Formal Specification of Ecosystem Services and their Assessment

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The contemporary paradigm in ICT

• **Internet of Things** – all physical or ideal objects which are consumers and producers of information and are interconnected.

• **Future of Internet** – next generation of Internet communication where M2M communication has a key role.

• **Intensive** usage of modern high performance databases.

• **Artificial Intelligence** penetration.
Main issue of databases

• In general even the open databases are isolated - stove pipes
• The information supplied is in most cases are proprietary export formats or csv files.
• Almost no semantical information is presented. It can be guessed from not very clearly supplied relational information.
A simple example

- Let us have a plant. What kind of plant?
- Tree plant. What kind of spices?
- Tree plant of Austrian oak species. What kind of quality?
- Tree plant of Austrian oak species with high quality.
- Now let us present this information in a standard way as a table.

<table>
<thead>
<tr>
<th>Plant type</th>
<th>Species</th>
<th>Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>tree</td>
<td>Austrian oak</td>
<td>high</td>
</tr>
</tbody>
</table>

The characteristics described in that table can be understood only by software specially written to consider such a table.

In the case of high complexity of ecosystem and ecosystem services processing the related information (tables) will involve a lot of programming resources.

The conclusion is that this is not the way!
One possible solution - Ontologies

• We need to know about what it is that we’re providing data.

• We need to know, amongst other things, about the entities to which data apply (and the relationships between those entities), the investigations that produced those investigations, the provenance of the information and the information itself.

• Ontologies are about describing definitional information about entities in a field of interest and thus are an option for the means by which we provide information about what our data are about. To re-iterate the short elevator pitch, “we need to know what we’re talking about” and that’s why we use ontologies.

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Ontology definitions

- Gruber, Borst “Ontologies are a formal specification of a shared conceptualization”
- Studer “An ontology is a formal, explicit specification of a shared conceptualization. Conceptualization refers to an abstract model of some phenomenon in the world by having identified the relevant concepts of that phenomenon. Explicit means that the type of concepts used, and the constraints on their use are explicitly defined.”
Methods of Ontology

• Usage of first order logic predicate computing. On the base of a set of symbols, logical operations and arithmetical operations compute whether a statement is true or false - FOL.
• Usage of description logic - DL.
• Usage of Web Ontology Language – OWL.
• Usage of software engineering technique - UML.
## Relation between that languages

<table>
<thead>
<tr>
<th></th>
<th>FOL</th>
<th>DL</th>
<th>OWL</th>
<th>UML</th>
</tr>
</thead>
<tbody>
<tr>
<td>unary predicate</td>
<td>concept</td>
<td>class</td>
<td>class</td>
<td></td>
</tr>
<tr>
<td>binary predicate</td>
<td>role</td>
<td>property</td>
<td>attribute</td>
<td></td>
</tr>
<tr>
<td>constant</td>
<td>individual</td>
<td>individual</td>
<td>individual</td>
<td>object</td>
</tr>
</tbody>
</table>
How the ontology can help the ecosystem services valuation?

• Presenting highly complex information about ecosystem units and services in a machine readable format thus facilitating M2M information transport.

• Armed with such information presentation and modern FIWARE software we can easily gather large semantically consistent data volumes in order to valuate ecosystem units and respective ecosystem services.

• Ontologies are integrated part of Artificial Intelligence, which will be applied in close future in ecology and respectively in ecosystem services management.
How to build an ontology

• **Acquire domain knowledge**
  Assemble appropriate information resources and expertise that will define, with consensus and consistency, the terms used formally to describe things in the domain of interest. These definitions must be collected so that they can be expressed in a common language selected for the ontology.

• **Organize the ontology**
  Design the overall conceptual structure of the domain. This will likely involve identifying the domain's principal concrete concepts and their properties, identifying the relationships among the concepts, creating abstract concepts as organizing features, referencing or including supporting ontologies, distinguishing which concepts have instances, and applying other guidelines of your chosen methodology.

• **Flesh out the ontology**
  Add concepts, relations, and individuals to the level of detail necessary to satisfy the purposes of the ontology.

• **Check your work (validation)**
  Reconcile syntactic, logical, and semantic inconsistencies among the ontology elements. Consistency checking may also involve automatic classification that defines new concepts based on individual properties and class relationships.

• **Commit the ontology (verification)**
  Incumbent on any ontology development effort is a final verification of the ontology by domain experts and the subsequent commitment of the ontology by publishing it within its intended deployment environment.
How the ontology will be applied to ecosystem services valuation?

• **Build a formal mathematical model of ecosystem unit and valuation.** Create a set definition of basic ecosystem unit components including biotic and abiotic components.

• **Define valuation functions for ecosystem unit component.**

• **Apply engineering approach in designing of base concepts (classes).**
  • Choose a description language – OWL and UML in our case.
  • Create formal description that concept applying OWL and UNL.

• **Apply First Order logic to check the logical correctness.**
  • Present concepts as unary predicates.
  • Present relations between concepts as n-ary predicates.

