Content Self-awareness in Distributed Multimedia Publishing: the Need for a Unifying Theory

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Abstract. A distributed publishing system is like the pages of a book floating in the breeze: hypertext pulls these together with a non–linear thread but still leaves the pages like a book without an index. When the pages belong to multimedia documents, the indexing has not only to be dynamic but to cope also with the heterogeneous data structures. A survey of current research projects shows the need for unifying principles.

A formal abstract theory of indexing for multimedia objects leads to the concept of machine awareness, presented here in the context of constructive database models and drawing on the latest results using category theory. Geometric logic can provide a universal representation in mathematics of concepts such as objects, limits, adjunctions and Heyting implications, all needed to deal with closure over open document contexts in hypermedia.

Suggested Keywords:
Multimedia objects, hypertext, information retrieval, category theory, adjoints, Heyting algebra.

1 Introduction

Publishing has always involved the concept of dissemination of information even before the printing press which introduced mechanized methods of writing in bulk. Now the need is for technical support for reading in bulk because of the quantity of information published in electronic form especially on the information superhighway. The wealth of information available today online cries out for systems to have some awareness and alerting capability to identify automatically relevant documents. The need for an alerting function was recognized early in subjects like law[5] where it has always been necessary to handle large quantities of data[1]. This is now a problem which faces an average user of electronic mail[2] and any distributed business system[89]. An electronic message of complaint is now much easier to dash off than a traditional letter or even a fax for customers and citizens wanting to exert their rights. Businesses, government bodies, radio, television and newspapers need to have sophisticated management processes in place to deal with what may soon become avalanches of email as more and more homes have PCs with modem connections[3].

As business information systems become larger and more complicated it is very easy for the user to get lost. Even intelligent hypertext becomes inadequate. It can provide the user with a non-linear connectivity but to be of value the system needs to know where the user is, where the user has come from and where the user is going, all relative to the contents of the information at any point.

Furthermore users need to be assured of the quality of their information system. The quality controller like in any industrial process has to be at a separate supervisory level. This is a trigger mechanism in the system to identify relevant information in context and is also a self awareness where the information checks itself for completeness and its own limitations. Intelligent hypertext is an initial step at this level but intelligence is insufficient without a layer of consciousness. Closure is a key feature. The quality assurance level is a closure over all participating sub-systems, whether local to the end-user or global and belonging to external information providers.

Without proper coordinated principles for document processing, multimedia hypertext can result in a loss of integrity. No externally imposed coordination is possible. Organization can only arise from the application of natural universal principles. To ensure consistency, some formal language is needed to underpin interoperable subsystems[87]. There is only one scientific language that is truly universal and that is mathematics. As information systems are real–world and open, principles and theories need to be drawn from constructive mathematics[87] where intuitionistic logic seems to be able to give a high formalism to common sense reasoning and experience. This paper explores how category theory and geometric language can be applied to give a universal reference model for multimedia objects.

[1] Full text retrieval has always been important for law and the 1970s saw a proliferation of legal systems which failed The historical description in [5] can provide a helpful warning to the exploding internet service providers of the 1990s.

[2] An extreme example is the electronic mail bag of the Pope. The Vatican receives 300,000 messages of greeting around Christmas time[75].

[3] The technology itself can of course assist with automated provision of standard replies but these raise problems of false interpersonality and may have dangerous legal ramifications unless these systems can cope at the semantic level.

2 Background to Multimedia Document Research

2.1 Multimedia Trends in Electronic Publishing

Current tools[4] to explore and handle information overload on the Internet depend on preset buttons, predetermined indexes and algorithms, statistical clustering or human intervention. These methods are proving inadequate. Systems now need to exhibit some characteristic of self–perception. They need to be aware of their own contents to provide the user with dynamic links to be made in context at run–time. The current state of the art[63, 69] like the use of dynamic frames has more to do with formatting displays than connecting and identifying relevant content. The hypertext markup language of theWorld Wide Web provides the facility of tags for connecting to related material elsewhere on the Web but the user has to provide the means for identifying the material[5].

Enhancements of SGML and proprietary software[6] are attempting the concept of mark–up in a semantic context but are still limited to some predetermination. New environments and operating systems[7] now come with built–in facilities for network surfing.

The trend seems to be in the direction of surfing with more interface facilities and a corresponding downgrading of the importance of local storage and processing by those promoting the concept of the network computer. Products in this area have recently been announced[8]. Database providers[9] are currently designing DBMS versions for the proposed network computer to incorporate HTML-like facilities with substantial parallel processing for use in an organization's own *intranet* which may in turn be accessible through a gateway over the Internet. Other commercial products are now appearing with local functions for web page publishing and security on intranets[10]. This raises the question of the interaction between internet packages and different intranet implementations.

The information in the subsystems may come in any form or format. A modern document is composed of heterogeneous objects. Of great importance for many businesses is the image data found in multimedia for the large quantities of documents that are being imported through scanners[11]. Bit images of any

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[4] like Gopher, Wais, UseNet, Mosaic, Telnet, Veronica, Jughead, Netscape Navigator, Windows Explorer, Lycos, WebCrawler, Alta Vista, Cerfnet, Digex, NetCon, Panic, Pipeline, Uunet, The Well, The World, Acadia, Airnfs, Cello, Chameleon NFS, Eudora, InternetWorks, Netscape Navigator, Wingopher and Archie (see for example Falk[31]).

[5] Packages available include Mime, WebMaker, CyberLeaf, Interleaf, Internet Suite, Web Author, and Hot Metal Pro.

[6] like Heads from Hitachi, DotBook from Novell, HotJava from Sun, with Java derivatives like PageMill and Acrobat from Adobe and Shockwave from Macromedia.

[7] like Windows95 or Normandy from Microsoft.

[8] The majority of manufacturers of Windows-type terminals are now offering a network computer to a common reference standard.

[9] eg Oracle and Informix.

[10] like Lotus Notes, Netra for Web–page publishing and SunScreen for intranet security.

[11] including the new range of 3D–scanners for the CAD/CAM market.

type of three–dimensional object may be imported into information systems for applications like virtual reality or for reconstructing evidence. The study of the communication of these images in distributed systems is a current research topic[12]. A hypertext system that cannot search, identify and retrieve the contents of documents held as image bits or sound bytes is today only a partial system[13].

It is important to see this awareness in information systems in the context of the whole of the research relevant to this subject. Information systems have now subsumed electronic publishing, hypertext, multimedia, databases, information retrieval and much of computational linguistics, cognitive science, artificial intelligence[14], etc. Mixtures and different combinations of these are being repackaged to appear under a bewildering array of new subjects and acronyms. Research projects[28] are under way at every level from multi-government agencies to research institutes, universities, commercial companies and individuals.

2.2 Research into Enabling Technologies

Many projects in communications including discourse study, natural language processing and computational linguistics (some even dating from the machine language research of 30 years ago) have now become very relevant to multimedia applications. It is to be noted that a number of these are involved at the higher order logic level of the intension of a document[15].

In the US the NSF and DARPA are engaged on SIMULATE[16] as part of an extensive programme into HLT/HLR[17]. In the European Union there is the SICMA investigation[18] within the ACTS project, TIDE–ACCESS Project 1001 to provide interface tools for people with disabilities and the GLOSSASOFT project LRE 61003[19]. There is a centralized organization for the validation and distribution of speech, text and terminology resources and tools for the telematics community provided within ELRA[20]. Standards in language engineering have been provided since 1993[27] by EAGLES[21]. There are Swiss projects at the Laboratoire d'Informatique Théorique of the Federal Institute of Technology [22]

[12] eg the European investigation in the ACTS project SICMA on a Scaleable Interactive Continuous Media Server.

[13] but moves in this direction to provide features for heterogeneous data can be seen in systems like HyperNet[64] and packages like Mbone, vat, CU-SeeMe vic, sd and vgw.

[14] For the use of AI in the construction of digital libraries, see the IEEE Expert issue for June 1996.

[15] This corresponds to the natural transformation level in the language of category theory to be used later in this paper.

[16] Speech Text Image and Multimedia Advanced Technology Effort.

[17] Human-Language Technology and Human-Language Resources.

[18] into a Scalable Interactive Continuous Media Server.

[19] sponsored by the European Commission in its Telematics Applications Programme for the OSI standard EDIFACT.

[20] European Language Resources Association.

[21] The Espert Advisory Group on Language Engineering Standards.

[22] for example TALC (Text Alignment and Consistency) at LITH-EPFL[59].

into multilingual parallelism and other natural language processing (NLP) for document engineering (DE) involving text analysis and synthesis to study the intentions behind documents.

The French ILC (Informétrie, Language et Connaissance) Project applies a statistical approach to noun phrases and collocations for a user to extract knowledge from documents without reading them and then within DIALOGUE[26, 51] to provide reference interpretation for task–oriented dialogues. We also see the application of dynamic logic to resolve ambiguity in natural language understanding[104], of plain geometry to improve the correctness of hand–written input at a natural language interface (NLI) in the Hungarian project INPUT [23], and of other methods and tools in Italy[50] at ILC[24].

