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A generic ontological network for agri-food experiment integration - Application to viticulture and winemaking

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Abstract

This paper presents an ontological approach of observational data integration across complementary sub-domains, i.e., agriculture production and food processing, with an application to viticulture and winemaking process. The two main steps in this approach are i) to integrate preexisting ontologies to create a so-called ontology network and ii) to populate the ontology network with actual experimental data from different sources. The Agri-Food Experiment Ontology (AFEO), a new ontology network was developed based on two existing ontology resources, i.e., AEO (Ontology for Agriculture Experiment) and OFPE (Ontology for Food Processing Experiment). It contains 136 concepts which cover various viticultural practices, and winemaking products and operations. AFEO was used to guide the data integration of two different data sources, i.e., viticulture experimental data stored in a relational database and winemaking experimental data stored in Microsoft Excel files. Two potential uses by researchers of viticulture-winemaking integrated data using AFEO are shown. The first one is about wine traceability and the second one is related to the influence of grape varieties, irrigation practices, and different winemak-

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ing methods on GSH concentration in wine. Those examples show that data integration guided by an ontology network can provide researchers with the information necessary to address extended research questions, illustrated in the paper by viticulture and winemaking processes.

Keywords: ontology network, data integration, viticulture, winemaking

1. Introduction

Research in agri-food and related domains dealing with sustainability is evolving more and more extensively in recent years to be more integrative, collaborative, and interdisciplinary [1]. These tendencies consider the agri-food domain as an interconnected system with various entities and complex relationships among them [2]. Consequently, data sources over the whole food chain are becoming available and can be combined to address new questions. For example, to answer a question or to test a hypothesis about the effects of different viticulture treatments on wine quality, researchers need to access various data sources from a set of winemaking experiments and viticulture practices. Data analysis could then provide better information and understanding of what actually happened during a set of experiments and give the possibility of acquiring new knowledge all along the agri-food chain.

However, to access and to incorporate various data sources, researchers have to deal with some obstacles. Data are commonly stored in scattered places that sometimes make it difficult to combine them. Moreover, data are very diverse in terms of formats, naming, storage mechanisms, and query or retrieval mechanisms. The heterogeneity of scientific data may come from many factors, such as (i) most scientific data are collected distinctively based on independent research projects; (ii) the data structures are frequently selected according to the collection methods (e.g., to make data easier to record) or the format is

22 suggested by analysis tools, instead of standard data representations (e.g., re-
23 lational database schema); and (iii) the terms and concepts used to label data
24 are not standardized, neither within nor across scientific disciplines and research
25 groups [3]. The difficulty of organizing available data and knowledge in a unified
26 way not only limits research productivity but also reduces data traceability [4].

27 Research experiments are commonly divided into some sub-domains, such
28 as agriculture production, post-harvest, and food transformation process. Even
29 though the explicit relation between them is clearly understandable, each of
30 these has different objectives, scopes, and circumstances. For instance, the
31 agricultural experiments are normally performed in the fields, in which external
32 factors have a significant contribution while food processing experiments are
33 generally carried out in the laboratory with more controllable environments.
34 From a practical point of view, they require different methods for collecting
35 and organizing observational data that would lead to differences in the data
36 format or structure and in the way the data are stored. The heterogeneity
37 also occurs due to the vast scope of agri-food domains, ranging from plant
38 cultivation up to the final processed food product. Each discipline uses its own
39 knowledge expression, terms, concepts and semantic relations that might cause
40 some difficulties to share the observational data.

41 Studies in the last two decades have shown that ontologies represent a flexi-
42 ble way to link the information contained in heterogeneous data sources within
43 or across domains [4, 5]. Ontologies also provide the common concepts for data
44 integration, thus opening the possibility to draw more comprehensive conclu-
45 sions and to view data from different perspectives. Ontologies also allow certain
46 types of automated reasoning to be performed in order to fulfil some specific
47 requirements. The capabilities of data and knowledge sharing as well as rea-
48 soning will help to develop more advanced Information Systems able to manage

49 heterogeneous data sources and to design platforms for more collaborative and
50 accurate scientific data analysis.

51 The contribution of this work is to provide a method to prepare and to inte-
52 grate data sources prior to further analysis in order to answer complex questions
53 that require access to various agri-food scientific data sources. This method
54 works out in viticulture and winemaking to solve complex questions using het-
55 erogeneous experimental data sources. To achieve this purpose, we developed
56 the Agri-Food Experiment Ontology (AFEO), a new ontology network resource,
57 based on two ontology resources, i.e., AEO¹ (Ontology for Agriculture Experi-
58 ment), which is also an original contribution of this paper, and OFPE² (Ontol-
59 ogy for Food Processing Experiment). The AEO and OFPE are ontologies that
60 have been developed separately in research laboratories as generic knowledge
61 representations of two respective sub-domains, i.e., agricultural production and
62 food transformation process. By following the NeOn [6] methodology, we inte-
63 grated these two ontologies into an ontology network, in order to facilitate data
64 integration across these complementary sub-domains. An ontology network [6]
65 is a new ontology engineering concept, which allows ontology re-use and avoids
66 custom-building new ontologies from scratch.

67 Although in this paper the proposed ontology is specialized and tested for
68 viticulture and winemaking experiments, the core elements of AFEO are fairly
69 generic and might be adapted to other food products. Furthermore, the onto-
70 logical definitions (concepts and relations) can be used to impose and preserve
71 a logical structure for new types of scientific data, that may appear due to new
72 sensors, protocols and analyses.

73 This paper is structured as follows: Section 2 gives a brief survey on recent

¹<http://agroportal.lirmm.fr/ontologies/AEO>

²<http://agroportal.lirmm.fr/ontologies/OFPE>

74 work related to scientific data integration and agri-food ontologies; Section 3
75 describes the global agri-food experiment ontology design process, introduces
76 the two ontology resources used, their integration and specialization to viticul-
77 ture and winemaking experiments; Section 4 presents how the new proposed
78 ontology network is instantiated to integrate two different data sources: Section
79 5 is dedicated to discussion and a potential use in the domain of viticulture
80 and winemaking; Finally, in Section 6, conclusions are drawn and further work
81 outlined.

