TOWARDS SEMANTIC KNOWLEDGE MAPPING: AN EXTENSION OF COMPENDIUM WITH SEMANTIC KNOWLEDGE REPRESENTATION

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ABSTRACT

Compendium is a knowledge mapping application equipped with graphical representations of ideas and arguments. Extension of the processes in Compendium with Semantic Web technologies can be beneficial for the intelligent searching of concepts or ideas, and supporting decision making process. This paper presents the extended Compendium which exploits the Semantic Web for knowledge representation and user interaction. The result evaluated by the experts and users showed that the extension eases and streamlines the decision making process.

KEYWORDS

Compendium, Decision Matrix, Wicked Problem, IBIS, Semantic Web, Ontology

1. INTRODUCTION

Consideration of different criteria and their weight is the most important step towards a decision making process. One of the software application that helps in the process with graphical user interface is Compendium [1], [2]. It is an Issue Based Information System (IBIS) [3], which visualises the connection of ideas and information in a graphical user interface. The ideas and information are illustrated in various kinds of nodes. Each node is identified by its own symbol name and description. The nodes can be created, arranged and linked to each other by the popular drag and drop feature and short-cut keys.

The existing system with extensions still lacks semantic representation of the knowledge. Various extensions of Compendium with additional features have shown promising results in streamlining the decision-making processes. Some of the examples are the *Option-vs-Criteria* matrix, *Global-Parameters* matrix and *Goals-vs-Criteria* matrix [4]. These matrices are table having different headers such as criteria, options and goals. For example in *Option-vs-Criteria* matrix, the criteria are lined along the left column of a table and options are arranged along the top row of the table. However, there are still some improvements expected on the extensions such as making the knowledge of the matrices usable, reusable, searchable and portable. One of the possibilities is to exploit Semantic Web technologies to represent the knowledge, which fulfils these expectations. Moreover, it can store, retrieve and update the information representing criteria, goals and parameters; check consistency in the information; and present the information in a semantic hierarchy.

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This paper focuses on exploiting Semantic Web technologies in order to make the decision matrices [4] more meaningful and reusable. One of such technologies is domain ontology, which describes states and processes of a domain. In this work, the ontology representing the knowledge of matrices in Compendium was created manually with help from domain experts. The knowledge was provided with options to check consistency and export into several useful formats. This paper extends the decision matrices presented in [4] with Semantic Web technologies. Therefore, processes and goals of these matrices are not the scope and the contribution of this paper. The following are the of contributions of this paper;

(1) **Explicit representation of knowledge**: It makes the implicit information explicit that is imbedded in various decision matrices such as *Option-vs-Criteria* marix, *Global-Parameters* matrix and *Goals-vs-Criteria* matrix.
(2) **Reusability of the existing tools**: It increases the reusability of the existing tools incorporating the matrices by adopting the Semantic Web technologies. Furthermore, the knowledge is more adaptable, portable and shareable as it is represented in a W3C[1] standard format.
(3) **User friendly interface**: In addition to representing the knowledge in a homogeneous and standard format, the current work extends the system with Semantic Web oriented user interface. In particular, for users are guided with useful information in each step of the decision making process.

The rest of the paper is organised as follows. The background of Compendium is described in section 2. Some earlier approaches of adding useful functionalities to Compendium are presented in section 3. Section 4 describes the extended Compendium with new features and integration of Semantic Web technologies 6. The section 7 concludes the paper with recommended works.

2. BACKGROUND

Compendium is a knowledge mapping software tool developed by Open University, which uses IBIS and has been developed over a decade [3]. The major elements of the IBIS are topics, issues and positions. A topic defines the overall view of a problem that needs solving. The issues are also referred to as questions or problems that need to be answered. Likewise, the positions or alternative-positions represent the possible solutions or answers. The issues are also associated with arguments, which describe the pros and cons of a position or another argument.

A topic representing a problem can be very complex and is referred to as *Wicked Problem* [5]. In an IBIS, the system deals with every issue related to a topic and finally come to an overall solution. However, while treating an issue, another issue may arise. The newly emerged issue may create further issues. The new and the subsequent issues are treated in the same way as the main issue. In a practical scenario, while solving a problem, a complex and nested structure of problems is formed which are called *Wicked Problems*. They are extremely hard or almost impossible to solve due to their contradictory, incomplete and everchanging requirements, and are very difficult to recognise [5].

The Compendium has been developed as a result of evolution in IBIS. There have been so many changes and developments in IBIS since its inception. The most significant progress was the development of graphical IBIS also referred to as gIBIS [6], where issues and positions are visualised graphically as distinct nodes. It was designed to work in a team of people who are working on the same project, which assisted the team members to understand and work in collaboration. Since its popularity spread over, there had been several attempts to make similar kinds of systems. One of the most successful and popular systems is Compendium.

