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Geo-ontology Concepts and Issues

Report of a workshop on Geo-ontology, Ilkley UK, 16–17 September 2002

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Acknowledgements

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The workshop was sponsored by Ordnance Survey Research & Innovation. The subject of the workshop and this report reflects long-term research interests of Ordnance Survey, and not necessarily the focus of current Ordnance Survey business.

1 Introduction

1.1 Background to workshop

Research and discussion on the nature and efficacy of ontologies in geographical information (GI) have featured strongly across the GI Science community over the past few years. Being inherently a multidisciplinary community, use and meaning of the term 'ontology' in GI tends to differ depending on user perspective and objectives (Winter 2001)[1]. That said, motivation for investigating ontologies in GI is soundly grounded in some key and distinct problems facing the advancement of GI content, service and application development. Improving the meaning of GI to the end user, interoperability of GI data, internet-based data mining and knowledge discovery, for example, are all areas where application of an ontological approach could aid both the user and GI industry.

Arising from active research interest in this field, Ordnance Survey Research & Innovation sponsored a workshop on 'Geo-ontology[2]' with the aim of highlighting current concepts, issues, and research requirements within ontologies for GI. Rather than attempt to define ontology in the context of GI, the workshop sought to recognise the diversity of approach and perspective brought by its participants. This is a report of that workshop, summarising its main discussion points and putting forward suggestions for future research focus.

1.2 Workshop objectives and format

The purpose of the workshop, to examine perspectives on geographical ontologies and associated current research issues, was approached through the positioning presentations of the workshop participants and subsequent identification and discussion of key conceptual issues.

Objectives of the workshop were primarily to:

- Examine the state of the art in geo-ontology
- Identify key concepts and issues in the formation of geo-ontologies (for example, vagueness in geographical things, spatio-temporal processes)
- Identify research requirements in geo-ontology
- Promote exchange of ideas and foster collaborations

In outline, half a day was devoted to positioning presentations, followed by two half days of breakout group discussions.

[1] Winter, S. 2001, Ontology: buzzword or paradigm shift in GI science? *International Journal of Geographical Information Science*, **15 (7) ,** 587-590.

[2] 'Geo-ontology' is used in this report as a general term for ontology of geographical information.

1.3 Content of this report

The remaining sections of this report contain:

- Introductory presentations from Ordnance Survey Research & Innovation and Leeds University School of Computing
- A summary of main points from the workshop participants' presentations
- A summary of the workshop discussions on key issues in geo-ontology, and identification of researchable questions

Positioning papers and presentation slides are included at appendix A, followed by a list of participants at appendix B.

2 Presentations and discussion points

2.1 Introductory presentations from Ordnance Survey Research & Innovation and Leeds University School of Computing

2.1.1 Ordnance Survey research interest in spatio-temporal cognition and geo-ontology

Jenny Harding [8], Ordnance Survey

Context of Ordnance Survey research interest

As a provider of geographical information, the success of Ordnance Survey depends significantly on the content of the information it provides, and the usefulness of that information in a wide spectrum of user contexts. While Ordnance Survey's large-scale product, OS MasterMap™, is an advanced, detailed, digital topographic dataset of Great Britain, it still represents a largely cartographic abstraction of the real-world. Geographical features are currently portrayed as a 2-dimensional surface of discretely bounded polygons with unique identifiers and certain attribute information. Aspects of the real-world such as relationships between real-world features, processes of change affecting features or the fact that some features overlap in space, are not represented.

A crucial question to be addressed concerns how the content of geographical information can be improved in order to better serve the needs of existing end users and potential end users of the future. It is necessary to research now how to enrich the content and structure of geographical information in anticipation of new applications in information systems and technologies of the future.

Different users of geographical information, both professional and non-professional have their own, context dependent, view of the 'real-world' and needs for geographical information to inform decision making. It is important that a national mapping agency's conceptual view of the real-world, with which it models, captures and supplies information, can support the disparate conceptual views of different users, or at least provide a framework to which they can relate.

Many aspects of spatial cognition need to be investigated with different types of users in order to understand the critical aspects of geographical information in support of their different decision making processes. Further research is required, for example, into how geographical aspects of the real-world are described and categorised, the nature of relationships between entities, the importance of uncertainty in both category and location, and the importance of process and time.

An ontological approach is required that not only defines what entities are represented in a conceptual view, but also how the spatio-temporal concepts mentioned above are to be expressed and represented. In addition, users of information need to understand how *fit* that information is for their *purpose*. Besides providing details of the specification, it is important for geographical information providers to supply meaningful data quality information.

