Modelling and Linking Transformations in EPCIS Governing Supply Chain Business Processes

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Abstract. Supply chains comprise of complex processes spanning across multiple trading partners. The various operations involved generate large number of events that need to be integrated in order to enable internal and external traceability. Further, provenance of artifacts and agents involved in the supply chain operations is now a key traceability requirement. In this paper we propose a Semantic web/Linked data powered framework for the event based representation and analysis of supply chain activities governed by the EPCIS specification. We specifically show how a new EPCIS event type called "Transformation Event" can be semantically annotated using EEM - The EPCIS Event Model to generate linked data, that can be exploited for internal event based traceability in supply chains involving transformation of products. For integrating provenance with traceability, we propose a mapping from EEM to PROV-O. We exemplify our approach on an abstraction of the production processes that are part of the wine supply chain.

Keywords: Supply chains, EPCIS, Transformation events, ontologies, Semantic Web, Linked data.

1 Introduction and Motivation

Data integration in supply chains for the purposes of tracking, tracing and transparency is increasingly becoming an important challenge. Barcodes and more recently RFID tags have provided initial solutions to this challenge by recording the traces of product movement as specific occurrences of "events". Some examples of supply chain events include: receiving or shipping of goods, aggregating small units into large consignments, storing goods on a specific shelf in a specific store at a specific business location, transactions carried out on a specific quantity of goods and more recently production of new artifacts from existing ones via the process of transformation.

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The Electronic Product Code Information Services (EPCIS)[1] and the Core Business Vocabulary[2], are event oriented specifications prescribed by GS1[3] for enabling traceability [3] in supply chains. The data associated with the business context of scanning a barcode or RFID tag is encapsulated within the abstraction of an "EPCIS event".

Recently the EPCIS specification has been revised and a new event type "Transformation Event" has been introduced. Transformation events capture information that are part of an event or a series of events in which one or more physical objects are consumed as inputs to produce one or more outputs. Transformation events are mostly likely to be recorded and utilised in a production/manufacturing scenario where internal operations need to be tracked to guarantee product safety, increase consumer confidence and improve the overall traceability of the supply chain.

Agri-food is one of the most important sectors which could benefit from enabling transformation event based internal traceability. Transformation events when recorded using self describing metadata descriptors in a format that enables sharing and linking of information, could provide valuable insights while investigating and identifying causes of food outbreaks and epidemics. Event based traceability information made available as linked data could seamlessly enable tracing back from finished goods to processing facilities, ingredients and even further back to the crop growing and cattle harvesting conditions in the farm.

In this paper we present a framework for the formal modelling and representation of transformation events in supply chain business processes. We extend EEM(EPCIS Event Model)[4] - our domain model for representing supply chain, EPCIS events on the Web of data to include transformation events As provenance is a crucial aspect of traceability, we present a mapping of key entities in EEM and its supporting vocabulary, CBVVocab[5] into entities from the PROV-O[6] ontology for provenance interchange on the Web. Finally we show how the integrated datasets can be interrogated by exploiting inferences over expressive characteristics of relationships asserted between event instances and SPARQL 1.1 features such as property chaining. Our exemplifying scenario is an abstraction of the steps involved in the production of wines within the wine supply chain.

The paper is structured as follows: Section 2 presents our motivating scenario. Section 3 provides a brief background on the conceptual model behind EEM and presents related work. Section 4 illustrates the modelling of transformation events. Section 5 presents a mapping of EEM entities to PROV-O. Section 6 presents our traceability architecture and formalisation of the queries for our motivating scenario. Section 7 presents conclusions.

[1] `http://www.gs1.org/gsmp/kc/epcglobal/epcis`
[2] `http://www.gs1.org/gsmp/kc/epcglobal/cbv`
[3] `http://www.gs1.org/`
[4] `http://purl.org/eem#`
[5] `http://purl.org/cbv#`
[6] `http://www.w3.org/ns/prov-o`

2 Data Integration in the Wine Supply Chain

We present a scenario from the processing stages of wines in a winery, which is an integral part of the wine supply chain. As illustrated in Figure 1, the process of transforming grapes into bottled wines involves the following main operations: *Grapes pressing*, *Musts treatment*, *Fermentation*, *Blending* and *Bottling*.