The advantage of graphical IBIS in Compendium is that the whole design of problem-solving process can be visualized as a tree, and problems can be visually tackled from leaf to root. It makes the process transparent, as the progress of selecting position for an issue can be clearly visualised, and the team will be aware of the depth of the problem more accurately. Compendium illustrates ideas and information via various kinds of nodes, which have their own symbols, names and description. The nodes can be created, arranged, rearranged and linked together by the convenient drag and drop feature, and short-cut keys. Figure 1 shows the different types of nodes in the working environment of Compendium. These features in Compendium enable dynamic visual modelling and mapping of dialogs and arguments. They also help in interchanging each other's idea and information in a team in an efficient way, which expedites and streamlines decision-making processes.

There are three elements in Compendium namely 1) hypermedia concept mapping, 2) conceptual framework and 3) meeting facilitation. In the concept mapping element, the issues, positions and options are visually represented to show their inter connection in the form of a map. The map can be populated with the issues, and the issues are connected with the possible solutions and their pros and cons. In the conceptual framework element, most common problems can be tackled by using some templates. The templates are created by following standard operating procedures, best practices and some other appropriate approaches. In the meeting facilitation element, the discussions, arguments and the subsequent decision made in a meeting are recorded. This process is also referred as Dialog Mapping.

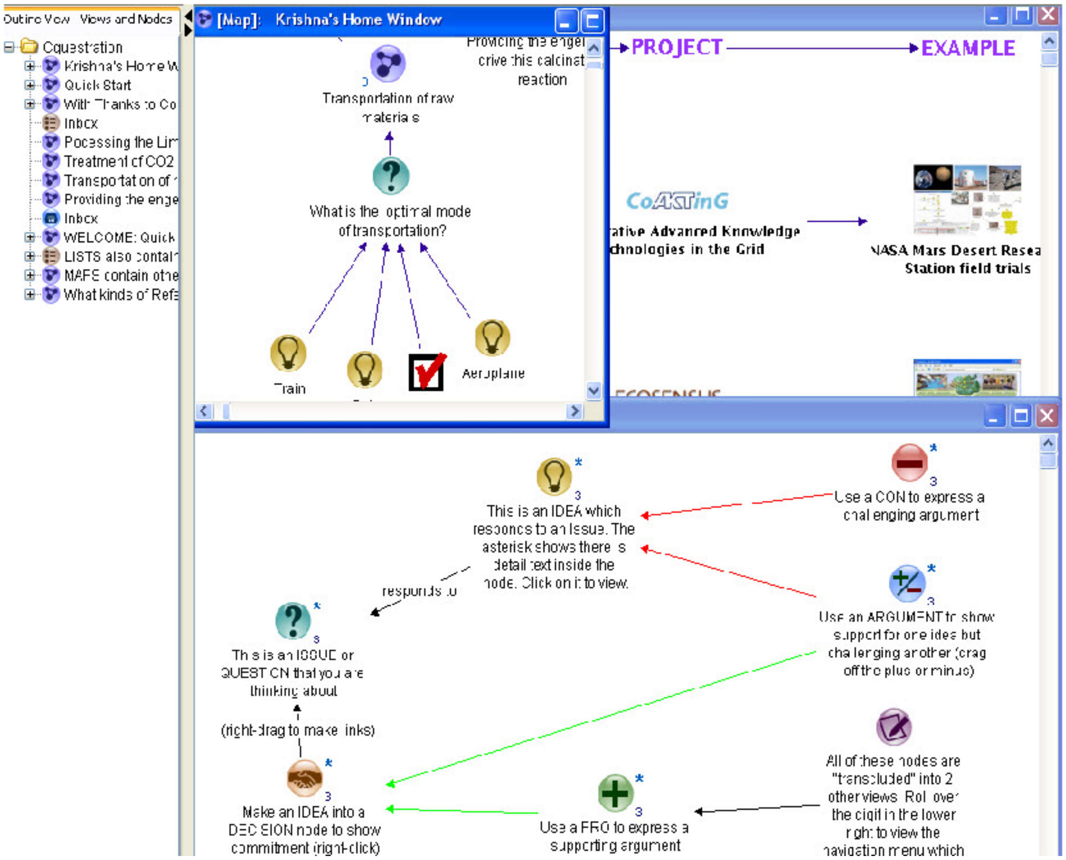
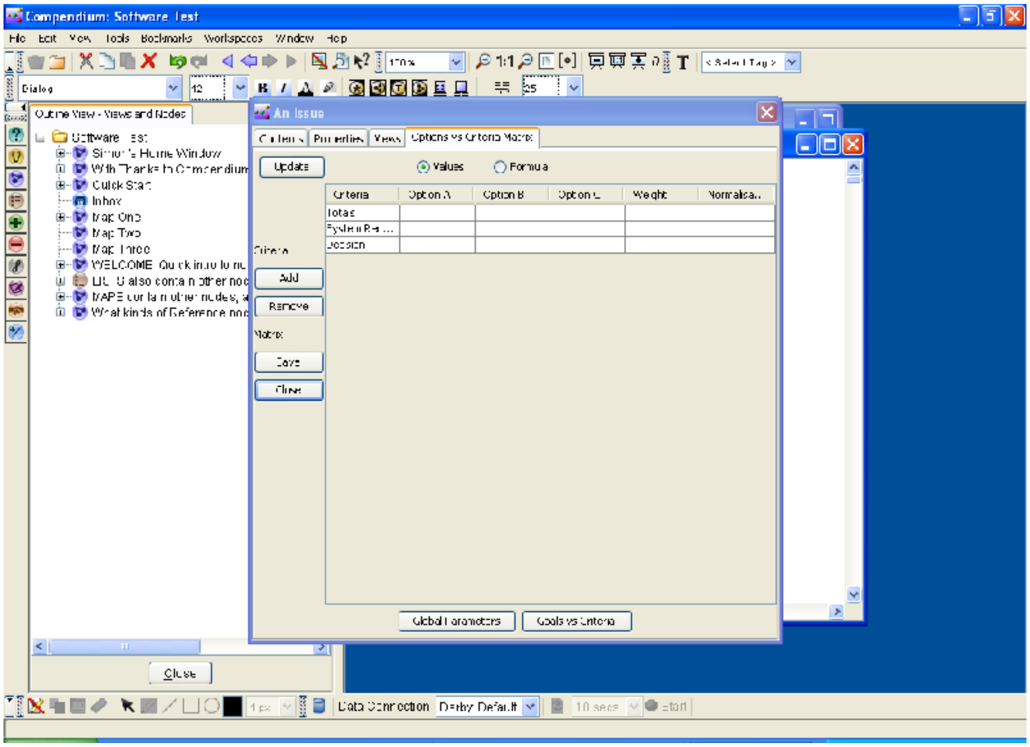