The Italian Istituto di Linguistica Computazionale (ILC-CNR) has extended its well–known textual database system DBT of search and language analysis tools for use on distributed literary and linguistic text archives in DBTWEB. It uses CGI (Common Gateway Interface) scripts as a structured browser to retrieve compound information, for example extended contexts. These gateways are recursive interfaces as the results of one generic query may be dynamically transformed into a HTML page which can then be further queried.

LOLITA[25] at the Laboratory for Natural Language Engineering (LNLE) of the University of Durham[60] seeks to employ a wide range of software engineering tools for natural language translation. Sherpa[93] at INRIA, Grenoble, designs tools and models for knowledge representation of identification (object-oriented), behavioural (equational), methodological (task models) and terminological (hypertext and lexicon) knowledge. Vrije University has developed a stateless protocol HushTalk[48] to deal with *inline applets* in interactive web pages for chat applications. The difficulty of patching an essentially static distribution system for a dynamic one in advancing the web as a general communications network with audio and visual streams calls for a Real Time Protocol (RTP) which is being carried out at GMD, Berlin, and INRIA, Sofia-Antipolis.

Eastern European activity is increasing with Albania contributing to ETCETERA[26] to promote West-East commerce with information on SMEs and HANNIBAL[27] to provide brokerage facilities for ETCETERA[29]. Hungarian SZTAKI is experimenting with a Distributed Systems Department (DSD) to integrate local and global network notices at the Computer and Administration Research Institute of the Hungarian Academy of Sciences and is part of the VASIE (Value Added Software Information for Europe) project of ESSI[28]. There are also similar moves in the Czech Republic as reported by Zpravodaj,

[23] Inductive Logic Programming learning method at the Computer and Automation Research Institute of the Hungarian Academy of Sciences.
[24] The Institute for Computational Linguistics of the Italian CNR.
[25] Large scale, Object-based, Linguistic Interactor, Translator and Analyzer
[26] East-West Technical Cooperation in Research and Development of Electronic Trading
[27] HyperAgent Network and Navigation for Implementing Business Acceleration and Liaison
[28] the European Software and Systems Institute

the newsletter of the Computer Science Institute of the Masaryk University at Brno[111].

Another EU project under the Telematics Applications Programme is CoopWWW[11][29] using the GMD's BSCW (Basis Support for Cooperative Work) providing a shared workspace platform-independent for documents, pictures, tables, spreadsheets or www links capable of supporting user groups up to 30 or 40 members. Version 2 released in March 1996 has computer graphics interface scripts. The CoopWWW provides a collection of interoperable tools and services integrated around this kernel for synchronous and asynchronous awareness, version management, document format conversion, desk top conferencing and interfaces to enterprise information systems.

Likewise sound is an essential ingredient in today's multimedia. Developments in voice with the ability to provide voice mail, voice annotations of documents are becoming common[30]. Data generated by the voice processing industry includes speech synthesis, speech recognition, and natural language understanding[66]. Speech research also shows that relevant developments in special purpose VLSI chips may be outpacing progress in software and even interface devices. Off-the-shelf applications integrating hardware and software platforms in computer and telephony environments (CTI) are now possible through the VersitCTI Encyclopedia[31]. New chips now have their sights specifically set on multimedia targets[32]. There is also a trend to merge with the connectionist approach of neural nets[108] although much of current speech processing and recognition is still based on the Hidden Markov Models[33]. Vision chips may be further away. The Japanese[34] are aiming for a portable chip with flexible complexity to deal with media in digital form and consider that the capability of interactivity and bidirectional communication for moving pictures and 3D graphics will require 500M transistors and less than 1W power dissipation[35]. The present state of the art can be see in the system Chabot[73] and on work at Carnegie-Mellon University in the US digital library initiative[107]. There is in fact a general trend from software into multimedia hardware. Intel is phasing out the i-860 chip and planning to provide Pentium based processors with MultiMedia Extended instruction sets to accelerate multimedia data in Pentium and Pentium Pro chips[68].

[29] Interoperable tools for Cooperation Support using the world- wide web

[30] These facilities were introduced in versions of MS Word from Windows 95.

[31] as adopted by IBM, Siemens, AT&T and Apple but apparently not MicroSoft. See [68]

[32] for example the vector microprocessor for speech the Spert-II based on the single chip Torrent vector instruction–set architecture with an external interface supporting 4Gb of memory[108].

[33] The paper by Power[76] with its references provides a survey of the current state of speech processing.

[34] according to Hajine Sasaki, a president of NEC Tokyo, in an address at the IEEE International Solid State Circuits Conference in February 1996.

[35] By comparison the Spert-II (which is smaller that 2cm square) has only 0.75M transistors but consumes 12W[108].

The world-wide consortium W3C hosted jointly by Computer Science at MIT and INRIA to promote the industrial use of the Web[106] are using Hakon Lie's Cascading Style Sheets incorporating sound and vision components of presentation to provide a common reference standard[36]. However, it should be noted that for the distribution of materials like high-quality digital video it is necessary to use broad-band networks with technology like the Asynchronous Transfer Mode (ATM). There are some problems which are currently being dealt with by use of compression techniques because of the difficulties in storing and communicating large quantities of data as required by vision and sound. However, it is likely that these are just transitional problems and such techniques can be discarded as an unnecessary complication. Hardware miniaturization is improving all the time[37]. Other general methods for audio- video applications are also relevant to distributed multimedia[38]. The state of the art for displays at Xerox PARC can provide seven million pixels onto a 13-inch flat panel screen[12] using active matrix technology[39].

Mobile computing with terrestrial communication in PMR (Private Mobile Radio) is becoming available to a limited extent with the bandwidth on demand digital transmission of the TETRA[40] and is likely to give rise to some new form of mobile document equivalent to an electronic fax. Satellites[41] on the other hand have the capacity for much better multi-megabit communication rates. The fastest commercial communication rate today is about 2.5 Gb/sec. Teams from Fujitsu, NTT, AT&T Research and Lucent Technologies have shown that it is possible to transfer through optical fibre at the rate of a terabit a second[12].

Mobile computing also benefits the mobility of handicapped persons particularly those who are sight- or hearing-impaired[42]. Alternative terrestrial modes of mass communication for multimedia over the electricity distribution supply form the subject of two UK EPSRC projects at Sheffield and Lancaster Universities in collaboration with NORWEB (the North-Western Electricity Board)[9]. An alternative challenger is optical wireless communication using WDM (Wavelength Division Multiplexing) and ray modelling at the Centre for Communications Research at Bristol University[8]. Mobile document systems for hand-held 'intelligent tourist guide` is underway in the Distributed Multimedia Research Group[23] at Lancaster University and for more general awareness of the user`s context [10].

[36] A working draft of this standard is available on the World Wide Web[21]

[37] Current hardware capacity for storage which is commercially viable is about a quarter of a gigabyte per square millimetre.

[38] such as IP multicasting, RSVP, IPv6 flows and RTP

[39] This is three times the pixel density of current displays and can give up to 30 times the resolution of present lap top computers.

[40] Trans European Trunked Radio[110].

[41] Voice and data services are already available in mobile and multimedia satellite systems on satellite orbits GEO, LEO, MEO and HEO[65].

[42] Orange Communications, Portset Systems and Dundee and Bristol Universities are working on standards in the use of personal communications technology for the deaf[4].

2.3 Authoring Systems

In the digital library field DELOS has long-term research for efficient and cost–effective development of digital libraries. The Swiss Laboratoire d'Informatique Theorique has a web browser (SpiderWooman), IDEA[43] for the management and navigation of multilingual documents, HYPOCAMPE for the automatic generation of hypertext documents with conceptual links, AGENDA applied to a healthcare system using optical recognition of hand- written notes, and DICA for distributed groups with a transparency of document/user interface. German work on knowledge-based production of synthetic multimodal documents and into textual typing is being extended into hypernodes based on rhetorically motivated structures as part of KOMET[53].

Authoring environments are available in the French Thot system[78]. OPERA[72] projects at INRIA and in Alliance[1] provide privacy, security and authentication in HTTP (HyperText Transfer Protocol) scripts, document and fragments for group working, Tamaya[100] uses CSS[21] (the Cascading Style Sheets of Hakon Lie) in a visual graphics editing mode to handle multiple-views of several documents treated together. In the same Thot context INRIA-Rennes are producing methods for structured indexes[79].

TORUS[101] at the UK Central Laboratory of the Research Councils is addressing the problems of real-time distributed design documents by developing a prototype DMS (Document Management System) to enable reuse of SGML design documents by transferring them to the ISO-standard data modelling language STEP/EXPRESS. This can employ the high-level design methodology known as GFM (Goal Function Modelling) and can be extended in EXPRESS-P to include and integrate process models. SID (Structured and Intelligent Documents project) at the University of Helsinki[44] is developing methods to attach intelligent features to structured documents[95].