82 **2. State of the art**

83 The works on ontologies have increased recently not only in computer science
84 but also in various domains, including agri-food related domains. This is driven
85 by the need to communicate and share knowledge with common understanding.
86 This section is divided into two subsections: i) scientific data integration with
87 respect to an ontological approach and ii) current work on agri-food ontologies.

88 *2.1. Scientific data organization and integration*

89 Over the recent years researchers have faced significant problems to manage
90 scientific data due to their increasing volume and complexities. This causes
91 researchers to spend quite a bit of time to manage and integrate scientific data
92 rather than to directly focus on their analysis [7] /* BRIGITTE: AJOUT REF
93 PHENOME */. Scientific data are generally collected from measurements di-
94 rectly linked to real-world phenomena [8]. Within the agri-food domain, cross-
95 disciplinary scientific data are required to explore complex and temporal aspects
96 of food quality and the impact of practices and operations.

97 The need for a more adaptable mechanism to organize scientific data has
98 been addressed in the literature, both in non-ontological based approaches such
99 as, LabKey Server [9] and SciPort [10]; and in ontological based approaches

100 such as proposed in [11], [7], [12], [3], [13] and [14]. Some of these approaches
101 are targeted to specific scientific domains while the others are developed to be
102 more generic and extensible. The non-ontological approach mostly relies on data
103 models, such as database or XML schema, where attributes and relationships
104 of domain concepts are captured in standardized structures. The ontological
105 approach has some additional advantages in terms of data interoperability and
106 knowledge reasoning [15, 16, 17, 18].

107 To the best of our knowledge, we did not find an ontological approach to
108 represent scientific experiments as well as observational data which fulfill all our
109 needs. An ontology of scientific experiments, the EXPO [19], has been proposed
110 to formalize the generic concepts of experimental design, methodology and result
111 representation. However, this ontology does not provide a clear explanation
112 about scientific data representation. Neither does this ontology describe how to
113 manage a set of experiments in which several interrelated experiments have to
114 be conducted in a given order. The Extensible Observation Ontology (OBOE)
115 has been developed to serve as a formal and generic conceptual framework for
116 describing the semantics of observational data sets (i.e., data sets consisting
117 of observations and measurements) [7]. The basic concepts of the observational
118 model consists of five classes and six properties [3]. This ontology can be applied
119 to various types of observations. Nevertheless, it is more suited to representing
120 scientific data which are generated from measurement by sensors. It does not
121 provide other types of observational data such as expert judgements or results
122 from a calculation procedure.

123 *2.2. Agri-food ontologies*

124 In order to fulfill the needs of representing complex knowledge, sharing
125 common understanding within or across scientific domains and reusing domain
126 knowledge in agri-food sectors, some ontologies have been proposed, either very

127 general or more specific. Some researchers focused on building ontologies to con-
128 ceptually model agricultural practices related to crop productions, such as, hilly
129 citrus production ontology [20], precision agriculture ontology [21], crop-pest
130 ontology [22] and potato ontology [23]. Meanwhile, some works concentrating
131 on food taxonomy have also been carried out, such as FOODS (Food-Oriented
132 Ontology-Driven System) [24] and wine classification [25].

133 The valid definition of concepts and a complete taxonomy for agricultural
134 practices and food processing are important to model agri-food experiments.
135 Most of the above ontologies refer to the terms or concepts listed in AGROVOC.
136 AGROVOC is a multi-lingual vocabulary developed by the Food and Agricul-
137 ture Organization (FAO) of the United Nations and covers divers areas includ-
138 ing food, nutrition, agriculture, fisheries, forestry, environment etc [26]. Some
139 ontologies extend these concepts in order to accommodate their data sources
140 according to the target domains, such as shown in [20],[22], and [23].

141 Another part of the agri-food domain that recently attracted the attention
142 of researchers is related to food traceability. It is driven by a growing interest
143 in developing systems for the food supply chain. Some essential works in this
144 domain have been carried out, such as The Food Track and Trace Ontology
145 (FTTO) [27] and TraceALL [28]. Even though the FTTO is dedicated to food
146 traceability management, this ontology provides representative food concepts
147 that also become valuable resources for food processing experiments. This on-
148 tology includes four core concepts: actor, food product, process and service
149 product.

150 The ontologies mentioned above have proven useful in their own domain.
151 However those ontologies mostly cover one sub-domain, for example only agricul-
152 tural practices or only food processing. The question of data integration across
153 complementary sub-domains often has not been discussed yet in the Agri-food

154 sector.

155 **3. The global Agri-food experiment ontology design approach**

156 In this section, we explain how we built an ontology network (AFEO), start-
157 ing from two complementary existing ontologies (AEO and OFPE), in order
158 to integrate heterogeneous data sources, both from field experiments and from
159 food processing processes. To design AFEO ontology, we have followed the
160 NeOn methodology [6]. NeOn provides methodological support for constructing
161 an ontology network (AFEO in our case), when different pre-existing resources
162 must be re-engineered in order to be reused for a new purpose. NeOn per-
163 mitted us to design iteratively the AFEO ontology network based on some of
164 the nine scenarios proposed in the methodology which cover commonly occur-
165 ring situations. The section is divided into three parts. The first part defines
166 the requirements associated with the desired result, the AFEO ontology net-
167 work. The second part presents the scope of both selected ontology resources
168 (AEO and OFPE) as inputs of the ontology integration process. The third part
169 describes the ontological transformations used to integrate AEO and OFPE on-
170 tologies into AFEO in order to fulfill the requirements. Main OWL 2 (Web
171 Ontology Language, second edition) ontological constructs used in this paper
172 are presented in [29].

173 *3.1. AFEO ontology requirements*

174 Following NeOn scenario 1 (From specifications to implementation), we es-
175 tablished the ontology requirements (called OR in the rest of the paper). AFEO
176 must

- 177 • model a global food chain linking the biomass production process to the
178 biomass transformation process (OR1),

- represent experimental observations all along the integrated process (OR2),
- be able to be specialized for a given food chain which is, in this paper, viticulture and winemaking (OR3).