Figure 1 : Compendium home window [1].

3. EXTENDED COMPENDIUM WITH DECISION MATRICES

A team at Oxford Brookes University and University of Oxford [4] extended Compendium by creating and integrating useful tools to support the decision-making process. The key extensions are the decision related matrices such as *Option-vs-Criteria* matrix, *Goals-vs-Criteria* matrix, *Global-Parameters* matrix and *Design-Rationale* [4], [7], [8]. In the previous version of Compendium, the above matrices were represented in external spreadsheet files. The extended Compendium provided the facilities of entering, deleting, editing and updating the matrix visually in an integrated environment. The users found the extended Compendium as very useful, as it eliminated the complication involved in importing external files and having to establish connections with external applications in order to edit and update the information. The graphical representation of the matrix in the integrated Compendium is depicted in Figure 2.


Compendium: Software Test
File Edit View Tools Bookmarks Workspaces Window Help
170%
< Select Tag >
Dialog
12
25
Outline View - Views and Nodes
Software Test
Simon's Home Window
With Thanks to Compendium
Quick Start
Inbox
Map One
Map Two
Map Three
WELCOME Quick intro to nc
LIL Is also contain other noc
MAPS contain other nodes, a
What kinds of Reference noc
Close
An Issue
Contents
Properties
Views
Options vs Criteria Matrix
Update
Criteria
Add
Remove
Matrix
Save
Close
Global Parameters
Goals vs Criteria
Data Connection
Derby Default
10 secs
start

◉ Values ○ Formula

Criteria	Option A	Option B	Option C	Weight	Normalisa..
Totals					
System Re...					
Decision					

Figure 2: *Options vs Criteria* Matrix tab for the Issue node

The *Options-vs-Criteria* matrix facilitates the selection of the best option from the all the available options considering the relevant criteria [9]. This matrix is associated with every question node, where every alternative can be evaluated against a set of criteria. It is visually represented as a table by placing the options along the top row and criteria along the left column. Each criterion is supplied with its weight, which represents its degree of importance in the decision process. Figure 2 shows the *Options-vs-Criteria* matrix created by the team. This matrix was implemented in a decision supporting tool called DRAMA [7], which was used in wastewater plants. It recorded all the design objectives, selected and rejected options and all the decisions made.

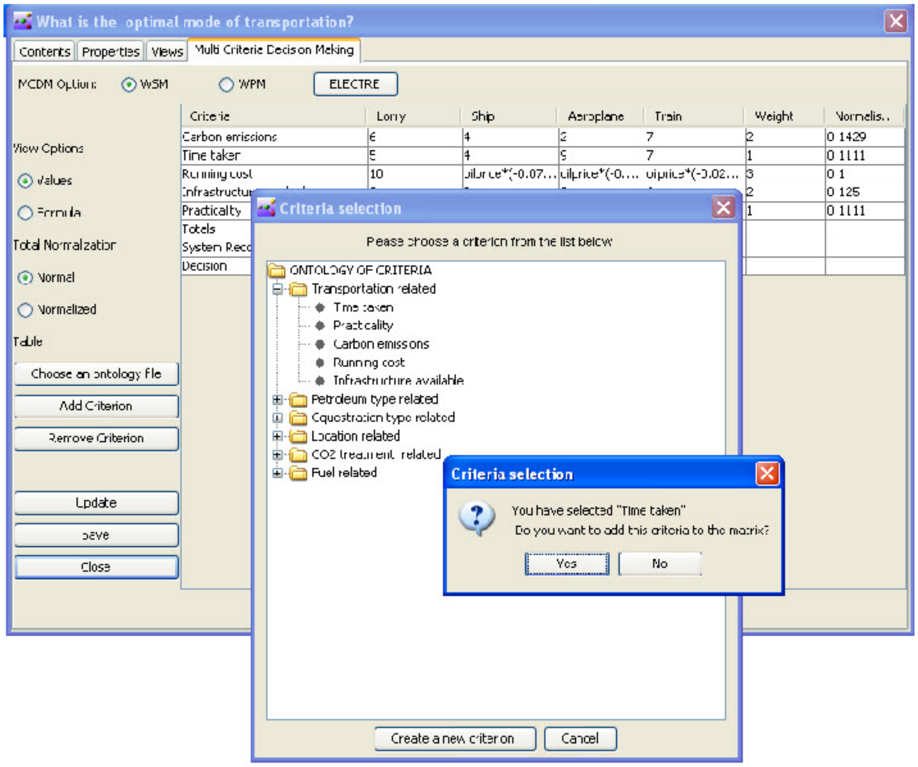
Decision Rationale explains the reason behind a decision made by going through all the options and their criteria available [10]. Using this information in the future will be particularly helpful to analyse the effects of changing some of the micro decisions on overall decision. A decision made at a point of time could be inappropriate at another time. For an example, if there were options to choose from materials x, y and z and the cost of x was cheaper a year ago but now y is the cheapest. In this case, the decision to choose material based on its cost has changed and has an impact on subsequent decisions, which have been re-evaluated.