2.4 Browsers and Search Engines

Current projects in Europe specifically addressing World Wide Web problems include ZENO giving group decision support, Sherpa Project designing tools and models for knowledge representation[93], SISU[45] carrying out Internet Survey to assess the viability of the web for professional usage, ICS-FORTH investigating web brokers for caching and pre-fetching with awareness of updating, the Vrije University of Amsterdam writing Hush extensions called HushTalk to execute script code inside an html page[48] and the Czech Academy of Sciences developing a HIT browser with utilities for structured help information in an interactive situation. Sweden is also investigating information retrieval based on stylistic criteria[94].

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[43] the Interactive Document Engineering Application

[44] Within the electronic printing and publishing programme of the Finnish Technology Development Centre (TEKES).

[45] Swedish Institute for Systems Development[97].

Italian work is proceeding jointly between the Institute of Bologna and the Fondazione Ugo Bordoni on agent-oriented architectures. In this work an interface agent interacts with users connecting and mediating with remote agents transparently. Special purpose agents like the Mail Agent, News Agent, Meeting Agent, and Info Agent can be customized to users' interests cooperating and communicating through KQML a Knowledge Query and Manipulation Language protocol. An agent has an internal structure for example the Interface Agent consists of two subagents the Local Retriever and the External Retriever. Other toolkits, utilities and contextual help are available in the portable (platform independent) object-oriented environment of the HIT browser of the Czech Academy of Sciences but this lacks JAVA and VML at present. At the German GMD link maintenance is being dealt with in BASAR[46] using interface, task and network agents. These provide a user's model[3] to locate, relocate and filter as adapted to the user's needs.

Parallel work with a slightly different thrust is proceeding in the US Digital Library Initiative (DLI)[47]. The DLI project at the University of Illinois is searching federated databases of scientific literature via multiple views of a single virtual collection by extracting the semantics from documents using the scaleable technology of concept spaces based on context frequency. However, compare for instance the Italian work on agents with very similar (but nor directly correlated) work at Michigan as part of the UMDL (University of Michigan Digital Library) project[6] which employs three types of agent: UIA (User Interface Agents), CIA (Collection Interface Agents) and Mediators[48]. The Conspectus language is used to connect content providers and users through the needs and capabilities of the agents as described by that language,. On the other hand the Informedia project on intelligent video at Carnegie-Mellon[107] referred to above employs an *object* rather than an *agent* approach. This fragmentation cries out for unification.

The ISO CGM (Computer Graphics Metafile) is registered as an Internet mime of type image with viewers available for Unix and Windows such as Gplot from Pittsburgh Supercomputer Centre, Figleaf from Carberry Technologies and RAL-CGM from the Rutherford Appleton Laboratory. The French ILC Project DIALOGUE[26, 51] referred to above may also used to provide browsing with reference interpretation in task–oriented dialogues.

Projects on image or sound querying are rarer than text but the Greek I^2Cnet project at ICS-FORTH is providing services for image classification and descriptors (image posting) and image analysis for context-based access to networked medical images[49]. Virtual Reality Markup Language is a further development of SGML and HTML leading to MUVR the multi-user virtual reality where there is intense work into the development of browsers[49]. The Atlas Detector project[105] based at CERN is a VRML browser for distributed development

[46] Building Agents Supporting Adaptive Retrieval

[47] See the special issue on the Digital Library Initiative of *IEEE Computer* for May 1996 and also the special issue of *Communications of ACM* for April 1995.

[48] the Mediator class of agent has also a subclass of Facilitators.

[49] by commercial companies like Sony, Black Sun Interactive, and Online Technologies.

work in context carried out from anywhere. DEVRL[25] the Distributed Extensible VR Laboratory project involving the universities of Nottingham, Lancaster and UCL over SuperJANET is building a collaborative information retrieval system with 3D visualization for query interrogation with special VR search tools.

2.5 Social Contexts

To appreciate the full power and effect of modern information systems, it is necessary to consider them in their social[50] as well as scientific and engineering context. Education is a related area where developments[51] need to keep in step with changes in electronic publishing. To understand some of the logical attributes of non-physical documents it is even possible to look at examples before the introduction of the printing press that give some insight into the intrinsic nature of informally distributed information. Examples can be found in the relativism within ancient manuscripts[44] and in the oral tradition of pre-written law. Moving from the past to the other extreme of the future, there are also the current developments in cyberspace which are relevant to the concept of a multimedia document. It is difficult in view of the embryonic nature of cyberspace to deal with these here as adequately as they warrant. In the UK cyberspace is often used as a synonym of the information superhighway. But of course cyberspace is much more than this, it includes the whole new concept of living, being educated, buying and selling, and generally satisfying the informational needs of human beings. The information superhighway is just one strand[56] in the development[35]of cyberspace[52].

There are political developments in personal privacy[13] and in the liberalization of telecommunications which come into force in Europe in 1998[53]. Likewise it is necessary to take into account the recent implementation of the EU directive on the legal protection of databases[54]. There are problems at the liberty/censorship interface. These are very much in the semantics if automatic controls are to be attempted in areas like pornography, child-targetted advertising[15], sexual harassment by email, etc.

For applications a good example on the Internet of a virtual guided tour of a museum is the Darmstadt Museum[22]. Electronic journals which have been tried a number of times over the past 20 or 30 years can now provide a better standard of presentation on the Internet. They are becoming more electronic customized as for example SIGCHI[96], the quarterly publication of the ACM special interest group on human-computer interaction, where it has been found

[50] SISU[97] gives a sociometric study of world-wide web usage.

[51] eg the Pegasus Foundation of the European Parliament which is leading a project into introducing school children from an early age to appreciate their place growing-up as citizens in the information society.

[52] Discussion of current developments in interactive TV and multimedia can be found in [18, 58].

[53] under the Treaty of Rome Article 90.

[54] from 26th February 1996 with a new exclusive *sui generis* right for database creators valid for 15 years.

that a simple structure that can support both browsing and serial reading is to be preferred. More demanding is the daily issue of the Portuguese daily newspaper PUBLICO[77]. There is also the Scandinavian University Press journal for Fokus på Familien produced by the VTT information service NordEP (Nordic Centre for Electronic Publishing)[70] and many academic sites and research establishments providing on-line bulletins as shown in the references to this report. Another example of bringing together heterogeneous data in a hypertext environment for medical data is the HYPERMEDATA[55] project[52].

2.6 Research into the Theory

Some database and knowledgebase theories are being extended for multimedia databases[99] but there seem to be few new theoretical models advanced for hypertext. The Dexter initiative is an interesting example using formal methods[37] but while it is restricted to the methodology of set theory it cannot be universally extended to provide comprehensive closure over all the levels needed in real-world information systems. Use of other formal methods like Petri nets can provide some dynamic behavioural features in networks[34] which is an essential component for multimedia information systems but Petri nets still suffer from the same restrictions as set theory.

ETN (Extended Transition Network) provides a labelled transition system to model information systems jointly between the UK Central Laboratory of the Research Councils and the Italian IEI-CNR claims to provide comprehensive environment for system verification[30]. The Working Group on Formal Methods is coordinating this very diverse methodology to improve the notational problems, resulting from the lack of models, in order to promote industrial take-up of formal methods[109]. SZTAKI is also carrying out some theoretical work on symbolic computational tools to perform exact (as opposed to approximate) calculations for use in engineering and scientific research and education.

By comparison even less attention is being paid to the underlying philosophy but a notable exception is the work on ontological foundations of knowledge engineering at LADSEB-CNR which is investigating ontological and linguistic tools for conceptual modelling (DLTCM)[74].

Nevertheless all current packages and research projects require a common theoretical underpinning if the whole information market is not to fall apart for lack of scientific cohesion. A striking example is the very successful Java project[36]. Java has found great appeal because it is not compiled like C++ but is interpreted and so can run anywhere on any platform where a Java interpreter is available. So in a Java application for instance a short animation sequence can be built into a web page as an applet and run when the page is accessed by a whole variety of types of user. However Java security has been questioned[24]. According to the Online Business Consultant[71], although Java checks that a code is valid it then expects all code that passes the validation tests to be

[55] Hyperlinked Multimedia Medical Data

properly constructed under the rules. This provides an opportunity for rogue applets to carry into a system any type of computer virus.

This may be a theoretical problem because the design is based on a Boolean closed-world assumption that does not apply to the real world. Boolean weaknesses would require an infinite number of patches for multimedia which as we shall see obeys a Heyting logic, not a Boolean one. The only solution that *is aware* of all possible problems is a proper Heyting closure. This is not just a theory for an 'all singing all dancing' system but a higher-level abstraction of everything which does not lose any low-level detail. It can then take on the challenge of including the fundamental pursuit of system self-consciousness.

3 Types of Awareness

Any modern document system needs to provide a variety of awareness features. There is the nature of the information relative to the informational needs of the user and incidentals like the appropriate methods of displaying the data relative to the user's individual preferences. More important is the self-awareness of the information relative to information elsewhere, for example to a source of continuous updates. Otherwise, hypertext can misinform.

Whether computers will in the future exhibit the characteristics of human consciousness is an interesting subject of speculation. Of more current importance is the need for information systems to have a current awareness of the contextivity of the information that is available. This encompasses both local disks, CD ROM, etc under the user's physical control as well as the interaction between these and any distributed on-line facility where the user has logical control at least as far as electronic access and availability.

