The Geographic Information Science and Technology and Information Technology Bodies of Knowledge: An Ontological Alignment

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ABSTRACT
In this paper, we present a philosophical discussion of ontological alignments between the fields of Geographic Information Science and Technology (GIS & T) and Information Technology (IT) based on existing bodies of knowledge (BOKs). We argue that tighter integration of concepts from GIS & T into IT curriculum can provide three specific opportunities for IT education - enhanced spatial thinking, new interdisciplinary and innovative application areas, and student employment opportunities. We also discuss specific ideas for curricular integration based on the alignments and provide a list of free and open source GIS & T software, data and learning resources for IT educators interested in incorporating GIS & T concepts and technologies into their teaching.

Categories and Subject Descriptors
K.3.2 [**Computer and Information Science Education**]: Curriculum, Information systems education

General Terms
Management, Documentation, Design, Theory

Keywords
Curriculum, Geographic Information Science and Technology.

1. INTRODUCTION
Information Technology (IT), as both a formal academic discipline and industrial sector, has seen substantial development in the past 20+ years. Geographic Information Science and Technology (GIS & T), which shares many conceptual and technological alignments with IT, has also seen formal development as an academic discipline and industrial sector in the past 20 years. Despite having a heavy computing focus, the GIS & T field still very much unknown within IT circles. In this paper, we present a philosophical discussion of ontological alignments between GIS & T and IT based on existing bodies of knowledge (BOKs). We argue that tighter curricular integration of concepts from GIS & T into IT curriculum can provide three specific opportunities for IT education - enhanced spatial thinking, new interdisciplinary and innovative applications, and student employment opportunities. We use a student success vignette from the Rochester Institute of Technology (RIT) as evidence of the opportunities that GIS & T and IT integration can provide.

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The structure of the paper is as follows. We first provide background on the GIS & T and IT bodies of knowledge as a context for their ontological alignments. Next, we discuss specific ontological alignments between the BOKs. This discussion is followed by a conceptual discussion of the three specific opportunities for IT education that GIS & T offers as demonstrated with a student success vignette. The paper concludes with a summary and ideas for future curricular integration work. We also provide a list of free and open source GIS & T software, data and learning resources for IT educators interested in incorporating GIS & T concepts and technologies into their teaching.

2. BACKGROUND
In this section we discuss the GIS & T and IT BOKs separately to provide context for subsequent discussion of their alignment.

2.1 The Geographic Information Science and Technology Body of Knowledge

2.1.1 *What is GIS & T?*
For millennia, societal needs have necessitated the creation, storage and representation of geographic information about processes and activities related to human and natural interactions at the Earth's surface – most often, but not exclusively, in the form of maps. GIS & T has emerged as an interdisciplinary field to investigate science and technology issues related to geographic information. GIS & T has been formally defined based on the intersections of three sub-domains [1]. The first is Geographic Information Science (GIScience). GIScience is a basic research domain with a focus on the underlying theoretical elements of geospatial technologies such as geographic information visualization, representation, interaction, and sense making, spatiotemporal reasoning, the impacts of geospatial technologies on society and individuals, the impacts of society and individuals on geospatial technologies and spatially-oriented themes from fields such as geography, geodesy, and cartography [2]. Furthermore, GIScience is fundamentally interdisciplinary through integration of theory and concepts from the fields of geography, information science, cognitive science, computer

science, psychology, mathematics, philosophy, statistics, and anthropology. The second sub-domain is geospatial technology, which has been defined as "the specialized set of information technologies that handle georeferenced data" [1:5]. Well-known geospatial technologies include Global Positioning System (GPS), Google Earth, and web-based mapping tools such as Bing or Google Maps. The third sub-domain is GIS & T applications. Countless examples of GIS & T applications exist such as community planning, disaster response, public safety and utilities (see [3] for a discussion of an overview of numerous GIS & T applications and the GIS & T industry).

2.1.2 *A brief history and overview of the GIS & T Body of Knowledge (BOK)*

The Association of American Geographers (AAG) published the GIS & T BOK in 2006[1]. It was an outcome of an initiative by the University Consortium for Geographic Information Science (UCGIS)[2] to consolidate over 10 years of previous efforts at formally defining an ontology for the GIS & T domain. The broader goal for developing the GIS & T BOK was to provide curricular guidelines to meet emerging and growing Geospatial Technology industry and research needs. The GIS & T BOK was modeled after the ACM Computing Curricula 2001 [1]. Thus, the GIS & T BOK shares many commonalities in terms of structure with other computing bodies of knowledge. A full discussion of intellectual evolution of the GIS & T BOK is beyond the scope of this paper, for more information on its evolution see: [1].