3.2. Description of the initial ontologies

Following NeOn scenario 3 (Reusing ontological resources), AEO and OFPE ontological resources must be inspected in order to determine if they are good candidates to fulfill the AFEO requirements and to analyze their granularity. AEO and OFPE ontologies were built separately for different intended communities. AEO serves as a representation of expert knowledge in the field of agricultural practices while OFPE was developed to represent the knowledge related to food processing experiments. It is the reason why they have been selected as their union should satisfy OR1 requirement presented in section 3.1. The present section describes both ontologies, in terms of their concepts and relations, in order to determine if some knowledge is missing to fulfill AFEO requirements.

3.2.1. Agricultural Experiments Ontology (AEO)

Table 1: Some important object properties of AEO

Property name	Inverse	Descriptions
includes	included	relation among cultivation locations (FarmArea, CultivationArea and its subclasses)
applies	appliedTo	relation between classes under AgriActivity and some classes under ObservedAgriEntity. For instance, an instance of Fertilizing is applied to an instance of Plot or SubPlot
hasPart	partOf	relation between Plant class and Organ class
hasLocation	locationOf	relation between AgriExperiment and CultivationArea
involves	involvedIn	relation between AgriExperiment and AgriActivity as well as ObservedAgriEntity.

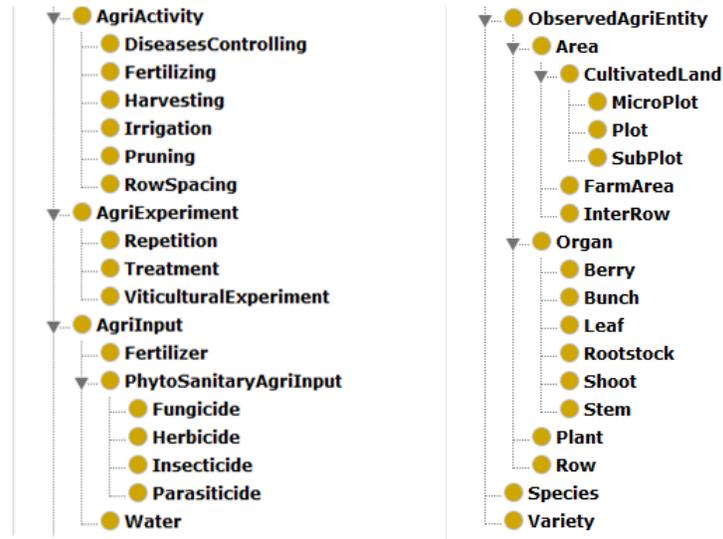


Figure 1: Concept hierarchies in AEO.

195 AEO is an ontology aimed to represent objects related to agricultural prac-
 196 tices. It is based on three main concepts, *AgriExperiment*, *ObservedAgriEntity*,
 197 and *AgriActivity* (Figure 1). *AgriExperiment* is a concept that represents ex-
 198 periments carried out by researchers. *ObservedAgriEntity* represents objects
 199 that are observed and followed during field experiments while the *AgriActiv-*
 200 *ity* represents common activities or operations performed during experiments.
 201 Some important semantic relations have been defined between those concepts
 202 as shown in Table 1. Object property *includes* plays an important role in this
 203 ontology. It is used to represent the relation between spatial locations, e.g., *Far-*
 204 *mArea* a concept that represents the area of agricultural land used for farming.
 205 This type of relation also applies to *Plot*, *Sub-plot* and *Micro-plot* which are sub-
 206 classes of *CultivatedArea*. Each plot may be composed of several subplots and
 207 each subplot has two or more micro-plots. By defining *includes* object property
 208 as a transitive object property, we can easily navigate between locations. This
 209 object property also represents the multi-scale aspect of locations that is useful

210 for tracking the origin of a particular product.

211 3.2.2. *Ontology for Food Processing Experiments (OFPE)*

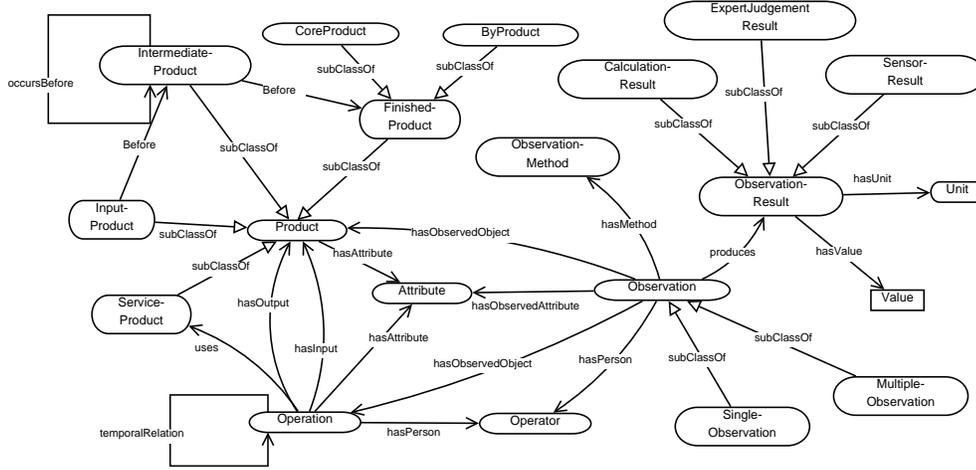


Figure 2: Core concepts and relations in OFPE.

212 OFPE (called Onto-FP in [30]) is an ontology dedicated to food processing
 213 experiments, where raw materials are transformed into final products. It
 214 includes different classes that represent products and activities during food trans-
 215 formation processes, which can be classified into four main concepts, i.e., *Prod-*
 216 *uct*, *Operation*, *Attribute*, and *Observation*. The core concepts and relations of
 217 OFPE are presented in Figure 2.