Even with the old printed medium there were and still are various levels of information providers and information users. At one end, there is the very limited consciousness that a book seller has of the availability of information. This extends little beyond a stock of items currently in market demand or potential demand together with a list of titles and authors that can be ordered. Unless specialized, the bookseller's awareness will not normally extend beyond books in print. Librarians have more regard for the content of the information but this information may not go far beyond books currently in print and the use of bibliographies. A reference librarian on the other hand has more interaction with the contents of the information. That is the librarian actually opens the books in question.

At the other extreme is the lawyer whose function is to dispense the information in the form of advice involving the construction and application of legal source documents to clients who may never actually see the books themselves or even know that they exist. The lawyer has to have an appreciation of knowing what exists and how to find it. Because of the volume and complexity of the information available, the awareness carried around in the lawyer's head is only how to go about finding some relevant piece of information and not any particular source. Legal hypertext must mimic these processes[46]. Extracting legal information from legal sources is not just looking up rules of law. It involves legal reasoning. This is why legal hypertext is analagous to legal reasoning.

However, a legal hypertext is not a special case, only one where it is more obvious. It is the same sophisticated aim to make conscious reasoned connections that hypertext in general must address. It is this kind of awareness that information systems need to provide in all subject areas for a great untapped world–wide potential market. For humans to carry out these activities, as shown by the example of the lawyer, requires long training and experience and even then is an expensive and time–consuming activity. Despite several decades of research into areas of research such as information retrieval, databases, artificial intelligence, knowledge engineering and hypertext, etc, these facilities are only just coming to hand in information systems.

4 Connections in Multimedia

Hyperspace is equivalent to a multimedia database composed of complex objects in contrast to traditional types of data. Databases for simple data have developed out of advanced file handling and the need was soon recognized to identify the kind of relationship which existed between data. The traditional structures are the network, hierarchical and the relational model of Codd. With networks based on the theory of directed graphs, the hierarchical or nested trees and the relational model relying on mathematical sets, these are still only lean representations of relationships in the real world.

Semantic models have developed to meet the need to specify information about the kinds of relationships[56] to capture more meaning through the introduction of rules of relationships and integrity. The most popular of the semantic models is probably the E-R model of Chen but this has been extended in different ways[57]. The important deficiency of manipulation and the specification of behavioural characteristics has been satisfied in later models[58]. The complex nature of the objects on the other hand has been satisfied by the development of object-oriented models[59].

These developments show the importance of semantics and some of these models have already been applied to document structures[60]. None of the semantic models even with extensions have all the necessary features. The kinds of relationships needed in document links are extensive:

- abstractions such as aggregation, generalization, specialization, inheritance, classification, definition, designation, associative;

[56] like the way that the relational model was extended in Codd's Tasmanian model RM/T[16].

[57] to suit different users[98]. For instance the type and attribute form had to be added to Chen's original style of representation and Sakai[90] added generalization.

[58] eg by Taxis, Event and SHM+

[59] such as the Semantic Association Model SAM* for use in statistical databases.

[60] for example E–R[43, 83], extended relational and Taxis[84], and object–oriented and SQL relational[85].

– structural such as models, nets, tables, hierarchies, entity classes, E-relations, P-relations;
– statistical such as summation, averages, probabilistic, fuzzy;
– ordering such as sequence, Markov chain, probabilistic, temporal, stochastic;
– reductionist such as projection, parallax, derivation, view;
– behavioural such as dynamic, functional, transaction, operational;
– synthetic such as composition, join, union, cross-product, combined, concatenation, insertion, injection, embedded, tributory;
– analytic such as selection, intersection, adjacency, parametric, attribution;
– parallel such as synchronization, collaborative, collateral, adjacency, adjoin, redundant, orthogonal, anti-parallel, contributory.

Database technology has made progress with some but not all of the above categories. In some relations, the user is not concerned with detailed procedures and these may be the beginnings of automated reasoning. For instance, in aggregation the user is unaware of the way in which subobjects are put together. An example of putting subobjects together is the way that the current version of a section of an English Act of Parliament may be derived from a number of textual amendments in later Acts. Automatic identification of objects and their characteristics is needed to make the selection with the right inter-connections for the aggregation. From a database point of view, the identification is provided by the keys in the system[83]. Some universally recognized form is necessary to recognize the keys. This enables documents to be addressed and cross–referenced in a natural manner with a standard identification mechanism. Data typing can be used to characterize components of the keys so that documents can be composed from their underlying subsections (subobjects) in a transparent way. The use of natural keys and relations avoids the unnecessarily reductionist methods of early legal retrieval systems.

Elaborate data management systems are needed to provide the high functionality required for structuring, manipulating and maintaining the data with the necessary integrity to provide professional information systems so that end-users may have access transparently to goal-information in a highly organized state. To do this the management system has therefore to recognize inherent relationships in the data to make the necessary hypertext links.

There are often very many, if not an infinite number of, natural connections that can be made. The author or information provider may predefine certain of these based on some expectation of the user's requirements. Alternatively it may be possible to provide some automatic assistance based on predetermined criteria. It is a simple matter to have a dynamic button to pick up references for a glossary or thesaurus where there is a direct connection usually because the item in the text is itself a simple key to the citation. Where there is a partial or a composite key, the system has to have some awareness functionality of what is needed[88].

But there are limitations. The system needs to be able to follow any potential connection under the control of the user. This requires the system to be conscious of where the user is within the document. A very simple example might be given of anaphora in parliamentary debates like American Congress or the Hansard records of the British Houses of Parliament. When reading from a Hansard CD-ROM, to deal with a sentence beginning with

"As I said in my speech on 28th October to this House ..."

the system needs to be aware of the name of the speaker, of whether the current speech is being made in the House of Commons or the House of Lords and of the date of the speech to identify the appropriate year for the 28th October. This necessary awareness required is therefore beyond intelligent hypertext. It also illustrates the practical point that this awareness needs to be a runtime facility. For identifying all possible cross references in advance when only very few of them will ever be required is very inefficient in preprocessing and storage and almost impossible manually.

This awareness is now essential in very many areas of business which need continual access to information on changing standards and regulations. This awareness function can be achieved by overlaying another layer of metadata on top of the basic hypertext system. This is a necessary part of intelligence in information retrieval systems[40]. We have to provide this additional layer to simulate a human metamemory for any type of document[81]. This layer needs to be reliable and comprehensive so that it provides closure to an open system[41] in an analagous manner to consciousness.

5 Formal Modelling under Geometric Logic

The logical reasoning obtained with axiomatic methods are subject to the uncertainties of the applicability of the axioms. Constructive mathematics on the other hand attempts to develop logically what works in practice and can provide the necessary universality for interoperability of heterogeneous data systems with consistency and quality assurance in the real–world. Geometric logic is particularly appropriate for modelling relationships in hyperspace[45] for it is essentially concerned with links between objects.

From the simple concept of the arrow, formal categories can be constructed of objects with arrow links between them. These provide a natural model for a document. Geometric logic is the formulation between the categories and can therefore represent manipulation of documents in this model of hyperspace. In a formal representation it turns out that linking documents and reasoning are equivalent.

We are concerned with general categories which may be used to represent any system or a class, object, entity, set, etc. that satisfy the four categorical axiomatic constructs for arrows namely composition, compatibility, associativity and compositional identity[2, 45]. These required constructs do not cause many problems in applying category theory to real–world models which deal with things that actually exist. However, it may be necessary to check carefully that the components of a virtual reality system satisfy the definitions of a category. Because categories are general it is often only a matter of convenience for a particular model how objects and arrows are to be identified. With hypertext a document forms a natural category. Other categories are always available to provide the necessary typing. For example a particular Act of Parliament can be considered as a category **Act**. **Act** can be typed by an arrow from the category **Enact** of statutes consisting of all parliamentary enactments including both civil law codes (from the subcategory **Code**) as well as statutes (of the subcategory **Stat**) found in common law jurisdictions.

Figure 1 shows functor arrows K, L between categories $\mathbf{A}$ and $\mathbf{C}$ containing objects $A, B, C, \ldots$ interrelated by arrows $f, g, \ldots$. In Figure 1, K assigns from the source object A the target object K(A) to C and from a source arrow f the target arrow K(f) to g. These are covariant arrows. The direction of K and L may be reversed to give the dual contravariant arrow.