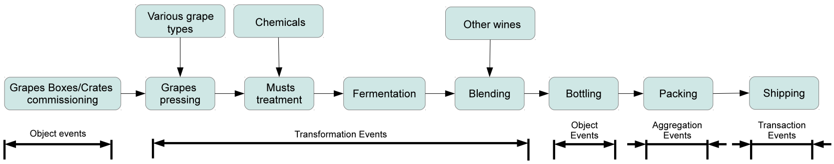

Fig. 1. EPCIS events generated during the wine processing stages

At each of these stages, event based data (timing, location and business context) recorded for the transformation events, have to be integrated with process related information such as data about the inputs and machinery used in the processing, environmental variables such as temperature and humidity, data about the tanks used for the storage of intermediate products, quantities and measurements of the inputs consumed and outputs produced. Besides linking to the data from the transformation processes, data on bottled wine also needs to be linked to the meteorological and botanical information on the grapes used in its production. Some data is entirely internal to the winery such as the temperature of a given vat at a given time, other data is external such as that provided by laboratory tests or data about the soil conditions of vineyards, not all of which may owned by a particular winery.

In order to derive traceability information, the integrated datasets need to be appropriately reasoned about and interrogated against the traceability metrics. While, there is a possibility that some information, e..g, provenance of grapes used in the production could be made available without querying the interlinked knowledge base, for realising event based traceability, the queries need to be formulated such that the information retrieved is directly associated to an EPCIS event, i.e., the fact that specific boxes/crates of grapes were actually used in the production of wines has to be derived by querying for transformation events that utilised the grapes in those boxes/crates as inputs and following the typed links to extract the information from the event instances.

Here we provide some examples of informal queries for deriving traceability information from the integrated datasets at the winery:

Q1 **Tracking Ingredients:** What were the inputs consumed during processing in the batch of wine bottles shipped on date X ?

Q2 **Tracking Provenance:** Which winery staff were present at the winery when the wine bottles were aggregated in cases with identifiers X and Y?

Q3 **Tracking External Data:** Retrieve the average values for the growth temperature for grapes used in the production of a batch of wine to be shipped to Destination D on date X.

3 Background and Related Work

An Electronic Product Code (EPC) [7] is a universal identifier that gives a unique, serialised identity to a specific physical object. As the RFID-EPC tagged object moves through the supply chain, EPCIS implementing applications deployed at key locations record data against the EPC of the object.

EEM is an OWL 2 DL ontology for modelling EPCIS events. EEM conceptualises various primitives of an EPCIS event that need to be asserted for the purposes of traceability in supply chains. A companion standard to EPCIS is the Core Business Vocabulary(CBV) standard. The CBV standard supplements the EPCIS framework by defining vocabularies and identifiers that may populate the EPCIS data model. *CBVVocab*[8] is an OWL ontology that defines entities corresponding to the identifiers in CBV. Development of both the ontologies was informed by a thorough review of the EPCIS and the CBV specifications and extensive discussions with trading partners implementing the specification. The modelling decisions [11] behind the conceptual entities in EEM highlight the EPCIS abstractions included in the ontology. The EEM ontology structure and its alignment with

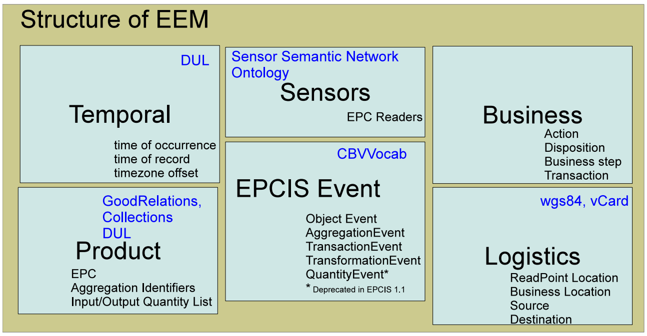

Fig. 2. Structure of EEM and its alignment with external ontologies (noted in blue coloured text)

various external ontologies is illustrated in Figure 2. The ontology is composed of modules that define various perspectives on EPCIS. The *Temporal* module captures timing properties associated with an EPCIS event. It is aligned with temporal properties in DOLCE+DnS Ultralite (DUL)[9]. Entities defining the

