Term Project Final Report

The Ontology

Of

Information Science

INFSCI 2906
Knowledge Representation

By

Kittipong Techapanichgul
Sue Yeon Syn

Kittipong Techapanichgul
Sue Yeon Syn

Contents

Kittipong Techapanichgul
Sue Yeon Syn

MEMORANDUM

TO: Prof. Douglas Metzler
FROM: Kittipong Techapanichgul and Sue Yeon Syn
DATE: December 14, 2005
SUBJECT: Report on the term project.

1. The Description of Hypothetical Application

1.1. Goals of the application

The desired system which will be implemented based on the ontology of a science domain is for people especially who are trying to find a university and an advisor, or a person that fits to their research interests in the domain. The basic aim of this system is to help future graduate students find a professor or university that is closely involved in their own interested research areas therefore decide which school to enter and start study. Moreover, it is also effective to find colleagues in specific area who have a similar research interest or has an interest in what you need to work with for a specific research project.

Therefore as mentioned subjected users of this system include people who are interested to start study as a graduate or doctoral student and also eager to find the proper university where they can learn and research what they are interested in, and also researchers who are trying to find other researchers in educational institutions with same or expected research interests.

This idea for the system was first planned based on the facts that there is a very wide range of field covered by a science domain, and depend on a person's interest even in a similar field the focus of research may differ significantly. Also, the research area of each domain for an individual can cover across different fields depends on the research features. Moreover, there are different universities having program for certain domain however due to the facts mentioned the focus or the strength of schools depends on the member of school, meaning people conducting different research activities on their areas, resulting the choice of school more difficult. With this system, we hope to lead users to proper educational environment where they can inspire their research interest best and find researchers for further research.

Kittipong Techapanichgul
Sue Yeon Syn

1.2. Functionality

According to the system goals, this system will have following functionalities.

- Help future graduate students find advisor who has same or similar research interests
- Help future graduate students register for a proper university that supports their research interests
- Help future/current graduate students find proper faculty members or researchers or students from other educational institutions for research domain discussions, advices or activities
- Help researchers find other researchers who has similar research interest in the domain
- Help researchers find other researchers with different research interests who might be interested in participating their research projects or activities

1.3. Data Description

Since the system basically aims to find people in a science domain, the system deals with information on people, mainly faculties from different universities. Also the system will take into consideration on the specific research areas in the domain. Faculty information will be consisted of name of faculty, university or educational institute that the faculty is involved, title and status, interested research area, and other information related to research area such as knowledge background, teaching courses, publications and projects. The science domain information will differ depend on what domain it is. For simplicity of this prototype, the system will implement domain of Information Science and provide results in faculty information of Information Science Schools. To implement mentioned functionalities and deal with the data, ontology on Information Science domain and ontology on people in Information Science Schools are designed.

Kittipong Techapanichgul
Sue Yeon Syn

2. Ontology Design

2.1. Ontology and Based Concepts

An ontology is a set of concepts - such as things, events, and relations - that are specified in some way (such as specific natural language) in order to create an agreed-upon vocabulary for exchanging information. Ontology describes the concepts and relationships that are important in a particular domain, providing a vocabulary for that domain as well as a computerized specification of the meaning of terms used in the vocabulary. Ontology is used in many applications such as knowledge management systems, e-commerce, and semantic web services.

To achieve the goals of the system described above, the system needs at least two ontologies in describing about **knowledge concepts**, which will be used as a knowledge base. Those two ontologies are presented as follow:

1. **The "Information Science Domain" Ontology**
   It is an ontology describing about the knowledge and/or concepts in the information science field. The ontology needs to be a scalable and extensible ontology which will let other new knowledge concepts in the field easily be added as appropriate. However, the complete ontology is very big and quite complicated which will be time-consuming, so we decided to present only a part of the entire ontology.

2. **The "Information Science Academia" Ontology**
   It is an ontology describing mainly about people and their academic works involving with this particular field. For the system, the ontology provides knowledge about the academic environment to the system in order to extract hidden knowledge concepts from people and their works. To be clear, the following topic will give readers an idea about the knowledge concepts in what we mean in this context.

For these ontology, it should be clear what we mean by knowledge concepts. Each knowledge concept is an abstract class, the purpose of which is to describe knowledge in the particular field (it means Information Science (IS) field in our system). It can contain either other knowledge concepts or only concept about itself. For instance, cognitive science is a knowledge concept about study of knowledge and how it is acquired, combining aspects of philosophy, psychology, linguistics, anthropology, and artificial intelligence. The knowledge concept of cognitive science contains other knowledge concepts such as AI, Reasoning, etc.

Kittipong Techapanichgul
Sue Yeon Syn

2.2. Pre-Research on Domain

As mentioned above, for the system prototype the ontology of Information Science domain is built. At the earlier stage of the ontology building, research on knowledge concepts in the interested areas needed for the desired application were carried out. Also, gathering some instances in focusing knowledge concepts can help us to define the appropriate attributes by generalizing those attributes about the concepts. With these purposes, two pre-research were conducted, one on defining information science from previous literatures, and the other on educational environment of information science schools by searching on curriculums, faculty research interests, and projects, etc. from top information science schools. Because the two main ontologies that we concerned are **information science ontology** and **information science academia**, the following topic might give report readers some basic ideas about the word “information science”.

Lai discussed about the origin of Information Science in [4]. According to the paper, several authors regard Vannevar Bush's 1945 article "As We May Think," as the origin of information science. Some researchers tend to think that 1937, American Documentation Institute-ADI was founded this year, was the origin of information science. However, following the historical investigation of Jesse Shera and W. Boyd Rayward, Lai believes that we should go back the origin of information science to 1895. In this year, the International Institute of Bibliography was founded by Paul Otlet and his colleagues to organize a universal bibliographical catalog.

It may still not be clear what exactly Information Science is because of its fuzzy boundary unlike other sciences like Math or Physics that seem to have clear boundary. In 1963, Robert S. Taylor offered a statement of scope for information sciences in an article for Library Journal:

1. The study of the properties, structure and transmission of specialized knowledge.
2. The development of methods for its useful organization and dissemination.

Fritz Machlup and Una Mansfield [5] describe four principal uses of the term "information science:"

1. In its broadest sense, it stands for the systematic study of information and my include all or any combination of the academic disciplines ...;
2. When included in the phrase "computer and information science," information science denotes the study of the phenomena of interest to those who deal with computers as processors of information;
3. In library and information science, it indicates a concern with the application of new tasks and new technology to the traditional practices of librarianship; and
4. In its narrowest sense, information science is used as the name for a new area of study that is evolving from the intersection of the other three mentioned areas.

Harold Borko [2] offered the following extended definition of "information science" reflecting the position of those who were active in this newly emerging area of research: *"Information science is that discipline that investigates the properties and behavior of information, the forces governing the flow of information, and the means of processing information for optimum accessibility and usability. It is concerned with that body of knowledge relating to the organization, collection, organization, storage, retrieval, interpretation, transmission, transformation, and utilization of information. This includes the investigation of information representations in both natural and artificial systems. It is an interdisciplinary science derived from and related to such fields as mathematics, logic, linguistics, psychology, computer technology, operations research, the graphic arts, communications, library science, management, and other similar fields. It has both a pure science component, which inquires into the subject without regard to its application, and an applied science component, which develops services and products."*

Martha E. Williams [7] emphasized the multidisciplinary character of the field and the range of problems it tries to address: *"Information science brings together and uses the theories, principles, techniques and technologies of a variety of disciplines toward the solution of information problems. Among the disciplines brought together in this amalgam called information science are computer sciences, cognitive science, psychology, mathematics, logic, information theory, electronics, communications, linguistics, economics, classification science, systems science, library science and management science. They are brought to bear in solving the problems associated with information -- its generation, organization, representation, processing, distribution, communication and use."*

As you can see from the history, dealing with abstract thing like knowledge is quite a difficult task because we cannot see the characteristics of classes apparently. Furthermore, humans have dissimilar pictures in their heads although they are talking about the same concept. Even though they have the same pictures, they express the concept definition differently. Those are reasons why the ontology about the same concepts might differ from person to person.

However, those definitions gave us a sense about "information science" which leads to the proposed ontology shown in next topics. All in all, we cannot deny the fact that the ontology is not complete or cover all the information science concepts. However, the ontology can be used in the mentioned system and provides reasonable answers for the given system query.

2.3. Proposed Ontology

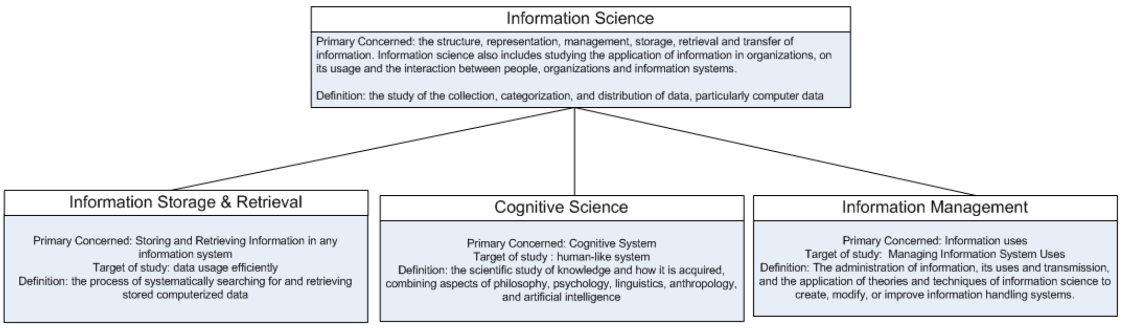
Based on the pre-research, the characteristics are analyzed to understand necessary classes and attributes in building ontology among fields in Information Science domain. Classes are defined to represent research areas of Information Science domain for Information Science Domain Ontology and research activities in Information Science Academic environment for Information Science Academia Ontology.

2.3.1. Ontology of Information Science Domain

2.3.1.1. Information Science class

The top of the ontology is *"information science"* class, which contains all sciences and/or concepts that are concerned with the gathering, manipulation, classification, storage, and retrieval of recorded knowledge. Due to a big number of subclasses under this class, we just pick an interesting subclass and study those subclasses in depth. The subclasses that we chose are *"information storage & retrieval"*, *"cognitive science"* and *"information management"* (Figure 1).

The reason that we pick these three areas as the main areas of information science is that these three areas seem to influence the way information science people (only focus on both faculty and student) extremely study about and/or pay a big attention to. Another reason that support that belief is the fact that after pre-research on the curriculum of the top information science schools (e.g., Drexel university, University of Maryland at College Park, Syracuse University , University of Pittsburgh and Carnegie Mellon University), they have common study areas consisting of information storage & retrieval, cognitive science and information management.



<Figure 1> Information Science class and its main components

2.3.1.2. Cognitive Science class

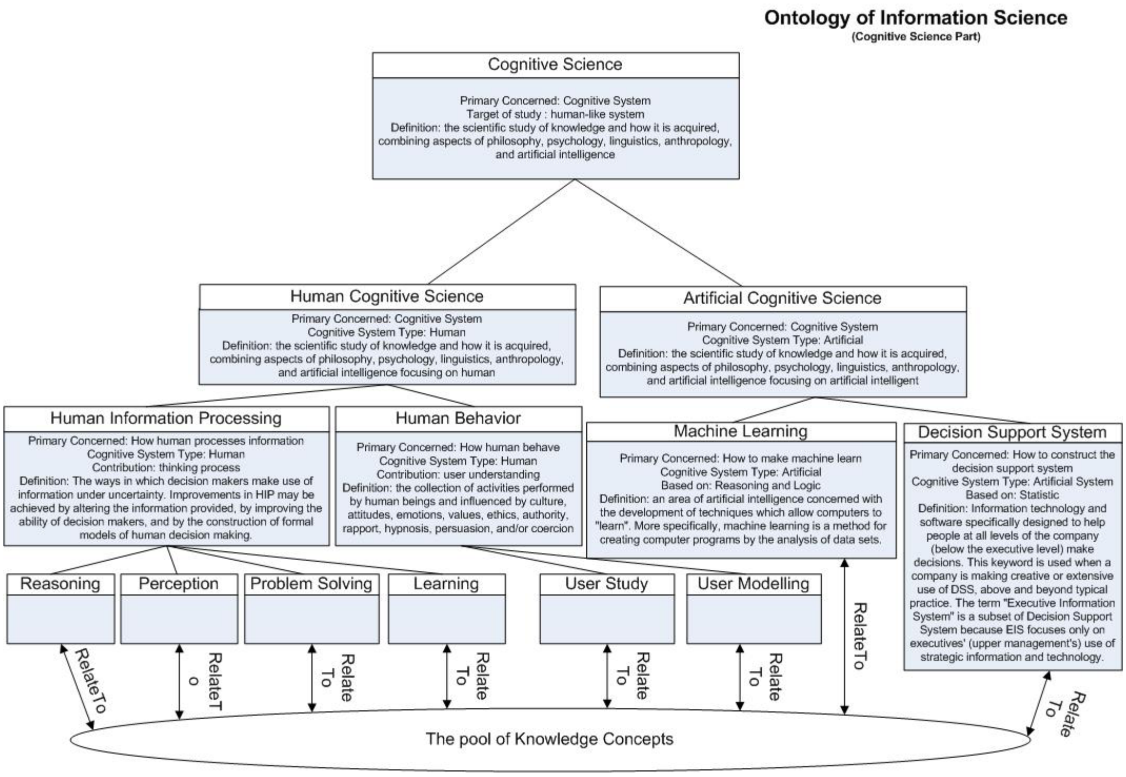
Cognitive Science tends to view the world outside the mind much as other sciences do; thus it has an objective, observer-independent existence. Cognitive science is usually

Kittipong Techapanichgul
Sue Yeon Syn

seen as compatible with and interdependent with the physical sciences, and makes frequent use of the scientific method, as well as simulation or modeling, often comparing the output of models with aspects of human behavior. Still, there is much disagreement about the exact relationship between cognitive science and other fields, and the inter-disciplinary nature of cognitive science is largely both unrealized and circumscribed.