Research aims

Ordnance Survey Research & Innovation aims to identify a way forward for improving geographical information to better meet the needs of disparate users, and to develop an ontological framework for geographical information which can flexibly underpin information capture and supply. Acknowledging the large body of existing and ongoing research in the area of geographical information concepts and ontologies, the research team believes that its objectives from the perspective of a national mapping agency provides a practical context in which to apply, test and further develop concepts and approaches in geo-ontology.

Current research aims are focused in three interrelated areas: user communities, ontological concepts and data quality.

User communities – Based on analysis of user conceptual views of the real-world, the research is aimed at understanding real-world views in different user contexts, and what elements of geographical information are essential in these contexts.

Ontological concepts in GI – Drawing on analyses of user communities, research in this area is focused on the identification and definition of key spatio-temporal concepts of 'real-world' conceptualisations, and methodologies and techniques with which to express them within a geo-ontology.

Data quality – This research aims to identify where and how the quality of geographical information is critical in different user contexts, and how information quality may be effectively assessed/measured and expressed to the user.

2.1.2 Geo-Ontology

Brandon Bennett **[1]**, School of Computing, University of Leeds

*An extract from Brandon Bennett's paper appears here. The full paper, to which reference numbers in this extract relate, is given at appenidix A, paper **[1]**.*

Why do we need a field of Geo-Ontology? Superficially, it may seem that the fields of geography and ontology are very far apart, both in their subject matter and methodology. Geography is a practical `down-to-earth' science, which seeks to understand the concrete reality of the world. Ontology, by contrast, is a very abstract discipline, concerned with the meanings of concepts but hardly at all with the particular circumstances of reality. Yet both involve systematisation of the world: whereas geography aims to represent the actual physical structure of the world, ontology is concerned with the conceptual structure of the ways we describe the world. This commonality brings the two subjects together, since we cannot hope to fully understand the world unless we understand our means of describing it.

Why we need Ontology in Geo-Science. In recent years `ontology' has become a buzz-word in practically all areas of information processing. In the context of information systems, an ontology refers to a precise specification of the meanings and inter-dependencies of a set of concepts [18]. This specification will normally be given in some kind of formal language – often a variant of the standard 1st-order logic. The scope of ontologies varies widely: many deal with only a small set of concepts relevant to a limited domain, or application; other ontologies (for example, CYC [14]) are extremely large and specify a wide range of concepts.

As far as information systems are concerned, the primary purpose of an ontology is to provide a rigorous specification for interpreting the concepts in terms of which data is stored. This specification can be used to check and maintain the integrity of a database, and also to facilitate integration and inter-operation between different databases. It may also be used as a basis for implementing functionality for querying and presenting information, which requires flexible, multi-perspective, access to data.

It is now widely recognised that formal ontologies could have very significant benefits for the development of sophisticated GIS. A number of features of geographic information and its applications suggest that ontology can be particularly useful in this area. Specifically GIS applications exemplify the following factors:

- a diverse vocabulary of highly interdependent concepts,
- terminology is deeply affected by conceptual ambiguity and vagueness,
- lots of complex data is available,
- applications require very flexible interpretation of data.

Over many different domains, ontologies have been developed and used in similar ways. So one might wonder whether there is anything more to *Geo- Ontology* than simply applying general ontology techniques to the domain of geography. While it would be wrong to claim that geography is uniquely different from other domains, it does seem that geographic concepts present some particularly tough and fundamental problems for ontology construction [28]; and because of this I would argue that Geo-Ontology does merit the status of a significant sub-field of Ontology [17, 21].

Why Ontology should address Geography. Let us now consider why the field of ontology should pay special attention to geography. Perhaps the most obvious reasons coincide with reasons why ontology is useful for geographic applications. Namely, this is a domain with a rich vocabulary of highly interdependent concepts, which is deeply affected by ambiguity and vagueness. But there are other factors that further amplify the significance of geography for ontology. I suggest that the following two points are of particular importance:

- Geographic concepts stand in highly complex relationships to underlying physical reality.
- Fundamental issues (for example, vagueness, temporality, identity, ...) appear in varied subtle forms.