The GIS & T BOK consists of ten knowledge areas the cover the GIS & T domain. Each knowledge area contains units which in turn, contain topic sets that provide specific concepts, techniques, applications and methods [1]. Further discussion of specific GIS & T BOK knowledge areas, units and topics are provided in section 3.

2.2 The ACM Information Technology Curriculum

2.2.1 *A Brief history of IT as a formal discipline*

As the field of computing has evolved over the last fifty years, there have been several sub disciplines that have matured. One of these is Information Technology (IT). IT has been formally defined as follows: "Information Technology (IT) in its broadest sense encompasses all aspects of computing technology. IT, as an academic discipline, is concerned with issues related to advocating for users and meeting their needs within an organizational and societal context through the selection, creation, application, integration and administration of computing technologies" [4:9].

2.2.2 *The ACM Information Technology Curriculum*

In the Fall, 2001, IT faculty from a small number of colleges and universities began to meet to discuss curriculum for the IT discipline. In July, 2003, the Special Interest Group for IT Education (SIGITE) was formed as part of ACM. In addition to conferences, a subcommittee of SIGITE developed the curriculum guidelines that are in use today [4]. This curriculum contain the IT Body of Knowledge (IT BOK) that was developed by the committee. The IT BOK specifies content in thirteen high level knowledge areas. Of interest to this paper, the IT BOK does include a brief reference to **spatial databases** as its own topic under *IM. Special Purpose Databases*. "Mobile databases" and "Scientific (e.g. genomic) databases" are included as sub-topics under the spatial databases topic [4].

3. Ontological Alignments the GIS & T and IT BOKs

In this section we outline specific areas where the two BOKs have ontological alignments. We first briefly discuss the methodology used for aligning the two BOKs.

3.1 Alignment Methodology

The two BOKs are ontologies in the philosophical sense in that they attempt to define the language of concepts that exists in each respective domain [5]. Furthermore, they are not represented in an ontology syntax like Web Ontology Language (OWL) used in sematic web applications (see [6] for a discussion of OWL). Development of each BOK into formal ontology syntax was beyond the scope of the work reported in this paper. Thus, their alignments cannot be automatically computed using ontology matching tools such as *Agreement Maker* [7]. Based on these circumstances, the two BOKs were manually aligned by the authors using semantic similarity between terms and definitions in each BOK, a simple yet effective technique that is the basis for overcoming semantic heterogeneity [8]. Wherever possible, we have matched respective concepts based on exact word matches or interpretations of terms based on our combined experiences as computing professionals - Tomaszewski has a Ph.D. in Geography/GIS & T, Holden has forty years of IT industry experience. We acknowledge that this is a subjective process. However, we believe the semantic closeness of many of the concepts mitigates any unintended bias or misalignments.

3.2 Alignments between the GIS & T and IT BOKs

As discussed previously, each BOK uses a hierarchal structure of concepts. Table 1 outlines the hierarchical levels between each BOK to demonstrate how a given level in one BOK relates to the corresponding level in the other BOK.

Table 1 – BOK Hierarchical Levels

GIS & T BOK	IT BOK
1st Level – "Knowledge Area" – example: *Analytical Methods (AM)*	1st Level– "Knowledge Area" – example: *Information Management (IM)*
2nd Level – "Unit", a sub part of a knowledge area – example: *Unit AM3 Geometric measures*	2 nd Level – "Unit", a sub part of a knowledge area – example: *IM. Data Modeling*
3rd level – "Topic" – sub part of Unit – example: *Topic AM3-1 Distances and lengths*	3rd level – "Topic" – sub part of Unit – example: *Conceptual Models* (topics not given alpha-numeric designation)

Table 2 lists the ontological alignments between the two BOKs. We report each alignment at the Unit and Topic levels as these levels were found to have the greatest alignment semantic power. Alignments are listed based on alphabetical ordering of GIS & T BOK units. Ordering does not imply priority of an alignment. Specific alignments are referred to by their ID value in the text following Table 2.