[7] http://www.gs1.org/gsmp/kc/epcglobal/tds/tds_1_6-RatifiedStd-20110922.pdf
[8] http://purl.org/cbv#
[9] http://ontologydesignpatterns.org/ont/dul/DUL.owl

EPC, aggregation of EPCs and quantity lists for transformation events are part of the *Product* module. The GoodRelations[10] ontology is exploited here for capturing concepts such as an `Individual` Product or a lot (collection) of items, `SomeItems` of a single type. Information about the business context associated with an EPCIS event is encoded using the entities and relationships defined in the *Business* module. RFID readers and sensors are defined in the *Sensor* module. The definitions here are aligned with the SSN[11] ontology.

Some of the main conceptual entities in EEM are illustrated in Figure 3. EEM defines a generic event class and four specialised event classes. `EPCISEvent` is the "abstract" root or super class of all events. `ObjectEvent`, `AggregationEvent`, `QuantityEvent`[12], `TransactionEvent` and `TransformationEvent` are specialised classes of `EPCISEvent`. For further details on EEM and its applications in real world scenarios, the interested reader is referred to [10, 11].

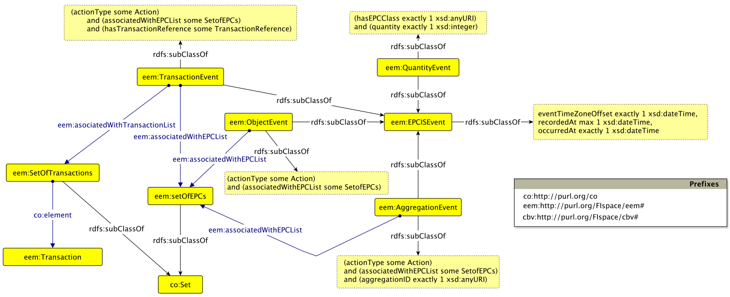

Fig. 3. EPCIS event classes as represented in EEM

Semantic Web research has widely explored the notion and representation of events as ontological models. A plethora of interpretations can be derived from and assigned to the term "Event" depending on the contextual domain and the temporal dimension of its occurrence. The Event ontology[13] emerged from the need of representing knowledge about events related to music. The Linking Open Descriptions of Events (LODE) [14] [9] ontology is similar in spirit to the EEM in that it focuses on the four factual aspects of an event. The Simple Event Model (SEM)[15], with weak semantics and requirements drawn from the domain of history and maritime security and safety is presented in [13]. In contrast to some of the general purpose event models, EEM is domain specific. For practical purposes, the data model underlying EEM, restricts the entities, relationship and attributes to a subset of the EPCIS specification, albeit a large subset.

[10] `http://purl.org/goodrelations/v1`
[11] `http://purl.oclc.org/NET/ssnx/ssn`
[12] Deprecated in the revised version of EPCIS
[13] `http://motools.sourceforge.net/event/event.html`
[14] `http://linkedevents.org/ontology/`
[15] `http://semanticweb.cs.vu.nl/2009/11/sem/`

Tracking and tracing of food products through the supply chain has become a major issue both for research and practice in the industry. Thompson et al. provide an excellent overview of the area, even if focussed on seafood, and discuss the potential of a number of technologies [12]. One of the important points is that because tracking and tracing is mandated by law, legal frameworks in one region of the world, say the EU, impact food producers all over the world because of the interlinked nature of food systems. Fritz and Schiefer provide a more recent perspective on the importance and complexity of tracking and tracing systems [4] and consider a number of technologies including RFID and what role they can play. Ruiz-Garcia et al. [8] present a software architecture for managing tracking and tracing in a web-based system. Their approach makes use of OGC standards rather than GS1 standards.

