Toward an Ontology for Ocean Ecology and Sustainability

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The 21st century is said to be the century of ocean, and researches (for example, those on energy, biology, environment, and so on) have been carried out by many countries for a long time. Throughout these researches, there left many valuable documents such as observational data, experimental results, papers, and patents as well. However, documents from different institutes are usually different from each other both in the format and in teleological and taxonomical viewpoints. Ontology can be used as a middleware to facilitate data sharing and cooperation among these institutes. In this paper, we show a prototype ontology of ocean mainly focusing on its ecology and sustainability. We mainly introduce how to model the interactions between plants, animals, micro-organisms and non-living physical factors and their roles in the matter cycles in ocean.

1. Introduction

The 21st century is said to be the century of ocean, and researches (for example, those on energy, biology, environment, and so on) have been carried out by many countries for a long time. Throughout these researches, there left many valuable documents such as observational data, experimental results, papers, and patents as well. However, documents from different institutes are usually different from each other both in the format and in teleological and taxonomical viewpoints. For example, calamary is categorized as a nekton by its living habits from a viewpoint of environment, and as a cephalopoda by its body structure from a biologist. "Dissolved inorganic phosphorous", "dissolved inorganic phosphate" and DIP refer to the same thing in environmental research, even worse is that DIP may be the abbreviation of "Dual inline package" in the domain of microelectronics. The integration and utilization of these heterogeneous resources are crucial for scientific research cooperation and crisis management among ocean researchers, government, aquaculturists and other marine agencies.

Metadata will facilitate the interoperability between marine agencies and make it easier to find, use and share marine data. There has been an international standard (Marine Community Profile of ISO 19115) for metadata, which includes a metadata schema and uses Global Change Master Directory (GCMD) Science Keywords as its controlled vocabulary (available at: http://gcmd.gsfc.nasa.gov/Resources/valids/gcmd_paramet ers.html).

But as is well known, ocean is a very complex ecosystem which plays important role in the Earth's environment. Metadata can not properly describe the interactions between plants, animals, micro-organisms and non-living physical factors in ocean. Therefore, a higher level semantics is needed to represent the disciplines among the ocean system. Ontology as "a formal, explicit specification of a shared conceptualization" [Gruber 1993] can serve this task. An ontology "consists of concepts, hierarchical (*is-a*) organization of them, relations among them (in addition to *is-a* and *part-of*), axioms to formalize the definitions and relations" [Mizoguchi 2003]. The aim of ontology research is therefore to develop knowledge representations that can be shared and processed by machines as well as people.

In the literature, there have been some researches on geo-ontology which is a specification of geographic entities, their properties, and relations [Kashyap 1996], [Fonseca 2001], and [Smith 1998]. Fonseca [Fonseca 2001] introduces Ontology-Driven Geographic Information Systems which use geo-ontology to handle semantic heterogeneity among different GIS's. In China, Du et al. [Du 2005] use geo-ontology for the integration of multi-source spatial data of coastal areas. Application systems show the effectiveness of the ontology. In Japan, Yoshida et al. [Yoshida 2007] use ontology to integrate four frameworks of soil category. Ono et al. [Ono 2007] use ontology for the interoperability between different environmental data.

Recently, the importance of ecological ontology has been addressed [Fonseca 2002], [Smith 1999]. Smith and Varzi [Smith 1999] stress the need to develop formal ontologies in the field of ecology. Fonseca extends the work of Rodríguez [Rodríguez 1999] and his own [Fonseca 2001] on geo-ontologies, into the realm of ontologies that represent the environment, eco-ontologies [Fonseca 2002]. In [Fonseca 2002], Fonseca highlight the structural differences that should be taken into account when we move from geo-ontologies to eco-ontologies. The main idea is to use roles to represent the diverse character of the geographic entities and to avoid the problems of multiple inheritances.

But as far as we know, there are yet no researches to finely represent the interactions between plants, animals, micro-organisms and non-living physical factors and their roles in the matter cycles in ocean. In this paper, we try to model the mechanism of matter cycles by adapting the framework of device ontology discussed by Kitamura [Kitamura 2006].

2. Construction of Ocean Ontology

In addition to the theoretical basis, methodology for constructing an ontology is also important. There have

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been good methodologies available from the researcher's own experiences of constructing ontology [Mariano 1999] [Noy 2001]. We adapted those methodologies and take four steps: specification, knowledge acquisition, conceptualization, and implementation. These four steps repeated in bottom-up manner or top-down manner during the construction of ocean ontology.

