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Knowledge Cartography: Software tools and mapping techniques

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Knowledge Cartography: Preface

The eyes are not responsible when the mind does the seeing.

Publilius Syrus (85-43 BC)

Maps are one of the oldest forms of human communication. Map-making, like painting, pre-dates both number systems and written language. Primitive peoples made maps to orientate themselves in both the living environment and the spiritual worlds. Mapping enabled them to transcend the limitations of private, individual representations of terrain in order to augment group planning, reasoning and memory. Shared, visual representations opened new possibilities for focusing collective attention, reliving the past, envisaging new scenarios, coordinating actions and making decisions.

Maps mediate the inner mental world and outer physical world. They help us make sense of the universe at different scales, from galaxies to DNA, and connect the abstract with the concrete by overlaying meanings onto that world, from astrological deities to signatures for diseases. They help us remember what is important, and explore possible configurations of the unknown. Cartography — the discipline and art of making maps — has of course evolved radically. From stone, wood and animal skins, we now wield software tools that control maps as views generated from live data feeds, with flexible layering and annotation.¹

“Foundational concept, fragmented thinking, line of argument, blue skies research, peripheral work”: we spatialise the world of ideas all the time with such expressions. *Maps* can be used to make such configurations tangible, whether sketched on a napkin or modelled in software. In this book we bring together many of the leading researchers and practitioners who are creating and evaluating such software for mapping intellectual worlds. We see these as new tools for reading and writing in an age of information overload, when we need to extract and construct meaningful configurations, around which we can tell different kinds of narrative.

For a visual generation of children who have never known a world without ubiquitous information networks, we might hypothesise that knowledge maps could have particular attraction as portals into the world of ideas. Moreover, *the network* is not only dominant when we think about our social and technical infrastructures, but almost an ontological stance in postmodernity, where we hold our viewpoints to be precisely that: always partial and contextualised. Weaving connections between nodes in the network is the most flexible way to bring ideas and information into locally coherent relationships with each other, knowing that there is always another viewpoint on the validity of these patterns. Modelled in software, the vision is that intellectual continents, islands and borders can be invoked and dissolved at different scales, as required.

¹ Our sister volume in this series, *The Geospatial Web*, explores the convergence of spatial data, mapping tools and the social web (Scharl and Tochtermann, 2006).

Knowledge Cartography can be defined as:

- the art, craft, science, design and engineering of different *genres of map* to describe intellectual landscapes — answering the question *how can we create knowledge maps?*
- and the study of *cartographic practices* in both beginners and experts as they make and use such maps — answering the question *how effective are knowledge maps for different kinds of user?*

The particular focus of the authors in this volume is on *sensemaking*: the process by which externalising one's understanding clarifies one's own grasp of the situation, as well as communicates it to others — literally, the *making of sense* (Weick, 1995: p.4). While “sense” can be expressed in many ways (non-verbally in gesture, facial expression and dance, and in prose, speech, statistics, film...), knowledge cartography as construed here places particular emphasis on digital representations of connected ideas, specifically designed to:

- I. *Clarify the intellectual moves and commitments at different levels.* (e.g. Which concepts are seen as more abstract? What relationships are legitimate? What are the key issues? What evidence is being appealed to?)
- II. *Incorporate further contributions from others, whether in agreement or not.* The map is not closed, but rather, has affordances designed to make it easy for others to extend and restructure it.
- III. *Provoke, mediate, capture and improve constructive discourse.* This is central to sensemaking in unfamiliar or contested domains, in which the primary challenge is to construct plausible narratives about how the world was, is, or might be, often in the absence of complete, unambiguous data.

Our intention with this book is to provide a report on the state of the art from leaders in their respective fields, identify the important challenges as they are currently seen in this relatively young field, and inspire readers to test and extend the techniques described — hopefully, to think more critically and creatively. Many of the tools described are not sitting in research labs, but are finding application in diverse walks of life, with active communities of practice. These communities represent the readership we hope for: learners, educators, and researchers in all fields, policy analysts, scenario planners, knowledge managers and team facilitators. We hope that practitioners will find new perspectives and tools to expand their repertoire, while researchers will find rich enough conceptual grounding for further scholarship.

Genres of knowledge map

A range of mapping techniques and support tools has evolved, shaped by the problems being tackled, the skill of mappers, and the sophistication of software available. We briefly characterise below the main genres of map. The appendix summarises at a glance which mapping approaches and software tools are presented in each chapter.