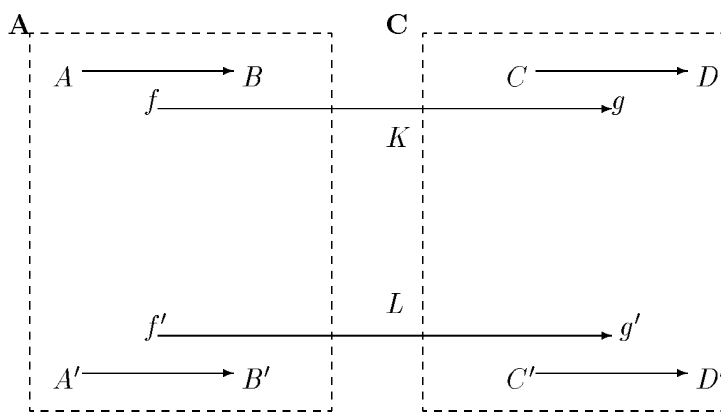

Fig. 1. Functors compare Categories

Documents and the concepts they contain may be represented by categories $\mathbf{A}, \mathbf{B}, \mathbf{C}, \ldots$. The functor arrow generally represents a hypertext link between documents. The functors can also represent inferences. In geometric logic a deductive system is based on the arrow as a proof:

$$\frac{F : \mathbf{A} \longrightarrow \mathbf{B} \quad G : \mathbf{B} \longrightarrow \mathbf{C}}{GF : \mathbf{A} \longrightarrow \mathbf{C}}$$

where $F : \mathbf{A} \longrightarrow \mathbf{B}$ is more than a proof theory entailment. Lambek & Scott[54] argue that the arrow is the *reason* why $\mathbf{A}$ entails $\mathbf{B}$ (at page 47). Up to natural isomorphism this is valid as a general (higher–order) predicate logic expression. Thus the *reasons* F and G may be a mixture of propositional and predicate logic and may even include the modals like deontic logic. The inference in the composition GF is then a graph in geometric logic of human reasoning. At the same time it is calculable through the algebraic form.

However a logical model of the market place is insufficient without some philosophical basis to be taken of its role in life. Hypertext too can exist entirely in neither a practical nor a philosophical vacuum. Therefore it is perhaps worth mentioning in passing the ontology of this formal model. Reality in the everyday world is made up of rational links as discussed in the first part of this paper. What exists are limits in the sense of geometric logic. A hypermedia is a model of these limits in some cyberspace. These can be represented in this way because of the universal abstract character of category theory.

In general a finite limit in the category $\mathbf{C}$ means a limit of a functor $\mathbf{J} \longrightarrow \mathbf{C}$ where $\mathbf{J}$ is a finite category. An object in the functor category $\mathbf{C}^{\mathbf{J}}$ is a geometric diagram in $\mathbf{C}$ of type $\mathbf{J}$ which can be represented in general by the cone (together with dual cocone)[80].

The nature of proof in category theory should be emphasised. The diagram is a formal diagram. It is a geometric representation equivalent to an expression in algebra. We are in constructive mathematics and the one proof needed is the proof of existence. Therefore so long as it can be shown that the entities belong to formal categories[32], proof up to natural isomorphism is by composition. A formal diagram is in effect a *quod erat demonstrandum.* Freyd & Scedrov[33] give a formalization of the diagrammatic language (at p.29–36).

The value of category theory is that unlike in naive set theory where functions are external to a set, objects and arrows on the other hand are internally integrated and mutually intrinsic. This means that the logic comes already integrated within the structure of categories. Geometric logic is strictly then the logic of categories.

It may be appropriate at this stage to draw attention to the way we are using the word *object* which conforms to its usage in category theory. This is not necessarily in the same sense the word object is used in the object-oriented paradigm of computer science. It is rather unfortunate that the paradigm has developed independently of the concept of category which was already well established in mathematics. *Object* in the object-oriented sense corresponds usually to a category in the mathematical sense. This seems to have arisen because the object-oriented paradigm has emerged empirically from practical situations. Objects which are themselves categories are the most common in practice and it is quite natural to pick on this definition. However, these are not primitives but complex objects and therefore different object-oriented methods have emerged like BM (Bosch Method), OMT (Object Modelling Technique) and OOSE (Object- Oriented Software Engineering) which cannot be easily unified[61] and the usage[62]

[61] UM (the Unified Method) was confidently predicted for the near future at OOPSLA95 but at Software Development 96 it was admitted that it was only the language and not the methods that were ready for unification. See *IEEE Computer* June 1996 and *IEEE Software* July 1996. A draft of the unified notation is available at [102].

[62] Standards like CORBA[19] (The Common Object Request Broker Architecture) are therefore to be used with care. Although it is a standard for interface specification in

can lead to unnecessary complications[63].

Because of the universality of the mathematical sense an object can be an element, a set, a class or something corresponding to the natural units of language which are well beyond naive set theory. There are also alternative uses of the word *category* in language theory[103] where its use should be carefully distinguished for language processing is also relevant to multimedia information systems. The pure approach would be to use only arrows but for historical reasons western thinking is more at home with concrete objects rather than the abstract concept of process. The advantage of category theory is that it can provide a natural bridge between all the senses of the word object by the concept of the arrow. An arrow may be an ordinary object in a category (as an identity arrow), a category (as an identity functor), a functor or even a natural transformation. So in geometric logic objects can be arrows and arrows can be objects. In real-world modelling, relationships between transformations are often needed. Any set theoretic representation of these soon becomes unwieldy. In category theory it is simply a category where the objects are themselves arrows.

Object is used in this paper as the basic unit. Even the word *unit* is misleading because objects need not be discrete for example in natural language. It can be seen that the concept of an arrow causes less problems of connotation. However, whether objects or arrows, they are universal and the same formalism can be used here to describe interacting multimodal objects, text (in its widest form), speech and other forms of sound, graphics including dynamic versions in the form of video, touch and indeed all *objects* perceivable by the senses. For this reason we are able to refer to links between objects of any type as hypertext where the term hypertext is used in a general overloaded sense.

5.1 Adjointness

Adjointness between two categories

$$F \dashv U : \mathbf{A} \longrightarrow \mathbf{B}$$

has left and right components which specify how an arrow in category $\mathbf{A}$ is related to an arrow in category $\mathbf{B}$. This is the fundamental concept of implication to be found in geometric logic. The left component is the free functor $F : \mathbf{A} \longrightarrow \mathbf{B}$ and the right component the underlying functor $U : \mathbf{B} \longrightarrow \mathbf{A}$. F is left adjoint to U and U is right adjoint to F. This is a natural bijection between arrows which holds subject to the condition for all objects $A \in \mathbf{A}$ and all $B \in \mathbf{B}$ such that:

$$F(A) \longrightarrow B \text{ implies and is implied by } A \longrightarrow U(B)$$

support of interoperable distributed computing, CORBA does not provide a security specification. A CSI (Common Secure Interoperability) has had to be proposed[39].

[63] There are particular problems in addressing the right level, leading to great difficulties in using object-oriented techniques for group working[17].

Written as a geometric logic inference where the double line indicates the biconditional[64](iff):

$$\frac{1_{\mathbf{A}} \leq UF}{\overline{FU \leq 1_{\mathbf{B}}}}$$

With this condition there are two natural transformations or unit of adjunction:

$$\eta : 1_{\mathbf{A}} \longrightarrow UF, \quad \epsilon : FU \longrightarrow 1_{\mathbf{B}}$$

Adjointness is particularly relevant to hypertext for it represents the concept of relative ordering which is the basis of the connections between documents. $A \leq B$ means B is a later document than A in a hypertext trail. The unit of adjunction is a natural transformation that amounts to an abstraction of the components of the adjointness representing the concepts, objects, message passing, etc which connect the documents.

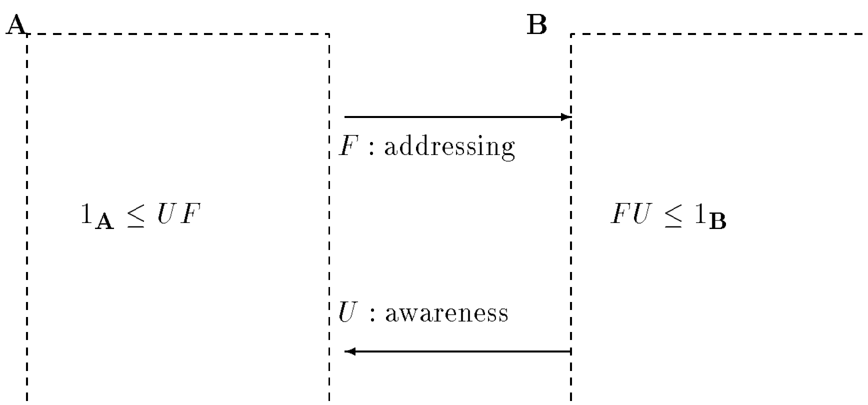

Fig. 2. Adjointness in Indexing

[64] The biconditional iff, *if and only if,* is used here as a way to explain adjunctions as we are only concerned with applied mathematics. A better pure mathematics approach as found in the categorial literature is to show that adjunctions can be constructed from primitive arrows. This in fact rigorously defines the biconditional, a concept which has to be plucked out of the air in classical logic. Any conditional is then a category of a particular type. A biconditional is an adjunction and may be represented equationally by a pair of natural transformations i.e. the units of adjunction.

By virtue of the adjoint functor theorem[33], left adjoints preserve colimits (right–exactness) and right adjoints preserve limits (left–exactness). Colimits are the dual of limits. Both limits and colimits will be examined in more detail.

