A Navigation Ontology for Outdoor-Indoor Space (Work-in-progress)

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ABSTRACT

People's daily lives are situated in both outdoor and indoor space. However, traditional GIS focuses only on outdoor space. Therefore, research on providing a unified model of the two spaces and making the navigation between and within them seamless is important. This study lays the ontological and formal foundations for a model of navigation in a unified outdoor and indoor space. Four levels of ontologies are under construction: upper ontology (being constructing by using and revising those concepts introduced in previous work), domain ontologies (structure ontologies of spaces), navigation task ontology, and application ontologies.

Categories and Subject Descriptors

H.1.1 [**Models and Principles**]: Systems and Information Theory—*Information Theory*; H.1.2 [**Models and Principles**]: User/Machine Systems—*Human information processing.*

General Terms

Design, Theory

Keywords

indoor space, built space, ontology, GIS, navigation

1. INTRODUCTION AND MOTIVATION

The terms "outdoor space" (O-space) and "indoor space" (I-space) here both refer to built rather than natural environments. I-space covers the enclosed interiors of buildings above the ground and spaces underneath the ground that afford platforms for human activities.

Traditional geospatial science focuses on O-space. However, humans spend most of their time in indoor environments. In 1992-1994, the EPA conducted the National Human Activity Pattern Survey, where 9,000 participants across the USA were involved. The average percentage of time spent indoors was 87% [11]. It is important, therefore, to investigate I-space and also to explore the relationships and connections between the two spaces. With this approach, I-space can be explored and a unified outdoor-indoor space (OI-space) model can be constructed by leveraging existing mature theories for O-space. We are developing the underlying principles necessary to make navigation seamless between O-space and I-space by building a unified model of the two spaces. Such a seamless model is important in many applications. Consider, for example, emergency response to a fire in a complex indoor space. Ideally, responders need support for seamless navigation both for their route to the building, and then for navigation and co-ordination within it.

Based on the exploration of the relationships between the two spaces [19], we are constructing a navigation ontology for OI-space. In this paper, section 2 describes the background, section 3 presents the ontologies under construction and their evaluations, and section 4 draws brief conclusions and describes future work.

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2. BACKGROUND

In this section we provide a background to research on navigation ontologies. In our work, general concepts (i.e., event, object, state, setting) are introduced using ideas from upper ontologies proposed by Smith and Grenon[1], Galton [6], Worboys [18], and in SUMO [4]. We will use the theories of affordance to discover the entities and their relationships in our ontologies. The term "affordance" was originally introduced by Gibson [7], referring to the action possibilities perceived in a direct, immediate way with no sensory processing (for example, buttons for pushing and levers for sliding). Norman [14] interpreted affordance in the field of human-computer interaction (HCI) to refer to just those action possibilities that are readily perceivable by an actor. The concept is thus dependent both on the physical capabilities of an actor and the actor's past experiences.

We will also use domain specific ontologies, termed "microworlds". Microworlds were proposed by Sowa [17] as limited ontologies that have a small number of concepts being tailored for single applications. Most theories of navigation concern O-space, and the role of landmarks is often discussed. Landmarks play similar roles in both O-space and I-space, being recognizable and memorable [16]. They are used to help people remember the route in unfamiliar environments by something having singularity or sharp contrast with its surroundings and/or by the prominence of its spatial location [13] at decision points of routes, and to communi-

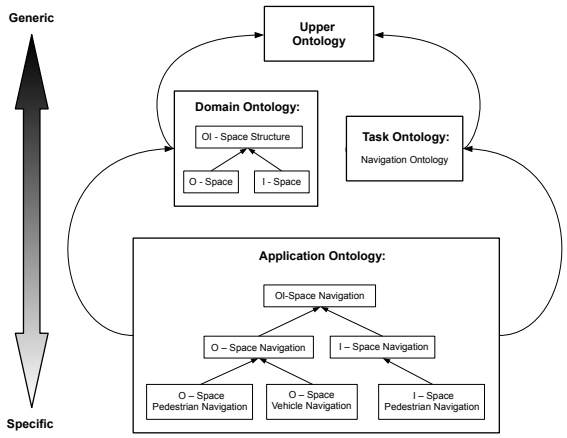

Figure 1: Ontology levels (after Guarino[9]).