Mind Mapping was developed by Tony Buzan in the early 1970s when he published his popular book “*Use Your Head*.” Mind Mapping requires the user to map keywords, sentences and pictures radiating from a central idea. The relatively low constraints on how elements can be labelled or linked makes it well suited for visual notetaking and brainstorming.

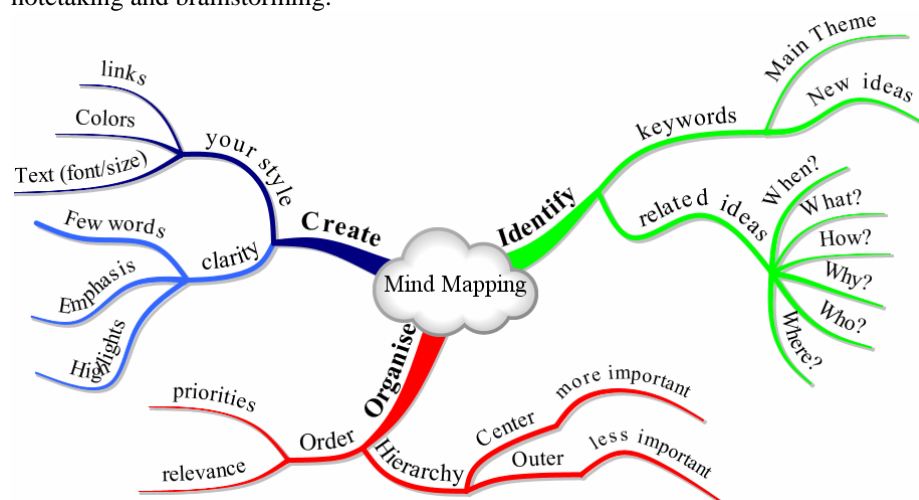


Figure1. Mind Map created with Buzan's iMindmap

Concept Mapping was developed by Joseph Novak around 1972, based on Ausubel's theory that meaningful learning only takes place when new concepts are connected to what is already known. Concept maps are hierarchical trees, in which concepts are connected with labelled, graphical links, most general at the top. Novak and many others have reported empirical evidence of the effectiveness of this technique, with an international conference dedicated to the approach.

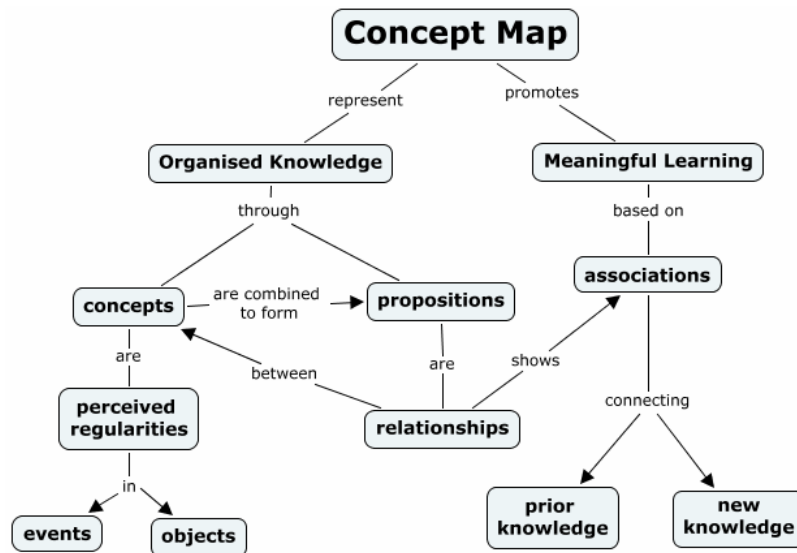


Figure2. Concept Map created with CMap Tools

Argument and Evidence Mapping was first proposed by J.H. Wigmore in the early 1900s to help in the teaching and analysis of court cases. The objective is to expose the structure of an argument, in particular how evidence is being used, in order to clarify the status of the debate. Still used in legal education today, the idea has been extended, formalised (and reinvented) in many ways (Buckingham Shum, 2003; Reed *et al.*, 2007), but all focused on elements such as *Claims, Evidence, Premises* and supporting/challenging relations.