The first point concerns the relationship of geographic concepts to purely physical concepts. While geographic concepts are in most cases highly dependent on physical reality, the means of systematisation used by geographers are in many cases not overtly reductionist. Thus it is unclear whether the geographic realm can or should be reduced to the physical. Philosophers use the terminology `A is *supervenient* on B' to say that A is dependent upon but not definable in terms of B [20]. However, from the point of view of formal ontology, it is not clear whether supervenience offers more than a fig leaf to hide rather than solve the problem. Indeed, certain results of formal logic suggest that complete dependence entails definability [29]. In my opinion, the situation is simply that the explication of the geographic in terms of the physical is extremely complex and subtle; and this subtlety is compounded by the pervasive presence of deep ambiguity and vagueness. But whatever, is the correct analysis, the status of concepts of the geographic realm is certainly of interest to philosophical ontology.

The second point, is simply that the geographic domain is a particularly rich source of issues that are problematic for both formal and philosophical ontology (many of these issues are discussed in the special issue of *Topoi* on The Philosophy of Geography [30]).

I have suggested that ontology may provide a solution to certain problems in manipulating spatial information that arise due to lack of precise specification of the meanings of geographic terminology. But I have also acknowledged that geographic concepts present a particularly severe challenge to ontological formalisation. Could it be that applying ontology to geography is just a case of substituting one set of problems for another? It is true that ontology does not offer a ready-made or simple solution for systematising geographic information. What it does offer is just a methodology, a set of formal and philosophical tools for analysing the problem. Constructing an adequate representation for geographic concepts is in essence an ontological problem and so should be tackled with this in mind.

Key problems for Geo-Ontology

The remainder of this paper by Brandon Bennett considers in more detail the key problems faced in constructing an adequate ontological framework for geo-information. He puts forward and considers the following key problems:

- We need a highly expressive, yet practically manipulable, language for describing spatial and material properties.
- Complex temporal factors must be accounted for.
- Deep ambiguity and *sorites* vagueness are pervasive.
- Size and complexity of ontology building task is enormous, so we need a *methodology*.

The full paper can be found at appendix A, paper ***[1].***

2.2 Summary of scope & main points from workshop presentations

Three broad themes emerged from participants' presentations on geo-ontology, within which some recurring concepts could be identified as important foci for workshop discussion. Summarised below, under these broad theme headings, are the main points from the presentations. Referenced presentation papers and slides are included at appendix A of this report.

Human cognition of geographical reality

Identity

Identity is an important and by no means simple concept in ontologies for geographical entities3. Entities may be identified and described in different ways depending on context, and it is important that systems for geographical information can allow for identifying the same entity in different ways. Different descriptions of identity may exist for an entity at the same point in time ('synchronic identity') or at different times ('diachronic identity') **[5]**.

[3] The term 'entity' is used in this document to denote a geographical thing/construct in the real-world.

From a human cognitive or linguistic perspective, the identity of a geographical entity may or may not change through time, depending on the nature of change to its properties. This suggests there are properties that an entity can gain or lose without affecting its identity, and others which do affect identity, with respect to the conceptual view of the geographic domain [5].

Geographical entities

Many researchers take the view that object formation from geographical reality is a process of the human mind and is necessary for rational thinking. An individual's object formation rules may be seen as related to a 'theory' (of how to go about something) and are dependent on intention. [6]. The 'theories' of driving a car or ownership of property, for example, determine what objects are conceptualised in order to carry out these practices. Further, the importance and nature of boundaries (whether vague or distinct for instance) will depend on the 'theory' in question [6].

A particularly prevalent problem of the 'natural' geographic domain, is that entities may have a distinct identity (for example, Mount Everest) but an indistinct extent; an ontology of the geographical domain needs to allow for vague or graded boundaries [11]. The identity or categorisation of geographical entities may further differ between different natural languages (for example, as in the case of waterbodies) [11] raising semantic interoperability issues.

The temporal dimension – time, process, events

As suggested in the context of identity, time is a concept which should also be part of a geo-ontology.

Approach to spatio-temporal ontology

Two different yet compatible approaches to spatio-temporal ontology can be put forward . In the 'snapshot' approach ('SNAP'), the ontology is concerned with enduring entities as perceived at specific points in time [2]. An alternative approach ('SPAN') is concerned with perduring entities such as processes, where time is an integral part of the ontology and entities extend in time [2]. Granularity is an issue for both approaches, so one will need to construct an ontology capable of handling conceptualisations at different levels of granularity or to use several different ontologies for different levels of detail. [2]. As demonstrated through cognitive robotics research, granularity issues are important with respect to the amount of information needed in different decision contexts [12].