• **Verify the built ontology with domain experts.** Do this not at the and but all the time during upper described process.
Semantic web languages

- Following definitions are according to www.w3.org
- XML – universal metalanguage for defining markup. But it does not provide semantic of data.
- RDF - a standard model for data interchange on the Web. RDF extends the linking structure of the Web to use URIs to name the relationship between things as well as the two ends of the link (this is usually referred to as a “triple”). Using this simple model, it allows structured and semi-structured data to be mixed, exposed, and shared across different applications.
- RDF/Schema – adds assumptions about any particular application domain and semantics of that domains.
Semantic web languages (Continued)

• OWL Full - the W3C Web Ontology Language (OWL) is a Semantic Web language designed to represent rich and complex knowledge about things, groups of things, and relations between things. OWL is a computational logic-based language such that knowledge expressed in OWL can be exploited by computer programs, e.g., to verify the consistency of that knowledge or to make implicit knowledge explicit. OWL documents, known as ontologies, can be published in the World Wide Web and may refer to or be referred from other OWL ontologies.

• OWL DL & OWL Lite - restrictions of OWL Full.
The presented example will be based on forest biocoenosis and especially trees. The other definitions can be built in a similar way.
Mathematical definitions related with trees

Definition 1: Tree species $T = \{ t_i : i = 1,..., n_1 \}$, where $t_i$ is a tree species and $n_1$ is the total number of all possible tree species.

Definition 2: Tree reserve of an EU $\Xi = \{ \xi_i : i = 1,..., n_1^* \}$, $\xi_i = \{ t_i, k_i, b_i \}, t_i \in T \}$, where $n_1^*$ is the tree species richness of a specific EU, $k_i$ are their weights and $b_i$ are the respective bonitos (productivity class) of that tree species. The tree bonitos is presented by a graded scale.
OWL description of tree

<owl:Class rdf:ID="tree">
  <rdfs:subClassOf rdf:resource="#plant"/>
</owl:Class>

<owl:Class rdf:ID="treeSpecies">
  <owl:oneOf rdf:parseType="Collection">
    <owl:Thing rdf:about="#Abies Alba Mill"/>
    ...
  </owl:oneOf>
</owl:Class>
OWL description of some tree properties I

```xml
<owl:ObjectProperty rdf:ID="isaTreeSpecies">
  <rdfs:domain rdf:resource="#tree" />
  <rdfs:range rdf:resource="#treeSpecies" />
</owl:ObjectProperty>

<owl:Class rdf:ID="treeQuality">
  <owl:oneOf rdf:parseType="Collection">
    <owl:Thing rdf:about="#high"/>
    <owl:Thing rdf:about="#medium"/>
    <owl:Thing rdf:about="#low"/>
  </owl:oneOf>
</owl:Class>
```
OWL description of some tree properties II

```xml
<owl:ObjectProperty rdf:ID="hasQuality">
  <rdfs:domain rdf:resource="#tree" />
  <rdfs:range rdf:resource="#treeQuality" />
</owl:ObjectProperty>

<owl:DatatypeProperty rdf:ID="hasTreeUnitPrice">
  <rdfs:domain rdf:resource="#treeSpecies"/>
  <rdfs:domain rdf:resource="#treeQuality"/>
  <rdfs:range rdf:resource="&xsd;double"/>
</owl:DatatypeProperty>
```
UML Definition of ecosystem unit

<owl:Class rdf:ID="ecosystemUnit">
  <owl:unionOf rdf:parseType="Collection">
    <owl:Class rdf:about="#biocoenosis"/>
    <owl:Class rdf:about="#abioticComponent"/>
  </owl:unionOf>
</owl:Class>
UML definition of ecosystem service
Ecosystem assessment related functions

Definition 3: Natural capital value function $\overline{C}: \Phi \rightarrow \mathbb{R}^+$. Let us denote the state of natural resources in an EU at $y^{th}$ year as $\Phi^y$.

Let us denote the expenses in ecosystem services with $X \subset \mathbb{R}^+$ and the income after their exploitation as $I \subset \mathbb{R}^+$.

Definition 4: Ecosystem service function $E: (\Phi^y \times X) \rightarrow (\Phi^{y+1} \times I)$.

This definition has a summary character in terms of ecosystem services, as the left side shows the state of ecosystem services in the current year, while the right side shows the state at the end of the following year.
In the same way we can define the rest of ecosystem services.
FOL description of ecosystem services

\[\forall y. \text{tree}(x,y) = \text{treeSpecies}(y)\]

\[\forall y. \text{tree}(x,y) = \text{treeQuality}(y)\]

treeQuality(x) = \{\text{high} \lor \text{medium} \lor \text{low}\}

ecosystemUnit(x) = \{\text{biocenosis} \lor \text{abioticComponent}\}

\[\forall x. \text{ecosystemService}(x) \rightarrow \text{service}(x)\]

\[\forall x. \text{provisioning}(x) \rightarrow \text{ecosystemService}(x)\]

\[\forall x. \text{provisioning}(x) \rightarrow \text{service}(x)\]
OWL ecosystem services assessment

<owl:DatatypeProperty rdf:ID="#hasExpense">
  <rdfs:domain rdf:resource="#service"/>
  <rdfs:range rdf:resource="&xsd;double"/>
</owl:DatatypeProperty>

<owl:DatatypeProperty rdf:ID="#producesIncome">
  <rdfs:domain rdf:resource="#service"/>
  <rdfs:range rdf:resource="&xsd;double"/>
</owl:DatatypeProperty>
OWL ecosystem services assessment II

<owl:ObjectProperty rdf:ID="manage">
  <rdfs:domain rdf:resource="#ecosystemUnit" />
  <rdfs:range rdf:resource="#ecosystemUnit" />
</owl:ObjectProperty>
THANK YOU!

ANY QUESTIONS?