The use of RFID technology in tracking and tracing in agri-food has its origins in livestock tracking (since the 1980s). Much recent work has explored how RFID tags can be used in various agri-food sectors such as the cold chain [1], halal food [2], and perishable foods [5,6]. An analysis of the use of RFIDs and EPCIS on food tracablity is provided in [7]. However, despite the widespread interest and concern, little work has focused on utilising Semantic Web standards and linked data technologies for the representation of supply chain events and traceability in the agri-food sector.

4 Extending EEM with Transformation Events

Transformation events capture information that is part of an event or a series of events in which one or more physical objects are consumed as inputs to produce one or more outputs.

The informal semantics of transformation events as described in the revised EPCIS specification are outlined below:

- A *TransformationEvent* captures information about an event in which one or more physical or digital objects are fully or partially consumed as inputs and one or more objects are produced as outputs.
- Input and output objects are identified through their serialised EPCs and/or quantity lists that define the quantities of the objects, the EPCClass (lot or batch identifiers) and the units of measurements.
- Some transformation business processes take place over a long period of time, and so it is more appropriate to represent them as a series of associated EPCIS events.
- The revised EPCIS specification defines a special attribute called "TransformationID" that provides the association between related transformation events. It is included as a common attribute among the events that are involved in realising a collective operation.
- When a specific transformation event is associated with other transformation events, the inputs to any of those events may have contributed in some way to each of the outputs in any of those same events. In this scenario, it is not mandatory to provide inputs and outputs for all the participating events.

– However, if a transformation event is not associated with any other transformation event, then it is mandatory for the event to define either the input EPCs or the input quantity list and the output EPCs or the output quantity list.

A `TransformationEvent` is an `EPCISEvent`. Input and Outputs EPCs lists for transformation events are represented as `SetOFEPCs`, specialising from `Set`[16].

Quantity attributes for input and output objects are represented as `QuantityElement` that specialises from `item`[17]. It has an `EPCClass` identifier and specifies a quantity along with its unit of measurement. We propose the use of vocabularies such as QUDT[18] for defining quantities and units of measurement that form a `QuantityElement`.

`InputQuantityList` and `OutputQuantityList` are composed of `QuantityElement` individuals. The EPCIS specification does not impose any ordering constraints on the elements in the list. We therefore define the lists as specialising from `bag`[19] rather than a list[20].

A `TransformationEvent` may be associated with other transformation events. While TransformationID is prescribed as the relating attribute, we believe that in the context of ontologies as data models, relationships between resources are the key enablers of data integration and therefore instead of including the "TransformationID" as a literal in the definition of the event, we introduce a special predicate that enables the association between events. We define an object property `associatedWithTransformtionEvent`, characterised as symmetric and transitive, that defines the relationship between transformation events.

We incorporate the constrains on the inputs and outputs as highlighted above and assert the following definition of a `TransformationEvent`:

```
Class: TransformationEvent
SubClassOf:
((EPCISEvent
 and (associatedWithTransformationEvent only TransformationEvent)
 and ((associatedWithInputEPCList only SetofEPCs)
 or   (hasInputQuantityList only InputQuantityList))
 or ((associatedWithOutputEPCList only SetofEPCs)
 or   (hasOutputQuantityList only OutputQuantityList)))
 or (EPCISEvent
 and (((associatedWithInputEPCList some SetofEPCs)
 or  (hasInputQuantityList some InputQuantityList))
 and ((associatedWithOutputEPCList some SetofEPCs)
 or   (hasOutputQuantityList some OutputQuantityList)))))
```

16 http://purl.org/co/
17 http://purl.org/co/item#
18 http://qudt.org/1.1/vocab/dimensionalunit
19 http://purl.org/co/bag#
20 http://purl.org/co/list#

5 Augmenting Event Descriptions with Provenance

Provenance in the wine supply chain is of critical importance. While many of the entities in EEM implicitly provide provenance related information about an event, mapping these entities to a dedicated provenance vocabulary such as PROV-O[21], provides an abstraction layer that facilitates retrieving information using a vocabulary specifically defined for that purpose.

Table 1 illustrates the mapping[22] between the key concepts in EEM and CBVVocab to entities in PROV-O.

