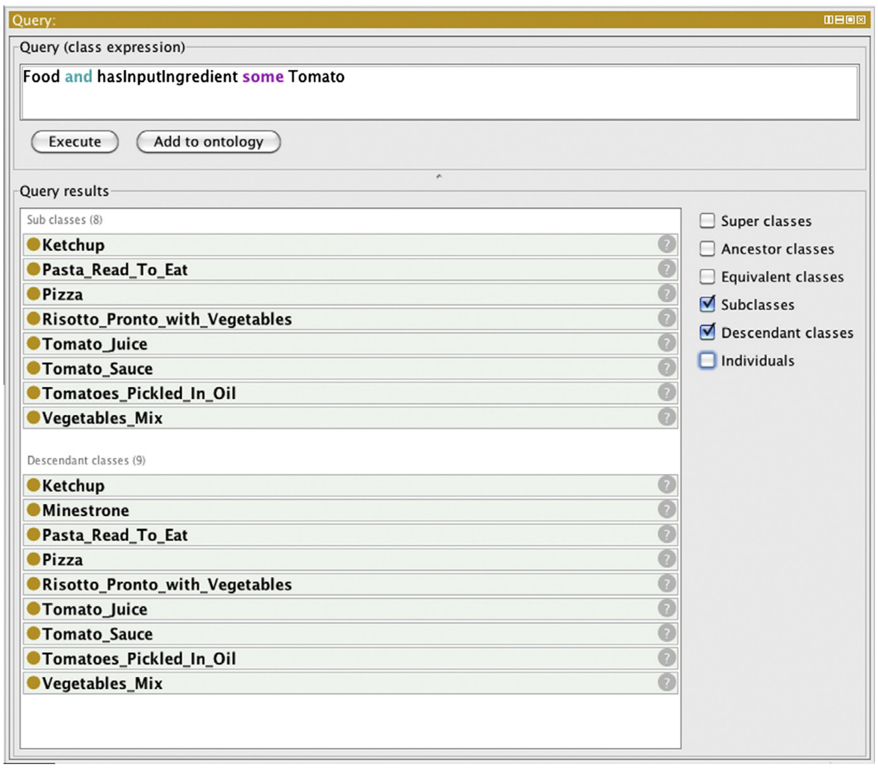

Fig. 7. DL Query expression and Results.

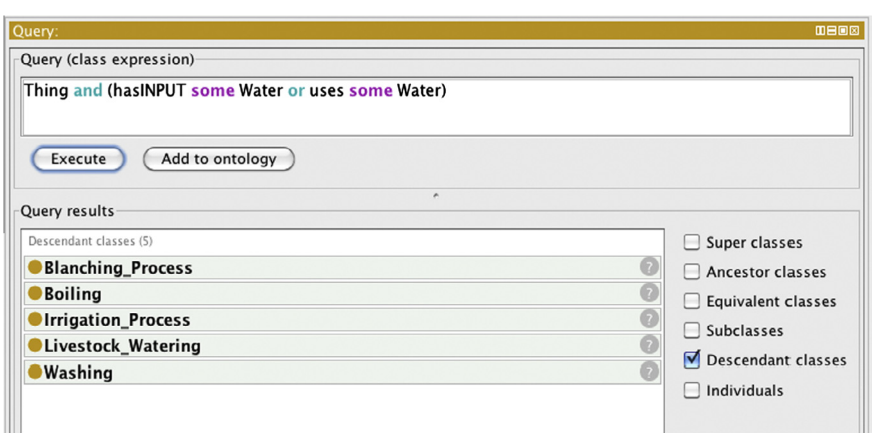

Fig. 8. DL Query expression and Results.

particular phase of the supply chain. This is the case in which water, for example, is used as common source for irrigating a parcel used for the growth of a particular vegetable and for watering the animal in a herd. The water, which is characterized by the presence of a particular contaminant, can lead to the contamination of the vegetables produces in that parcel and of the meat of the caw that drank the same water used for the irrigation.

The solution of the problem presented in the proposed scenarios can be easily obtained querying the FTTO ontology, and correlating the information conceptualize in the ontology with the information recorder in the database of each actor belonging to the supply chain. The results of a query on the use of water in the different processes that can be operated along the food supply chain are showed in Fig. 8.

At this step, it is important to pointing out that the FTTO ontology has been developed with the main aim of containing all the information related to the food traceability domain in a single hierarchy. FTTO, and the general framework in which it is involved, have been designed in order to define a traceability prototype able to assist in solving some exiting problems which deal with food traceability, such has the need to connect information on food, processes, products and actor involved during the manipulation of a particular products, and to identify the causes which lead to the definition of a particular problem of food origin.

6. Conclusions

This paper presents an ontology model for food traceability, the Food Track&Trace Ontology (FTTO). The ontology model is based on four different modules: Actor, Food Product, Service Product and Process. FTTO intends to be a reference ontological model for future works in the development of food ontologies with traceability purpose. FTTO is part of general framework for the traceability of food products able to support quality and safety control. In case of food outbreak disease FTTO can be easily queried to obtain essential information fundamental to connect data available in the food supply chain.

The OWL-DL language based on description logics is used to describe the food traceability domain. The ontology reasoning, in the case of the FTTO, is conducted proposing a series of competency questions and checking is the questions were being correctly answered. The queries are formulated in Description language (DL-QUERY). The Pellet plug-in is used as reasoner.

FTTO defines the context with which query and assertions are exchanged among agent belonging to the food supply chain. Currently, FTTO is a prototype but according to the different tests performed, it is possible to put in practice in a real SC.

In the future FTTO, which is general for the food domain, can be specialized and adapted to specific areas and domains in order to conceptualize it in a complete manner. In addition more facts can be added about food and processes. The ontology querying can be formulated for several purposes, and in particular, for identifying the causes of cases of food outbreak diseases. The structure proposed is able to solve some existing problems related to food traceability

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