Representing the information embedded in the matrices explicitly can make the process more meaningful and less error-prone. This can be reified by utilising the Semantic Web technologies. Furthermore, creation of these matrices could be semantically guided and consistently maintained and updated. Therefore, the goal of this project has been to exploit Semantic Web technologies in order to support the development and integration of the desired functionalities to Compendium, which is described in the next section.

4. Adding Semantics to Compendium

This section explains the process of representing the information in Semantic Web technology, which is required for the *Options-vs-Criteria* matrix and its dependent matrices in Compendium. Representing the information explicitly for shared conceptualisation facilitates the users to work together, reuse the information and distribute them in an efficient way [11]. In the newly extended Compendium, Semantic-Compendium, it enables users to be guided through the process of creation, selection, removal and update of the options, criteria and parameters in Compendium. An example of how the selection of criteria is guided by the newly extended system is depicted in

Figure 3. Furthermore, it facilitates the decision-making process. This section describes the process of ontology creation with the use of Protégé OWL Editor, and it also explains the interactions between the information in the ontology and Compendium. The relevant information is presented to users for matrices creation. The users are guided through the process of information selection while creating and manipulating the decision matrix and its dependent matrices. Once new information or instruction is created, added or changed, the users are able to save them in the ontology maintaining its consistency and structure. The overall processes are described under the following four phases.



What is the optimal mode of transportation?

Contents | Properties | Views | Multi Criteria Decision Making

MCDM Option: ● WSM ○ WPM ELECTRE

View Options: ● Values ○ Formula

Total Normalization: ● Normal ○ Normalized

Table

Criteria	Lorry	Ship	Aeroplane	Train	Weight	Normalis..
Carbon emissions	6	4	2	7	2	0 1429
Time taker	5	4	9	7	1	0 1111
Running cost	10	oilprice*(-0.07...	oilprice*(-0....	oilprice*(-0.02...	3	0 1
Infrastructur					2	0 125
Practicalty					1	0 1111
Totels						
System Reco						
Decision						

Criteria selection

Please choose a criterion from the list below

- ONTOLOGY OF CRITERIA
  - Transportation related
    - Time taken
    - Practicality
    - Carbon emissons
    - Running cost
    - Infrastructure available
  - Petroleum type related
  - Equestration type related
  - Location related
  - CO2 treatment related
  - Fuel related

Criteria selection

You have selected "Time taken"
Do you want to add this criteria to the matrix?

Figure 3: *Options-vs-Criteria* matrix and selection of new Criterion

4.1. Compendium Ontology Creation

A domain ontology describing the states and processes of Compendium was created manually using Protégé OWL Editor. The three important elements of the ontology are classes, individuals and properties. The classes are the concepts representing the entities and their important aspects. The individuals are the entities that fall under some classes. Let's take an example of **Human** as a class. Among the entities that fall under this class are **MichelleObama** and **BarackObama**; therefore considered as the individuals of **Human**. There are two types of properties associated with classes and individuals; object property and data-type property. The property holds two values on its two ends and the property itself sits in the middle. The value on the left is called domain and that on the right is called the range. The object property relates two individuals such as, in the above example, the object property **hasWife** relates **BarackObama** with **MichelleObama** as its domain and range respectively. The data-type property relates individuals with some data-type values such as string, integer, double and date. For example, in the above example, the data-type property **hasPostion** relates individual **BarackObama** with string value "**President**". There is a general practice that each object property is supplied with its inverse property, where the individuals of the domain and range are flipped on the right and left respectively. The inverse property also helps in making implicit information explicit. Besides, there are two other common terms that appear in ontology description namely T-Box and A-Box. In a simplified interpretation, the T-Box can be regarded as ontology with classes and axioms without individuals. Classes represent the concepts, and the axioms specify how the classes can be determined and are related to each other. Likewise, the A-Box represents the individuals and their properties.