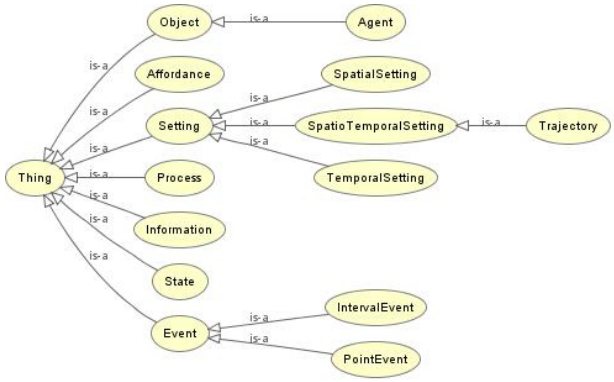

Figure 2: Upper ontology.

cate route directions. In O-space, both distant and local landmarks are recognizable. However, landmarks used in I-space are generally local, because corners or walls block our vision. Outdoor landmarks are usually fixed, whereas indoor landmarks may not be.

3. ONTOLOGY CONSTRUCTION

Building a collection of microworlds is more beneficial than a large single comprehensive ontology, because microworlds make it easier to share and reuse knowledge. After exploring the similarities and differences between O-space and I-space [19], we are developing different levels of microworlds (see Figure 1) in the context of navigation in O-space, I-space and OI-space based on affordance theory. Because some of the entities in O-space and I-space have similar affordances, Gibson's notion of affordance provides the possibility to bridge the gap between ontologies of O-space and I-space. In Figure 1, the arrows between different levels of ontologies indicate the inheritance relationships between different levels of microworlds, the lower levels inheriting the properties from all of the superior levels.

The taxonomy of our upper ontology is shown in Figure 2. A setting [18] may be purely spatial, purely temporal, and mixed spatio-temporal (Spatio-temporal settings are called trajectories [15], histories [8, 6] or geospatial lifelines [10].

The domain ontologies include structure ontologies of O-Space, I-Space and OI-Space. Figure 3 shows the taxonomy of the structure ontology of indoor space. The detailed taxonomies of the structure ontologies of O-space and OI-space may be found on our OI-space wiki [2]. The taxonomy of the task ontology (navigation task ontology) is shown in Figure 4. Below we list some of the definitions for the concepts within the domain and task microworlds. Some definitions are from OpenCyc [3] and WordNet [5].

Container: Anything whose primary function is to contain something. For example, outdoor cities and indoor rooms have the affordance of containing things.

Passage: A subclass of **Container**. A way or channel through or along which agents may pass. For example, outdoor roads and indoor corridors both afford the function of passage.

Connector: A subclass of **Passage**, assisting in transitioning through a barrier and connecting two objects that are separated by the barrier. For example, outdoor bridges and indoor stairs both perform the function of connectors.

Surface: A spatial thing that has extent in two dimensions and supports other objects. For example, outdoor pavement and indoor floors both have the affordance of surface.

Obstacle: A tangible object that can, when suitably situated, impede movement from one place to another. An example of an obstacle is construction work.

Barrier: A structure or object that impedes free movement. For example, walls and rivers afford the barrier function. Barriers can be fixed or movable.

Portal: An opening with or without a covering, affording the passage from one container to another. For example, both outdoor gateway and indoor doorway offer the affordance of portal. **Portal** has subclasses **OOPortal**, **IIPortal**, and **OIPortal**.

OOPortal: The two containers involved in the portal are both located in O-space.

IIPortal: The two containers involved in the portal are both located in I-space.

OIPortal: The two containers involved in the portal, one is located in O-space, and the other in I-space. **OIPortal** has subclasses of **Exit**, **Entrance**, **ExitEntrance** and **Window**.

Node: A connecting point representing an entity at which one or more links come together. For example, outdoor road junction and indoor corridor intersection both afford node functionality. It has subclasses **CellNode**, **PassageNode**, and **TerminalNode**.

CellNode: A node representing a cell (i.e. a room or a park).