218 The *Product* concept represents different types of material existing during
 219 the food transformations. As shown in Figure 2, four subclasses under this
 220 class are *InputProduct*, *IntermediateProduct*, *FinishedProduct*, and *ServiceProd-*
 221 *uct*. The first three subclasses are representation of product stages which occur
 222 during a set of transformation processes. Starting with *InputProduct*, repre-
 223 senting any product harvested from farm that act as raw material, followed by
 224 *IntermediateProduct* that models semi or unfinished products during process
 225 flow, and terminated by *FinishedProduct* that represents end products or final

Table 2: Temporal relations between operations

Relations	Inverse	Examples from winemaking
Before(A,B)	After(B,A)	Crushing is performed after destemming
Meets(A,B)	MetBy(B,A)	Draining is started after maceration
Overlaps(A,B)	OverlappedBy(B,A)	Malolactic fermentation can be started before alcoholic fermentation is finished
Starts(A,B)	StartedBy(B,A)	Alcoholic fermentation starts when Maceration is started
Finishes(A,B)	FinishedBy(B,A)	Sulfitation finished malolactic fermentation
During(A,B)	Contains(B,A)	Alcoholic fermentation occurs during maceration
Equal(A,B)		Extraction of ethanol is started and finished at the same time as alcoholic fermentation

226 outputs of food transformation process. The *ServiceProduct* represents all ma-
 227 terials used by operations to transform particular product during process flow.
 228 The *Operation* class conceptualizes the knowledge related to the transformation
 229 activities. The concept of *Attribute* represents all features or qualities belonging
 230 to Product or Operation classes.

231 *Observation* is an abstract model of activity where an instance of Attribute is
 232 measured. This class has an important role in representing measurement values
 233 of attributes collected from different experiments. Observation can be a single
 234 observation (*SingleObservation*) that means one time only measurement or a set
 235 of observation (*MultipleObservation*) where multiple measurements of a partic-
 236 ular attribute (of product or operation) are needed. An instance of observation
 237 links to an instance of product or operation and to one or more instances of at-
 238 tribute through object property *hasObservedObject* and *hasObservedAttribute*.
 239 This observation instance also has method which is represented by *Observa-*
 240 *tionMethod* class and produces result depicted by *ObservationResult* that holds
 241 the values of measurement. In food processing the observation results come
 242 in various forms, such as values directly recorded by sensors, values from ex-

243 pert judgement or values from a particular calculation. To accommodate those
244 forms, this ontology provides three subclasses under *ObservationResult*, includ-
245 ing *SensorResult*, *ExpertJudgementResult*, and *CalculationResult* (see Figure 2).

246 Relations among main classes in this ontology can be grouped into two parts,
247 i.e., product transformation and temporal aspects of operations. Product trans-
248 formation can be described either by using a transitive object property *Before*
249 (or its inverse *After*) or object property *hasInput* and *hasOutput*. The *Before*
250 links between different products, in particular between classes *InputProduct*, *In-*
251 *termediateProduct*, and *FinishedProduct* (see Figure 2). To describe temporal
252 aspects of operations, this ontology uses the concepts defined in the Ontology of
253 Time proposed in [31]. Examples of use of these temporal relations are presented
254 in Table 2.

255 3.3. AEO and OFPE re-engineering for integration

256 After inspection, the two selected ontology resources presented in Section 3.2.1
257 and Section 3.2.2 have been considered valid by domain experts for their respec-
258 tive intended domains, i.e. biomass production and food processing. However,
259 when both are directly merged, the result is not entirely suitable to support the
260 objective of this work which focuses on agri-food experimental data integration.
261 Indeed, OR1 requirement is not completely fulfilled because the linkage between
262 production and transformation is not done. Moreover, AEO does not permit
263 to represent experimental observations, which is required in OR2. Last, spe-
264 cialization to vineyard (resp. winemaking) (OR3) is not present in AEO (resp.
265 OFPE) ontology.

266 Therefore, we used scenario 6 (Reusing, Merging and Re-engineering Onto-
267 logical Resources) of the NeOn methodology. Firstly, AEO and OFPE ontologies
268 have been linked. Secondly, they have been re-engineered to generate AFEO, a
269 new ontological network.

270 **OR1 fulfillment** AEO and OFPE cover two different scientific disciplines
271 which are closely related. AEO covers the ontology terms related to entities and
272 activities occurring during field agricultural experiments, starting at planting
273 and ending at harvesting. OFPE contains various products and operations as
274 well as their attributes. It can be used to build semantic relations representing
275 a set of food processing experiments where several products and operations are
276 interrelated in a specific order. Normally, a particular set is started by receiving
277 raw materials as an input (represented by *InputProduct* class in OFPE) and
278 transformed by some operations to become a processed food. Most raw materials
279 in food processing are agricultural products that come from the field. They are
280 the result of harvesting activity (represented by the *Harvesting* class in AEO).
281 Based on that description, the object property *hasOutput*, part of OFPE, can
282 be used to link between *Harvesting* class part of the AEO, and *InputProduct*
283 part of OFPE. More formally, the domain of the object property *hasOutput*,
284 which is the *Operation* class in OFPE is enlarged to the alternative *Harvesting*
285 class of AEO. *Berry* and *Bunch*, which correspond to the *InputProduct*, are
286 considered as equivalent classes in AEO and OFPE (see Table 3). Moreover,
287 the object property *hasOutput* is defined with the cardinality one to many,
288 because in some cases one or more instances of *InputProduct* come from the same
289 instance of *Harvesting*. As *AgriActivity* and *Operation* can be considered as
290 equivalent classes in AEO and OFPE (see in Table 3), *Before* or more generally
291 all temporal relations presented in table 2, part of OFPE, can be used to link
292 between *AgriActivity* class, part of the AEO, and *Operation*, part of OFPE.
293 More formally, the domain of the object property *Before* or more generally all
294 temporal relations presented in table 2, which is the *Operation* class in OFPE
295 is enlarged to the alternative *AgriActivity* class of AEO. By using these formal
296 extended semantic relations, the ontology linking between AEO and OFPE can

297 be built and OR1 requirement is now fulfilled. Figure 4 shows with an example
 298 how these extended semantic relations are applied.

Table 3: Class mapping between AEO and OFPE.