A basic form of awareness is provided by the indexing of a traditional book. The simplest index is an inverted file (concordance) which is an example of adjointness, $F \dashv U : \mathbf{A} \longrightarrow \mathbf{B}$. The ordering in the book $\mathbf{A}$ is the order of the words of natural language. The indexer has complete free choice on how to index but subject to the initial ordering of $\mathbf{A}$. The arrow is the free functor F describing a particular choice of indexing, for example on words, concepts, chapter headings, figures, etc. $\mathbf{B}$ contains the ordering of the index, the simplest form is usually a lexical order of the important words in the text with the page numbers on which they appear. This is a totally free ordering in $\mathbf{B}$ but entirely subject to the ordering in $\mathbf{A}$. A reader uses the order in $\mathbf{B}$ to find the page required in $\mathbf{A}$, an operation of the underlying functor U. With this information the reader finds the required page leaving the index (with its own ordering) behind showing that U is also the forgetful functor.

If category $\mathbf{A}$ is a collection of multimedia objects, the arrows would be the relationships of conceptual links with higher–order arrows relating collections such as documents. The free functor F is the (arbitrary) addressing for each multimedia object in the collection. This formal theory of indexing in the adjointness of these two categories is illustrated in Figure 2.

Notice that $1_{\mathbf{A}} \leq UF$ consists of all the orderings in the text and $FU \leq 1_{\mathbf{B}}$ all the orderings in the index. Therefore the contravariant functor $U : \mathbf{B} \longrightarrow \mathbf{A}$ provides the overall awareness of the contents of the documents in category $\mathbf{A}$. The awareness of these can be retained with a more elaborate database management model[43]. Now we need the counterpart of a dynamic index for distributed multimedia data.

5.2 Adjointness between Text and Image Data

Imaging is rapidly becoming a major industry and the manipulation of image data based on content and meaning is a burning research topic. Geometric logic shows well the adjointness between textual and graphical information. Both are mapped into the electronic medium as a bit stream.

Multimedia are logical rather than physical based. They are therefore an abstract category of a document which may be represented as a textual file or as an image file resulting from input by means of a scanner. Clearly the two forms contain equivalent information although they would appear in quite different electronic forms. This is an important example of adjointness as demonstrated in Figure 3. $\mathbf{TXT(X)}$, $\mathbf{GRF(D)}$ and $\mathbf{E(2)}$ are categories corresponding respectively to text, graphics and electronic form. Each of these categories is a free functor. $\mathbf{TXT(X)}$ is a map from the alphabet X on to finite strings so a character, x, goes to a string, $x \mapsto <x>$. $\mathbf{E(2)}$ is correspondingly composed of strings of zeros and ones. $\mathbf{GRF(D)}$ is the much more interesting graphical version which contains all the semiotic significance of the text beyond the mere characters (i.e.

punctuation, capitalization, italics). There may be a loss of information from the category **GRF(D)** to **TXT(X)**.

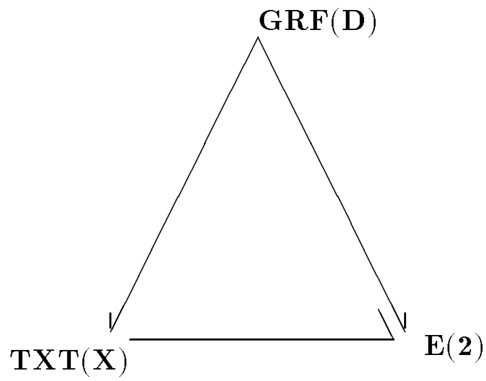

Fig. 3. Adjointness of Electronic Forms

5.3 Intension–Extension Mapping

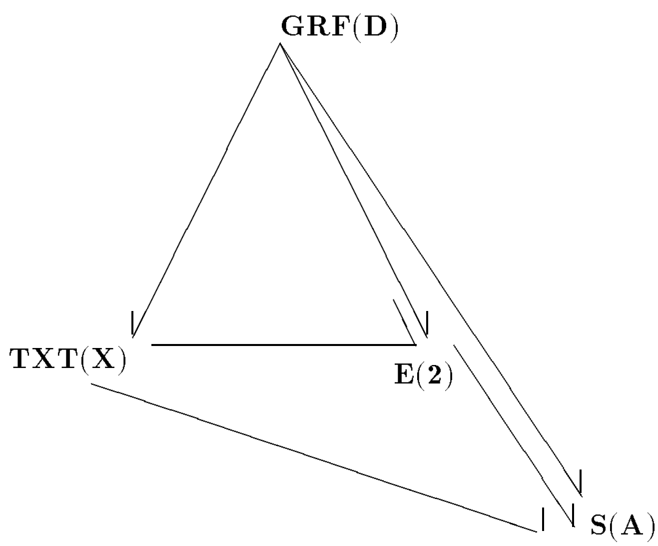

Fig. 4. Adjointness in Real–world Semantics

The links in multimedia may be at different levels. The mappings representing the links would therefore need to be typed in geometric logic. There is the simple linking between documents like a citation of a label or name (the intension). A more powerful level of connection is within the semantics (the extension). There is also the intension–extension relationship which has been shown by Lawvere[55] to be composed of adjoint contravariant functors.

The extension level of the abstract document is therefore the same for the three categories of text, graphics and electronic bits. Equality in geometric logic is provided for by composition. The possible relationships between the three categories of documents at the two levels can therefore all be summed up in a simple geometric formal diagram.

A real–world semantics $\mathbf{S}(\mathbf{A})$ can be represented in any of the three forms of graphical, textual and electronic. There will therefore be intension, and extension consisting of contravariant functors between each of the three and $\mathbf{S}(\mathbf{A})$ as in the diagram in Figure 4.

5.4 Geometric Database Models

Database modelling reduces to a small family of concepts in geometric logic. The various types of database relations described above may be summed up in Table 1. Fuller details that have been worked through for a product model based on limits are given elsewhere[67, 86].

database operation	categorical construct
abstractions	exactness
structural	adjointness
statistical	subobject classifier
ordering	adjoint functors
reductionist	co–exactness
behavioural	comma category
synthetic	exactness
analytic	co–exactness
parallel	adjointness

Table 1. Database Concepts in Categorical Terms

6 Formal Contextual Sensitivity

6.1 Limits, Colimits and Context

A very fundamental concept that has only been appreciated in the last thirty years is that of *limits* and *colimits*[61]. In arithmetic a limit is constructed by multiplication and colimits by addition, Within set theory, intersection is an example of a limit and disjoint union a colimit. With more general categories, limits and colimits become very powerful. A colimit is a deconstruction and provides no new information other than to make patent the latent components in the limit. The colimit of **A** and **B** is given by the fullest possible combination of taking them together and written $\mathbf{A}+\mathbf{B}$. A partial colimit would be obtained by taking together only certain parts of **A** and **B**. The parts that are significant when taken together may be provided by the context of a different category **C**. The pushout $\mathbf{A}+_{\mathbf{C}}\mathbf{B}$ as shown in Figure 5 then expresses this colimit in context.

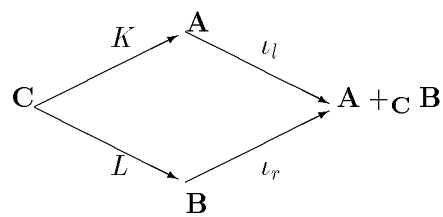

Fig. 5. Diagram of Pushout of **A** and **B** over **C**

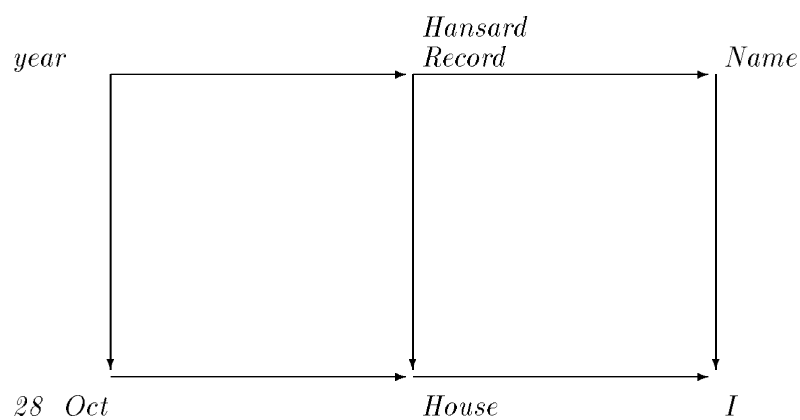

Fig. 6. Composition of Pushouts for

"As I said in my speech on 28th October to this House ..."

This is the geometric logic representation of the hypertext link which brings together the documents **A** and **B** through the context **C**. Note that this does not give any new information, but only identifies those parts of **A** and **B** which are relevant together in the context of **C**.

An example of pushouts can be seen in the geometric logic representation of the remark referred to earlier: "As I said in my speech on 28th October to this House ...". The diagram in Figure 6 shows a pasting together of pushouts in which the result of one pushout *House* (possibly represented by a multimedia icon) is included in turn in another pushout forming I.

New information attained by linking **A** and **B** is given by the product limit $\mathbf{A} \times \mathbf{B}$. This for a context **C** is the pullback $\mathbf{A} \times_{\mathbf{C}} \mathbf{B}$ shown in Figure 7. In general the difference between a limit and colimit may be summed up in that a limit produces some creative outcome of a link whereas the colimit is a link between standard information.