2.1 Specification

The main purpose of our study is to represent ontologically the interactions between plants, animals, micro-organisms and non-living physical factors and the roles of them in the matter cycles occurring in ocean. After that, we represent the influence of human activity upon the matter cycles and its linkage to some abnormal phenomena often occurring nowadays. In order to use such knowledge to facilitate research cooperation and crisis management, it is also necessary to address the relationship between crisis situations, causes, experts, and administrations.

In this paper, we mainly introduce how to model the matter cycles by adapting the framework of device ontology presented by Kitamura [Kitamura 2006].

2.2 Knowledge Acquisition

Since we are not experts on ocean science, we acquired knowledge to put together a preliminary version of ocean focusing on ecology and environment. Some books written by oceanography experts and environment experts help us a lot [Feng 1999], [Rich 1973], [Harasima 1997]. Wikipedia is also a good place for us to grasp ocean knowledge.

After that, we then considered reusing existing ontologies. Some resources of thesaurus such as GCMD Science Keywords mentioned above, GEMET (GEneral Multilingual Environmental Thesaurus, http://www.eionet.europa.eu/gemet/), Ecoterm by Environmental Information and Communication Network of Japan (http://www.eic.or.jp/ecoterm/) quite accelerated our knowledge collecting.

2.3 Conceptualization

Upper ontology, which explains what exist in the world with a higher level categorization, inspired our conceptualization of ocean ontology. We referr to the upper ontology of Mizoguchi [Mizoguchi 2005] and Guarino [Guarino 1998] when determine the *is-a* hierarchy of concepts of ocean ontology. First we separate things into *concrete object* and *abstract object*. Concrete object is further separated into *physical entity* and *process*. Physical entity includes *organism*, *matter*, *ocean*, *ocean part*, and *habitat*. Ocean part includes seabed and seawater which is further divided into pothic and apothic zones. Habitat (such as mudflat, vegetation,

sediment, photic zone and aphotic zone of seawater) often consists of some parts of ocean. Matter may be in the molecular, inorganic, or organic forms of a chemical element. Fig.1. is an image from Wikipedia, which shows the major oceanic divisions.
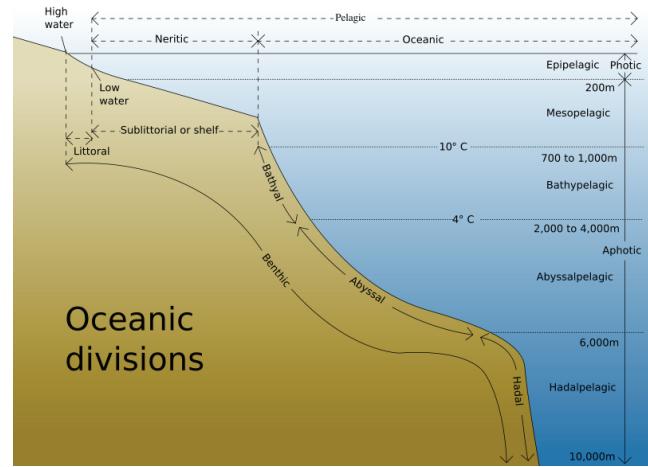
Fig.1. Major Oceanic Divisions. Available at
http://en.wikipedia.org/wiki/Ocean
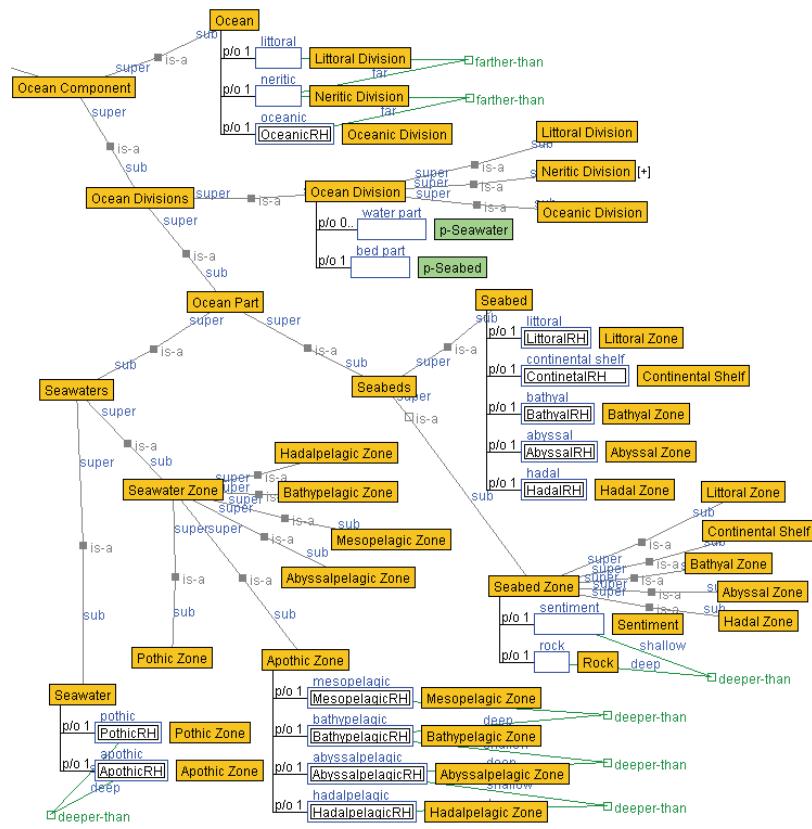
Fig.2. Conceptualization of Oceanic Divisions.