[1] http://www.aag.org/ (last retrieved 25 May 2012)

[2] http://www.ucgis.org/ (last retrieved 25 May 2012)

Table 2: Ontological Alignments

ID	GIS & T BOK	IT BOK
1	Unit: AM1 Academic and analytical origins Topic AM1-2 Analytical approaches	Unit: PF. Algorithms and problem solving Topic: Problem solving strategies Topic: Implementation approaches Topic: The concepts and properties of algorithms
2	Unit: AM2 Query operations and query languages Topic AM2-1 Set theory	Unit: MS. Math and statistics Topic: Functions, relations and sets
3	Unit: AM2 Query operations and query languages Topic AM2-2 Structured Query Language	Unit: IM. Database Query Languages Topic: SQL data manipulation Topic: SQL data definition
4	Unit: AM11 Network analysis Topic AM11-2 Graph theoretic (descriptive) measures of networks	Unit: MS. Graphs and Trees Topic: Trees Topic: Undirected graphs Topic: Directed graphs Topic: Spanning trees Topic: Traversal strategies
5	Unit: CF2 Cognitive and social foundations Topic Perception and cognition of geographic phenomena	Unit: HCI Human computer interaction Topic: Human factors
6	Unit: CF5 Relationships Topic CF5-3 Genealogical relationships: lineage, inheritance	Unit: IPT Integrative coding Topic: Design patterns Topic: Interfaces Topic: Inheritance

Table 2 (continued)

ID	GIS & T BOK	IT BOK
7	Unit: DA2 Project definition Topic DA2-1: Problem definition Topic DA2-2: Planning for design Topic DA2-3: Application/user assessment Topic DA2-4: Requirements analysis	Unit: SIA. Requirements Topic: Requirements elicitation, documentation, and maintenance Topic: Modeling requirements Topic: Use case model Topic: Modeling tools and methodologies Topic: Testing Topic: Project lifecycle phases
8	Unit: DA4 Database design Topic DA4-1 Modeling tools Topic DA4-2 Conceptual model Topic DA4-3 Logical models	Unit: IM. Data Modeling Topic: Conceptual Models Topic: Logical models Topic: Physical models
9	Unit: DA6 Application design Topic DA6-1 Workflow analysis and design	Unit: SIA. Organizational Context Topic: Business Process
10	Unit: DA6 Application design Topic DA6-2 User interfaces	Unit: HCI. Developing Effective Interfaces (p72) Topic: Graphical user interfaces
11	Unit: DA7 System implementation Topic DA7-3 System testing Topic DA7-4 System deployment	Unit: SIA. Integration and Deployment Topic: Testing/evaluation/benc hmarking Topic: Enterprise integration approaches, standards, and best practices

Table 2 (continued)

ID	GIS & T BOK	IT BOK
12	Unit: DM1 Basic storage and retrieval structures Topic DM1-1 Basic data structures	Unit PF Fundamental data structures Topic: Arrays Topic: Records Topic: Linked structures Topic: Knowledge of hashing function Topic: Use of stacks, queues Topic: Use of graphs and trees Topic: Strategies for choosing the right data structure
13	Unit: DM2 Database management systems Topic: DM2-2 Relational DBMS Topic DM2-3 Object-oriented DBMS	Unit: IM. Data Organization Architecture Topic: Data models (includes object-relational databases)
14	Unit: DN1 Representation transformation Topic: DN1-2 Data model and format conversion	Unit: IM Data modeling Topic: Conceptual models Topic: Standardized modeling in IDEF1, UML
15	Unit: GD12 Metadata, standards, and infrastructures Topic: GD12-1 Metadata	Unit: IPT. Data Mapping and Exchange Topic: Metadata
16	Unit: GS1 Legal aspects Topic: GS1-3 Liability Topic GS1-4 Privacy	Unit: SP. Legal Issues in Computing Topic: Accountability, responsibility, liability Unit: SP. Privacy and Civil Liberties
17	Unit: GS6 Ethical aspects of geospatial information and technology Topic: GS6-2 Codes of ethics for geospatial professionals	Unit: SP. Professional and Ethical Issues & Responsibilities Topic: Codes of professional conduct, such as IEEE, ACM, BCS, ITAA, AITP

Table 2 (continued)

ID	GIS & T BOK	IT BOK
18	Unit: O2 Managing GIS operations and infrastructure Topic: OI2-6 User support	Unit: SA. Administrative Activities Topic: User support and education Topic: Resource management
19	Unit: OI3 Organizational structures and procedures Topic: OI3-1 Organizational models for GIS management	Unit: SIA. Organizational Context Topic: Organizational culture