Having reading the explanation above, a possible ontology in cognitive science part that can be used in the desired system was designed like the chart below. As you can see from the chart, the cognitive science contains many elements but all of them seem to belong to cognitive science domain. Note that the bottom of the ontology is knowledge concepts that present some concepts about cognitive science.

The "*cognitive science"* class is a subclass of *"information science"* class. This class contains scientific study of knowledge and how it is acquired, combining aspects of philosophy, psychology, linguistics, anthropology, and artificial intelligence. Under this class, there are two subclasses that are *"human cognitive science"* and "*artificial cognitive science"* (Figure 2). Both subclasses focus on different type of cognitive system.



<Figure 2> Cognitive Science class and its components

Below are the description and explanation for the subclasses of *"cognitive science"* class.

Kittipong Techapanichgul
Sue Yeon Syn

Human Cognitive Science Class
The *"human cognitive science"* class is a subclass of "*cognitive science"* class. This class focuses on knowledge concepts about how humans acquire, perceive, recognize, express information and make a decision as well as problem solving. Under this class, there are two subclasses that are *"human information processing"* and *"human behavior"*. Both subclasses contribute to different things. Specifically speaking, "human information processing" will mainly contribute to think process while "human behavior" basically contributes to user understanding.

Artificial Cognitive Science Class
The *"artificial cognitive science"* class is a subclass of *"cognitive science"* class. This class focuses on knowledge concepts about how can make computers to learn and/or support human activities. There are two subclasses under this class that are *"machine learning"* and *"decision support system"*. Both subclasses bases on the different foundation. Specifically speaking, "machine learning" uses logics and reasoning as primary foundation while "decision support system" uses statistics as primary foundation.

Human Information Processing Class
The *"human information processing"* class is a subclass of *"human cognitive science"* class. This class focuses on knowledge concepts about the ways in which decision makers make use of information under uncertainty. Improvements in human information processing may be achieved by altering the information provided, by improving the ability of decision makers, and by the construction of formal models of human decision making. In fact, there are many subclasses under this class. So, the best way to present the subclass is to only pick some subclasses to show report readers what the subclass should be. Therefore, *"perception", "learning", "reasoning"* and *"problem solving"* are considered to be good examples of the subclasses.

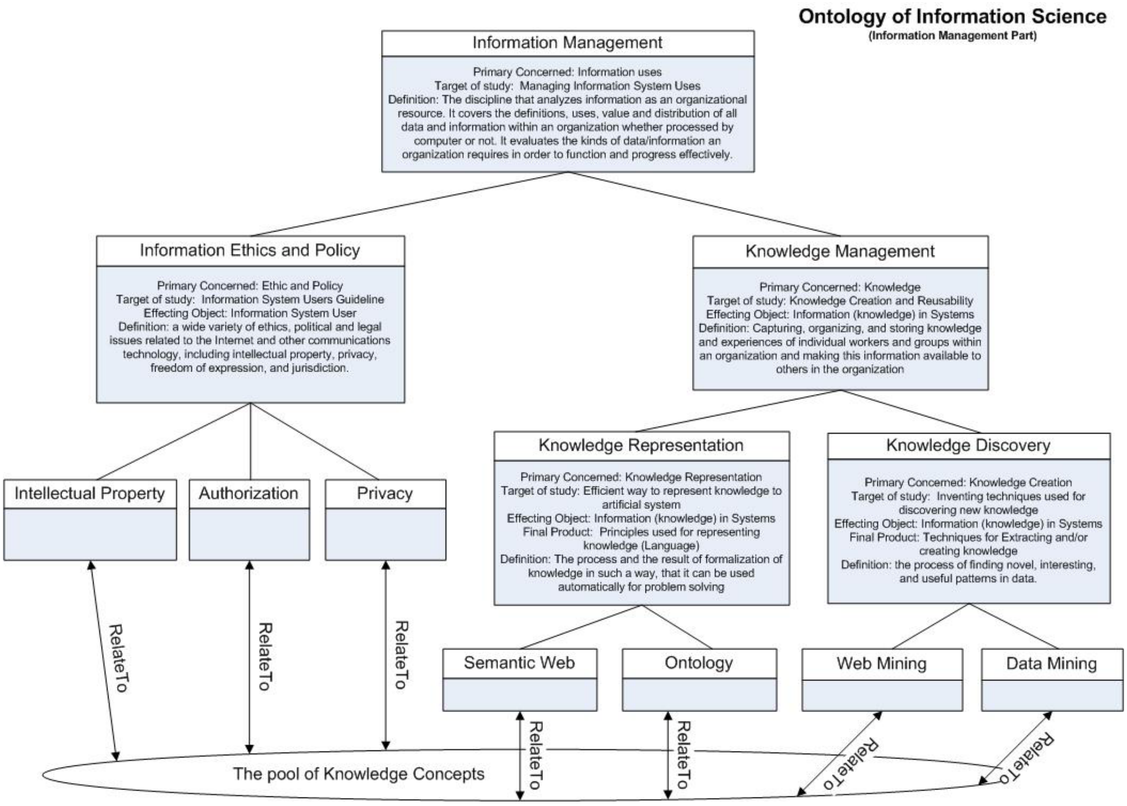
Human behavior Class
The *"human behavior"* class is a subclass of *"human cognitive science"* class. This class focuses on knowledge concepts about the collection of activities performed by human beings and influenced by culture, attitudes, emotions, values, ethics, authority, rapport, hypnosis, persuasion, and/or coercion. There are many subclasses under this class. As a result, the best way to present the subclass is to only pick some subclasses to show report readers what the subclass should be. Therefore, *"user modeling"* and *"user study"* are considered to be good examples of the subclasses here.

2.3.1.3. Information Management class

According to answer.com [1], it defines the term, information management, as the discipline that analyzes information as an organizational resource. It covers the definitions, uses, value and distribution of all data and information within an organization whether processed by computer or not. It evaluates the kinds of data/information an organization requires in order to function and progress effectively.

From that point of view, we can create a part of the information science ontology that will be used in the system to provide knowledge about the information management field. As you can see from the chart below, the classes in this particular area are presented in hierarchical structure.

The *"information management"* class is a subclass of *"information science"* class. This class contains scientific study about handling of knowledge acquired by one or many disparate sources in a way that optimizes access by all who have a share in that knowledge or a right to that knowledge. Under this class, there are two subclasses that are "*Information Ethics and Policy"* and "*Knowledge Management"* (Figure 3). Both subclasses affect different targeted object. Specifically speaking, *"Information Ethics and Policy"* class mainly affect information system users while *"Knowledge Management"* class mainly affect knowledge in information system.



<Figure 3> Information Management class and its components

Below are the description and explanation for the subclasses of *"information management"* class.

Information Ethics and Policy Class
The *"Information Ethics and Policy"* class is a subclass of "*Information Management"* class. This class focuses on knowledge concepts in wide variety of ethics, political and legal issues related to the Internet and other communications technology, including intellectual property, privacy, freedom of expression, and jurisdiction. For the subclasses, because providing subclasses in great detail can mess up the ontology, the best way to present them is to only pick some subclasses to show report readers what the subclass should be. Therefore, *"intellectual property"*, *"authorization"* and *"privacy"* are considered to be good examples of the subclasses.

Knowledge Management Class
The *"Knowledge Management"* class is a subclass of *"Information Management"* class. This class focuses on knowledge concepts about capturing, organizing, and storing knowledge and experiences of individual workers and groups within an organization and making this information available to others in the organization. Under this class, there are two subclasses that are *"Knowledge Representation"* and *"Knowledge Discovery"*. Both subclasses produce different outcome to the field. *"Knowledge Representation"* will lead principles about representing knowledge which will be a kind of Languages being able to use in computer system while *"Knowledge Discovery"* brings new techniques used for knowledge extraction and/or creation to the field.

Knowledge Representation Class
The *"Knowledge Representation"* class is a subclass of *"Knowledge Management"* class. This class focuses on knowledge concepts about the process and the result of formalization of knowledge in such a way, that it can be used automatically for problem solving. The subclasses that we pick here are *"Semantic Web"* and *"Ontology"* which belong to "knowledge representation" domain.

Knowledge Discovery Class
The *"Knowledge Discovery"* class is a subclass of *"Knowledge Management"* class. This class focuses on knowledge concepts about the process of finding novel, interesting, and useful patterns in data. The subclasses that we pick here are *"Web Mining"* and *"Data Mining"* which belong to "knowledge discovery" domain.

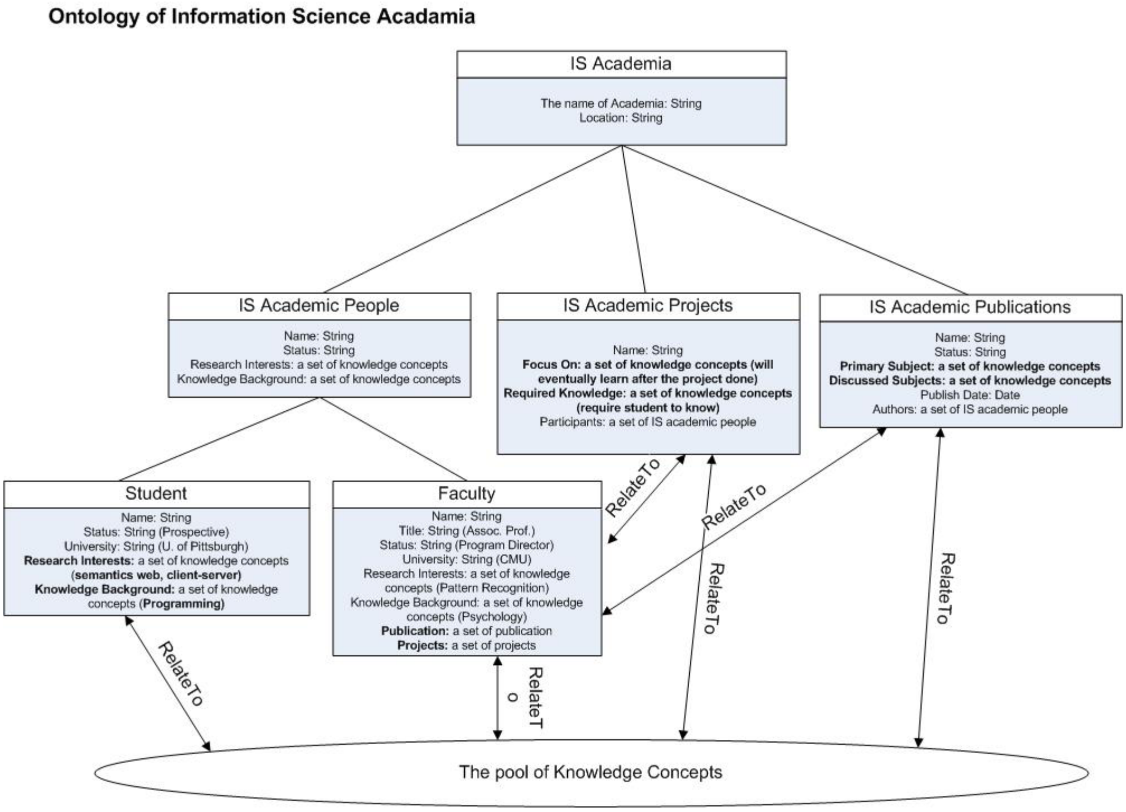
2.3.2. Ontology of Information Science Academia

Information science academia ontology is another ontology that needs to be used along with the information science ontology in order to help the system achieve the system goals. Since the information science ontology provides knowledge about the Information science concepts to the system only, system requires another ontology that can give more

Kittipong Techapanichgul
Sue Yeon Syn

information about academic environment. As a result, the ontology of information science academia was created (Figure 4).