AEO class	OFPE class	Mapping
Berry	Berry	owl:equivalentClass
Bunch	Bunch	owl:equivalentClass
AgriActivity	Operation	owl:equivalentClass

299 **OR2 fulfillment** The next step after linking AEO and OFPE is re-engineering
 300 this new ontology network. Indeed, as presented in Section 3.2.1, AEO does not
 301 provide important concepts and properties with regard to observations, mea-
 302 surement data representation, as well as observed attributes. Contrary, the
 303 OFPE contains a specific part that is dedicated to accommodate observation
 304 activities. In order to fulfill OR2 requirement, we re-engineered the new ontol-
 305 ogy network by the following steps which implement scenario 8 (Restructuring
 306 ontological resources). Firstly, we re-used the semantic relation *hasAttribute*
 307 (existing in OFPE) to link the *ObservedAgriEntity* and *AgriActivity* classes in
 308 AEO to the *Attribute* class. Formally, the domain of the object property *hasAt-*
 309 *tribute*, which is the *Product* class in OFPE is enlarged to the *ObservedAgriEn-*
 310 *tity* and *AgriActivity* classes of AEO. Secondly, we re-used semantic relations
 311 regarding the observation which exist in OFPE. In OFPE, the *Observation* class
 312 links to two classes, i.e. *Product* and *Operation* by using the semantic relation
 313 *hasObservedObject* (see Figure 2). The *ObservedAgriEntity* and *AgriActivity*
 314 classes in AEO have a similar role to *Product* and *Operation* which represent
 315 objects of observation in OFPE. Thus, formally, we enlarged the range of the
 316 *hasObservedObject* object property to the *ObservedAgriEntity* and *AgriActivity*
 317 in AEO.

318 **OR3 fulfillment** As stated in OR3, AFEO has to be applied to a specific
 319 domain, in this paper, viticulture and winemaking experimentation. However,

320 from the inspection of Section 3.2.1 and Section 3.2.2, it can be seen that both
321 ontology resources (AEO and OFPE) do not include any specific terms of viti-
322 culture and winemaking experiments. Therefore, AFEO needs to be restruc-
323 tured. In this case, the scenarios 2 (Reusing and re-engineering non-ontological
324 resources) and 8 (Restructuring ontological resources) of the NeOn methodol-
325 ogy were performed to get a new version of AFEO. The list of specific terms
326 related to viticulture and winemaking was provided by domain experts. These
327 terms were formalized as new concepts to specialize AFEO (Ontology special-
328 ization activity of scenario 8). AFEO preserves all the classes from AEO (see
329 Figure 1) which provides generic classes that mostly also exist in viticulture.
330 Some specific classes have been added, such as *CanopyManagement* (sub-class
331 of *AgriActivity*), *GreenHarvesting* (sub-class of *Pruning*), *Vineyard* (sub-class
332 of *CultivatedArea*), *GrapeVariety* (sub-class of *Genotype*) and *Grapevine* (sub-
333 class of *Plant*). Figure 3 shows the new required specific classes under the
334 *Product* and the *Operation* classes for winemaking.

335 To illustrate the final structure of AFEO³, we present a part of the whole
336 ontology in Figure 4. This diagram contains different viticulture entity and
337 activity classes, winemaking specific classes of product and operation, and their
338 semantic relations.

339 Another interesting point illustrated in Figure 4 refers to the practical ap-
340 plication of complex temporal relations between operations. For example the
341 *Crushing* is performed before the *AlcoholicFermentation*, the *PumpingOver* has
342 to be done during the *Maceration*, etc.. By using these semantic relations, a
343 particular sequence or itinerary of operations (experiments) can be investigated.
344 The ability of finding a specific sequence of products and operations as well as
345 linking to agricultural activities and entities is a strong point of AFEO ontology

³<http://agroportal.lirmm.fr/ontologies/AFEO>

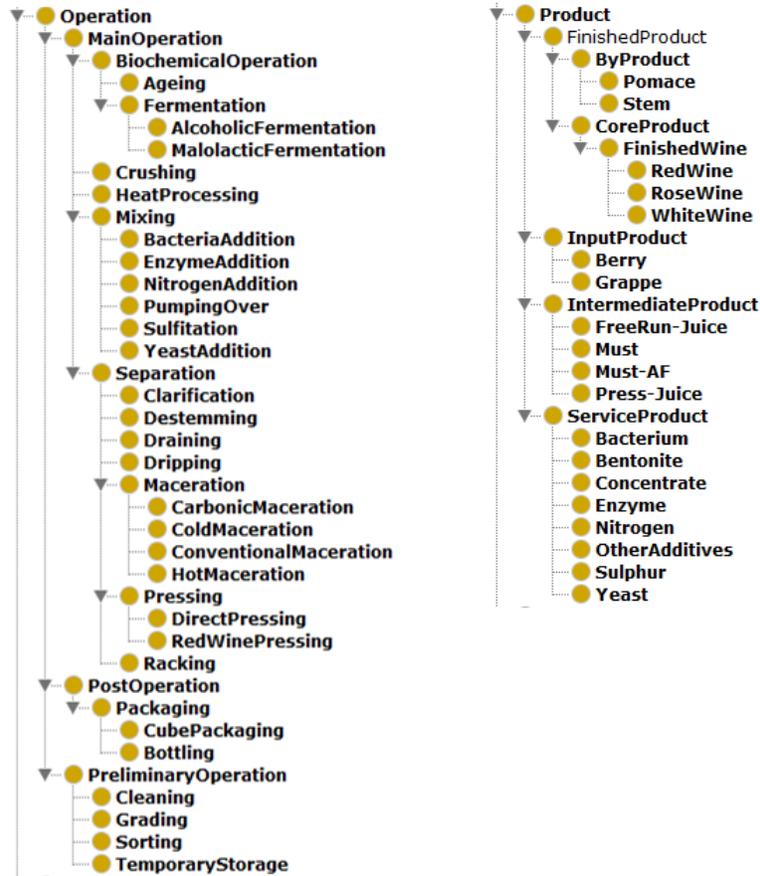


Figure 3: Operation and product specialization of the AFEO for winemaking experiment.

346 network because it gives a reliable way to build a connection between observa-
 347 tional data belonging to interrelated experiments. AFEO ⁴ (resp. AEO ⁵ and
 348 OFPE ⁶) ontology is available on AgroPortal, derived from BioPortal [32] for
 349 agronomical ontologies.