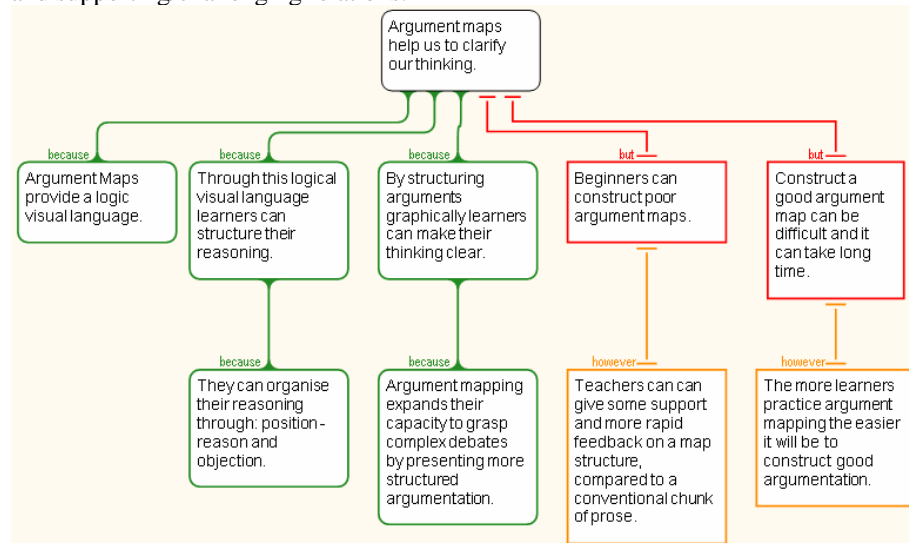


Figure3. Argument Map created with Rationale

Issue Mapping derives from the “Issue-Based Information System” (IBIS) developed by Horst Rittel in the 1970s to scaffold groups tackling “wicked” socio-technical problems. IBIS structures deliberation by connecting *Issues*, *Positions* and *Arguments* in consistent ways, which can be rendered as textual outlines and graphical maps. “Dialogue Mapping” was developed by Conklin (2006) for using IBIS in meetings, extended as “Conversational Modelling” by Sierhuis and Selvin (1999) to integrate formal modelling and interoperability with other tools.

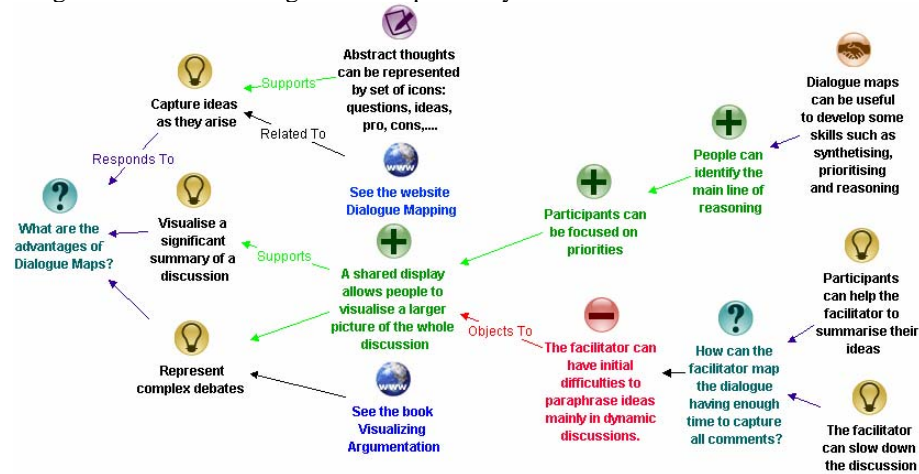


Figure4. Issue Map created with Compendium

Web Mapping appeared relatively recently as a result of the rapid growth of the internet. Software tools provide a way for users to capture, position, iconify, link and annotate hyperlinks in a visual space as they navigate, creating a richer trail which comes to have more personal meaning than a simple bookmark list.