This ontology has "*Information Science Academia*" as the root class. This class represents information science academic institutions that include labs, research centers and schools which primarily concentrate on information science area. With three subclasses that are people, project and publication, this class will contain necessary classes for the desired system. Since the class is designed to be extensible, most of things relating to academia can be added as subclasses without affecting any existing subclass.



<Figure 4> Ontology of Information Science Academia

Below are the description and explanation for the subclasses of "*Information Science Academia*" class.

Information Science Academic People Class

This class is created for all people involving in Information Science field. However, the system focuses only students and faculties. As a result, there are only two types of people in the ontology. A student research interests and knowledge background will be used for making a query to find an appropriate advisor while faculty who is the answer of the query is likely to have common research interests according to their knowledge background, projects and publication he possesses. From this class, there are only two subclasses that are student and faculty.

Information Science Academic Projects Class
Having common research interests is not enough power to say that student and faculty will be a good match. As a consequence, knowledge concepts in projects that faculty is currently working on can be used as additional information. The *"Information Science Academic Projects"* class was created from that reason.

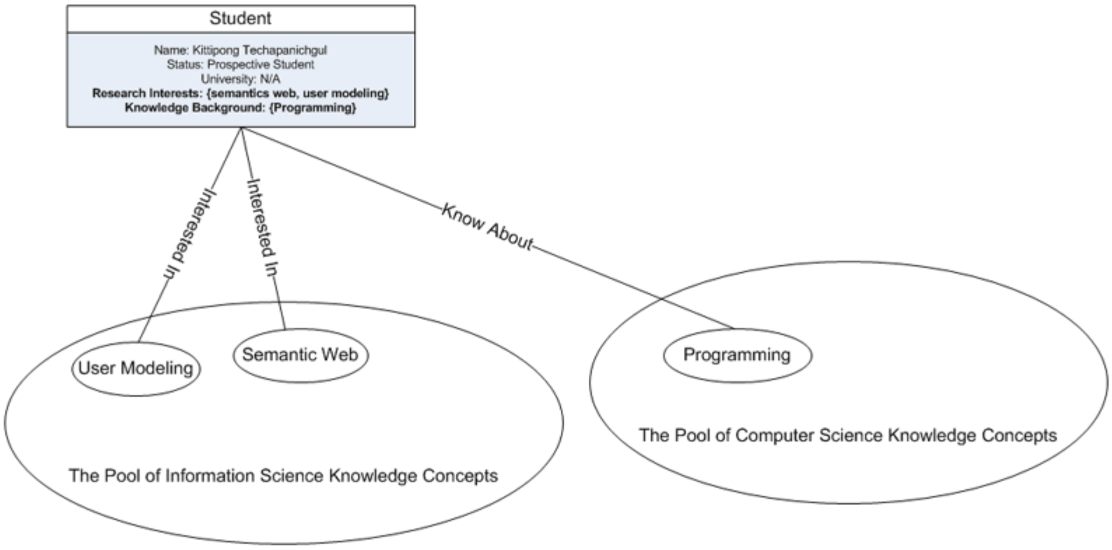
Information Science Academic Publication Class
Like the *"Information Science Academic Projects"* class, knowledge concepts in faculty publication can also be used as extra information. The *"Information Science Academic Publication"* class was created to present related knowledge of the professor that doesn't explicitly indicate in his research interests.

2.4 How the hypothetical application works with the ontology?

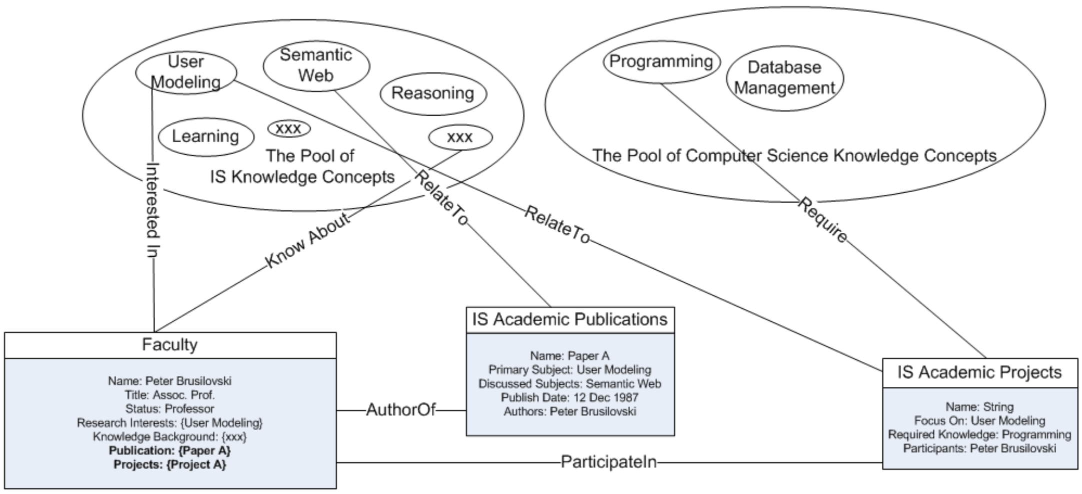
From the ontology we have mentioned above, it is time to describe how the system uses the ontology to successfully provide a reasonable answer for the given query. We will assume that instances of faculty, student, publication and projects already exist in the system. In order to help report readers understand the system architecture easily, we pick a given situation to show how system works along with the ontology. In this given situation, system will help a prospective student to find proper advisor with the condition that both of them have common research interests. The system will follow these steps.

- The system receives a query from a prospective student which contains information about the new student who wants to find an advisor. Student must indicate his interests in some levels. It can be either knowledge concepts or classes in information science ontology. Also, the student query can include knowledge background (which might need information from other ontology in another system in case that student graduated from non-information science field) to help system know more about that student.

Kittipong Techapanichgul
Sue Yeon Syn



- Information about the research interests and knowledge background will be linked to the same knowledge concept in the knowledge concept pool (which contains instances of knowledge concept in information science).
- All of the faculty instances in the faculty classes will be selected. Like student, research interests and knowledge background of each faculty will be linked to the knowledge concepts in the pool.



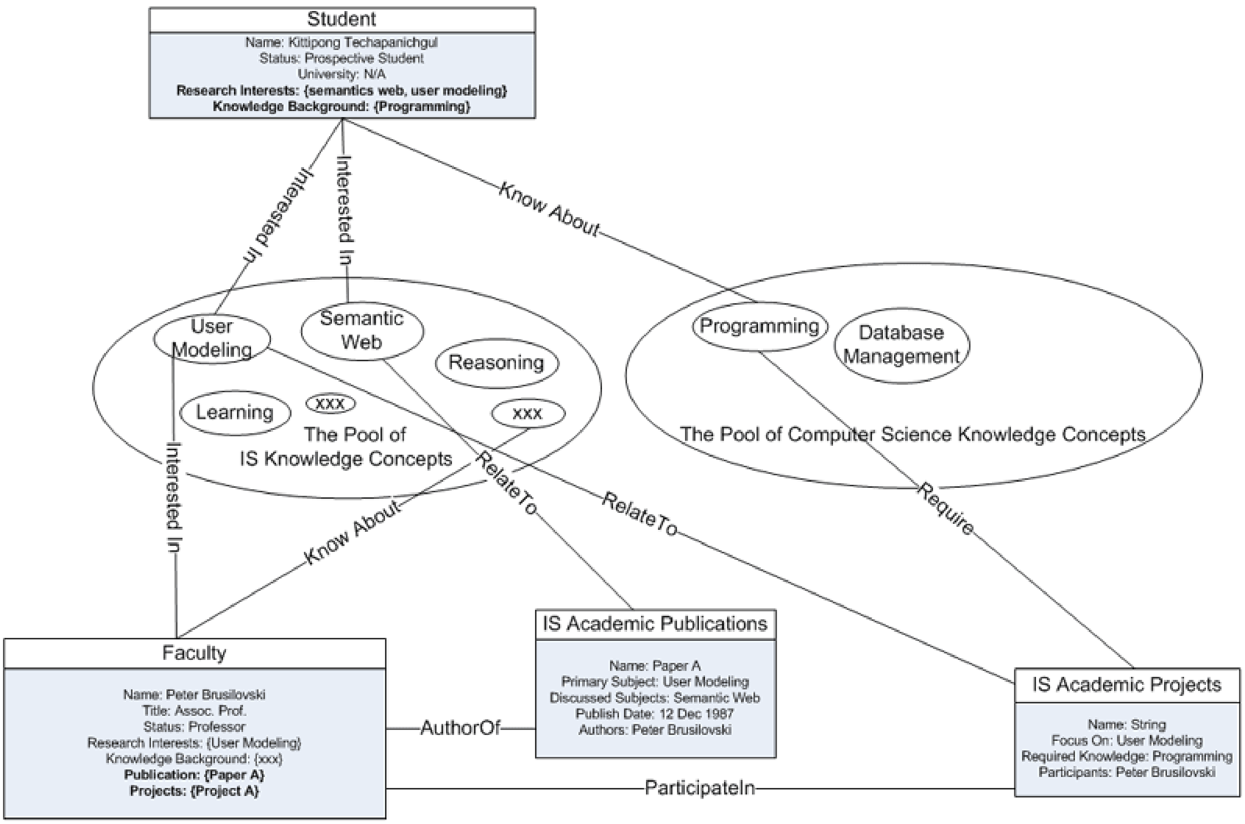
- In case that the faculty is supervising on information science projects, the knowledge about those projects will be interpret by the system and map them

Kittipong Techapanichgul
Sue Yeon Syn

to the pool of knowledge concepts by using value in attribute named "focus on".

- In case that the faculty has published papers in information science area, the subjects and discussed area will be interpret by the system and map them to the pool of knowledge concepts by using value in attribute named "primary subject" and "discussed subject".

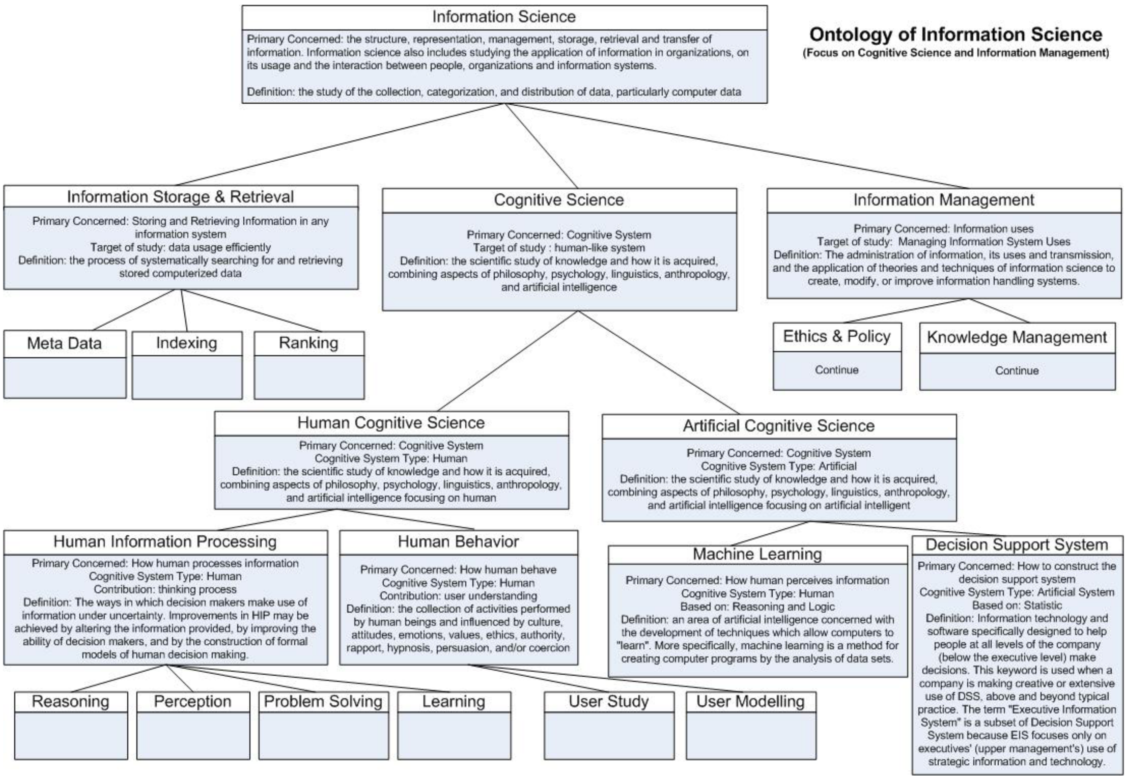
- After the system links the faculty to the knowledge concepts and links the student to the knowledge concepts, the system will find out from the knowledge base what the best pair of student and faculty is. The faculty in this pair will be the answer of the system according to the student research interests and his knowledge background. The chart below show the result once both student and faculty are linked to knowledge concept pool.