Geo-phenomena

The inter-relation of things in space and time give rise to 'Geo-phenomena', which may be defined as 'spatio-temporally constituted difference, driven by feedback between the causal and contingent and highlighted by human intentionality' (for example, a hazard zone can be defined by the return period of a flood of a specific height) [13]. 'Geo-phenomena are identified through the ego-centric view, with respect to human intentionality and salience in the social and physical environment, and possibly provide a mechanism for identifying important spatial and temporal primitives of a geo-ontology' [13].

Change and events

The fact that real-world entities change, needs to be taken into account. Change may be of different types, and an examination of linguistics describing 'situation' reveals a number of concepts (for example, state, occurrence, process, event) [15]. Events themselves may have instances and classes, relationships, taxonomy, partonomy and granularity [15]. Interdisciplinary research is needed into possible ontologies of the dynamic world, including human cognition of events and processes and development of appropriate computational models [15].

Events may be seen as entities in time, on a par with objects in space, and form an important concept within a geo-ontology [7]. A four-fold ontology may be proposed for geographical information, comprised of events together with locations, times and objects [7]. Distinction can be made between continuous events (processes), discontinuous events, natural and fiat events (results of intentional human action) [7].

Information retrieval and geo-ontology

Semantic problems in geographical information, such as finding a dataset with suitable semantics for a service application, or to support users in searching for a geographic information service to meet their needs, require ontologies for geographical information [10]. It can be argued that such ontologies need to combine entities and process, in order to keep semantics of data and services consistent, and to allow for abstract data types [10].

In the context of reasoning about spatial relevance of a concept (for example, finding all types of eating places for Italian food in a given area) a common frame of reference is needed for areas referred to by place names. An approach based on polygonal Standard Reference Tessellations can provide flexible support for complex spatial queries [14].

Much geographical information exists on the World Wide Web, but is not necessarily described as such, and presents particular research issues for the management of this information [4]. Terminologies used in different web pages depends on the subject domain and natural language used. Current mark up languages are defective for the representation of ontology of geographical objects [4].

It must be recognised that any approach to ontological issues, such as determining properties of entities, cannot be independent from some limiting context [3]. A modular approach to ontology may offer a means of connecting between top-level ontologies developed in accordance with different assumptions [3].

3 Summary of workshop discussions

Collated here are notes, main points and questions raised from group discussion sessions. The first session of group discussions aimed to identify key issues and concepts in geo-ontology. The second session focussed on selected issues and concepts identified in the first session, with the aim of identifying researchable questions.

3.1 Identification of key issues and concepts in geo-ontology

Ordnance Survey past, present and future mapping

- In terms of ontology Ordnance Survey provides a generalist view of the world. Could this be the basis of a 'core' geographical information ontology?
- There should be an ontology for cartographic maps. This is different to an ontology of geographical reality.

Approach to GI ontology

- There could be value in having a 'core' ontology to which domain ontologies could relate. Some issues associated with this are: intersections in domain ontologies and dependencies of core ontologies.
- View points differ as to whether it is feasible to have one ontology for geographical information, or whether geo-ontologies necessarily are multiple and domain specific.
- The terminology used for describing entities is largely in accordance with a particular context or domain. It appears difficult to construct a geo-ontology independently of semantics for describing geographical things. However in different natural languages, landforms, for example, may be described in different ways. Boundaries between different groups of features may be different according to which language is doing the describing. An approach attempting to overcome these differences could be to use more scientifically descriptive terminology based for example on form and materials (for example, a 'lake' could alternatively be described as a waterbody with x,y,z dimensions).
- An approach for investigating what is needed within a geo-ontology is to focus on analysis of real-world problems that need solving. Should, however, the development of an ontology be user driven or driven by some kind of 'scientific' analysis of the domain?

Identity and persistence

- The concept of identity is required in geo-ontology.

Identity tends to be socially constructed, for example, the A34 may be seen primarily as a socially constructed object, rather than as the physical substance of the road, but social and physical modes of identification are relevant and contribute to a deep ambiguity in the meaning of A34. Identity of an entity can vary according to view point.

- Is description of reality independent of use or driven by the context of use?
- Is 'identity' more a question of function? Geographic objects can be thought of by their function, for example, a park could be identified as a place to walk, or a place to park the car.
- Objects/entities can be in the same category but have different functions. Physical properties of entities determine their possible uses.
- How can identity be tracked over time? In terms of portrayal, persistent features could be portrayed in more intense colours, changeable features in lighter colours?

Object view, Field view

- The 'field view' of the real-world (where attributes vary continuously over space) may be seen as pre-ontological. Identification of objects in the real-world 'gives it' ontology.
- The level of granularity of spatial observation or measurement determines whether the view is field or object based. For example, you can't pick out a forest by measuring at millimetre scale.