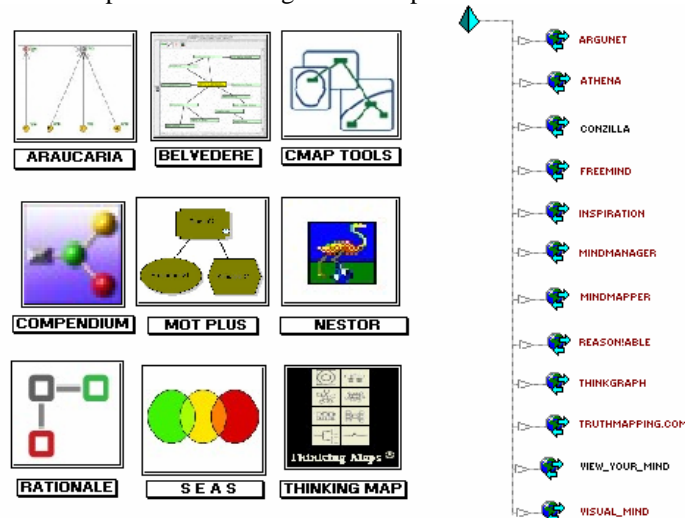


Figure5. Web Map about mapping tools with Nestor Web Cartographer

Thinking Maps as defined by Hyerle (Chapter X) contrasts all of the above with a set of abstract visual conventions designed to support core cognitive skills. Hyerle's eight graphic primitives (expressing basic reasoning about, e.g. *causality*, *sequence*, *whole-part*) are designed to be combined to express higher order reasoning (e.g. *metaphor*, *induction*, *systems dynamics*).

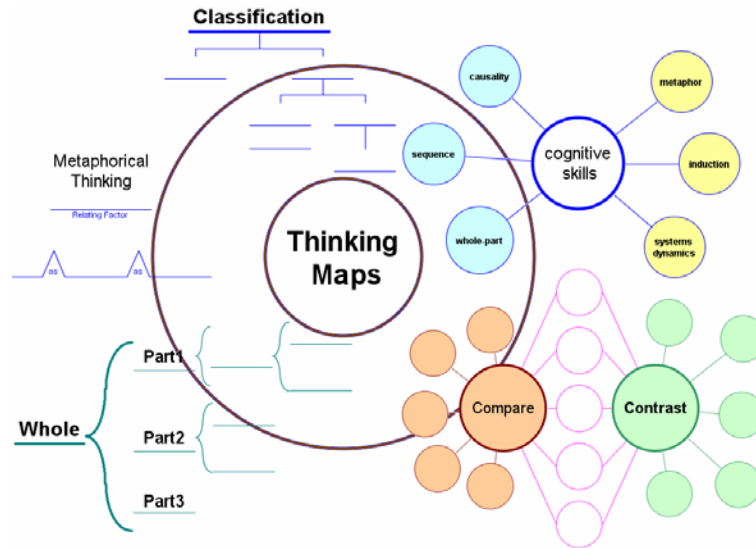


Figure6. Thinking Maps created with Thinking Maps © tool

Finally, a note on what we might term **Visual Specification Languages**, which are designed for software interpretation by imposing constraints on how links and often nodes are labelled and combined. This is a huge field in its own right, with schemes such as Unified Modeling Language (UML) supporting user communities far larger than any of the others listed here, plus innumerable other notations and tools that exploit the power of visualization for modelling processes, ontologies and organizations. These are not, however, heavily represented in this book (though see Chapters X[sierhuis] and Y[basque]) for the simple reason that this book's interest in sense-making focuses on the analytical work required at the upstream phases in problem solving, or in domains where formal modelling is contentious because of the assumptions it requires. Once the problem, assumptions and solution criteria are agreed and bounded, there is a clearer cost/benefit tradeoff for detailed modelling.

Overview of the book

This book has 17 chapters organised in two parts, defined by whether the primary application is in formal learning or the workplace. However, while this distinction reflects two large audiences, readers will find ideas cross-fertilising healthily between chapters. The first half, *Knowledge Maps for Learning and Teaching*, focuses

on applications in schools and universities. We start with tools for learners, opening with a literature survey, followed by examples of different approaches (concept mapping, information mapping; argument mapping). Attention then turns to the kinds of maps that educators need. In the second half we broaden the scope to *Knowledge Maps for Information Analysis and Knowledge Management*, examining the role that these tools are playing in professional communities—but with great relevance also to more formal learning contexts. We start with an analysis of the knowledge cartographer’s skillset, followed by three case studies around issue mapping, one on evidence mapping, concluding with case studies on two additional approaches.

