Human Computer Interaction in Constructing and Managing the Dynamic Knowledge Base for Geospatial Cyberinfrastructure: A Cognitive Perspective

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While Cyberinfrastructure (CI) enables advanced integration of heterogeneous data and computational resources to conduct scientific research and to derive novel scientific theories and knowledge, constructing and managing a knowledge base is critical throughout the course of data and system development, integration, and sharing over the CI among the broad scientific communities. Today ontologies are well-known solutions for the purpose of enabling knowledge sharing and reuse [1][2]. By focusing on the logical structure and rule of a domain knowledge, its concepts [or called classes] and the relations between them, knowledge base (KB) can be composed of the ontology together with a set of individual instances of concepts or classes. Ontologies and KB are critical for developing intelligent systems and for CI applications that integrate digital resources from diverse communities.

The above highlighted words, however, activate my memory regarding the research in cognitive psychology, which is also about the intelligence or knowledge development, logic, concepts, relation, assimilation [vs. integration] of concept, cognitive order [vs. rule] and structure [or knowledge framework], of the human beings. Interestingly, computers or agents are designed and developed by human beings to implement a certain task within a limited domain knowledge and expertise. Applying cognitive psychology theories into computer systems research and the CI applications will help understand 1) why the knowledge base is dynamic, and 2) why human-computer interaction is an eternal theme in managing the dynamics and integration of knowledge base from the diverse communities. Geospatial CI provides an exemplary case to understand and prove such a conclusion.

In geographic learning, for example, the concept of “atmospheric circulation” has been a cognitive difficulty to many students who cannot understand and assimilate it into their cognitive structure to formulate an effective and successful knowledge representation in their brain for reuse [in exam for example]. For some students, no matter what and how the teacher could explain the global pattern of atmospheric circulation, they just could not understand this concept, its pattern and dynamics, and the reason of formulation. Many of them may have to adopt the rote learning approach but this concept cannot be logically organized with other concepts in their mind and their short memory of scattered concepts may not support their reuse, reorganize, and repeat the concept in a logical way to answer relevant questions and then fail.

David Ausubel’s meaningful verbal learning theory [3][4] of cognitive psychology provides an answer to help understand why such cognitive problems could happen and how to help student to improve their learning process and quality. Ausubel’s theory emphasized that when student assimilates new information, meaningful learning happens if the new concept can be linked with the relevant concepts that are already existent in the student’s cognitive structure. When a student encounters a certain cognitive obstacle, it may be not because the student cannot understand or assimilate the new concept, but because in the student’s existing cognitive structure, there is no relevant concept that can be associated with the newly encountered information. Given the example of “atmospheric circulation”, the reason that student could not assimilate and understand this new concept is because the student may not have sufficient and relevant knowledge about math and physics, not just the new concept itself.

The concepts in the cognitive structure that can be associated with the new learning materials are regarded as the cognitive anchors. To make meaningful learning happens, the instructor has to develop the curriculum that follows the routine of knowledge development by bridging the cognitive anchors into a learning process. In this way, the correlation between concepts can be logically associated so that student can understand the new concept meaningfully when they can recall something in their memory that has inferential meaning to the new concepts. Whenever cognitive problems happen, the instructor needs to help student to figure out which cognitive anchors are missing or weak and then develop a new learning curve with specific tasks.
In summary, meaningful learning happens based on certain conditions;
- The content and concepts in the learning materials should have logical relation and inferential meaning;
- Appropriate and sufficient concepts should be found in student’s existing knowledge base or framework and cognitive structure to establish contact with the new concepts to be introduced
- If the prior knowledge is not sufficient enough to support the meaningful assimilation and learning of the new concepts, other required prior concepts should be introduced first. After the students’ cognitive structure can be updated by assimilating required prior concepts, new concept can be assimilated [integrated] into their knowledge framework accordingly.

The meaningful learning process of a student can be an analogy to the KB construction and management of the CI. It seems the integration [assimilation] of varied ontologies from diverse communities may not be a simple process by putting ontology documents together into a computer system which is then supposed to be able to function successfully. A critical implication from the meaningful learning theory is the concept of prior knowledge of a computer system, which would integrate the ontology from another source. Previous research may have ignored the process to examine whether the [new] concepts in a certain ontology to be integrated into a computer system can be linked to the any concepts in the existing ontology and semantic definition within that system, whether such similar or same concepts should be merged into an integrated new ontology framework or just keep them separate and unchanged. Especially when new concepts cannot be associated with any ontology defined within the existing KB of the CI, new concepts and new domain knowledge has to be introduced into the system as implied by the cognitive psychology. In this case, knowledge engineers of the CI have to create a new anchor for the new domain knowledge and identify the relationship of the new knowledge with other existing domain knowledge in the CI. After the KB can be updated and upgraded with newly defined ontology and semantic definition, new KB can be integrated and processed successfully.

Ausbéľ’s theory reveals that knowledge base construction and ontology integration [or assimilation] will not be a one-stop-for-all process, but rather, will be a long term dynamic evolution in which the intelligence [or KB] of such complex systems will keep growing and updating. Whenever new semantics and concepts are specified and new knowledge domain are introduced into the system, there will be continuing update and upgrade within the KB and CI in all related aspects.

It seems that the difference between human intelligence and artificial intelligence is – human beings can either passively develop the conceptual linkage between old and new concepts with the aid of instructors, or they can actively bridge the old and new concepts through their exploration via varied approaches from diverse resources, while a machine can only do something passively by following the design and command of human beings. For this reason, human computer interaction is required in identifying and modifying the relationship between old concepts and the assimilated new ones in the KB during the process of ontology integration or assimilation from diverse sources.

Given the example of geospatial Cyberinfrastructure, USGS creates and publishes an ontology A, which defines the geospatial features F1 and F2 that have a spatial relationship of “intersected”, while EPA creates and publishes an ontology B, which defines the geospatial features F3 and F4 that have a spatial relationship of “intersected”. When each organization creates the ontology, they may not have any awareness about what and how the concepts and features defined in the other ontologies. While conceptually F2 may be defined as an “equivalentClass” [concept] of F4, this does not mean they are equivalent spatially. Even if they are both conceptually and spatially equivalent, it may be impossible to derive the relationship whether F1 and F3 are intersected or not. Considering the polyhierarchy and faceted classification in ontology creation, ontology integration or assimilation over the CI may not be an automatic task for computers without the instruction and interaction of human beings.