Fig.2. shows our conceptualization of oceanic divisions in Hozo [Kozaki 2002], [Kozaki 2006] format. Note that we added some structural concepts such as O*cean Component*, *Seabeds*, and *Seawaters*.

Our conceptualization then proceeded to the modeling of matter cycles that link together almost all the concrete objects of ocean ontology. We adapt the theory of

Kitamura [Kitamura 2006] on device ontology to do this. In [Kitamura 2006], one of the key concepts is *behavior* (see Fig.3.), which is defined as temporal change of another *physical-entity* called an *operand*. The *device* is defined as a role-holder (for the definitions of role and role holder, the readers are referred to [Mizoguchi 2007]) played by a physical-entity, which operates on the operand
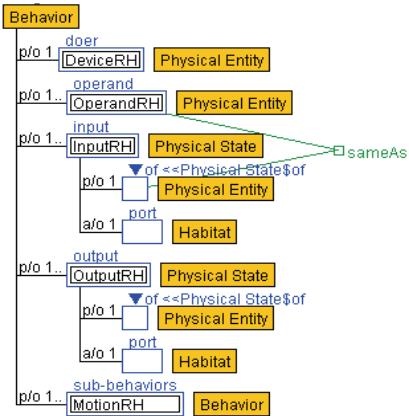

Fig.3. Conceptualization of *Behavior*.

and changes its *physical-attributes*. The operand is something that flows through the device and is affected by the device. The *operand role* can be played by ion, phytoplankton, bacteria, etc. The temporal change of operands is represented as a pair of *physical-states* as *input* and *output* of the device, each of which represents a value of a physical-attribute at a port of the device. A *port* of a device is a virtual interface for propagation of physical-attribute's values to another device. Each device is connected to each other through its input and output ports. The changes in a behavior are caused by sub-behaviors, which are a sequence of finer-grained behaviors. A *medium* is something that holds an operand and enables it to flow between devices.

In our ocean ontology, every organism is considered as a device which changes the form and/or location of some matters. For example, the location of nitrogen may change in a sequence of atmosphere, soil, seawater, phyto-plankton, zooplankton, bacteria, seawater, and again to atmosphere. The form of nitrogen may change in a sequence of nitrogen gas, nitrate, organic nitrogen, and again to nitrogen gas. Any of the objects (such as nitrogen gas, ions, phytoplankton, etc.) can play the

role of operand of the organism device. Operand contains some forms of matters.

All the organisms of an ecosystem connect with each other through the habitats in the ecosystem. From this viewpoint, habitat can play the role of port of device and the role of medium which holds operand to be processed by the device.

Any device has transitive behaviors and intransitive behaviors. For example, phytoplankton has an intransitive behavior of drifting and a transitive behavior of nutrition. The nutrition behavior of zooplankton (see Fig.4-a) usually performed in the pothic zone of seawater. Zooplankton eats phytoplankton and transforms it into carbohydrate and protein, stores them in its body and excretes feces to pothic zone of seawater.

Matter cycle (see Fig.4-b) can be considered as a sequence of processes performed by organisms' behavior, where the output of preceding behavior can be divided to flow to the inputs of more than one successor, and finally the output of the terminal behavior can totally or partially flow to the input of the initial behavior. There may be sub-cycles in the whole cycle with its input and output identical to the output of preceding middle process and the input of succeeding middle process respectively.