Table 1. Mapping EEM and CBVVocab to PROVO-O

EEM entity	mapping	PROV-O concept
`EPCISEvent`	`rdfs:subClassOf`	Entity
`EPC`	`rdfs:subClassOf`	Entity
`EPCReader`	`rdfs:subClassOf`	Agent
`Action`	`rdfs:subClassOf`	Activity
`ReadPointLocation`	`rdfs:subClassOf`	Location
`recordedByReader`	`rdfs:subPropertyOf`	wasAttributedTo
`eventOccurredAt`	`rdfs:subPropertyOf`	generatedAtTime
`hasReadPointLocation`	`rdfs:subPropertyOf`	atLocation
CBV entity	mapping	PROV-O concept
`BusinessStep`	`rdfs:subClassOf`	Activity

Mapping `Action` to `Activity` associates it with a PROV `Agent` through the `wasAssociatedWith` relationship. This provides us with the capability to assert facts about entities involved in carrying out an `Action`, recorded as part of an event description. The practical implication of this mapping wrt. the scenario outlined in Section 2 is that winery staff involved in carrying out the processing of wines can be linked to the events themselves. This information could be extremely useful in investigating claims of counterfeit wines being introduced in the supply chain.

6 Linking Transformation Events

Figure 4 illustrates our framework for generating linked data from legacy data sources that are part of the information system deployed at the winery.

From RDB to RDF for Events in the Winery

We acquired data from an RFID winery pilot currently running in Spain. The datasets were originally stored in a MySQL relational database. As the original

[21] `http://www.w3.org/ns/prov-o`
[22] `http://fispace.aston.ac.uk/ontologies/eem_prov.html`

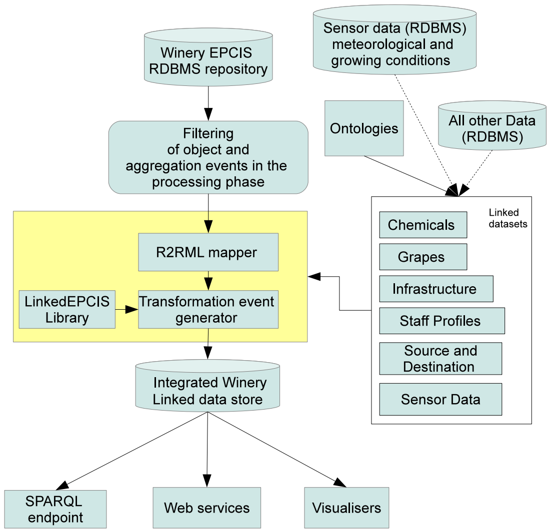

Fig. 4. Generating and interlinking transformation events

datasets were curated when transformation events were not yet a part of the EPCIS specification, the EPCIS events raised during the processing phase were recorded as aggregation events or object events.

We implemented an "Event filtering" component that filtered the events recorded during the processing phase from the database. The filtering algorithm took into consideration the time between event occurrence, the disposition type and the business step type defined for an event in order to filter it as a transformation event.

We wrote an R2RML[23] mapping script to map the relational database entries and generate linked data using the EEM and CBVVocab ontologies. The process of mapping took into consideration the integration with the other datasets and generated corresponding transformation events as linked data.

Integrating Event Data with Supporting Data

As highlighted in Section 2, in order to achieve full traceability, event data needs to be integrated with supporting data that contextualises the events. Traceability data being commercially sensitive, most trading partners are wary[24] of sharing it outside their B2B setup. Based on representative data from the pilot, we generated synthetic linked datasets for supply chain artifacts such as: grapes, the environmental parameters (sensor data) under which they were grown, equipment used in the processing stages from grape pressing to bottling, chemicals

[23] `http://www.w3.org/TR/r2rml/`

[24] Due to this constraint, we are unable to reproduce the actual real-time product, infrastructure and environmental datasets in this paper.

used in the treatment of wines, volumes of outputs produced at each stage, profiles of winery staff and final destinations for the wines.

The integrated datasets were stored in a triple store (OWLIM-SE 5.4.686) to be queried later for traceability information. The linked data generation and query applications were built using our LinkedEPCIS[25] library which provides a Java API and a reference implementation for capturing EPCIS events as linked data.