As you can see from the chart above, both student and faculty have only one knowledge concept in common that is "user modeling". As a result, student might think that the faculty would not be a good match because of a few common research interests (assume that student have searched information through university website about the program, faculties, etc.). However, this system presents another perspective on this same issue. Since the faculty has published a paper about "user modeling" and discussed on

Kittipong Techapanichgul
Sue Yeon Syn

"semantic web" which is in students' research interest. So, the faculty could be very good advisor because the faculty has common interests with the student but doesn't indicate to the system explicitly. Besides, when the system considers the student's knowledge background, the system figured out that this student might be able to help the faculty in his project that he is supervising because the student has programming skills and this skills can give the faculty a hand. As a result, this match seems to be a reasonable answer obtained from the system according to the given query.



With the information science ontology, the system will have capabilities of generalizing students and faculties' research interests. For example, if student is interested in user modeling, the system figure out that he might be interested in user study also. Why? It is due to the ontology structure that knowledge concept about user modeling is in the same domain as user study. As a result, the ontology tends to give hidden facts about the students' interests which will allow system to provide creative and reasonable for any given query.

3. Representations of Ontology

There are different technologies in representing and using ontology in systems. For this project, the designed two ontologies are presented in three different technologies depending on their characteristics in processing ontologies for the system. The selected three technologies are first-order logic, OWL, and Protégé.

3.1. First-Order Logic

First-order logic (FOL) is symbolized reasoning in which each sentence, or statement, is consists of a subject and a predicate. FOL is used to model the world in terms of objects, properties, relations and functions. This formalism is chosen to present ontologies since it is know as simple and convenient in reasoning and also clear in representation.

R1. $\forall x \forall y \forall z$ [Contains(x, y) $\rightarrow$ Contains(x, z) $\wedge$ Contains(z, y)]
R2. $\forall x$ [Faculty(x) $\rightarrow$ x= a1 $\vee$ x= a2 $\vee$ x= a3 $\vee$ x= ….]
R3. $\forall x$ [Student(x) $\rightarrow$ x= a1 $\vee$ x= a2 $\vee$ x= a3 $\vee$ x= ….]
R3. $\forall x \forall y$ [WorkAt(x, y) $\rightarrow$ Faculty(x) $\wedge$ HasAttribute(Faculty, {Name = x, University = y})]
R4. $\forall x \forall y$ [InterestedIn(x, y) $\rightarrow$ Faculty(x) $\wedge$ HasAttribute(Faculty, {Name = x, Research Interests = y})]
R5. $\forall x \forall y$ [HasProject(x, y) $\rightarrow$ Faculty(x) $\wedge$ HasAttribute(Faculty, {Name = x, Projects = y})]
R6. $\forall x \forall y$ [Teaches(x, y) $\rightarrow$ Faculty(x) $\wedge$ HasAttribute(Faculty, {Name = x, Class Taught = y})]
R7. $\forall x \forall y$ [Published(x, y) $\rightarrow$ Faculty(x) $\wedge$ HasAttribute(Faculty, {Name = x, Publication = y})]
R8. $\forall x \forall y \forall z$ [InterestedIn(x, y) $\rightarrow$ Contains(y, z) $\wedge$ InterestedIn(x, z)]
R9. $\forall x \forall y \forall z \forall a$ [InterestedIn(x, y) $\rightarrow$ HasAttribute(y, z = a) $\wedge$ InterestedIn(x, a)]
R10. $\forall x \forall y \forall z$ [InterestedIn(x, z) $\rightarrow$ HasProject(x, y) $\wedge$ IsA(y, z)]
R11. $\forall x \forall y \forall z$ [InterestedIn(x, z) $\rightarrow$ Teaches(x, y) $\wedge$ IsA(y, z)]
R12. $\forall x \forall y \forall z$ [InterestedIn(x, z) $\rightarrow$ Published(x, y) $\wedge$ IsA(y, z)]
R13. $\forall x \forall y \forall z$ [InterestMatches(x, y) $\rightarrow$ InterestedIn(x, z) $\wedge$ InterestedIn(y, z)]
R14. $\forall x \forall y \forall z$ [BestMathches(x, y) $\rightarrow$ The highest InterestMatches]

<Figure 5> the list of defined relations and functions base on the ontologies

Based on the design of two ontologies, some functions/rules were defined (Figure 5). With functions and rules defined, some relations are also defined. Below is the list of defined objects, properties, relations and functions. Here it is taken into account that Contains(x, y) indicates that x is superclass of y and y is subclass of x. Also HasAttribute(x, y = z) is representing that a class x has attribute with name y and value z. IsA(x, y) is to indicate that an object or class x has a concept of y which is one of the concepts or classes defined by the ontology.

R1 indicates that a class contains all subclasses of a subclass. R2 and R3 are to insert instances of faculty and student. From R4 to R7 defines functions of WorkAt(x, y), InterestedIn(x, a), HasProject(x, b), Teaches(x, c), Published(x, d) where x is an instance of people mainly faculty and y, a, b, c, and d are the values of the faculty attributes. a, b, c, and d are from attributes Research Interests, Projects, Class Taught, and Publication respectively which all defined to represent research interest in the system in different aspects. Therefore in R10 – R 12, they matches to their related concepts and are made to be an area of research interest. R8 represents the inheritance of the hierarchy in the ontology. R9 conclude the value of attribute which describes interested field to be a concept of study area. The InterestMaches(x, y) matches two people x and y who has same research interest area. The BestMaches(x, y) will go through all found InterestMatches and figure out the best match meaning the most proper person of shared research interest.

In this paper, to show how defined functions and rules work in the process of reasoning in system, an example of using FOL in system process is provided. For the example, we will only focus on the field of Cognitive Science in Information Science domain for simplicity. Note that with the complete full ontology, the process is much more complicated because of larger number of overlapping interest matches and different weights on concepts and values of attributes to find the best match.

Let's say that John, a future graduate student is trying to find a university that will support his research interest in terms of providing courses, projects, and mostly the proper faculty members. He will provide which research areas he is interested in to the system as an input query.

Future student, John

Is interested in cognitive system in terms of designing systems based on understanding user needs, user modeling, and system development that can support a human-like processes

<Figure 6> The input query

The query can be expressed in FOL as below.

Q1. $\exists$ y [Student(y) $\rightarrow$ y=John]
Q2. InterestedIn(John, Cognitive System)
Q3. InterestedIn(John, user understanding)
Q4. InterestedIn(John, User Modeling)
Q5. InterestedIn(John, human-like system)

Kittipong Techapanichgul
Sue Yeon Syn

<Figure 7> Query in FOL

From the IS People Ontology and its instance, a system can search faculties who may be take into consideration. For example, if there is a fact in Knowledge Base shown in Figure 4, it is possible to do reasoning as Figure 5 when it is combined with facts and rules of ontologies. .

Faculty at University of Pittsburgh, Dr. Stephen Hirtle
Is interested in classification, cognitive science
Has projects of Spatial Cognition and Computation(SCC) and Classification Society of North America(CSNA)
Teaches Human Information Processing

F1. $\forall$x [Faculty(x) → x=Stephen Hirtle]
F2. WorksAt(Stephen Hirtle, University of Pittsburgh)
F3. InterestedIn(Stephen Hirtle, {Cognitive Science, Classification})
F4. HasProject(Stephen Hirtle, {SCC, CSNA })
F5. Teaches(Stephen Hirtle, Human Information Processing)
F6. IsA(SCC, Cognitive Science)
F7. IsA(CSNA, Classification)
F8. IsA(Human Information Processing, Human Information Processing)

<Figure 8> Fact in Knowledg Base and its FOL expression

Q2. Interested(John, Cognitive Science)
F3. InterestedIn(Stephen Hirtle, Cognitive Science)
R13. $\forall$x$\forall$y$\forall$z [InterestMatches(x, y) → InterestedIn(x, z) $\wedge$ InterestedIn(y, z)]

$\therefore$ InterestMatches(John, Stephen Hirtle)

<Figure 9> Example of Reasoning Process

As shown in Figure 5, it is possible to find numerous InterestMatches of different faculties and even multiple matches for one faculty depend of the weights and amount of overlap. Based on the number of InterestMatches for each faculty searched, it is possible to find the BestMatch of faculty and university. Also it is possible to provide the extension of research interest area with the matching result and the IS domain ontology. To see the example of FOL process, see Appendix 1.

3.2. OWL

The OWL Web Ontology Language [6] can be used to explicitly represent the meaning of terms in vocabularies and the relationships between those terms. The OWL is intended to be used when the information contained in documents needs to be processed by applications. OWL adds more vocabulary for describing properties and classes compared to XML, RDF, and RDFS. The reason the OWL is used in representing ontologies in this project is that OWL has more facilities for expressing meaning and semantics than XML, RDF, and RDF-S, and thus OWL goes beyond these languages in its ability to represent machine interpretable content on the Web.

The OWL representation of the proposed ontologies is attached in Appendix 2.

3.3. Protégé

Protégé is a free, open source ontology editor and knowledge-base framework. It supports Frames, XML Schema, RDF, RDFS and OWL. It provides a flexible and easy environment in developing applications with ontologies. Protégé is chosen as a method to present ontologies for this project because it implements a rich set of knowledge-modeling structures and actions that support the creation, visualization, and manipulation of ontologies in various representation formats.

The Protégé representation of the proposed ontology is provided in attached electronic files. However, we also have documented class hierarchy, summarized all class descriptions and noted slot descriptions that we created in the protégé file in this report as well to help user readers see an overall picture of the ontology described before.

Ontology Class Hierarchy

- Information Science (Root of Information Science ontology)
  - Congitive Science
    - ArtificialCognitiveScience
      - DecisionSupportSystem
      - MachineLearning
    - HumanCognitiveScience
      - HumanBehavior
        - User Modelling
        - User Study
      - HumanInformationProcessing
        - HumanPerception
        - Learning
        - ProblemSolving
        - Reasoning
  - Information Management

            - Information Ethics and Policy
                - Authorization
                - Intellectual Property
                - Privacy
            - KnowledgeManagement
                - Knowledge Discovery
                    - Data Mining
                    - Web Mining
                - Knowledge Representation
                    - Ontology
                    - Semantic Web
        - InformationRetrieval
            - Indexing
            - MetaData
            - Ranking
- Information Science Acadamia
    - Information Science Academic Project
    - Information Science People
        - Faculty
        - Student
    - Information Science Published Paper

Class information table

Class Name	SuperClasses	Subclasses	Slots	Documentation
Information Science	THING	• InformationRetrieval • CongitiveScience • InformationManagement	• ConceptDescription • PrimaryInterest	This class contains all sciences and/or concepts that are concerned with the gathering, manipulation, classification, storage, and retrieval of recorded knowledge.
InformationRetrieval	Information Science	• MetaData • Ranking • Indexing	• ConceptDescription • PrimaryInterest • TargetOfStudy	This class contains knowledge concepts of systematically searching for and retrieving stored computerized data
CongitiveScience	Information Science	• HumanCognitiveScience • ArtificialCognitiveScience	• ConceptDescription • PrimaryInterest • TargetOfStudy	This class contains scientific study of knowledge and how it is acquired, combining aspects of philosophy, psychology, linguistics, anthropology, and artificial intelligence
InformationManagement	Information Science	• Information Ethics and Policy • KnowledgeManagement	• ConceptDescription • PrimaryInterest • TargetOfStudy	This class contains concepts about administrating of information, its uses and transmission, and the application of theories and techniques of information science to create, modify, or improve information handling systems