⁴<http://agroportal.lirmm.fr/ontologies/AFEO>

⁵<http://agroportal.lirmm.fr/ontologies/AEO>

⁶<http://agroportal.lirmm.fr/ontologies/OFPE>

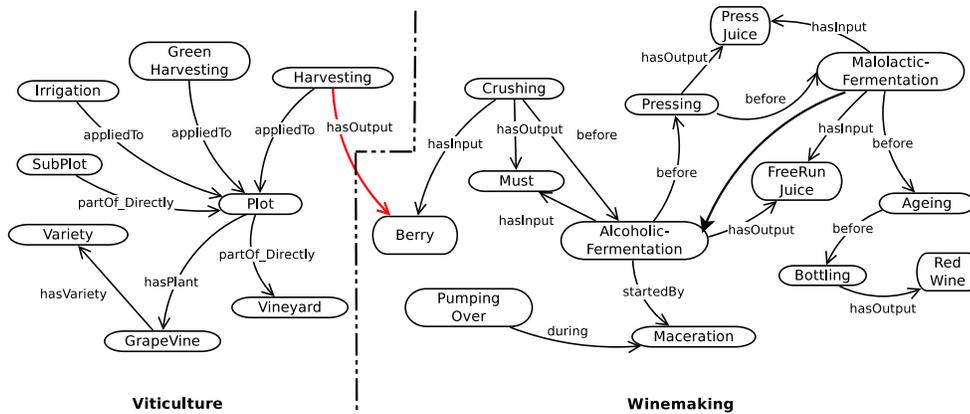


Figure 4: A part of the AFEO that represents viticulture and winemaking integration.

350 4. Ontology population with viticulture and winemaking experimen- 351 tal data

352 In a domain specific ontology development stage, an ontology instantiation
353 (population) is an important step. The main task is to semantically annotate all
354 related resources based on the proposed ontology. AFEO, result from Section 3,
355 can be seen as an agri-food experiment knowledge layer that acts as a container
356 for viticulture and winemaking experimental data integration. From a practical
357 point of view, this ontology network needs to be instantiated with actual exper-
358 imental data so that specific data queries can be performed to support further
359 statistical analysis. This section presents how AFEO has been instantiated in
360 order to integrate the experimental data from various stages of agri-food exper-
361 iments. The first part describes two different data sources used in this work and
362 the second part explains the principles of the ontology population step.

363 4.1. Data sources

364 Data sources used for this work can be divided into two groups, i.e., viticul-
365 ture and winemaking experimental data. Both are temporal data, however they
366 are different in terms of structure and storage formats.

367 The viticulture experimental data were collected during several years of viti-
368 cultural experiments from different vineyards in the south of France. These
369 data contain information about vineyards, plots, sub-plots, grapevines, different
370 treatments of experiment (for example irrigation, non irrigation, green harvest-
371 ing, non-green harvesting, etc.), and a huge number of observations regarding
372 the grape characteristics during the growing season. They are stored in a single
373 relational database linked to *Silex-VitiOeno Pilotype*, a web application that
374 manages viticulture experimental data.

375 The winemaking experimental data contain information about different stages
376 of the winemaking process, different wine products as well as a big amount of
377 observational data about operations and products characteristics during process
378 flow. These data were collected annually from the *Unité Expérimentale de Pech*
379 *Rouge*, France, where the winemaking experiments were conducted. Unlike the
380 viticulture experimental data, these data are recorded in the form of Microsoft
381 Excel files. To the current date, more than 500 Microsoft Excel files have been
382 collected. These files can be classified into two groups: i.e,

- 383 • a group that represents different operations during the winemaking pro-
384 cess. Each file consists of a single sheet that contains a table of operations
385 used during a set of winemaking experiments, started from harvesting to
386 bottling. The table also contains the attributes of each operation;
- 387 • a group that records observational data concerning the different product
388 features. Each file consists of three sheets, where each sheet represents
389 observational results of some attributes for a particular product stage,
390 such as grape, must, must after alcoholic fermentation, and finished wine.

391 4.2. *Ontology instantiation process*

392 Both data sources have to be transformed into uniform format based on
393 AFEO ontology network. Consequently, the Resource Description Framework

394 (RDF) format has been chosen to represent these data. The RDF is a standard
 395 model for data interchange and metadata processing [33]. It has features that
 396 facilitate data linking even if the underlying schema differ. The RDF can be
 397 seen as a graph data model that uses URIs to name two nodes as well as the
 398 relationship between them. Due to the different source data formats, we devel-
 399 oped two specific scripts using the Python language as illustrated in Figure 5.
 400 The first script creates instances by performing some queries to the viticulture
 401 database and transforming them to RDF format. The second script is special-
 402 ized for making instances from the Microsoft Excel winemaking experimental
 403 data files. Both of them were developed guided by the AFEO ontology net-
 404 work. RDF data are stored in a triplestore, a specific database for storing and
 405 retrieving RDF triples through semantic queries expressed in SPARQL.

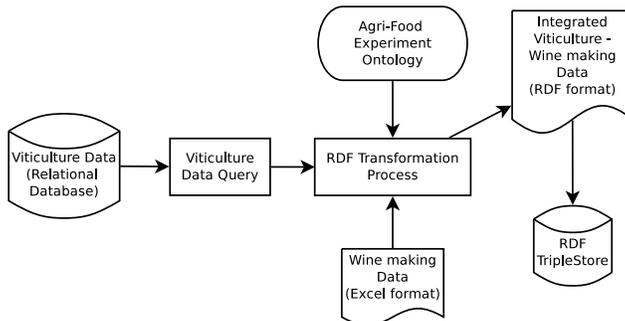


Figure 5: Data population processing steps.

406 5. Results and discussion

407 The RDF data produced in Section 4.2 are viticulture-winemaking integrated
 408 data that contain objects and activities/operations along with observational re-
 409 sults from various experiments. These data can be used in many ways by query-
 410 ing them according to the user requirements. This section presents two examples
 411 on how this integrated data can help viticulture and winemaking researchers to

412 find some related data prior a statistical analysis. The first part describes a
413 practical use related to wine traceability and the second part explains how to
414 extract and analyze interrelated observational data between viticulture practices
415 and wine qualities.

416 *5.1. Wine traceability*

417 Wine is a food product whose value is generally determined by three groups
418 of characteristics, i.e., appearance, flavour, and aroma. In the recent years,
419 wine consumers are more and more oriented to consider detailed information
420 about those characteristics as well as the overall process from the grape to the
421 bottle [34]. The information is used to confirm the wine identity (authenticity)
422 and to ensure it is produced transparently in order to avoid fraud and toxico-
423 logical issues [35]. The viticulture-winemaking integrated data generated from
424 Section 4.2 can be queried in order to get such traceability information, giving
425 valuable knowledge about the entire process from viticulture practices through
426 selected winemaking operations, until finished product delivery.