3.3 Alignment Discussion

The following are three general observations made from the alignments. The first is that the strongest connections between the two BOKs lie in areas related to data and databases. By "strongest connection", we mean (1) where exact words were found in each BOK, and (2) our understanding of the respective topics based on our computing experience. For example, alignments 2, 3, 8, 12, and 13 all deal specifically with database topics. In the GIS & T BOK, data is the focus of two knowledge areas - Data Modeling (DM) and Data Manipulation (DN). In the IT BOK, data-related topics tend to fall under the Information Management (IM) knowledge area. The second observation is that many alignments are semantically similar, but in the GIS & T BOK, have a spatial orientation. For example, in alignment 15, Metadata in the GIS&T BOK is focused a metadata related to geospatial data assets, whereas in the IT BOK, metadata is agnostic of any particular domain and is related to XML. In alignment 16, the GIS&T BOK discusses spatial aspects of privacy (i.e., data aggregation), whereas the IT BOK discusses specific privacy laws such as HIPPA and FERPA and other privacy issues. For alignment 17, both areas are similar but are related to organizations germane to each industry. For example, the American Society for Photogrammetry and Remote Sensing (ASPRS) for GIS & T and ACM/IEEE for IT. Alignments 18 and 19 deal with topics such as user support and organizational structure that also have a spatial distinction in the GIS & T BOK. The third observation is that there are several alignments related to end-user application development. Of particular note in this regard is that the entire application development process is generally represented - from requirements analysis and definition (alignment 7), to application development (alignment 9) and user interface design (alignment 10) to system implementation (alignment 11). Furthermore, it was interesting to note that Human Computer Interaction (HCI) was not explicitly listed as a knowledge area, unit or topic in the GIS & T, despite many GIScientists drawing upon HCI literature for Geovisualization technology development [9]. Although not explicit, many HCI-related issues however are in alignment 5.

Application development alignments between the BOKs could also be a reflection of IT's focus on applications and integration [4]. Furthermore, it could be anticipated, although not investigated here, that alignments exist with other informatics disciplines, such as Bioinformatics and Medical Informatics. If that is the case then it may be an opportunity to find the commonality among the informatics disciplines. Ultimately, this could potentially lead to a movement to add informatics as a pillar of IT. This would further link IT more closely with the domain/technology integration for which it is known. We at RIT have already begun to look at informatics as a component of future program redesign.

4. Specific opportunities for IT education

In the following sections, we outline three opportunities for IT education based on the alignments.

4.1 Enhanced Spatial Thinking

Spatial thinking is the idea that the concepts of space, representation tools and reasoning processes can be used to find answers to problems [10]. A simple example of spatial thinking would be navigating to a destination by making observations of landmarks and using a map. Spatial thinking is a critical component in science and technology for addressing pressing societal issues and is useful in everyday life. For example, problems such as large scale disasters are inherently spatially when the geographic scale and inter-relationships between affected entities are considered (see: [11, 12] for specific examples of how spatial thinking can be used to solve disaster management problems) . We argue that bringing a spatial thinking perspective into IT educational practice can (a) help develop the next generation of applied science and technology innovators to address spatially-oriented problems, and (b) develop higher levels of reasoning and problem solving skills in IT students. Spatial thinking has been explicitly identified as a priority area by the US National Science Foundation (NSF) within broader STEM innovation advocacy [13].

4.2 Interdisciplinary and innovative applications– examples from the Rochester Institute of Technology

The Information Sciences and Technologies (IST) Department at the Rochester Institute of Technology (RIT) in Rochester, NY, USA has been making one of the first efforts to formally integrate GIS & T concepts into existing IT curricula as opposed to the more common situation of GIS & T curricula being taught in a Geography department. These integrations have led to exciting new application areas at the intersections of IT and GIS & T. The following is a short description of one interdisciplinary application area.

Faculty from the RIT IST department have been engaged in a National Science Foundation (NSF) funded Science Master's degree Program (SMP) titled "Decision Support Technologies for Environmental Forecasting and Disaster Response " (NSF DGE-1011458)[3]. The broad goal of the SMP is to train students from different disciplines to create a STEM (Science, Technology, Engineering, and Mathematics) workforce for disaster response. In the 2011-2012 academic year, an IT Master's Student was included in the SMP student cohort. This student had completed an undergraduate IT degree from RIT and was in the second year of the IT MS program when selected for the SMP cohort. Before being selected for the cohort, the student had never taken any GIS & T related courses or been exposed to GIS & T concepts. The student did, however, have a strong background in IT areas such as web development and databases. Within the timeframe of one academic year, the student took three GIS & T classes. The student was able to quickly grasp GIS & T concepts and utilize spatial thinking for developing new technologies to create map-based representations of disaster area extents from text-based disaster descriptions [14]. The combination of underlying IT concepts (programming and web systems) when mixed with GIS & T concepts (spatial data, cartography) created an intellectual and innovation synergy for this student and led to the student having job and internship offers with government and industry organizations not typically considered by IT graduates.