HumanCognitiveScience	CongitiveScience	• HumanInformationProcessing • HumanBehavior	• ConceptDescription • PrimaryInterest • TargetOfStudy • CongnitiveSystemType	This class contains scientific study of knowledge and how it is acquired, combining aspects of philosophy, psychology, linguistics, anthropology (Human only)
ArtificialCognitiveScience	CongitiveScience	• HumanInformationProcessing • HumanBehavior	• ConceptDescription • PrimaryInterest • TargetOfStudy • CongnitiveSystemType	This class contains scientific study of knowledge and how it is acquired, combining aspects of philosophy, psychology, linguistics, anthropology (Artificial only)
HumanInformationProcessing	HumanCognitiveScience	• HumanPerception • ProblemSolving • Reasoning • Learning	• ConceptDescription • PrimaryInterest • TargetOfStudy • CongnitiveSystemType • Contribution	This class contains knowledge concepts explaining how humans process surrounding information
HumanBehavior	HumanCognitiveScience	• User Modelling • User Study	• ConceptDescription • PrimaryInterest • TargetOfStudy • CongnitiveSystemType • Contribution	This class covers knowledge concepts about activities performed by human beings and influenced by culture, attitudes, emotions, values, ethics, authority, rapport, hypnosis, persuasion, and/or coercion
Information Ethics and Policy	InformationManagement	• Intellectual Property • Authorization • Privacy	• ConceptDescription • PrimaryInterest • TargetOfStudy • EffectingObject	This class contains knowledge concepts in a wide variety of ethics, political and legal issues related to the Internet and other communications technology, including intellectual property, privacy, freedom of expression, and jurisdiction.
KnowledgeManagement	InformationManagement	• Knowledge Representation • Knowledge Discovery	• ConceptDescription • PrimaryInterest • TargetOfStudy • EffectingObject	This class contains knowledge concepts about capturing, organizing, and storing knowledge and experiences of individual workers and groups within an organization and making this information available to others in the organization
Knowledge Representation	KnowledgeManagement	• Semantic Web • Ontology	• ConceptDescription • PrimaryInterest • TargetOfStudy • EffectingObject • FinalProduct	This class contains knowledge concepts about the process and the result of formalization of knowledge in such a way, that it can be used automatically for problem solving
Knowledge Discovery	KnowledgeManagement	• Web Mining • Data Mining	• ConceptDescription • PrimaryInterest • TargetOfStudy • EffectingObject • FinalProduct	This class contains knowledge concepts about the process of finding novel, interesting, and useful patterns in data.
Information Science Academia	Thing	• Information Science People • Information Science Academic Project • Information Science	• AcadamiaName	This class contains all the academic institutions which primararily contribute to knowledge, study and/or invention in this Information

		Published Paper		Science field.
Information Science People	Information Science Academia	• Faculty • Student	• AcadamiaName • Name • Status • KnowledgeBackground • ResearchInterests	This class covers people considered to be in the Information Science Academia (e.g, mainly implies faculty and student)
Faculty	Information Science People	None	• AcadamiaName • Name • Status • KnowledgeBackground • ResearchInterests • Publication • AdministratingProject	Faculty is the class containing people who are expertise in Information Science field
Student	Information Science People	None	• AcadamiaName • Name • Status • KnowledgeBackground • ResearchInterests	This class contains people who have main interests in Information Science Study.
Information Science Academic Project	Information Science Academia	None	• AcadamiaName • ProjectName • PrimaryFocus • TeamMembers	The class covers the projects contributing to information science field growth in some ways
Information Science Published Paper	Information Science Academia	None	• Author • DiscussedTopic • PaperName • PrimarySubject • PublishedDate	This class contains published papers contributing mainly to Information science field.

Slot information table

Slot Name	Documentation
AcadamiaName	Indicate the name of the academia
AdministratingProject	Indicate a list of project name that the person is working on
Author	Indicate the name of the paper author who might be faculty and expert in some particular field.
BasedOn	Indicate the knowledge concepts used as a step for developing new concept
ConceptDescription	The description of current concept to provide an explanation about the concept in fine detail (For now, it uses description from dictionary)
CongnitiveSystemType	Indicate the type of cognitive system which can be either human or artificial only.
Contribution	Indicate the other knowledge concepts that the current concept mainly contributes to
DiscussedTopic	Indicate the information science topics that has been discussed in the paper.
EffectingObject	names the objects that are affected by this knowledge
FinalProduct	Indicate the final outcome from production of the current knowledge concept
KnowledgeBackground	Indicate all the knowledge that a person knows and has lernt.
Name	Indicate the name of a person
PaperName	Indicate the name of the paper

PrimaryFocus	Indicate the knowledge concepts that is the ultimate project goal.
PrimaryInterest	Indicate a knowledge concept that can represent the entire current concept
PrimarySubject	ate the concepts that the author considers as the primary subject.
ProjectName	Indicate the name of the project.
Publication	Indicate the publication of a faculty
PublishedDate	Indicate the publishing date
ResearchInterests	Indicate knowledge concepts that are in person interests at that time
Status	Indicate the status of people
TargetOfStudy	Indicate what kind of ultimate goals the study will bring
TeamMembers	Indicate persons who are working as a part of project team

4. Conclusion

Having tried so many times to design an appropriate ontology for the information science area, we realized that it is such a difficult task to design an ontology dealing with abstract things because people tend to have different pictures in their head although they are talking about the same thing. Comparing to the ontology about physical things like animals or furniture which people usually see what it looks like, the ontology about information science area is more complicated. To make people see the same way, we have to provide reasonable claim with strong support evidences. That becomes one of the hardest tasks as we spent more than 3 weeks to comprehensively study about this particular area. It would be better to consult with experts in the field who is familiar with the entire concepts. Also, creating a standard used to classify the knowledge concepts in the field might be very helpful and reduce time and effort ontology developers would spend. One technique that we noticed from this assignment is that making class at the top as broad as possible because it will make the rest of that subclass easy to extend. Doing serious research and extremely concentrate on a part of the ontology can help ontology developers design a reusable ontology, which will allow other ontology to build upon.

Kittipong Techapanichgul
Sue Yeon Syn

Reference

[1] Answer.com, http://www.answer.com

[2] Borko, H. "Information science: what is it?" American Documentation, 19(1), 1968.

[3] Debons, A., "Information Science: Forty Years of Teaching". In The Proceedings of ISECON 2000, v 17 (Philadelphia): §412.

[4] Lai, T., "The Origin of Information Science", Journal of Educational Media and Library Science, 32(1), 40-49, September 1994.

[5] Machlup, F. and Mansfield, U., The study of information: interdisciplinary messages, John Wiley & Sons Inc, 1983.

[6] OWL Web Ontology Language Overview, http://www.w3.org/TR/owl-features/

[7] Williams, M.E. "Defining information science and the role of ASIS". Bulletin of the American Society for Information Science, 14(2), 17-19, 1987.

Kittipong Techapanichgul
Sue Yeon Syn

Appendix 1. Example of First-Order Logic Process

Note that with the complete full ontology, the process is much more complicated because of larger number of overlapping interest matches and different weights on concepts and values of attributes to find the best match.

1. Given situation

Following are the existing facts in Knowledge Base. This provides the name of faculty, university name, faculty's research interest, projects, teaching courses, and publication. As can be realized, there is a possibility that a professor might be working on projects or publication or courses that are not directly related to their explicitly mentioned research interest. In the system, this aspect is dealt by using the full IS Domain Ontology with relations and weights, however in this example only Cognitive Science aspects are taking parts of process.

1) Faculty at University of Pittsburgh, Dr. Peter Brusilovsky
Is interested in text retrieval, user modeling
Has projects on tutorial systems TaLeR
Teaches Information Storage and Retrieval

2) Faculty at University of Pittsburgh, Dr. Stephen Hirtle
Is interested in classification, cognitive science
Has projects of Spatial Cognition and Computation(SCC) and Classification Society of North America(CSNA)
Teaches Human Information Processing

3) Faculty at University of Pittsburgh, Dr. Susan Wiedenbeck
Is interested in human behavior, cognitive science
Has projects of End-user Software Engineering
Teaches Design of interactive systems, Analysis of interactive systems, Human Information Processing

2. Given query

Query is given to the system by users. This is the basis of the process to search for the matching results.

Future student, John

Is interested in cognitive system in terms of designing systems based on understanding user needs, user modeling, and system development that can support a human-like processes

3. Knowledge Base

The Knowledge Base includes all facts known and rules applied with which the reasoning process will be conducted based on the query provide by the user.

3.1. Based rules

R1. $\forall x \forall y \forall z$ [Contains(x, y) → Contains(x, z) $\wedge$ Contains(z, y)]
R2. $\forall x$ [Faculty(x) → x= a1 $\vee$ x= a2 $\vee$ x= a3 $\vee$ x= ….]
R3. $\forall x$ [Student(x) → x= a1 $\vee$ x= a2 $\vee$ x= a3 $\vee$ x= ….]
R3. $\forall x \forall y$ [WorkAt(x, y) → Faculty(x) $\wedge$ HasAttribute(Faculty, {Name = x, University = y})]
R4. $\forall x \forall y$ [InterestedIn(x, y) → Faculty(x) $\wedge$ HasAttribute(Faculty, {Name = x, Research Interests = y})]
R5. $\forall x \forall y$ [HasProject(x, y) → Faculty(x) $\wedge$ HasAttribute(Faculty, {Name = x, Projects = y})]
R6. $\forall x \forall y$ [Teaches(x, y) → Faculty(x) $\wedge$ HasAttribute(Faculty, {Name = x, Class Taught = y})]
R7. $\forall x \forall y$ [Published(x, y) → Faculty(x) $\wedge$ HasAttribute(Faculty, {Name = x, Publication = y})]
R8. $\forall x \forall y \forall z$ [InterestedIn(x, y) → Contains(y, z) $\wedge$ InterestedIn(x, z)]
R9. $\forall x \forall y \forall z \forall a$ [InterestedIn(x, y) → HasAttribute(y, z = a) $\wedge$ InterestedIn(x, a)]
R10. $\forall x \forall y \forall z$ [InterestedIn(x, z) → HasProject(x, y) $\wedge$ IsA(y, z)]
R11. $\forall x \forall y \forall z$ [InterestedIn(x, z) → Teaches(x, y) $\wedge$ IsA(y, z)]
R12. $\forall x \forall y \forall z$ [InterestedIn(x, z) → Published(x, y) $\wedge$ IsA(y, z)]
R13. $\forall x \forall y \forall z$ [InterestMatches(x, y) → InterestedIn(x, z) $\wedge$ InterestedIn(y, z)]
R14. $\forall x \forall y \forall z$ [BestMathches(x, y) → The highest InterestMatches]

3.2. Facts from IS Domain Ontology

3.2.1. Defining classes

C1. Contains(Information Science, {Information Science & Storage, Cognitive Science, Information Management})
C2. Contains(Cognitive Science, {Human Cognitive Science, Artificial Cognitive Science})
C3. Contains(Human Cognitive Science, {Human Information Processing, Human Behavior})

C4. Contains(Human Information Processing, {Reasoning, Perception, Problem Solving, Learning})
C5. Contains(Human Behavior, {User Study, User Modeling})
C6. Contains(Artificial Cognitive Science, {Machine Learning, Decision Support System})
C7. Contains(Information Science & Storage, {Classification, Clustering, Ranking})
C8. Contains(Information Management, {Ethics & Policy, Security, Knowledge Management})

3.2.2. Defining attributes

A1. HasAttribute(Information Science, Primary Concerned)
A2. HasAttribute (Information Storage & Retrieval, {Primary Concerned = Storing and Retrieving Information in any knowledge system, Target of study = efficient data usage})
A3. HasAttribute(Cognitive Science, {Primary Concerned = Cognitive System, Target of study = Human-like system})
A4. HasAttribute(Information Management, {Primary Concerned = Information uses, Target of study = Managing Information System uses})
A5. HasAttribute(Human Cognitive Science, {Primary Concerned = Cognitive Science, Cognitive System Type = Human})
A6. HasAttribute(Human Information Processing, {Primary Concerned = How human processes, Cognitive System Type = Human, Contribution = thinking process})
A7. HasAttribute(Human Behavior, {Primary Concerned = How human behave, Cognitive System Type = Human, Contribution = user understanding})
A8. HasAttribute(Artificial Cognitive Science, {Primary Concerned = Cognitive Science, Cognitive System Type = Artificial})
A9. HasAttribute(Machine Learning, {Primary Concerned = How human perceives information, Cognitive System Type = Artificial System, Based on = Reasoning and Logic})
A10. HasAttribute(Decision Support System, {Primary Concerned = How to construct the decision support system, Cognitive System Type = Artificial System, Based on = Statistic})