427 By using the RDF integrated data, specific queries allow to trace products
428 or operations during various experiments. It can be done backwardly, from
429 finished wine as a final product to the plot or vineyard where the grapevines
430 are planted, or forwardly. The following lines is an example of SPARQL query
431 to trace the origin of wine products.

432 **Query 1.**

```
433 SELECT ?w ?t ?l ?nv ?na
434 WHERE
435 {
436   ?o ofpe:After ?h .
437   ?w rdf:type ofpe:FinishedWine .
```

```

438 ?o ofpe:hasOutput ?w
439 ?h aeo:appliedTo ?l
440 ?l aeo:included ?p
441 ?p rdf:type aeo:Plot
442 ?p aeo:hasVariety ?v
443 ?v rdfs:label ?nv
444 ?l aeo:included ?a
445 ?a rdf:type aeo:Vineyard
446 ?a rdfs:label ?na
447 }

```

W (FinishedWine)	T (BerryGrape)	L (SubPlot)	NV (GrapeVariety)	NA (Vineyard)
wt_12001	g_12001	PR-Cha-i1	Chardonnay	Pech Rouge
wn_12001	g_12001	PR-Cha-i1	Chardonnay	Pech Rouge
wn_12002	g_12002	PR-Cha-i0	Chardonnay	Pech Rouge
wt_12002	g_12002	PR-Cha-i0	Chardonnay	Pech Rouge
wt_12003	g_12003	RIE-Gre-i0	Grenache	Rieux
wn_12003	g_12003	RIE-Gre-i0	Grenache	Rieux
wn_12021	g_12021	StSAU-Cha-i1	Chardonnay	Saint Sauveur
wt_12021	g_12021	StSAU-Cha-i1	Chardonnay	Saint Sauveur
wn_12020	g_12020	StSAU-Cha-i0	Chardonnay	Saint Sauveur

Figure 6: List of finished wine instances and their origin

448 Figure 6 shows a screen shot of the query result which lists instances of fin-
449 ished wine, their input products, sub-plots and vineyards where the grapes are
450 planted, and their grape varieties. In Query 1, the *After* object property is
451 used in order to trace all existing products during winemaking process. By
452 using the *After*, which is defined as a transitive property, this SPARQL query
453 performs an inference to determine link between *BerryGrape* instance (t) as an
454 input product and *FinishedWine* instance (w) as the final product, whatever the
455 number of intermediate products and associated operations. Figure 6 highlights
456 some information about wine traceability that might help researchers to know
457 global information about the origin of finished wine products. For instance,

458 we can see that, from the same berry grape lot, can be produced two different
 459 finished wine products: wt_12001 and wn_12001 are finished wine instances that
 460 have the same input product, i.e., g_12001. This indicates that probably there
 461 were different treatments during the winemaking process, that may affect the
 462 characteristics of the final product.

463 *5.2. Influence of viticulture practices on grape and wine qualities*

464 As said above, wine quality can be analysed by three groups of characteris-
 465 tics. Each group can be further detailed by various attributes. For example, the
 466 appearance is determined by the color attribute along with other visual features
 467 such as clarity and fluidity, while the wine flavour has some basic attributes,
 468 such as sweetness, acidity, bitterness, fruit flavour, etc. These attributes are
 469 influenced by various interrelated factors, both viticulture practices (e.g., grape
 470 variety, location, vintage, etc.) and winemaking selected operations (e.g., crush-
 471 ing method, maceration, pressing, yeasts added, etc.).

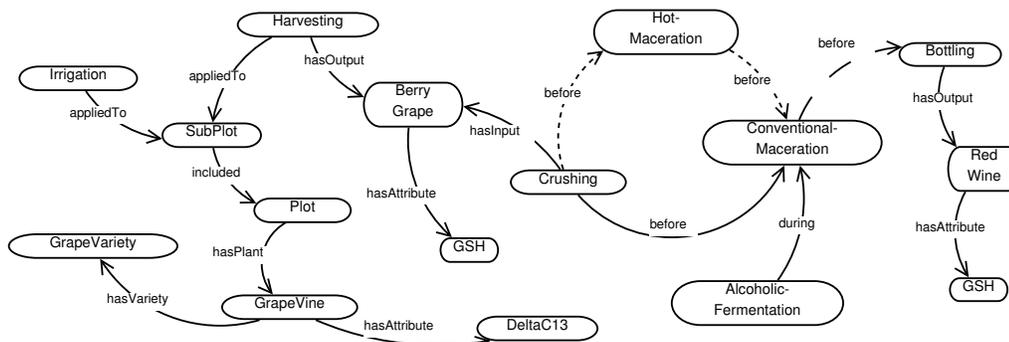


Figure 7: Semantic relations linking GSH concentration in grape and red wine.

472 To illustrate the interest of viticulture-winemaking integrated data, we now
 473 present one set of experiments that has been conducted in the *Pilotype* project,
 474 funded by OSEO innovation and the Languedoc-Roussillon regional council.
 475 This project includes multi-site experiments located in the south of France. The

476 same experimental design was set up in seven sites across the Languedoc Rous-
477 sillon region in order to test for the effects of vine stress status and winemaking
478 protocol on grape potential and wine quality in contrasted environmental con-
479 ditions. We discuss here a subset of these experiments. Three grape varieties
480 are being studied, i.e. Merlot, Syrah and Cabernet Sauvignon; and two different
481 winemaking methods, i.e., with an innovative hot pre-fermentation maceration
482 and without it (classical method). In the experimental plots, the wine water
483 status has been monitored by different means: on-line sap flow sensors, pre-
484 dawn leaf water potential and DeltaC13 at harvest time. The last one, which
485 is a global indicator of the water stress experienced by the vine, will be used in
486 the following. Many quality parameters resulting from physico-chemical analy-
487 ses are available to assess grape composition at harvest time, must composition
488 and finished wine composition. Among them, let us take the example of the
489 glutathione (GSH) concentrations in wine and berry grape. GSH, a natural tri-
490 peptide found in grapes and wine, is a powerful antioxidant that protects wines
491 from oxidation and loss of aroma or flavor. Glutathione levels fluctuate during
492 production, as the compound can be absorbed by yeast and then released after
493 fermentation. If final GSH levels are low in wines, they will experience faster
494 loss of fresh varietal and fruity aromas, and poor ageing potential. By using
495 the AFEO, this experiment can be represented semantically as visualized in
496 Figure 7.