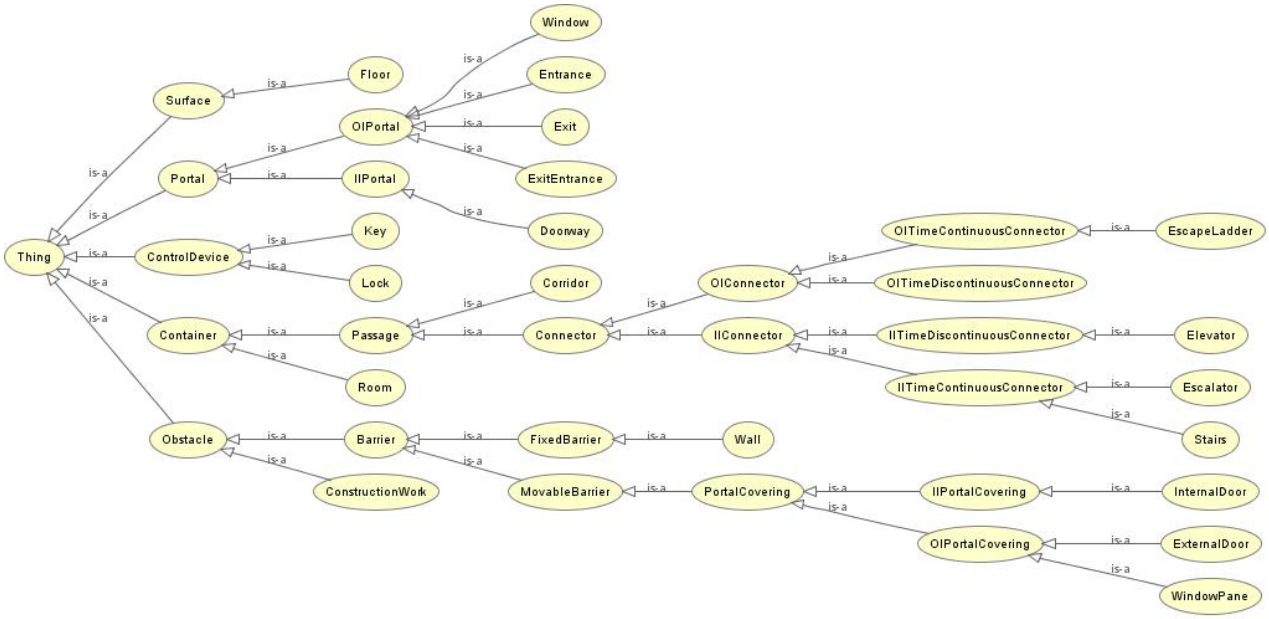

Figure 3: Structure ontology of I-Space.

Figure 4: Navigation task ontolgoy.

PassageNode: A node representing entities that are located on or near a passage. It has subclasses **TurningNode** (representing a single turn in the passage), **DecisionNode** (representing a choice of directions), **LandmarkNode** (representing the proximity of a landmark), and **PortalNode** (representing the proximity of a portal).

TerminalNode: The begin node and end node of a **Path**. It can be **PassageNode** or **CellNode**. It has subclasses **BeginNode** and **EndNode**.

Link: Something that connects two nodes. It has subclasses **IntraContainerLink** and **InterContainerLink**.

IntraContainerLink: The two nodes connected by the link are located in the same container. It has the subclass **PassageLink** (a link connecting two passage nodes). An indoor example is the link between two portal nodes in a corridor.

InterContainerLink: The two nodes connected by the link are located in different containers. It has subclasses **PortalLink** (a link representing a portal connecting two nodes located within different containers) and **ConnectorLink** (a link representing a connector connecting two nodes located within different containers). An indoor example of a portal link is the link between a room node representing a room and a portal node in the corridor outside the room. An indoor example of a connector link is the link between two floors (e.g., a link representing stairs).

Path: A sequence of links and nodes along which an agent travels or moves.

4. CONCLUSIONS AND FUTURE WORK

The details of the application ontologies are currently under development by specifying concepts introduced in the upper, domain and task ontologies, and by seeking and constructing the intra-relationships between the concepts within each ontology and inter-relationships between the concepts in different ontologies. We will build three navigation application microworlds for pedestrians and vehicles in OI-space (see Figure 1): indoor navigation for pedestrians, outdoor navigation for pedestrians, and outdoor navigation for vehicles. We will take specific buildings as case studies for indoor pedestrian navigation and will evaluate our work using a mixture of syntactic and semantic approaches. Also, the ontologies that we develop will be informed by concepts from existing data models, such as CityGML [12]. The differences between indoor and outdoor landmarks will also be further investigated. This work is part of a larger project on OI-space, and human subject studies will contribute to further refinements of the model.

5. ACKNOWLEDGMENTS

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