The concepts in the ontology are organise in such a way that they correspond to the entities in Compendium, and they were developed under a class called **Compendium_Component**. The immediate subclasses under this class are **Issue**, **Position**, **Criteria** and **Parameter**. The layer containing these four classes is called upper layer. Another layer of subclasses of the upper layer classes was created and called the lower layer. The classes in the lower layer were populated with individuals and their description.

Figure 4 illustrates the T-Box of the ontology.

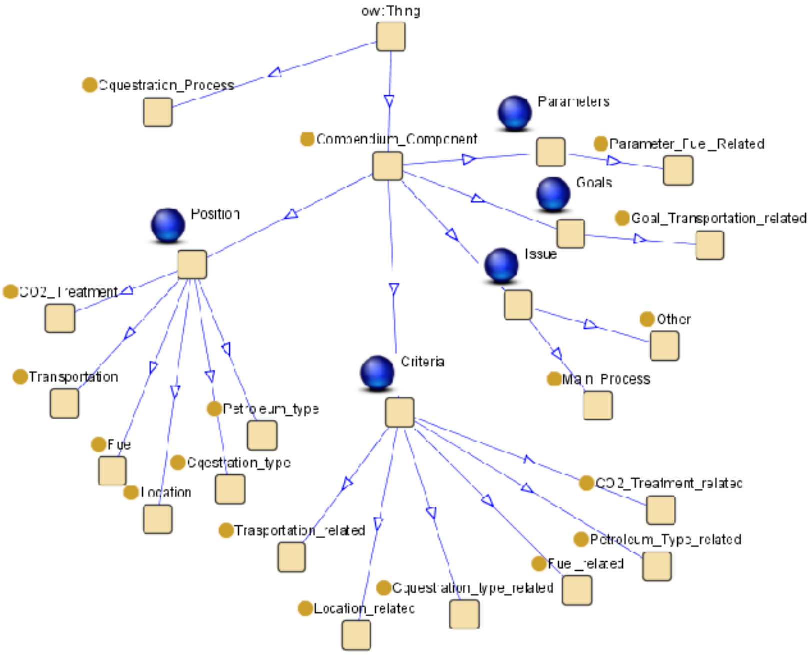
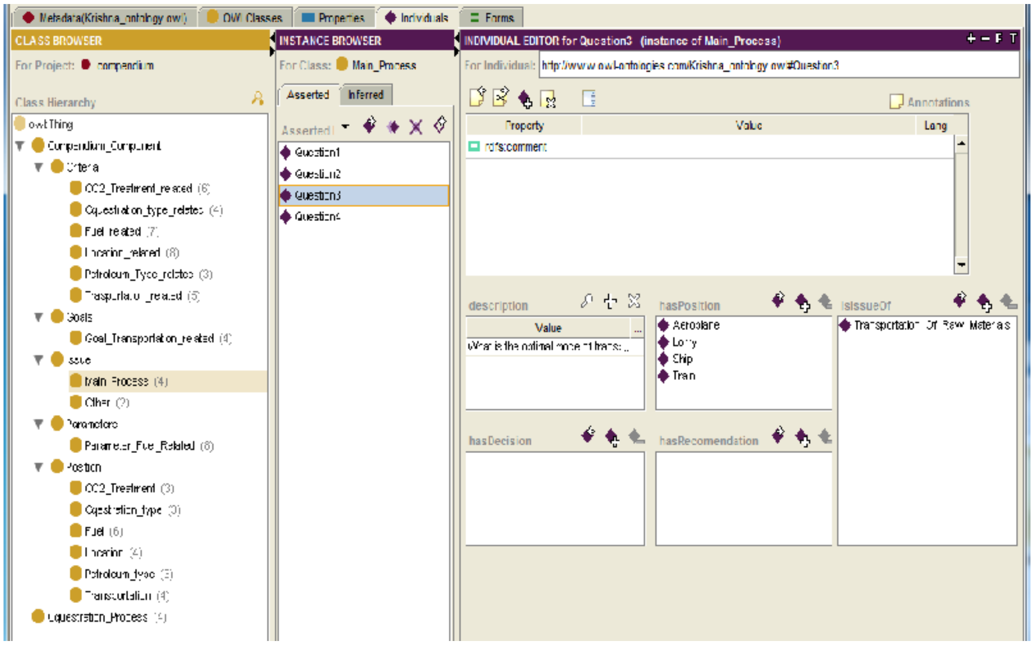


Figure 4: T-Box of Compendium.owl ontology

The properties creation is also an important and more thoughtful task in ontology engineering. The *Object Properties* created in the ontology are **hasCriteria, hasDecision, hasIssue, hasPosition, hasRecommendation**. It follows that each object property is coupled with its inverse property. As a result, a set of inverse property was created such as **isCriteriaOf, isDecisionOf, isIssueOf, isPositionOf, isRecommendationOf**. Let's take an example of an *Object Property*, **hasCriteria,** whose domain can have values from the union of **Position** and **Goal,** where as its range can only have values from **Criteria**.

Figure 5 illustrates Protégé OWL Editor Environment with the ontology showing some individuals and properties.