3.3. Facts from IS People Ontology for University of Pittsburgh

F1. $\forall$x[Faculty(x) $\rightarrow$ x=Peter Brusilovsky $\vee$ x=Stephen Hirtle $\vee$ x= Susan Wiedenbeck ….]
F2. WorksAt(Peter Brusilovsky, University of Pittsburgh)
F3. InterestedIn(Peter Brusilovsky, {Text Retrieval, User Modeling})
F4. HasProject(Peter Brusilovsky, TaLeR)
F5. Teaches(Peter Brusilovsky, Information Storage & Retrieval)
F6. WorksAt(Stephen Hirtle, University of Pittsburgh)
F7. InterestedIn(Stephen Hirtle, {Cognitive Science, Classification})
F8. HasProject(Stephen Hirtle, {SCC, CSNA })

F9. Teaches(Stephen Hirtle, Human Information Processing)
F10. WorksAt(Susan Wiedenbeck, Drexel University)
F11. InterestedIn(Susan Wiedenbeck, {Human Behavior, Cognitive Science})
F12. HasProject(Susan Wiedenbeck, {Graphical Passwords Project, End-user Software Engineering})
F13. Teaches(Susan Wiedenbeck, {Design of interactive systems, Analysis of interactive systems, Human Information Processing})
F14. IsA(TaLeR, Cognitive System)
F15. IsA(Information Storage & Retrieval, Information Storage & Retrieval)
F16. IsA(SCC, Cognitive Science)
F17. IsA(CSNA, Classification)
F18. IsA(Human Information Processing, Human Information Processing)
F19. IsA(Graphical Passwords Project, Security)
F20. IsA(End-user Software Engineering, Cognitive Science)
F21. IsA(Design of interactive systems, User Modeling)
F22. IsA(Analysis of interactive systems, User Study)

3.4. Query

Q1. $\exists$ y [Student(y) → y=John]
Q2. InterestedIn(John, Cognitive System)
Q3. InterestedIn(John, user understanding)
Q4. InterestedIn(John, User Modeling)
Q5. InterestedIn(John, human-like system)

4. Reasoning Process Using FOL

Following process can be conducted in reasoning to find the best-matching faculty and university from the Knowledge Base. As shown below, InterestMatches are found and finally the number of InterestMatches will result the BestMatches which indicate the faculty of highly related research interest.

(1) Q2 and R9 and A3
InterestedIn(John, Cognitive System)
$\forall$x$\forall$y$\forall$z$\forall$a [InterestedIn(x, y) → HasAttribute(y, z = a) $\wedge$ InterestedIn(x, a)]
HasAttribute(Cognitive Science, {Primary Concerned = Cognitive System, Target of study = Human-like system})

$\therefore$ InterestedIn(John, Cognitive Science)

(2) (1) and F3 and C2 and C3 and C5 and R8 and R13
Interested(John, Cognitive Science)
InterestedIn(Peter Brusilovsky, User Modeling)
Contains(Human Behavior, User Modeling)
Contains(Human Cognitive Science, Human Behavior)

Kittipong Techapanichgul
Sue Yeon Syn

Contains(Cognitive Science, Human Cognitive Science)
$\forall x \forall y \forall z$ [InterestedIn(x, y) → Contains(y, z) $\wedge$ InterestedIn(x, z)]
$\forall x \forall y \forall z$ [InterestMatches(x, y) → InterestedIn(x, z) $\wedge$ InterestedIn(y, z)]

∴ InterestMatches(John, Peter Brusilovsky)

(3) (1) and F7 and R13
Interested(John, Cognitive Science)
InterestedIn(Stephen Hirtle, Cognitive Science)
$\forall x \forall y \forall z$ [InterestMatches(x, y) → InterestedIn(x, z) $\wedge$ InterestedIn(y, z)]

∴ InterestMatches(John, Stephen Hirtle)

Appendix 2. Description of Ontologies in OWL

```
<?xml version="1.0"?>
<rdf:RDF
   xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
   xmlns:j.0="http://protege.stanford.edu/plugins/owl/protege#"
   xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
   xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
   xmlns:owl="http://www.w3.org/2002/07/owl#"
   xmlns="http://www.owl-ontologies.com/unnamed.owl#"
   xml:base="http://www.owl-ontologies.com/unnamed.owl">

<!-- Define Classes -->
<owl:Ontology rdf:about=""/>

<!-- Information Science Domain Ontology -->
<owl:Class rdf:ID="Information_Science">
   <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
            This class contains all sciences and/or concepts that are concerned with the gathering, manipulation,
classification, storage, and retrieval of recorded knowledge.
   </rdfs:comment>
</owl:Class>
<owl:Class rdf:ID="Congitive_Science">
   <rdfs:subClassOf rdf:resource="#Information_Science"/>
   <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
            This class contains scientific study of knowledge and how it is acquired, combining aspects of philosophy,
psychology, linguistics, anthropology, and artificial intelligence
   </rdfs:comment>
</owl:Class>
<owl:Class rdf:ID="Information_Management">
   <rdfs:subClassOf rdf:resource="#Information_Science"/>
   <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
            This class contains concepts about administrating of information, its uses and transmission, and the
application of theories and techniques of information science to create, modify, or improve information handling
systems
   </rdfs:comment>
</owl:Class>
<owl:Class rdf:ID="InformationRetrieval">
   <rdfs:subClassOf rdf:resource="#Information_Science"/>
   <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
          This class contains knowledge concepts of systematically searching for and retrieving stored computerized data
   </rdfs:comment>
</owl:Class>

<owl:Class rdf:ID="HumanCognitiveScience">
   <rdfs:subClassOf rdf:resource="#Congitive_Science"/>
   <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
            This class contains scientific study of knowledge and how it is acquired, combining aspects of philosophy,
psychology, linguistics, anthropology (Human only)
   </rdfs:comment>
</owl:Class>
<owl:Class rdf:ID="ArtificialCognitiveScience">
   <rdfs:subClassOf rdf:resource="#Congitive_Science"/>
   <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
            This class contains scientific study of knowledge and how it is acquired, combining aspects of philosophy,
psychology, linguistics, anthropology (Artificial only)
   </rdfs:comment>
```

```xml
</owl:Class>

<owl:Class rdf:ID="HumanInformationProcessing">
   <rdfs:subClassOf rdf:resource="#HumanCognitiveScience"/>
   <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
            This class contains knowledge concepts explaining how humans process surrounding information
   </rdfs:comment>
</owl:Class>
<owl:Class rdf:ID="HumanBehavior">
   <rdfs:subClassOf rdf:resource="#HumanCognitiveScience"/>
   <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
            This class covers knowledge concepts about activities performed by human beings and influenced by culture,
attitudes, emotions, values, ethics, authority, rapport, hypnosis, persuasion, and/or coercion
   </rdfs:comment>
</owl:Class>

<owl:Class rdf:ID="MachineLearning">
   <rdfs:subClassOf rdf:resource="#ArtificialCognitiveScience"/>
   <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
            This class contains knowledge concepts in the area of artificial intelligence concerned with the development
of techniques which allow computers to "learn"
   </rdfs:comment>
</owl:Class>
<owl:Class rdf:ID="DecisionSupportSystem">
   <rdfs:subClassOf rdf:resource="#ArtificialCognitiveScience"/>
   <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
            This class contains knowledge concepts and techniques used to develop a system that help people make
decisions.
   </rdfs:comment>
</owl:Class>

<owl:Class rdf:ID="Reasoning">
   <rdfs:subClassOf rdf:resource="#HumanInformationProcessing"/>
</owl:Class>
<owl:Class rdf:ID="HumanPerception">
   <rdfs:subClassOf rdf:resource="#HumanInformationProcessing"/>
</owl:Class>
<owl:Class rdf:ID="ProblemSolving">
   <rdfs:subClassOf rdf:resource="#HumanInformationProcessing"/>
</owl:Class>
<owl:Class rdf:ID="Learning">
   <rdfs:subClassOf rdf:resource="#HumanInformationProcessing"/>
</owl:Class>

<owl:Class rdf:ID="User_Study">
   <rdfs:subClassOf rdf:resource="#HumanBehavior"/>
</owl:Class>
<owl:Class rdf:ID="User_Modelling">
    <rdfs:subClassOf rdf:resource="#HumanBehavior"/>
</owl:Class>

<owl:Class rdf:ID="Information_Ethics_and_Policy">
   <rdfs:subClassOf rdf:resource="#Information_Management"/>
   <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
            This class contains knowledge concepts in a wide variety of ethics, political and legal issues related to the
Internet and other communications technology, including intellectual property, privacy, freedom of expression, and
jurisdiction.
   </rdfs:comment>
</owl:Class>
<owl:Class rdf:ID="KnowledgeManagement">
   <rdfs:subClassOf rdf:resource="#Information_Management"/>
```

```
   <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
            This class contains knowledge concepts about capturing, organizing, and storing knowledge and experiences
of individual workers and groups within an organization and making this information available to others in the
organization
   </rdfs:comment>
</owl:Class>

<owl:Class rdf:ID="Knowledge_Representation">
   <rdfs:subClassOf rdf:resource="#KnowledgeManagement"/>
   <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
            This class contains knowledge concepts about the process and the result of formalization of knowledge in
such a way, that it can be used automatically for problem solving
   </rdfs:comment>
</owl:Class>
<owl:Class rdf:ID="Knowledge_Discovery">
   <rdfs:subClassOf rdf:resource="#KnowledgeManagement"/>
   <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
       This class contains knowledge concepts about the process of finding novel, interesting, and useful patterns in data.
   </rdfs:comment>
</owl:Class>

<owl:Class rdf:ID="Semantic_Web">
   <rdfs:subClassOf rdf:resource="#Knowledge_Representation"/>
</owl:Class>
<owl:Class rdf:ID="Ontology">
   <rdfs:subClassOf rdf:resource="#Knowledge_Representation"/>
</owl:Class>
<owl:Class rdf:ID="Data_Mining">
   <rdfs:subClassOf rdf:resource="#Knowledge_Discovery"/>
</owl:Class>
<owl:Class rdf:ID="Web_Mining">
   <rdfs:subClassOf rdf:resource="#Knowledge_Discovery"/>
</owl:Class>

<owl:Class rdf:ID="Intellectual_Property">
   <rdfs:subClassOf rdf:resource="#Information_Ethics_and_Policy "/>
</owl:Class>
<owl:Class rdf:ID="Authorization">
   <rdfs:subClassOf rdf:resource="#Information_Ethics_and_Policy "/>
</owl:Class>
<owl:Class rdf:ID="Privacy">
   <rdfs:subClassOf rdf:resource="#Information_Ethics_and_Policy "/>
</owl:Class>

<owl:Class rdf:ID="Ranking">
   <rdfs:subClassOf rdf:resource="#InformationRetrieval"/>
</owl:Class>
<owl:Class rdf:ID="MetaData">
   <rdfs:subClassOf rdf:resource="#InformationRetrieval"/>
</owl:Class>
<owl:Class rdf:ID="Indexing">
   <rdfs:subClassOf rdf:resource="#InformationRetrieval"/>
</owl:Class>

<!-- Information Science Acadamia Ontology -->
<owl:Class rdf:ID="Information_Science_Acadamia">
   <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
            This class contains all the academic institutions which primararily contribute to knowledge, study and/or
invention in this Information Science field.
   </rdfs:comment>
</owl:Class>
```

```
<owl:Class rdf:ID="Information_Science_People">
   <rdfs:subClassOf rdf:resource="#Information_Science_Acadamia"/>
   <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
            This class covers people considered to be in the Information Science Academia (e.g, mainly implies faculty
and student)
    </rdfs:comment>
</owl:Class>
 <owl:Class rdf:ID="Information_Science_Academic_Project">
   <rdfs:subClassOf rdf:resource="#Information_Science_Acadamia"/>
   <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
            The class covers the projects contributing to information science field growth in some ways
   </rdfs:comment>
</owl:Class>
<owl:Class rdf:ID="Information_Science_Published_Paper">
   <rdfs:subClassOf rdf:resource="#Information_Science_Acadamia"/>
   <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
            This class contains published papers contributing mainly to Information science field.
   </rdfs:comment>
</owl:Class>
<owl:Class rdf:ID="Faculty">
   <rdfs:subClassOf rdf:resource="#Information_Science_People"/>
   <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
            Faculty is the class containing people who are expertise in Information Science field
   </rdfs:comment>
</owl:Class>
<owl:Class rdf:ID="Student">
   <rdfs:subClassOf rdf:resource="#Information_Science_People"/>
   <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
            This class contains people who have main interests in Information Science Study.
   </rdfs:comment>
</owl:Class>

<!-- Define ObjectProperty -->
<!-- ObjectProperty for IS Domain Ontology -->
<owl:ObjectProperty rdf:ID="PrimaryInterest">
   <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
            Indicate a knowledge concept that can represent the entire current concept
   </rdfs:comment>
   <rdfs:domain>
     <owl:Class>
       <owl:unionOf rdf:parseType="Collection">
         <rdf:Description rdf:about="http://www.w3.org/2002/07/owl#Thing"/>
         <owl:Class rdf:about="#Information_Science"/>
       </owl:unionOf>
     </owl:Class>
   </rdfs:domain>
</owl:ObjectProperty>

<owl:ObjectProperty rdf:ID="TargetOfStudy">
   <rdfs:domain>
     <owl:Class>
       <owl:unionOf rdf:parseType="Collection">
         <rdf:Description rdf:about="http://www.w3.org/2002/07/owl#Thing"/>
         <owl:Class rdf:about="#Information_Management"/>
         <owl:Class rdf:about="#Congitive_Science"/>
         <owl:Class rdf:about="#InformationRetrieval"/>
       </owl:unionOf>
     </owl:Class>
   </rdfs:domain>
   <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
            Indicate what kind of ultimate goals the study will bring
```