Traceability Queries

Section 2 highlighted some informal traceability queries for the winery scenario. We formalised those queries in SPARQL 1.1 and executed them against our integrated linked data store for the winery.

- **Tracking Ingredients(Q1):** The query illustrates the usage of reasoning with querying via the transitive and symmetric characteristics of the object property `associatedWithTransformationEvent` and the property path feature of SPARQL 1.1 on the property chain "`item o itemContent`". A single query allows us to recursively retrieve all the inputs associated with a set of transformation events.

```
PREFIX eem: <http://purl.org/eem#>
PREFIX co:  <http://purl.org/co/>
PREFIX prov: <http://www.w3.org/ns/prov#>
PREFIX ssn: <http://purl.oclc.org/NET/ssnx/ssn#>
SELECT ?input1 ?input2 WHERE{
       ?event1 a eem:TransformationEvent;
               eem:associatedWithTransformationEvent ?event2;
               eem:eventOccurredAt ?occurred;
               eem:hasInputQuantityList ?iql1;
       ?iql1   co:item/co:itemContent ?input1.
       ?event2 eem:eventOccurredAt ?occurred;
               eem:hasInputQuantityList ?iql2.
       ?iq2    co:item /co:itemContent ?input2.}
```

- **Tracking Provenance(Q2):** The query highlights the use of our mapping between the PROV-O ontology and EEM to track the provenance of the winery staff present when the wines bottles are aggregated.

```
SELECT ?staff ?x WHERE{
  ?event  a prov:Entity;
          eem:hasAggregationURI ?x;
          eem:action ?action.
  ?action prov:wasAssociatedWith ?staff.}
```

- **Tracking External Data(Q3):** The query shows end-to-end traceability where information is recursively traced back from the transaction/shipping event to the growth temperature in the location where the grapes were grown.

[25] `https://github.com/nimonika/LinkedEPCIS`

```
SELECT ?temperature WHERE{
  ?event a eem:TransactionEvent;
         eem:destination ?d;
         eem:eventOccurredAt ?x;
         eem:associatedWithEPCList ?epcTList.
  ?epcTList co:element ?epcAgg.
  ?aevent a eem:AggregationEvent;
          eem:hasAggregationURI ?epcAgg.
          eem:associatedWithEPCList ?epcList.
  ?tevent a eem:TransformationEvent.
        eem:associatedWithOutputEPCs ?epcOutList;
        eem:hasInputQuantityList ?qtyInList;
        ?qtyInList co:item/co:itemContent ?input.
  ?input a GrapeVariety;
         gr:grownAt ?loc;
  ?loc  a prov:Location.
  ?sensor a ssn:SensingDevice;
          prov:atLocation ?loc;
          ssn:madeObservation ?temp.
   ?temp  ssn:hasValue   ?tempValue.
  BIND (AVG(?tempValue) AS ?temperature)}
```

7 Conclusions

Little work has been done so far in the SW/LD community for the representation of traceability information in supply chain business processes. The representation of EPCIS events in an unambiguous and machine interpretable way is an important step towards achieving the objectives of sharing and interlinking traceability information both within organisations and among trading partners in a supply chain. In order to realise the vision, we have developed: EEM, an OWL DL ontology which incorporates the primitives required to represent EPCIS events using Semantic Web standards and linked data principles and LInkedEPCIS, a library for generating linked data based on types and typed links from EEM.

In this paper we have extended EEM with a new EPCIS event type, "TransformationEvent" that enables internal traceability, specifically in the production and manufacturing sectors, by providing the types and relationships to record the inputs consumed and outputs produced over a series of related processing stages. As provenance is a key requirement for tracking and tracing solutions, we have mapped EEM to PROV-O. Finally we have exemplified our approach for the wine supply chain where we develop an infrastructure for generating linked data from legacy sources and deriving traceability information using reasoning. Work is currently in progress on implementing a linked traceability monitor that provides relevant warnings in real time when an anomaly in the processing stages is detected, by monitoring the transformation events.

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