Examples of limits abound although they may not be explicitly recognized as such. For instance the subject of information retrieval has relied very heavily on the inner product of document vectors[91]. This is one particular reduced view of the limit $\mathbf{A} \times_{\mathbf{C}} \mathbf{B}$

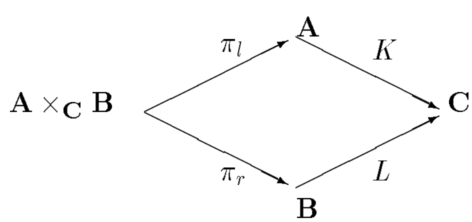

Fig. 7. Diagram of Pullback of **A** and **B** over **C**

Hypertext is a family of trails and it is important to recognize whether two trails are distinct or whether they merge. Thus there may be two parallel links between the same two documents. The question arises for the hypertext system whether two separate trails arriving at the first document are then merged. For example a legal case may cite a second case more than once during the report but it may be on two quite distinct points of law or even branches of law. Two cases may be connected on a substantive point of law and also quite separately on a point of legal procedure, adjectival law. A document often cites another more than once. Links between two documents in this situation become a limit point in the two trails if they merge there. However, geometric logic shows that there is a duality of limit also in this instance.

A coequalizer is the situation where there are distinct connections between the same two documents so that separate trails can pass across without merger. With the equalizer any separate trails arriving at the first document leave the second document by the same path. An equalizer is a context limit **C** represented in the diagram of Figure 8. All trails through **A** and **B** are merged through context **C** which will be shared by both **A** and **B**.

$$\mathbf{C} \rightarrow \mathbf{A} \rightrightarrows \mathbf{B}$$

Fig. 8. The Equalizer **C** as a context limit on arrows from **A** to **B**

The corresponding coequalizer is given by Figure 9. The context of **C** is null, that is the limits are independent in thought but from the document perspective there is a context of documents where the two trails coexist with local independence. In other words links between documents may be equalizers or coequalizers.

$$\mathbf{A} \rightrightarrows \mathbf{B} \rightarrow \mathbf{C}$$

Fig. 9. The Coequalizer **C** where two distinct trails coexist independently

This same equalizer and coequalizer distinction applies to higher-order links relevant to intellectual property. In organizing methods for payment of access to multimedia objects, it is necessary to have a theory of joint and common ownership. The objects may be quite fragmentary and widely distributed as in the extreme case of digital sampling in the music industry. Until a full theory is available, work on this aspect which is essential to the economic development of digital libraries[20] can only be *ad hoc* and restricted to a literal view of copyright. The payment is an equalizer or a coequalizer depending on whether the objects are subject to intellectual property rights, are in joint or common ownership, or indeed in the public domain. Likewise a systematic approach to attack the problems of policing the Internet to control its use for pornography, organized crime, drug trafficing, etc[57], can only be based on a theoretical structure underpinning the whole.

Two other special limits are the terminal object and (its dual) the initial object. An object in a category **C** where there is one and only one arrow from every other object to it is known as the final or terminal object of **C**. This may be denoted by $\top$ which is the last object in the trail. Dually (or oppositely) to the final object there may exist a corresponding initial object where there is an arrow from it to every other object in the category. This is $\perp$, the starting point in the trail and the arrows from it are every potential trail. This has significance for the reasoning and logical content that resides in the hypertext links.

In hypertext the initial and terminal objects may have only a local context. There may not be one single starting point, there may be a number of origins for any given trail. Likewise a trail may diverge to more than one finite point. Also natural language is a more general category than that of sets and the trails need not be disjoint. The same words could be used but with two distinct links in thought.

7 The Hypertext Lattice as a Heyting Algebra

As pointed out[7] by Ted Nelson in his early idea of hypertext as "non–sequential writing with reader–controlled links", links in hypertext are rarely linear[65] but branch and form a distributive lattice. The internal logic of a lattice is geometric logic which is more general than Boolean logic. The logic of a lattice is well–established. It is equivalent to a Heyting algebra. Any Heyting algebra has a fundamental binary operation of implication $\Rightarrow$: $\mathbf{A} \longrightarrow \mathbf{B}$. This arrow is commonly written in the form $\mathbf{A} \Rightarrow \mathbf{B}$ and this shorthand version will be used here. This implication arrow is defined by the adjunction

$$\frac{(\mathbf{C} \times \mathbf{A}) \leq \mathbf{B}}{\mathbf{C} \leq (\mathbf{A} \Rightarrow \mathbf{B})}$$

$\mathbf{A} \Rightarrow \mathbf{B}$ is the largest category connected with $\mathbf{A}$ which is contained in $\mathbf{B}$. In hypertext terms if the current document ($\mathbf{A}$) in its context ($\mathbf{C}$) precedes document $\mathbf{B}$, then $\mathbf{B}$ is the next document after $\mathbf{A}$ in that context. In terms of concepts rather than documents, the concept may not be represented by a document in existence and from the point of view of a writer would be the next document to write.

By the application of this implication we can obtain the more generalized type of negation found in natural systems. Indeed in natural language it is often possible to represent negative concepts in a positive way. This is also true in hypertext where falsity and truth are not simple atomic entities. These are geometric concepts. Truth is given by $\mathbf{B} \Rightarrow \top$ and falsity by $\mathbf{A} \Rightarrow \bot$, sometimes written $\neg\mathbf{A}$.

Truth and falsity are relative to context. In hypertext, $\mathbf{A} \Rightarrow \bot$ is (usually back) in the direction of the initial document, a state of ignorance, whereas $\mathbf{B} \Rightarrow \top$ is forward in the direction towards the last document to be viewed in the lattice, the state of enlightenment. Knowledge and ignorance in hypertext are the counterparts of true and false.

The nature of the pseudocomplement then $\mathbf{A} \Rightarrow \bot$, that is not $\mathbf{A}$, may be further understood by substituting the special instance $\bot$ for $\mathbf{B}$ in the definition of the adjunction above. We then get

[65] SGML and derivatives are essentially linear and this can give rise to problems of non-linearity in hypertext for instance when dealing with entities which are shared subobjects.

$$\frac{(\mathbf{C} \times \mathbf{A}) \leq \bot}{\mathbf{C} \leq (\mathbf{A} \Rightarrow \bot)}$$

In the real world two negatives do not always make a positive. This is familiar in natural language which opposes the principle of *tertium non datur*. The pseudocomplement is so important that natural languages often make it a separate word. For example the concept *relevant* has the pseudocomplement *irrelevant* which results in the further concept of *not irrelevant*. So *not irrelevant* is not equivalent to *relevant*. In fact there is a Heyting ordering:

$\mathbf{B} \Rightarrow \bot \quad \leq (\mathbf{B} \Rightarrow \bot) \Rightarrow \bot \leq \mathbf{B} \Rightarrow \top$

i.e. irrelevant $\leq$ not irrelevant $\leq$ relevant

In hypertext terms, this gives a ranking of the relevancy of the documents in general terms for **B** the next possible document. It is an irrelevant document, if it is in the direction of the first document. It is the required next relevant document, if it is in the direction of the final document in the trail. Note when it is not irrelevant. That is, if it is not in the direction of the first document, whether or not it is in the direction of the final document. It is this three–level ordering which is the basis of much fuzzy thought and a generalization of fuzzy sets.

In terms of the Heyting algebra, $\mathbf{C} \Rightarrow \bot$ is another special case of $\mathbf{A} \Rightarrow \mathbf{B}$. As noted above $\mathbf{A} \Rightarrow \mathbf{B}$ is itself a concept/document and $\mathbf{C} \Rightarrow \bot$ is an *irrelevant* context concept/document. A fundamental feature is that the pseudocomplement $\mathbf{A} \Rightarrow \bot$ is the largest category disjoint from **A**.

8 Geometric Consciousness

The human brain is able to handle well the integration of multimedia stimuli and hypermedia navigation is comparable to mental processes. Consciousness is increasingly being recognized as an inherent feature of any cognitive process[92] and needs to figure in any computational model involving human–computer interaction at the level of the mind[42, 82] to counteract critics of machine understanding.

From a taboo subject in orthodox scientific circles, consciousness is fast becoming an essential ingredient to be considered in any research involving human cognition[14, 38].

8.1 Contextual Awareness in Hypertext

The earlier discussion on context with pullbacks and pushouts deals with the simpler straight–forward type of static and objective contextuality but it is perhaps worth looking at the example previously raised:

"As I said in my speech on 28th October to this House ..."

A simple form of contextual awareness can be attained in this example by state of the art database techniques using fields, relations or keys. Thus the information identifying I, *House*, and *year* can be anaphorically resolved by reference to meta–records in the database system. Fuller details on how this works using keys in a Hansard database are given elsewhere[47, 83] where partial or composite keys are examples of colimits.