Kittipong Techapanichgul
Sue Yeon Syn

```
  </rdfs:comment>
</owl:ObjectProperty>

<owl:ObjectProperty rdf:ID="Contribution">
  <rdfs:domain>
    <owl:Class>
      <owl:unionOf rdf:parseType="Collection">
        <rdf:Description rdf:about="http://www.w3.org/2002/07/owl#Thing"/>
        <owl:Class rdf:about="#HumanInformationProcessing"/>
        <owl:Class rdf:about="#HumanBehavior"/>
      </owl:unionOf>
    </owl:Class>
  </rdfs:domain>
  <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
        Indicate the other knowledge concepts that the current concept mainly contributes to
  </rdfs:comment>
</owl:ObjectProperty>
<owl:ObjectProperty rdf:ID="BasedOn">
  <rdfs:domain>
    <owl:Class>
      <owl:unionOf rdf:parseType="Collection">
        <rdf:Description rdf:about="http://www.w3.org/2002/07/owl#Thing"/>
        <owl:Class rdf:about="#MachineLearning"/>
        <owl:Class rdf:about="#DecisionSupportSystem"/>
      </owl:unionOf>
    </owl:Class>
  </rdfs:domain>
  <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
        Indicate the knowledge concepts used as a step for developing new concept
  </rdfs:comment>
</owl:ObjectProperty>

<owl:ObjectProperty rdf:ID="FinalProduct">
  <rdfs:domain>
    <owl:Class>
      <owl:unionOf rdf:parseType="Collection">
        <rdf:Description rdf:about="http://www.w3.org/2002/07/owl#Thing"/>
        <owl:Class rdf:about="#Knowledge_Representation"/>
        <owl:Class rdf:about="#Knowledge_Discovery"/>
      </owl:unionOf>
    </owl:Class>
  </rdfs:domain>
  <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
        Indicate the final outcome from production of the current knowledge concept
  </rdfs:comment>
</owl:ObjectProperty>

<!-- ObjectProperty for Information Science Academia -->
<owl:ObjectProperty rdf:ID="ResearchInterests">
  <rdfs:domain>
    <owl:Class>
      <owl:unionOf rdf:parseType="Collection">
        <rdf:Description rdf:about="http://www.w3.org/2002/07/owl#Thing"/>
        <owl:Class rdf:about="#Information_Science_People"/>
      </owl:unionOf>
    </owl:Class>
  </rdfs:domain>
  <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
        Indicate knowledge concepts that are in person interests at that time
  </rdfs:comment>
</owl:ObjectProperty>
```

```
<owl:ObjectProperty rdf:ID="KnowledgeBackground">
  <rdfs:domain>
    <owl:Class>
      <owl:unionOf rdf:parseType="Collection">
        <rdf:Description rdf:about="http://www.w3.org/2002/07/owl#Thing"/>
        <owl:Class rdf:about="#Information_Science_People"/>
      </owl:unionOf>
    </owl:Class>
  </rdfs:domain>
  <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
        Indicate all the knowledge that a person knows and has lernt.
  </rdfs:comment>
</owl:ObjectProperty>

<owl:ObjectProperty rdf:ID="Publication">
  <rdfs:domain>
    <owl:Class>
      <owl:unionOf rdf:parseType="Collection">
        <rdf:Description rdf:about="http://www.w3.org/2002/07/owl#Thing"/>
        <owl:Class rdf:about="#Faculty"/>
      </owl:unionOf>
    </owl:Class>
  </rdfs:domain>
</owl:ObjectProperty>
<owl:ObjectProperty rdf:ID="AdministratingProject">
  <rdfs:domain>
    <owl:Class>
      <owl:unionOf rdf:parseType="Collection">
        <rdf:Description rdf:about="http://www.w3.org/2002/07/owl#Thing"/>
        <owl:Class rdf:about="#Faculty"/>
      </owl:unionOf>
    </owl:Class>
  </rdfs:domain>
  <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
        Indicate a list of project name that the person is working on
  </rdfs:comment>
</owl:ObjectProperty>

<owl:ObjectProperty rdf:ID="PrimaryFocus">
  <rdfs:domain>
    <owl:Class>
      <owl:unionOf rdf:parseType="Collection">
        <rdf:Description rdf:about="http://www.w3.org/2002/07/owl#Thing"/>
        <owl:Class rdf:about="#Information_Science_Academic_Project"/>
      </owl:unionOf>
    </owl:Class>
  </rdfs:domain>
  <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
        Indicate the knowledge concepts that is the ultimate project goal.
  </rdfs:comment>
</owl:ObjectProperty>
<owl:ObjectProperty rdf:ID="TeamMembers">
  <rdfs:domain>
    <owl:Class>
      <owl:unionOf rdf:parseType="Collection">
        <rdf:Description rdf:about="http://www.w3.org/2002/07/owl#Thing"/>
        <owl:Class rdf:about="#Information_Science_Academic_Project"/>
      </owl:unionOf>
    </owl:Class>
  </rdfs:domain>
  <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
```

```
            Indicate persons who are working as a part of project team
    </rdfs:comment>
</owl:ObjectProperty>

<owl:ObjectProperty rdf:ID="PrimarySubject">
    <rdfs:domain>
      <owl:Class>
        <owl:unionOf rdf:parseType="Collection">
          <rdf:Description rdf:about="http://www.w3.org/2002/07/owl#Thing"/>
          <owl:Class rdf:about="#Information_Science_Published_Paper"/>
        </owl:unionOf>
      </owl:Class>
    </rdfs:domain>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
            Indicate the concepts that the author considers as the primary subject.
    </rdfs:comment>
</owl:ObjectProperty>
<owl:ObjectProperty rdf:ID="Author">
    <rdfs:domain>
      <owl:Class>
        <owl:unionOf rdf:parseType="Collection">
          <rdf:Description rdf:about="http://www.w3.org/2002/07/owl#Thing"/>
          <owl:Class rdf:about="#Information_Science_Published_Paper"/>
        </owl:unionOf>
      </owl:Class>
    </rdfs:domain>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
            Indicate the name of the paper author who might be faculty and expert in some particular field.
    </rdfs:comment>
</owl:ObjectProperty>
<owl:ObjectProperty rdf:ID="DiscussedTopic">
    <rdfs:domain>
      <owl:Class>
        <owl:unionOf rdf:parseType="Collection">
          <rdf:Description rdf:about="http://www.w3.org/2002/07/owl#Thing"/>
          <owl:Class rdf:about="#Information_Science_Published_Paper"/>
        </owl:unionOf>
      </owl:Class>
    </rdfs:domain>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
            Indicate the information science topics that has been discussed in the paper.
    </rdfs:comment>
</owl:ObjectProperty>

<!-- Define DatatypeProperty -->
<!-- DatatypeProperty for IS Domain -->
<owl:DatatypeProperty rdf:ID="ConceptDescription">
    <rdfs:domain>
      <owl:Class>
        <owl:unionOf rdf:parseType="Collection">
          <rdf:Description rdf:about="http://www.w3.org/2002/07/owl#Thing"/>
          <owl:Class rdf:about="#Information_Science"/>
        </owl:unionOf>
      </owl:Class>
    </rdfs:domain>
    <rdfs:range rdf:resource="http://www.w3.org/2001/XMLSchema#string"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
            The description of current concept to provide an explanation about the concept in fine detail (For now, it uses
description from dictionary)
    </rdfs:comment>
</owl:DatatypeProperty>
```

```
<owl:DatatypeProperty rdf:ID="CongnitiveSystemType">
    <rdfs:domain>
      <owl:Class>
        <owl:unionOf rdf:parseType="Collection">
          <rdf:Description rdf:about="http://www.w3.org/2002/07/owl#Thing"/>
          <owl:Class rdf:about="#HumanCognitiveScience"/>
          <owl:Class rdf:about="#ArtificialCognitiveScience"/>
        </owl:unionOf>
      </owl:Class>
    </rdfs:domain>
    <rdfs:range rdf:resource="http://www.w3.org/2001/XMLSchema#string"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
            Indicate the type of cognitive system which can be either human or artificial only.
    </rdfs:comment>
</owl:DatatypeProperty>

<owl:DatatypeProperty rdf:ID="EffectingObject">
    <rdfs:domain>
      <owl:Class>
        <owl:unionOf rdf:parseType="Collection">
          <rdf:Description rdf:about="http://www.w3.org/2002/07/owl#Thing"/>
          <owl:Class rdf:about="#KnowledgeManagement"/>
          <owl:Class rdf:about="#Information_Ethics_and_Policy"/>
        </owl:unionOf>
      </owl:Class>
    </rdfs:domain>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
            names the objects that are affected by this knowledge
    </rdfs:comment>
</owl:DatatypeProperty>

<!-- DatatypeProperty for IS Acadamia -->
<owl:DatatypeProperty rdf:ID="AcadamiaName">
    <rdfs:domain>
      <owl:Class>
        <owl:unionOf rdf:parseType="Collection">
          <rdf:Description rdf:about="http://www.w3.org/2002/07/owl#Thing"/>
          <owl:Class rdf:about="#Information_Science_Acadamia"/>
        </owl:unionOf>
      </owl:Class>
    </rdfs:domain>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
            Indicate the name of the academia
    </rdfs:comment>
    <rdfs:range rdf:resource="http://www.w3.org/2001/XMLSchema#string"/>
</owl:DatatypeProperty>

<owl:DatatypeProperty rdf:ID="Name">
    <rdfs:range rdf:resource="http://www.w3.org/2001/XMLSchema#string"/>
    <rdfs:domain>
      <owl:Class>
        <owl:unionOf rdf:parseType="Collection">
          <rdf:Description rdf:about="http://www.w3.org/2002/07/owl#Thing"/>
          <owl:Class rdf:about="#Information_Science_People"/>
        </owl:unionOf>
      </owl:Class>
    </rdfs:domain>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
            Indicate the name of a person
    </rdfs:comment>
```