1. Suthers, in “**Empirical Studies of the Value of Conceptually Explicit Notations in Collaborative Learning**” reports on a series of studies which show that differences of notations or representational biases can lead to differences in processes of collaborative inquiry. The studies span face-to-face, synchronous online and asynchronous online media in both classroom and laboratory settings.
2. Canas and Novak present “**Concept Mapping Using CmapTools to Enhance Meaningful Learning**”. After briefly introducing the pioneering concept mapping approach and CmapTools software, they provide an update to what is probably the world’s largest systematic deployment of concept mapping, the “Proyecto Conéctate al Conocimiento” in Panama, reflecting on their experiences introducing concept mapping in hundreds of schools to enhance meaningful learning.
3. Marriott and Torres, in “**Enhancing Collaborative and Meaningful Language Learning Through Concept Mapping**” describe how concept mapping can help develop students’ reading, writing and oral skills as part of a blended methodology for language teaching called LAPLI. Their research was first implemented with a group of pre-service students studying for a degree in English and Portuguese languages at the Catholic University of Parana (PUCPR) in Brazil.
4. Hyerle, in “**Thinking Maps®: a Visual Language for Learning**” summarises a graphical language comprising eight cognitive maps called Thinking Maps® and Thinking Maps® Software. These tools have been used from early grades to college courses to foster cognitive development and content learning, across all disciplines
5. Zeiliger and Esnault, in “**The Constructivist Mapping of Internet Information at Work with Nestor**”, present the Nestor Web Cartographer software and the constructivist approach to mapping Internet information. They analyze a case study in Lyon School of Management (EM LYON), to show how the features of the software, such as a hybrid representational system, visual widgets and collaboration, help in constructing formalised knowledge.

6. Rider and Thomason, in **“Cognitive and Pedagogical benefits of Argument Mapping: L.A.M.P. Guides the Way to Better Thinking”**, show that in dedicated Critical Thinking courses “Lots of Argument Mapping Practice” (LAMP) using a software tool like *Rationale* considerably improves students’ critical thinking skills. They present preliminary evidence and discussion concerning how LAMP confers these benefits, and call for proper experimental and educational research.
7. Okada, in **“Scaffolding School Pupils’ Scientific Argumentation with Evidence-Based Dialogue Maps”** reports pilot work investigating the potential of Evidence-based Dialogue Mapping to foster young teenagers’ scientific argumentation. Her study comprises multiple data sources: pupils’ maps in Compendium, their writings in science and reflective comments about the uses of mapping for writing. Her qualitative analysis highlights the diversity of ways, both successful and unsuccessful, in which dialogue mapping was used by these young teenagers to write scientific explanations.
8. Rowe and Reed, in **“Argument Diagramming: The Araucaria Project”** describe the software package Araucaria, which allows textual arguments to be annotated to create argument diagrams conforming to different schemes such as Toulmin or Wigmore diagrams. Since each of these diagramming techniques was devised for a particular domain or argumentation, they discuss some of the issues involved in translating between the schemes.
9. Sherborne, in his chapter **“Mapping the Curriculum: How Concept Maps can Improve the Effectiveness of Course Development”** argues that ‘curriculum development’ is a process that naturally lends itself to visualisation through concept mapping. He reviews the evidence for how mapping can help curriculum developers and teachers, by promoting more collaborative, learner-centric designs.
10. Conole, in **“Using Compendium as a Tool to Support the Design of Learning Activities”**, reports work to help multimedia designers and university academics create and share e-learning activities, by creating a visual language for learning design patterns. She discusses how learning activities can be represented, and how the maps provide a mechanism to supporting decision making in creating new activities.
11. Opening the second half, Selvin, in **“Performing Knowledge Art: Understanding Collaborative Cartography”** focuses on the special skills and considerations involved in constructing knowledge maps with and for groups. He provides concepts and frameworks useful in analysing collaborative practice, illustrating them with a case study.