In summary, for example, in the Nitrogen cycle, phytoplankton which is ontologically an organism, plays
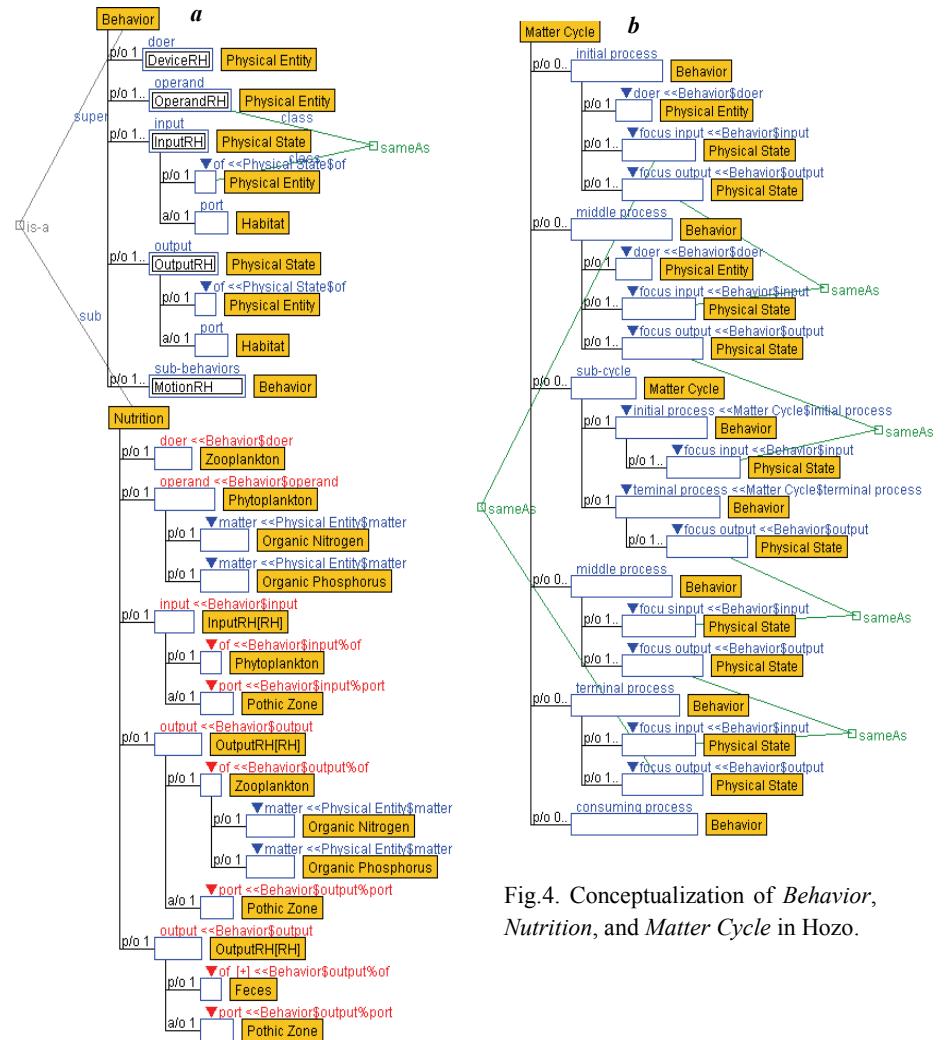

Fig.4. Conceptualization of *Behavior*, *Nutrition*, and *Matter Cycle* in Hozo.

the role of device to transform inorganic Nitrogen into organic Nitrogen, and at the same time, plays the role of food (operand) in the nutrition behavior of Zooplankton.

2.4 Implementation

We use Hozo as our ontology editor. We first imported the GCMD Science Keywords and GEMET into Hozo as the glossary basis of ontology construction. Then we implemented our prototype ontology by organizing the concepts according to the *is-a* and *part-of* relations between them.

3. Conclusion Remarks

We mainly discussed the modeling of matter cycles based on the framework of device ontology presented by Kitamura. By fix such a viewpoint consistently, we will refine the prototype ontology and have a discussion with some experts of oceanography and ocean ecology in our future work. After that, on the basis of ocean ontology, we will try to implement an application system for the sharing of observational data, experimental results, papers and patents among ocean-related institutes. In this system, Hozo API is used to do semantic reasoning on the ontology, and AllegroGraph [Franz] is used to store annotated instances in RDF files and to do retrieval tasks through SPARQL [W3C-SPARQL].

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