The hypertext system of awareness is one that identifies for the user the next document to see. This is available from the implication $\mathbf{A} \Rightarrow \mathbf{B}$. Thus awareness is the contravariant natural transformation $\phi : \mathbf{B} \longrightarrow \mathbf{A}$. Awareness in hypertext is therefore the self identification of the document $\mathbf{B}$ in $\mathbf{A} \Rightarrow \mathbf{B}$. In Figure 6, it is the document records. The awareness to identify I is the *Hansard Record*, the *House* and the *Year* as given in Figure 10. This figure shows how the awareness works. The identity of the speaker I is given by ϕ_3, the identification of which house (Lords or Commons) by ϕ_2 and the awareness of the date of the speech from ϕ_1. These can be obtained algebraically. For example $f \circ \phi_2 = \phi_1$. f is the meta–record giving the house where the speech is given. In a database implementation f consists of those parts of the composite key which uniquely identify the *House*.

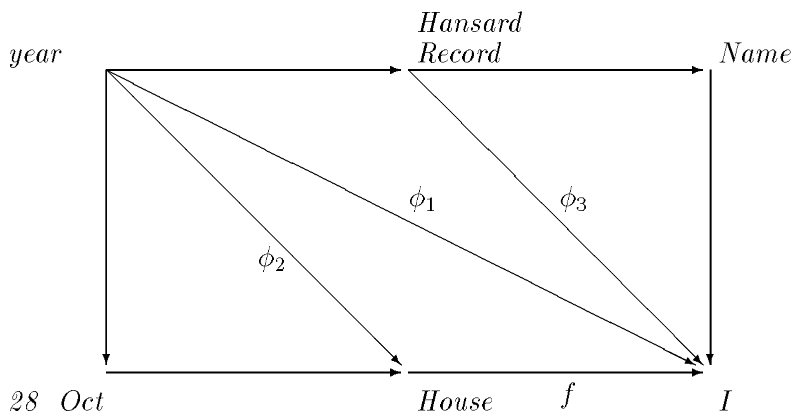

Fig. 10. Awareness to identify I and *House* in

"As I said in my speech on 28th October to this House ..."

8.2 Computational Model of Consciousness

While the basic purpose of hypertext awareness is for that next document $\mathbf{B}$ in $\mathbf{A} \Rightarrow \mathbf{B}$ to identify itself to the user, the position is complicated by the fact that the user is operating at two levels: the intension (represented by the document) and the extension (represented by the meaning). This identification is a precompositional contravariant arrow $\alpha^* : \mathbf{B} \longrightarrow \mathbf{A}$ which is a backward selection from the relevant documents of the document to which they are related.

Hypertext links are really connections between the semantic objects in the current document with related semantic objects in the documents to be retrieved. The connection is between objects $A_1, A_2, \ldots$ in the category $\mathbf{S}(\mathbf{A})$ (that is the meaning of the contents of the document under examination which is $\mathbf{A}$) with objects $B_1, B_2, \ldots$ in the category $\mathbf{S}(\mathbf{B})$ which are the meanings in the documents to be retrieved $\mathbf{B}$. The identification of the relevant documents depends upon the purpose and intentions of the user. This is a natural transformation $\eta_A : A \longrightarrow \mathbf{S}(\mathbf{B})$ as shown in Figure 11. The awareness is given by the inverse natural transformation α^*, preserving limits, colimits and implications.

$\alpha^*(\top) \cong \top,$
$\alpha^*(B \times B') \cong \alpha^*(B) \times \alpha^*(B'),$
$\alpha^*(\bot) \cong \bot,$
$\alpha^*(B + B') \cong \alpha^*(B) + \alpha^*(B'),$
$\alpha^*(B \Rightarrow B') \cong \alpha^*(B) \Rightarrow \alpha^*(B')$

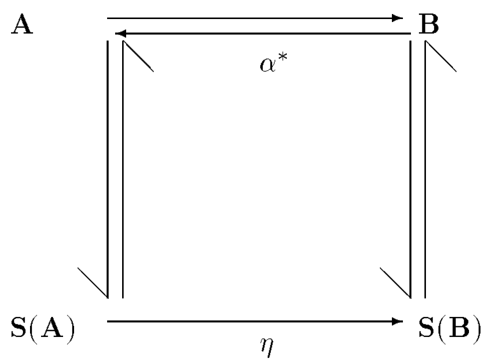

Fig. 11. Commuting Target Square for Awareness as a Natural Transformation

The signs for products and sums are again used to represent generally limits and colimits respectively. Table 1 shows that none of the database relationships and structures in section 4 require any operations beyond these. Therefore $\alpha^*(\mathbf{B})$ can claim to be a general awareness relationship.

This relationship is valid for reasoning by analogy only when implications are preserved. The test for the preservation of implications is well–established and known as the Frobenius identity[62]:

$$\frac{\alpha^*(B \times \alpha A)}{\overline{\alpha^* B \times A}}$$

This is equivalent to analagous reasoning because the inverse natural transformation α^* preserves limits and colimits as well as implications.

8.3 Relative and Dynamic Contexts

Simple categories may be built–up to represent the greater complexity found in hypertext systems. For instance a concept that emerges from a structure of related documents itself is a diagram as previously indicated and may be used to replace a single object A. These can be employed to give hypertext the facility to deal with dynamic, subjective content. In geometric logic this amounts to manipulating more sophisticated structures for diagrams are a more general form of objects and simple categories.

For example the comma category has attracted considerable attention in computing science[2] and can provide general contextuality. The comma category can add structure to an ordinary category by considering the arrows from the point of view of a particular object. Given a category $\mathbf{A}$ with a variable object A which may be represented by A' (when we want to distinguish different instances), the arrows $f : A \longrightarrow A'$ relative to C are objects in the comma category $\mathbf{A}/\mathbf{C}$ (sometimes written $\mathbf{A} \downarrow \mathbf{C}$) as shown in Figure 12. It should be emphasised that the objects in the comma category are arrows; the comma category arrows are triangles. For a map of the domain A and codomain A' together onto C specifies $f : A \longrightarrow A'$.

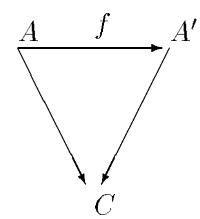

Fig. 12. Diagram of Comma Category

In practice hypertext does not just relate two documents but two documents in their respective categories. Therefore the hypertext link between document $\mathbf{A}$ (the one being viewed) and the next document $\mathbf{B}$ is given in Figure 13. The functor K is the hypertext link between the categories where the objects in each category are triangles composed of lower–level arrows. This shows up the dynamical aspects of context. Figure 14 shows the corresponding contravariant functor α^* between comma categories. Consciousness, with relative and dynamic context, is obtained by generalizing from the following relationships shown in Figures 13, 14:

$$K : \mathbf{A/C} \longrightarrow \mathbf{B/C'}$$

$$\alpha : f \longrightarrow g$$

$$\alpha^* : \mathbf{B/C'} \longrightarrow \mathbf{A/C}$$

The whole collection can be viewed as analagous reasoning thus confirming the equivalence of reasoning and hypertext.

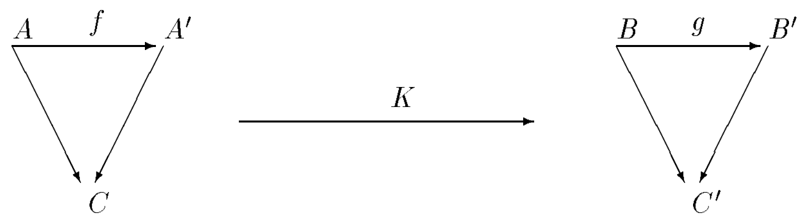

Fig. 13. Covariant Functor K between Comma Categories

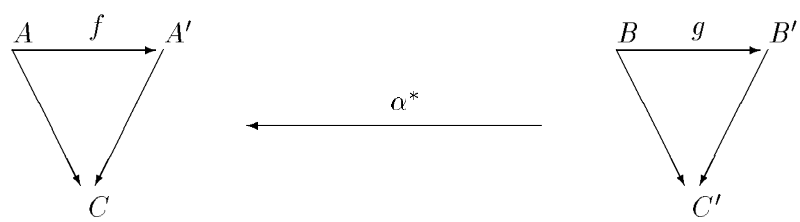

Fig. 14. Contravariant Functor α^* between Comma Categories

9 Conclusions

Multimedia has developed into a very sophisticated information system, one that is populated by a variety of distributed hypermedia source material. These heterogeneous materials are pulled together to create a contemporaneous document of the instant based upon the view of the user at the time as applied to the inherent structure in the source material. This view of the user is shaped by the real–world perceptions of the user interacting with the various documents encountered on the way. Because of the power to backtrack and because of inherent branches, it is more than just being shaped by a linear sequence of links.

A multimedia information system is a Heyting algebra of open concepts or ideas to be found in a variety of continuously changing forms and formats that are best represented in the current state of the art of constructive mathematics as universal objects. These objects related by geometric logic give a formal representation of awareness and implication. For if the system is to aid the user in handling this complexity, it is not only to show awareness of its own contents but must also be able to make the required inferences and connections. We have concentrated on a theoretical description in terms of geometric logic of the attributes of this machine consciousness as needed in information systems. This theory shows an equivalence of reasoning between documents and their contents.

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