For Project: compendium

Class Hierarchy

- owl:Thing
- Compendium_Component
  - Criteria
    - CO2_Treatment_related (6)
    - Sequestration_type_related (4)
    - Fuel related (7)
    - Location_related (8)
    - Petroleum_Type_related (3)
    - Transportation_related (5)
  - Goals
    - Goal_Transportation_related (4)
  - Issue
    - Main_Process (4)
    - Other (2)
  - Parameters
    - Parameter_Fuel_Related (8)
  - Position
    - CO2_Treatment (3)
    - Sequestration_type (3)
    - Fuel (6)
    - Location (4)
    - Petroleum_type (3)
    - Transportation (4)
- Sequestration_Process (4)

For Class: Main_Process

Asserted Instances

- Question1
- Question2
- Question3
- Question4

INDIVIDUAL EDITOR for Question3 (instance of Main_Process)

For Individual: http://www.owl-ontologies.com/Krishna_ontology.owl#Question3

Property	Value	Lang
rdfs:comment		

description

Value
What is the optimal mode of trans...

hasPosition

- Aeroplane
- Lorry
- Ship
- Train

isIssueOf

- Transportation Of Raw Materials

hasDecision

hasRecomendation

Figure 5: *Compendium.owl* ontology in Protégé-OWL Editor

4.3. Connection between the Ontology and Compendium

In order to work with ontologies in Java, there requires some communications between these technologies. Different applications and technologies use different data structures and function calls, which make the communication among the applications difficult. It can be alleviated by the use of Application Programming Interfaces (API). A Java API for ontology, Jena [12] acts as a bridge between ontology and Java. Jena retrieves the information in the ontology and converts it into a model which can be manipulated Sparql Query Language (SPARQL) [12]. In particular, the model can be queried, modified and updated using SPARQL. Jena also facilitates SPARQL features in Java. Figure 6 depicts the flow of information from ontology to Compendium.

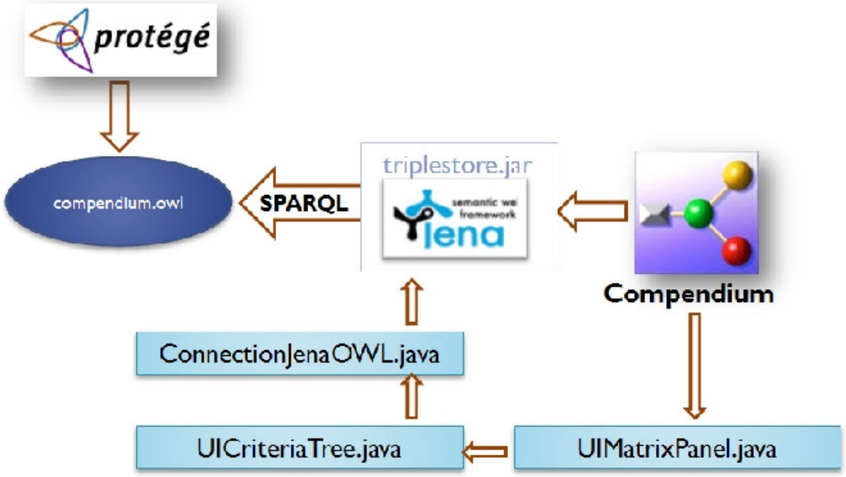


Figure 6: Connection and flow of information in the systems

In the Semantic Compendium, Jena was imported and implemented in a class called *ConnectionJenaOWL.java*, which provides three vector objects to hold information about the list of *Criteria*, *Goals* and *Parameters*. Compendium accesses this information and utilises it to render drop down lists in GUI panels. After the creation of the GUI panels to display information in trees, the vectors are modified to contain a complex data structure called *OWLData*. The *OWLData* contains categories of *Criteria*, *Goals* and individuals of *Criteria* and *Goals*. Figure 6 shows the structure of vectors and data produced by the class *ConnectionJenaOWL*.

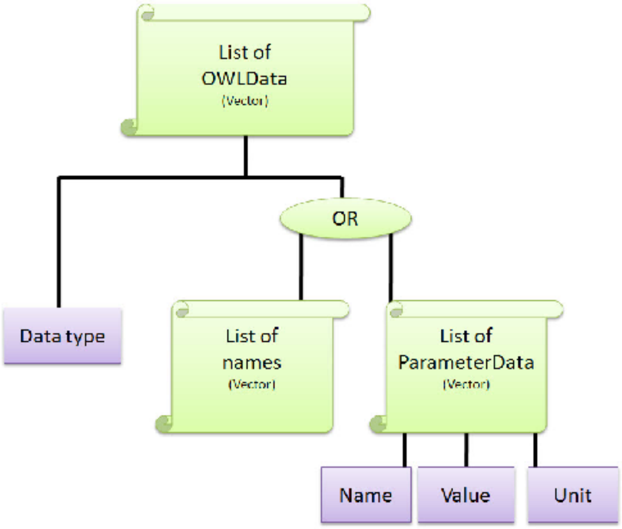


Figure 7: Structure of vectors and data provided by class *ConnectionJenaOWL*

4.4. Using the Ontology in Compendium

The ontological concepts are accessed by the Semantic Compendium in order to generate various graphical user interfaces such as trees of *Criteria*, *Global-Parameters* and *Goals* separately. The GUI tree creation processes are similar for all three components. Therefore, only the processes involved in the creation of *Criteria* tree is described here.