Temporal dimension and space

- Time references are an integral part of geo-references.
- There is an important distinction between the concept of 'space AND time' (where space is independent of time), and the concept of four-dimensional 'space-time'.
- Dimensions of time & space may be regarded as a basis for variation, but each does not have to be represented as a continuum.
- Temporal sequences of distinct spatial locations may be required for some entities, as some may change location between creation time and destruction time.
- Some geographical things or phenomena relate to intervals in time, some to points in time. We need a model of time which can handle both; that is, different levels of temporal granularity.
- Events may be seen as discrete occurrences in time. Could events be treated as 'objects' of the temporal dimension?
- Could the real-world be conceptualised in terms of events in time, where even objects are conceptualised as 'slow events'?
- It may be possible to distinguish 'primitive events', such as the creation and destruction of objects. (See 'primitives' below).
- Activities and events are significant in order to work out what are the important geographical objects. (Agents are also implicated in 'activities' and 'actions')
- Importance of process/events possibly relates to whether geographical objects are affected. If changes are brought about (to objects), the process or event effecting change may be important?

Geographical primitives

- Is it possible to reduce geographical reality to a set of low level, generally applicable primitives? Is there a need to attempt this, and to what level of granularity? This could help interoperability of datasets, but is a canonical model which may not be achievable.
- Can a primitive in one ontology be described in terms of primitives in another? A particular user group might have its own set of primitives that cannot be explained in terms of general primitives. For example, it may not be possible to describe 'political' entities in terms of 'geographic' primitives.

Vagueness

- It is a characteristic of many geographical entities, particularly 'natural' entities, that they lack a definite boundary.
- Vagueness of boundaries should not mean that it makes the definition of the entity any weaker. Or does it?

Ontology terminology

- As a general note, it was pointed out that there are ambiguities in the terminology used to describe ontology (for example, terms such as 'formalism' can mean different things to people from different backgrounds such as philosophy and logic) and confusions in how to define a methodology. Polysemy may be a particularly acute problem in the area of geo-ontology research in which many research disciplines are active, including geographical sciences, linguistics, computer science and artificial intelligence.

From the above discussion points the following concepts were selected as areas for more in depth discussion, with a view to defining researchable questions:

- Events and Identity through time
- Vagueness and identity
- Ontology architecture – core ontology versus multiple ontologies;
  – the role of primitives

3.2 Key concepts and identification of researchable questions

3.2.1 Events and identity

Discussion focused on the nature of situations where temporal aspects are significant from a use-based or natural language perspective. The nature of events and the distinction between events , process and objects was considered, together with relations to identity.

Researchable questions

Case studies of user groups: A series of grounded case studies are needed, to consult user groups about the significance of events in their use context. Investigation would include:

- How they classify the world into events/processes/objects/<?>
- Taxonomy of events/processes/objects
- How they would like to interact with a spatio-temporal information system (what kinds of questions of a spatio-temporal nature do they need answers to?)

Looking at entities in alternative ways: Are objects/entities and events separate things, or are events entities in themselves? Questions for investigation can include the following:

- Take, for example the concept 'city', in what ways may it be seen as process/object/event?
- Which conceptual view point is better for what type of geographical thing/phenomenon?
- How does conceptual viewpoint impact on identity?

Ontology design: How does one design a specific ontology which includes events, processes and objects?

- Design of ontology representation languages to facilitate such ontology construction

Identity and change: What sorts of change lead to the dissolution of identity?

- What kinds of events create/destroy entities, or otherwise impinge on identity?
- Can change be parameterised by object type?
- Build on existing research in this area, [cf. Hornsby and Medak].

Weaker notions of identity: Investigate, for example, the influence of spatial coincidence, legal succession and other notions on identity.

'Identity of events' (and processes): In what ways does identity apply to events and processes?

- Investigate mereology of events. For example, a flood in a river catchment is one flood event or made up of series of events?
- Identification of (temporal) boundaries of events

State of the art/bibliography: A review of existing research is needed in the area of events and identity.

3.2.2 Vagueness and identity

Discussion focused on approaches to vagueness in geographical extents, named areas and the nature of boundaries, and vagueness of identity.

Researchable questions

User need for extents and boundaries. In what user contexts or applications is it necessary to know the extent of named areas, including landforms, and how important is it to represent degree of vagueness of the extent?

In what scenarios does vagueness matter, and how does the scenario inform how vagueness needs to be modelled?