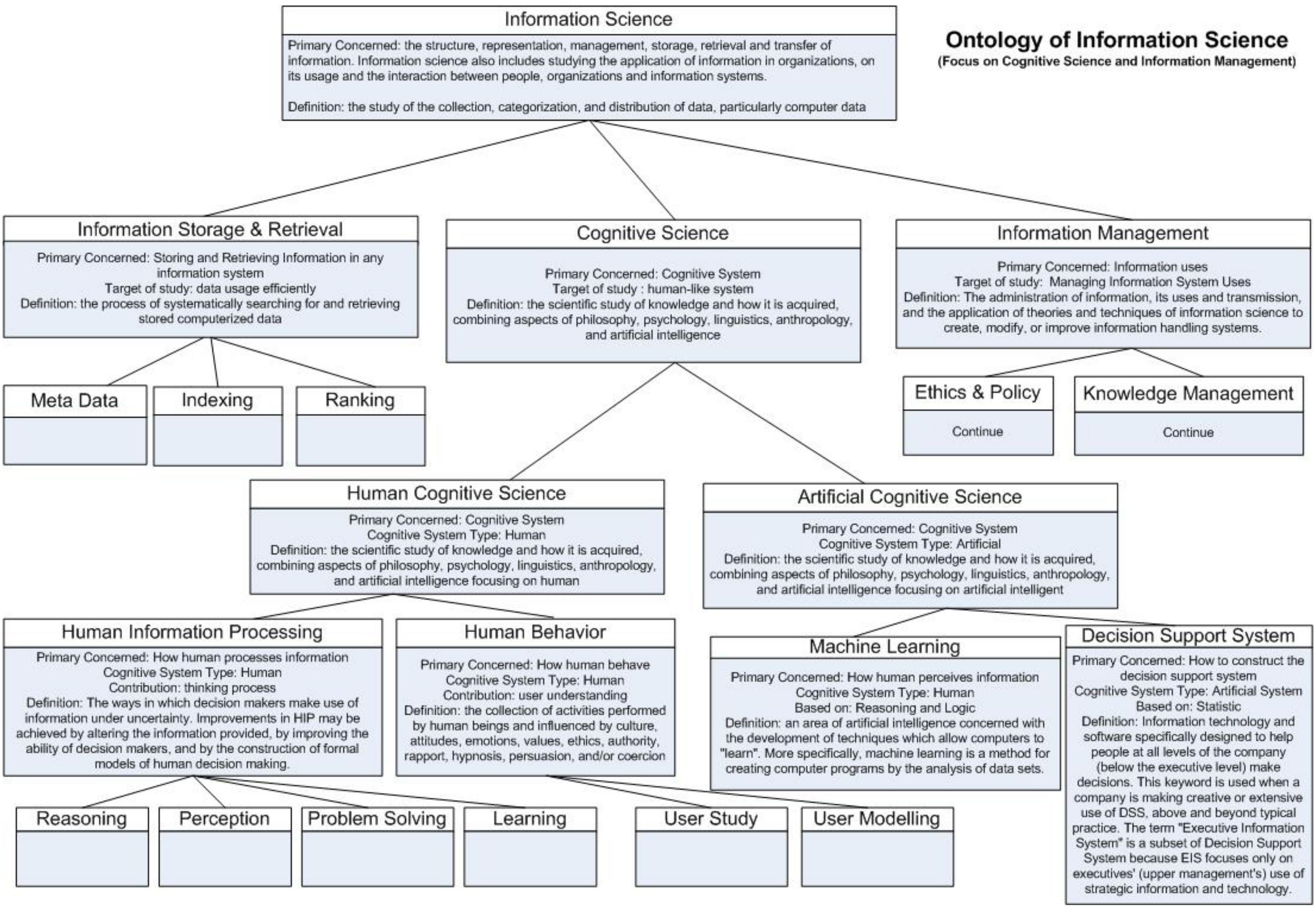
Kittipong Techapanichgul
Sue Yeon Syn

```
</owl:DatatypeProperty>
<owl:DatatypeProperty rdf:ID="Status">
  <rdfs:domain>
    <owl:Class>
      <owl:unionOf rdf:parseType="Collection">
        <rdf:Description rdf:about="http://www.w3.org/2002/07/owl#Thing"/>
        <owl:Class rdf:about="#Information_Science_People"/>
      </owl:unionOf>
    </owl:Class>
  </rdfs:domain>
  <rdfs:range rdf:resource="http://www.w3.org/2001/XMLSchema#string"/>
  <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
        Indicate the status of people
  </rdfs:comment>
</owl:DatatypeProperty>

<owl:DatatypeProperty rdf:ID="ProjectName">
  <rdfs:domain>
    <owl:Class>
      <owl:unionOf rdf:parseType="Collection">
        <rdf:Description rdf:about="http://www.w3.org/2002/07/owl#Thing"/>
        <owl:Class rdf:about="#Information_Science_Academic_Project"/>
      </owl:unionOf>
    </owl:Class>
  </rdfs:domain>
  <rdfs:range rdf:resource="http://www.w3.org/2001/XMLSchema#string"/>
  <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
        Indicate the name of the project.
  </rdfs:comment>
</owl:DatatypeProperty>

<owl:DatatypeProperty rdf:ID="PaperName">
  <rdfs:domain>
    <owl:Class>
      <owl:unionOf rdf:parseType="Collection">
        <rdf:Description rdf:about="http://www.w3.org/2002/07/owl#Thing"/>
        <owl:Class rdf:about="#Information_Science_Published_Paper"/>
      </owl:unionOf>
    </owl:Class>
  </rdfs:domain>
  <rdfs:range rdf:resource="http://www.w3.org/2001/XMLSchema#string"/>
  <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
        Indicate the name of the paper
  </rdfs:comment>
</owl:DatatypeProperty>
<owl:DatatypeProperty rdf:ID="PublishedDate">
  <rdfs:domain>
    <owl:Class>
      <owl:unionOf rdf:parseType="Collection">
        <rdf:Description rdf:about="http://www.w3.org/2002/07/owl#Thing"/>
        <owl:Class rdf:about="#Information_Science_Published_Paper"/>
      </owl:unionOf>
    </owl:Class>
  </rdfs:domain>
  <rdfs:range rdf:resource="http://www.w3.org/2001/XMLSchema#string"/>
  <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
        Indicate the publishing date
  </rdfs:comment>
</owl:DatatypeProperty>

</rdf:RDF>
```

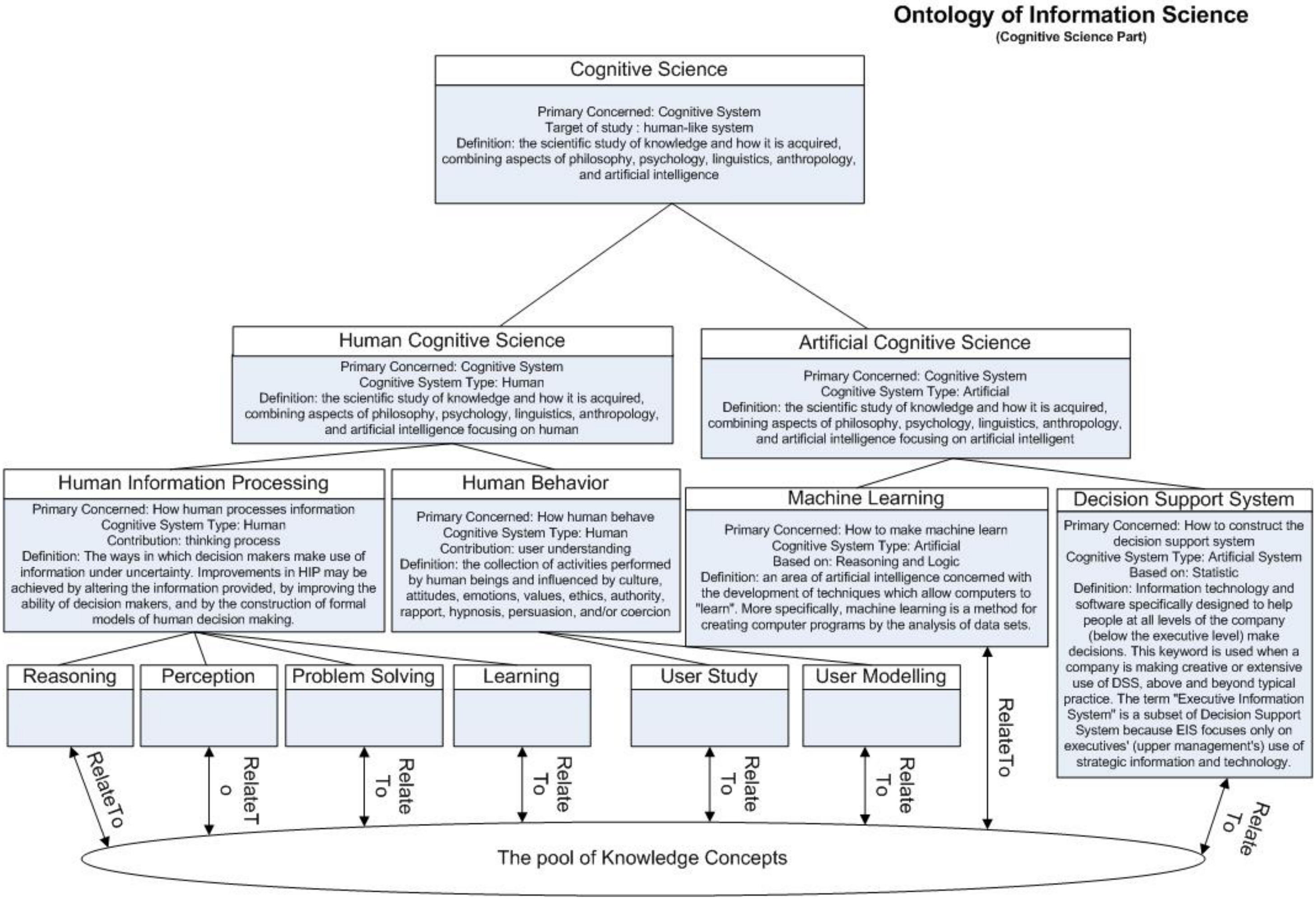
Kittipong Techapanichgul
Sue Yeon Syn

Appendix 3. Ontology Figures (Expanded Picture)

Information Science Ontology

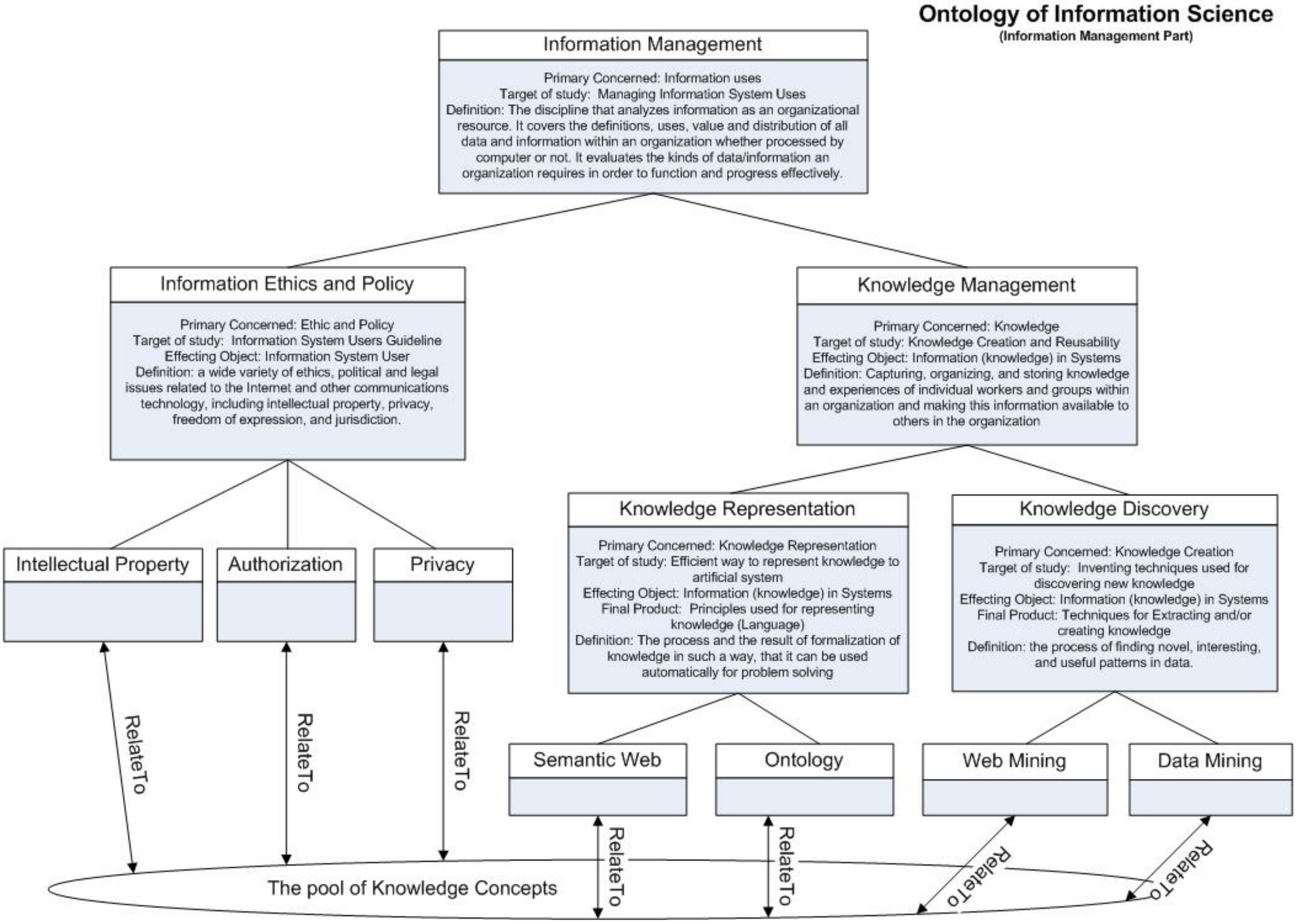


Cognitive Science Ontology as a part of IS Ontology



Kittipong Techapanichgul
Sue Yeon Syn

Information Management Ontology as a part of IS Ontology



Kittipong Techapanichgul
Sue Yeon Syn

Information Science Academia Ontology