During the *Criteria* selection process, a user selects the *Add Criterion* button, which creates a *UIDialog* containing an expandable tree of *Criteria*. *Criteria* are grouped under their relevant category maintaining the corresponding structure as in the ontology, and they can be expanded or collapsed as required. Clicking on a criterion selects and adds it automatically to the *Options-vs-Criteria* matrix. The criterion selection process requires the user's confirmation.

Figure 3 illustrates the structure of the *UIDialog* with the tree. The *Criteria* tree also provides an option to create a new *Criterion*, which is either created under the existing category of *Criteria* or a new *Criteria type* is created, and the *Criterion* is added under the newly created *Criteria type*. Changes made during this process are also updated in the *Options-vs-Criteria* matrix automatically. This information is also automatically updated in the working copy of the ontology for later uses.

4.5. Ontology for Consistency Checking

During this phase, the selected *Criterion* and the *Goal* in the *Goals-vs-Criteria* matrix are verified their relevancy by checking their specifications in the corresponding ontology. In particular, it ensures that the criterion is relevant enough to be considered for the goal in the matrix. In order to achieve this, the *Goals-vs-Criteria* matrix is populated with check boxes. After clicking on *Show-Related* button, the system computes the relevancy checking and fills the relevant check-boxes with tick marks. If a check-box is filled with a tick mark, it means that the goal and the criterion belonging to the check-box are related and should be considered for further computation. Selection of relevant *Goals* and *Criteria* and filling or emptying the check-boxes with tick marks can also be achieved manually. These changes are automatically updated on the ontology and the matrix.

Figure 9 is featuring the GUI of *Goals-vs-Criteria* matrix panel and consistency checking.
The extended system also provides options to collect a list of *Criteria* from three different sources. The sources can be the current issue node in the Compendium; all the issue nodes in the currently running Compendium project; or all the issues nodes from the ontology. A list of *Criteria* from the current issue node is collected by accessing the *Options-vs-Criteria* matrix of the current issue node. Similarly, a list of all the *Criteria* in a Compendium project can be collected by accessing the matrices of all the issue nodes. Likewise, the list of *Criteria* in the ontology is collected directly from the vector provided by the class *ConnectionJenaOWL*.

5. CASE-STUDY AND RESULT

The chosen project for the case study is based on a project carried out by Keong Hann Yeoh [13]. In this case study, *Carbon-Sequestration-Process* is analysed and different alternatives are compared using Compendium. This is a decision project, which has four main issue nodes and two sub-issue nodes. For the case study, the issue node about *transportation* is selected. In this node, the issue is "*What is the optimal mode of transportation?*", which has four possible alternatives i.e. *aeroplane*, *lorry*, *ship* and *train*. After evaluating the given *Criteria*, the Compendium recommended the *lorry* as the best alternative.

Figure 8 shows the redesign of the GUI in Compendium with new features. The issue and the positions, which are being discussed, are highlighted with the yellow colour. A properties dialog-box was instantiated by double clicking an issue node. The dialog-box contains *multi-criteria-decision-matrix*, which consists of the *Options-vs-Criteria* matrix and other matrices.

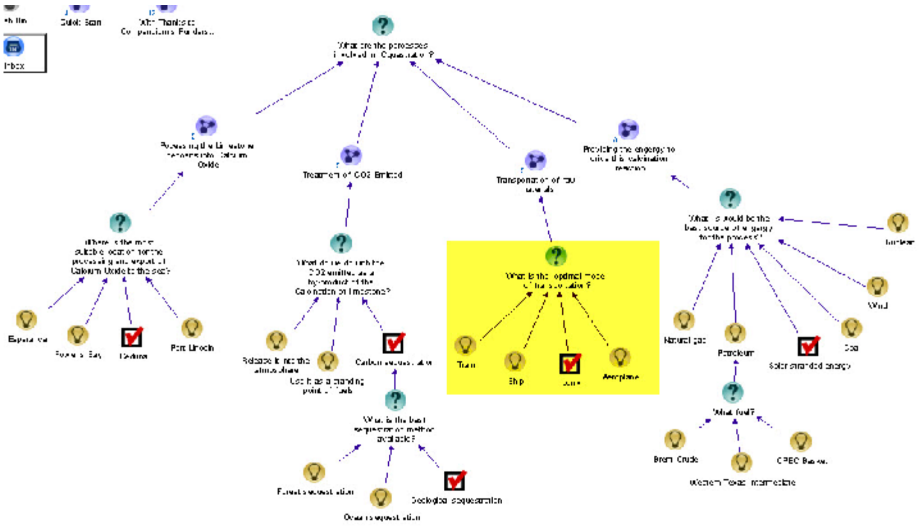
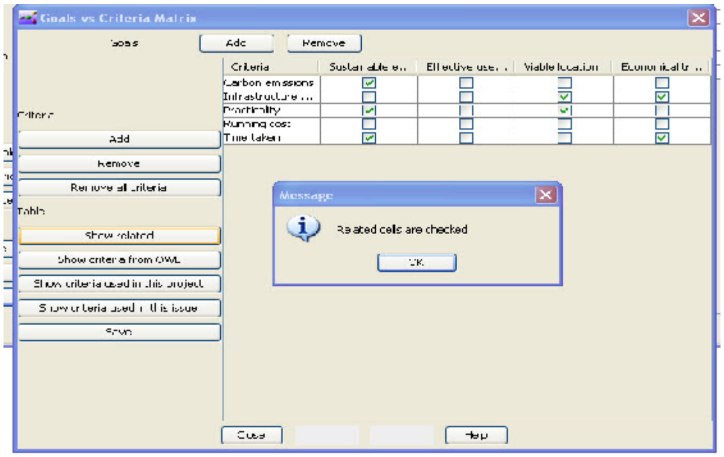