497 In order to perform a statistical analysis, some data sets need to be queried
498 from the viticulture-winemaking integrated data, including all the *RedWine*
499 instances and their corresponding *BerryGrape* instances along with their GSH
500 values, all the *Subplot* and *Plot* instances as the wines origin, all the correspond-
501 ing *GrapeVariety* instances, and all itinerary types which are used to identify
502 what winemaking methods are used. Using the SPARQL query statements,

503 data can be extracted from viticulture-winemaking integrated data. Based on
504 the available data which cover two years experiments (2012 and 2013), the query
505 provides the results as follow: there are a total of 40 instances of *RedWine* which
506 are produced from 20 instances of the *BerryGrape*, 20 instances of the *Subplot*
507 and 9 instances of the *Plot* as the origin of the *BerryGrape* instances. The
508 *RedWine* instances are divided equally into two groups, 20 instances from the
509 hot pre-fermentation maceration methods and the rest come from the classical
510 method.

511 The statistical study aims to determine if the winemaking protocol has a
512 significant influence on the GSH wine concentration. As data do not follow
513 a Gaussian distribution (as confirmed by a Shapiro test), the Wilcoxon test
514 on paired samples is run. It highlights a significant (p-value <0.05) difference
515 in GSH concentrations depending on the winemaking protocol: The hot pre-
516 fermentation maceration influences the wine GSH concentration and increases
517 it.

518 A graphical analysis is then done to visually explore, by taking advantage of
519 the links between viticulture and wine data, if the vine water status could have
520 an impact on that influence. Figure 8 shows, for each of the three varieties, on
521 the abscissa the grape GSH concentration and on the ordinate the corresponding
522 wine GSH concentration. Circles correspond to the year 2012, and squares to
523 the year 2013. The classical winemaking protocol is plotted in red, and the hot
524 pre-fermentation maceration one in blue. The size of the symbols is proportional
525 to the Delta C13 indicator: the higher Delta C13, the bigger the symbol and the
526 less the vine was exposed to water stress. Plots visually confirm the increase of
527 GSH in wine, for a given GSH in grapes, with the hot pre-maceration protocol,
528 but they do not show any influence of the vine water status.

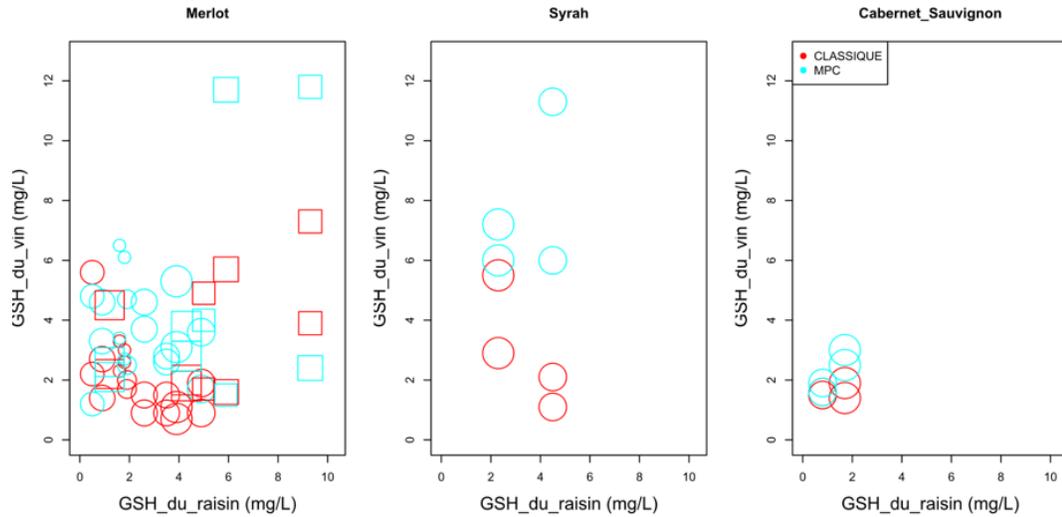


Figure 8: Plots of GSH concentration in red wine versus GSH concentration in grape.

529 6. Conclusion

530 This paper presents an ontology-based approach for experimental scientific
 531 data integration across complementary sub-domains, i.e., agricultural practices
 532 and food processing, with an application to viticulture and winemaking pro-
 533 cess. The two main steps in this approach are i) to develop an ontology network
 534 and ii) to populate the ontology with actual experimental data from differ-
 535 ent sources. The ontology network -Agri-Food Experiment Ontology (AFE0)-
 536 was developed based on two existing ontology resources, i.e., AEO (Ontology
 537 for Agriculture Experiment) and OFPE (Ontology for Food Processing Experi-
 538 ment). It contains 136 concepts which covers various viticulture practices, and
 539 winemaking products and operations. AFE0 was used to guide data integra-
 540 tion from two different data sources, i.e., viticulture experimental data which
 541 are stored as relational database and winemaking experimental data which are
 542 stored in Microsoft Excel files.

543 Results show the potential uses of the AFE0 along with viticulture-winemaking

544 integrated data to provide linked data to be used by researchers. Two practical
545 uses are presented, i.e. wine traceability and the influence of grape varieties
546 and different winemaking methods on GSH concentration. They give an idea
547 of how data integration can support extended research questions which require
548 data from different parts the Agri-food chain.

549 The development steps presented in this paper can also be viewed as an
550 effort to decrease the gap between scientific disciplines, by allowing researchers
551 from different disciplines to formulate their knowledge in a formal ontological
552 form, in order to share it and to build more comprehensive and collaborative
553 scientific researches.

554 AFEO focuses on viticulture and winemaking objects and experimental ac-
555 tivities. However, as indicated in Section 5 the weather and climate has signifi-
556 cant influence on grape quality. Therefore in the future, aligning AFEO with an
557 ontology that represents knowledge from the meteorological domain will allow
558 a better analysis of viticulture and winemaking experimental results. Another
559 interesting perspective is to specialize AFEO to other food products that require
560 linkage from agriculture practices to food transformation process.

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