[3] http://www.cis.rit.edu/EnvironmentalForecasting (last retrieved 24 May 2011)

4.3 Student employment opportunities

Although job prospects for IT graduates remains strong, we believe it is our prime responsibility as academics to be advocates for our students by helping them secure employment once they graduate. GIS & T has been identified as a key job growth area in the United States [15]. The US Bureau of Labor statistics within the last few years been releasing statistics on GIS & T related employment. Although labeled "Surveying and Mapping Technicians" and thus not directly representative of job opportunities available to IT/GIS & T graduates, the US Bureau of Labor statistics estimates a 16% employment rate in this category [16]. A particularly exciting recent development in terms of formally defining pathways and outlining competencies for student employment opportunities at the intersection of IT and GIS & T has been the geospatial technology competency model (GTCM). Specially, the GTCM has Software and Application Development as one of three, high level, industry-specific technical competencies for which there is great demand [3]. For example, an informal inspection of the GIS Jobs clearinghouse website[4] revealed strong GIS & T industry demand for application developers and database administrators.

5. FUTURE WORK

The philosophical perspectives presented in this paper are the basis for modifications we plan to do to existing IT courses to further and rigorously evaluate the three IT education opportunities outlined in section 4. Specifically, we plan to modify an undergraduate course focused on databases to include laboratory exercises related spatial databases and spatial query operators. We are particularly interested to see if making such modifications improves spatial thinking skills as measured by spatially-oriented problem solving tasks. We also plan to informally track new application areas students become interested in and document internship, employment or co-op opportunities students obtain that are GIS & T focused.

In addition, examining other informatics disciplines could lead to the expansion of the IT discipline to include an informatics focus.

6. SUMMARY AND CONCLUSIONS

In this paper, we have presented a philosophical discussion of the ontological alignments between two disciplines – GIS & T and IT based on their respective bodies of knowledge (BOKs). We demonstrated that IT and GIS & T share many specific commonalities. In particular, data and databases, application development and myriad areas that are conceptually close but differ in the spatial distinction that GIS & T makes in these areas. We also outlined three IT education opportunities these alignments make – spatial thinking, new innovative and interdisciplinary application areas and student employment opportunities. We also sketched out ideas for future educational research based on the alignments.

[4] http://www.gjc.org/gjc-cgi/listjobs.pl (last retrieved 24 May 2011)

Our hope is that the work reported in this paper will give IT educators new, innovative areas and ideas to consider in terms of curriculum development and STEM education. Ultimately, tighter integration between GIS & T and IT education can lead to improved education within both disciplines and problem solving for complex, interdisciplinary societal issues.

6.1 Recommended Resources

Table 3 is a non- exhaustive resource list for IT educators new to GIS & T and interested in incorporating GIS & T perspectives and tools into their educational practice. We have made of point to include only free-open source resources except in the case of Esri given their importance to the GIS & T industry.

Table 3: GIS & T resource list – All URLs listed are active as of August 2012

Item	Description	URL
Commercial GIS software	Esri – the primary commercial GIS & T company. Esri also provides free tools, data and offers open APIs	http://www.esri.com/
Open Source Software	Directory of Open Source GIS & T projects	http://www.osgeo.org/
Open Source Spatial Database	postGIS – an extension to postgreSQL	http://postgis.refractions.net/
Open Source Geo-data web server	Geoserver	http://geoserver.org/display/GEOS/Welcome
Open source web client	OpenLayers – similar to Google Maps API	http://openlayers.org/
Standards	Open Geospatial Consortium (OGC)	http://www.opengeospatial.org/
Data	Open Street Map – A free world-wide map with downloadable data	http://www.openstreetmap.org/
Data	Geonames – Free world gazetteer data	http://www.geonames.org/
Educational Materials	*The Nature of Geographic Information* – open GIS & T book	https://www.e-education.psu.edu/natureofgeoinfo/

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