Inbox
What are the processes involved in Sequestration?
Processing the Limestone into Calcium Oxide
Treatment of CO2 Emitted
Transportation of raw materials
Providing the energy to drive the calcination reaction
Where is the most suitable location for the processing and export of Calcium Oxide to the sea?
Esperance
Port Lincoln
What do we do with the CO2 emitted as a by-product of the Calcination of limestone?
Release it into the atmosphere
Carbon sequestration
What is the best sequestration method available?
Forest sequestration
Ocean sequestration
Geological sequestration
What is the optimal mode of transportation?
Train
Ship
Lorry
Aeroplane
What should be the best source of energy for the process?
Nuclear
Wind
Natural gas
Petroleum
Solar stranded energy
Coal
What fuel?
Brent Crude
Western Texas Intermediate
OPEC Basket

Figure 8: Compendium with new features[13]

In the *Options-vs-Criteria* matrix, a *Criteria-Selection-Tree* was presented. While selecting a *Criterion* called *Time-Taken* from the tree, a confirmation dialog was prompted to the user for verification. After the user verification, the *Criterion* was added to the matrix. Similarly, the *Global-Parameters* table provided a *Parameter-Selection-Tree.* In a *Parameter* selection process, the *uranium* was selected, and a confirmation dialog was presented to the user. The selection was verified and was added to the matrix. A *Parameter* contains two attributes i.e. *value* and *unit*. Likewise, in the *Goals-vs-Criteria* matrix, a *Goals-Selection-Tree* was instantiated with a confirmation dialog in order to select a *Goal***,** called *Sustainable-Energy,* from the tree, and the *Goal* was added to the matrix.

For the consistency test, a button labelled *Show-Related* in the *Goals-vs-Criteria* matrix panel helped to check whether it would tick the all the relevant check boxes if the *Goals* and *Criteria* were related. We received the expected result with check boxes and tick marks.

Figure 9 illustrates the process with a confirmation dialog.



Criteria	Sustainable e...	Effective use...	Viable location	Economical tr...
Carbon emissions	☑	□	□	□
Infrastructure ...	□	□	☑	☑
Practicality	☑	□	☑	□
Running cost	□	□	□	□
Time taken	☑	□	□	☑

Related cells are checked

Figure 9: *Goals-vs-Criteria* matrix and consistency checking

All the changes during these processes were updated in the system automatically, which was checked by opening the ontology in Protégé editor. The newly updated entities such as classes, individuals and properties, were thoroughly analyzed. The individual called **Viable_Location** was under the class named **Transportation_Related.** The individual had an object property called **hasCriteria**. Values of the property were checked to see whether there was any updated information. The values were found as **Infrastructure_Availability** and **Practicality**. The result confirmed that the information accessing and updating between Compendium and ontology had been successful, and the consistency checking process was performed accurately.

6. CONCLUSION AND FUTURE WORK

Compendium is a useful software tool, which is being used in dialogue mapping and to support the decision process. Compendium is evolving, as more and more features and functionalities are expected and being developed. One of the examples of added functionality was the integration of *Options-vs-Criteria* matrix in Compendium extending the previous system [4]. Further extension of the matrix with added semantics to guide users through the creation, manipulation and update has been desired in the engineering design processes. Implementation of Semantic Web technologies in the system can provide Compendium with additional adaptability and re-usability.

The project started with the aim of providing new features and tools to the existing *Options-vs-Criteria* matrix and its ancillary matrices with the added semantics. The main features added to the system are; 1) the communication between the system and its ontology, and 2) the availability of user guidance while creating, manipulating and updating of the featured matrices. The newly built system has met its merits in terms of successfully providing required information for all the matrices proposed in the project.

Although the project has been successfully completed in its merit, there are still many potential and desirable features for extension. The exploitation of Semantic Web technologies in order to utilize the ever evolving and useful software tool, Compendium, has been highly desirable in decision processes of scientific and engineering departments. This project is just a beginning in this long and adventurous journey of open source application development process. The best possibility of immediate extension of the work can be; 1) further development of *Goals-vs-Criteria* matrix and its role in the decision matrix, 2) adding more features and functionality of Protégé OWL Editor into Compendium, and 3) displaying OWL ontology in Compendium.

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