12. Buckingham Shum and Okada, in “**Knowledge Cartography for Controversies: The Iraq Debate**”, use the debate around the invasion of Iraq to demonstrate a knowledge mapping methodology to extract key ideas from source materials, in order to classify and connect them within and across a set of perspectives. They reflect on the value of this approach, and how it can be extended with finer-grained argument mapping techniques.
13. Ohl, in “**Computer Supported Argument Visualisation: Modelling in Consultative Democracy around Wicked Problems**”, presents a case study where a mapping methodology supported the analysis and representation of the discourse surrounding the draft South East Queensland Regional Plan Consultation. He argues that argument mapping can help deliver the transparency and accountability required in participatory democracy.
14. Sierhuis and Buckingham Shum, in “**Human-Agent Knowledge Cartography for e-Science: NASA Field Trials at the Mars Desert Research Station**”, describe the sociotechnical embedding of a knowledge cartography approach (Conversational Modelling) within a prototype e-science work system. They demonstrate how human and agent plans, data, multimedia documents, meta-data, discussions, interpretations and arguments can be mapped in an integrated manner, and successfully deployed in field trials which simulated aspects of mission workload pressure.
15. Lowrance *et al.*, in “**Template-Based Structured Argumentation**” present a semi-automated approach to evidential reasoning, which uses template-based structured argumentation. These graphical depictions convey lines of reasoning, from evidence through to conclusions. Their structured arguments are based on a hierarchy of questions (a tree) that is used to assess a situation. This hierarchy of questions is called the argument template (as opposed to the argument, which answers the questions posed by a template)
16. Vasconcelos, in “**An Experience of the Use of the Cognitive Mapping Method in Qualitative Research**”, analyzes concept mapping as a tool for supporting qualitative research, particularly to carry out literature reviews, concept analysis and qualitative data examination. He uses his own experience in applying CmapTools software to understand the concept of partnership.
17. Basque *et al.*, in “**Collaborative Knowledge Modelling with a Graphical Knowledge Representation Tool MOT: A Strategy to Support the Transfer of Expertise in Organizations**”, present a strategy for collaborative knowledge modelling between experts and novices in order to support the transfer of expertise within organisations. They use an object-typed knowledge modelling software tool called MOT, to elaborate knowledge models in small groups composed of experienced and less experienced employees.

Towards human-machine knowledge cartography

To summarise, *Knowledge Cartography* is a specific form of information visualization, seeking to represent spatially intellectual worlds that have no intrinsic spatial properties. We have emphasised the challenge of helping analysts craft maps of information resources, concepts, issues, ideas and arguments as an intrinsic part of their *personal and collective sensemaking*. As with all artistry and craft, the *process and product* should interweave: the discipline required to craft a good map should clarify thinking and discourse in a way that augments the analytic task at hand, and the emerging map should in turn provoke further reflection on the rigour of the analysis. We are interested in mapping the structure of *physical phenomena* (e.g. a biological process), of *intellectual artifacts* (e.g. a curriculum), and *intellectual processes* of inquiry (e.g. a meeting discussion, or a scientific or public debate).

This orientation complements the work that has emerged in recent years in Domain Visualization within the information retrieval community, and Meeting Capture from the multimedia analysis community. In Domain Visualization (e.g. Chen, 2003; Shiffrin and Börner, 2004), “maps of science” are generated from the analysis of text corpora and related scientometric indices (e.g. co-citation patterns in literature databases), with the analyst then able to tune parameters to expose meaningful patterns (e.g. emerging research fronts; turning points in the literature), and interactively navigate the visualization as they browse trails of interest. In Meeting Capture research (e.g. the European AMI and US CALO Projects), the analogous goal is to extract significant moments from audio and video meeting records (e.g. decisions; action items; disagreements), including generating argument maps (e.g. Rienks, *et al.* 2006) in order to index the meeting and support follow-on activity.

We envisage that human and machine knowledge mapping will eventually converge. Software agents will work continuously in the background and on demand, generating maps and alerts that expose potentially significant patterns in discussions and publications (e.g. term clusters; hub nodes; pivotal papers; emerging research fronts; supporting/challenging evidence; candidate solutions). Analysts will assess, further annotate, and add new interpretive layers. While some of the authors in this book focus on mapping domains where objective, ‘hard’ science data can be used to decide whether a map is correct or not, other authors are interested in how maps can support modes of interpretation and discourse across “softer” disciplines within the arts and humanities, and for teams confronted with wicked problems in policy deliberation and strategic planning, where there is no single, knowable solution.

The layers that analysts will add to machine generated maps will, therefore, also reflect the community’s deliberations—whether in meetings or the literature—adding important connections and summaries that are not in the source documents/datasets. Human and machine mapping should be synergistic. Machines will play a critical role by filtering the data ocean, extracting increasingly higher level patterns, and acting on those semi-autonomously. People will, however, sense connections between experiences and ideas, and constantly read new connotations into their physical and information environments, in ways that are hard to imagine in machines. Crafting maps by hand will, in this view, continue to be an important

discipline for sensemaking, even as our tools expand exponentially in computational power.