Representing vagueness of extent. How can boundaries of landforms be meaningfully defined? Can multiple conceptualisations of extent of a named place be managed?

Nearness relations. How important is it to be able to express nearness to geographical entities, in relation to use context.

3.2.3 Ontology architecture

Discussion focused on the questions of whether there is a place for one core geo-ontology, rather than multiple ontologies, together with the value of identifying primitives in a geo-ontology.

Researchable questions

Identify the best aspects of existing GI ontologies and data models. As a foundation for further research into improved ontologies and models for spatio-temporal, geographical information, the most effective aspects of existing ontologies and models need to be evaluated.

Core versus domain ontologies. Evaluation of the benefits of building a core ontology for GI as opposed to association of domain ontologies with no core ontology.

Layered approach to GI Ontology. Evaluation of the benefits of a layered approach to GI ontology. What layers are significant (for example, Scientific, legal)?

'Entification of identity'. Investigation of when the identity in geographic space signifies the existence of a geographical entity.

Primitives in GI ontology. Is there value in identification of primitives in GI ontology, and to what level of granularity. Evaluate arguments for and against.

Ontology of cartographic maps. Investigate the benefits of defining ontologies for cartographic maps.

4 Workshop conclusions and outcomes

Conclusions

Benefits of applying ontological approaches to GI may clearly be anticipated with respect to GI content provision and the development and interoperability of information systems. Geographical information does, however, present some particularly challenging ontological problems which need to be better understood and addressed. Those emphasised through the workshop fell into three broad groups.

Firstly, in the area of human cognition of geographical reality, the concepts of identity and extent of entities are essentially formulated by what matters from the user perspective in relation to their interest or purpose. The properties which give identity to an entity need to be understood in relation to user context, together with allowance of different identities for the same entity and of indistinct or vague extent.

Concepts of time were highlighted as a second broad area requiring incorporation in ontologies for GI. The dynamic nature of the real-world may be conceptualised in a number of ways, involving consideration of geophenomena, process and events for example.

A third area principally highlights GI concepts from the perspective of information retrieval. Again user context and process are highlighted as important considerations in relation to entities in GI.

In terms of overall approach to geo-ontology, discussion was divided on the question of whether a core ontology should or could be developed, to which domain specific ontologies could relate. Likewise, the notion of reducing geographical reality to a set of generally applicable primitives in an ontology requires further investigation as to its feasibility and value.

On a general note, the research area of ‘geo-ontology’ is interdisciplinary by nature. Clarity is therefore needed on how terms (for example, ‘primitives’, ‘vagueness’, ‘event’, ‘identity, and ‘ontology’ itself) are used and what is meant by them in the context of specific pieces of research.

Proposed areas for research

A series of researchable questions were put forward as the principal outcome of the workshop (section 3.2 of this report). These questions are aimed, it is hoped, at further stimulating research in three key areas of geo-ontology, motivated by practical interest in improving geographical information content and accessibility. Of the questions identified, many underline the need to investigate aspects of geo-ontology with respect to user context.

Appendix A Presentation papers and slides

Collated here are the papers and slides kindly provided by participants for the workshop.

[1] Bennett, B. *Geo-Ontology*. [paper]

[2] Bittner, T. *Spatio-temporal ontologies*. [paper]

[3] Borgo, S. *The Modular Approach to Ontology*. [paper]

[4] Cristiani, M. (On management/access of geographical information on the internet – slides not available)

[5] Eschenbach, C. *Identity and Change in the Geographic Domain*. [paper]

[6] Frank, A. *Ontology of Geography*. [slides]

[7] Galton, A. *Introduction and Example: A Spatio-temporal Ontology for Geo-information.* [paper]

[8] Harding, J.L. *Ordnance Survey research interest in spatio-temporal cognition and geo-ontology* [slides + see section 2.1.1 of this report]

[9] Hart, G. *Ordnance Survey and Research* [slides]

[10] Kuhn, W. *Geo-ontologies for Semantic Interoperability*. [slides]

[11] Mark, D.M. *Ontology of the Geographic Domain: Reality and Representation.* [slides]

[12] Randell, D. *What has Cognitive Robotics got to do with Geo-ontology?* [slides].

[13] Raper, J. *Geo-ontology and identity*. [slides]

[14] Vogele, T. & Schlieder, C. *Information Retrieval with Place Names. A Position Paper.* [paper]

[15] Worboys, M. *Geo-ontology workshop*. [slides]

Appendix B Workshop participants

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