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We are confronted today by ever more complex challenges at community, national and global levels. As we learn almost daily of new, unexpected connections between natural and designed phenomena, we have to find ways to teach these rich, multilayered webs to our children. More than ever, we need to find ways to build common ground between diverse groups as they seek to make sense of the past, the immediate challenges of the present, and possible futures. It would trivialise the dilemmas we face to declare a technological silver bullet. However, we cautiously propose that rigour and artistry in Knowledge Cartography has a significant role to play in shaping how stakeholders, young and old, learn to think, listen and debate.

*Alexandra Okada, Simon Buckingham Shum and Tony Sherborne*

Milton Keynes, October 2007

Companion website with supplementary resources:  
[kmi.open.ac.uk/books/knowledge-cartography](http://kmi.open.ac.uk/books/knowledge-cartography)

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## Appendix: Mapping approaches and software by chapter

*Part 1: Knowledge Maps for Learning and Teaching*

| <b>Chapter</b> |                                                                                                    | <b>Tool</b>               | <b>Technique</b>                | <b>Use Context</b>       |
|----------------|----------------------------------------------------------------------------------------------------|---------------------------|---------------------------------|--------------------------|
| 01             | Empirical Studies of the value of Conceptually Explicit Notations in Collaborative Learning        | Belvedere                 | Argument Mapping                | Undergraduate Science    |
| 02             | Concept Mapping Using CmapTools to Enhance Meaningful Learning                                     | CmapTools                 | Concept Mapping                 | Schools                  |
| 03             | Enhancing Collaborative and Meaningful Languages Learning Through Concept Mapping                  | CmapTools                 | Concept Mapping                 | Undergraduate Language   |
| 04             | Thinking Maps®: A Visual Language for Learning                                                     | Thinking Maps             | Thinking Maps                   | Schools                  |
| 05             | The Constructivist Mapping of Internet Information at Work with Nestor                             | Nestor                    | Web Mapping                     | Web Learners             |
| 06             | Cognitive and Pedagogical Benefits of Argument Mapping: L.A.M.P. Guides the Way to Better Thinking | Rationale                 | Argument Mapping                | Undergraduate Philosophy |
| 07             | Scaffolding School Pupils' Scientific Argumentation with Evidence-Based Dialogue Maps              | Compendium                | Dialogue Mapping                | Schools                  |
| 08             | Argument Diagramming: The Araucaria Project                                                        | Araucaria                 | Argument Mapping                | Undergraduate Philosophy |
| 09             | Mapping the curriculum: how concept maps can improve the effectiveness of course development       | CmapTools<br>Mind Manager | Concept Mapping<br>Mind Mapping | Schools                  |
| 10             | Using Compendium as a Tool to Support the Design of Learning Activities                            | Compendium                | Mind Mapping                    | Learning Designers       |

*Part 2: Knowledge Maps for Information Analysis and Knowledge Management*

| <b>Chapter</b> |                                                                                                                                                        | <b>Tool</b> | <b>Technique</b>         | <b>Use Context</b>                       |
|----------------|--------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|--------------------------|------------------------------------------|
| 11             | Performing Knowledge Art: Understanding Collaborative Cartography                                                                                      | Compendium  | Conversational Modelling | e-Science and other mission operations   |
| 12             | Knowledge Cartography for Controversies: The Iraq Debate”                                                                                              | Compendium  | Dialogue Mapping         | Policy Analysis                          |
| 13             | Computer Supported Argument Visualisation: Modelling in Consultative Democracy Around Wicked Problems                                                  | Compendium  | Modelling Mapping        | Government Public Consultation           |
| 14             | Human-Agent Knowledge Cartography for e-Science: NASA Field Trials at the Mars Desert Research Station                                                 | Compendium  | Conversational Modelling | e-Science for space exploration          |
| 15             | Template-based Structured Argumentation                                                                                                                | SEAS        | Evidence Mapping         | Intelligence and other Evidence Analysis |
| 16             | An Experience of the Use of the Cognitive Mapping Method in Qualitative Research                                                                       | CmapTools   | Concept Mapping          | Postgraduate Research                    |
| 17             | Collaborative Knowledge Modelling with a Graphical Knowledge Representation Tool MOT: A Strategy to Support the Transfer of Expertise in Organizations | MOT         | Conceptual Modelling     | Organizational Knowledge Sharing         |

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