Delivering Exploration Information On-line Using the WWW: Challenges, and an Australian Experience

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ABSTRACT

The AGCRC is in the process of implementing a flexible system for delivering structured (database) information, interactive modelling tools, and a document archive exploration through the World-Wide-Web on the internet. Some aspects of this have been straightforward, and techniques developed during prototyping will have widespread applicability. A number of challenges remain: in particular, enabling and encouraging our staff to use the WWW routinely for reporting research results, and developing a system to allow general documents to be located in response to specific technical queries. A proposal for the encapsulation of structured index information, using techniques developed in the digital library area, is presented.

INTRODUCTION

The Australian Geodynamics Cooperative Research Centre (AGCRC) has a mission to develop a geodynamic framework, including data handling, geology modelling and computer visualisation tools, that enhances the resource exploration potential of Australia. It was intended that be delivered in digital format using networked methods. Although we were essentially unaware of the world-wide-web (WWW) when the AGCRC was founded, the emergence of Hypertext Transfer Protocol (http) and the WWW provides the logical platform on which to base our system.

Designing and managing a web-based system for delivering the outcomes of the AGCRC's research involves some cultural shifts, as well as technical and resource considerations. Whereas some tasks are straightforward (in principle at least) a successful system will involve a number of components, and specific contributions from a variety of sources.

At the simpler end of the spectrum of tasks, there are many basic primary and secondary data sets that provide a significant basis for geodynamic interpretation. In most cases the primary reference for this data is geographic (i.e., maps, images, etc.). Many of these have now been compiled within a uniform and consistent digital framework as a service to the AGCRC's clients and research staff. As well as its use for fundamental broad-scale investigations, this compilation of continental data sets provides an important setting for finer scale studies.

Beyond this, however, we must consider how the results of arbitrary AGCRC research projects can be presented in a digital, networked medium.

The more detailed studies can be located, of course, within the broad framework. However, although the graphics commonly presented in research reports in the earth sciences often include apparently "hard" information such as maps, cross-sections, time-lines and sequences, these are frequently sketch-like, fragmentary, and rarely geographically registered or even subject to very precise standards of symbology. The task of capturing these into an integrated, structured digital information and modelling system, such as a GIS, is far from straightforward.

Furthermore, the underlying research outcomes of the AGCRC are mainly interpretative and synthetic, rather than presentations of primary data sets. Although there has been some investigation into the development of symbolic representation for stratigraphy, which is the core discipline of historical geology (Mann, 1977; Carimati *et al.*, 1982), and one team associated with the AGCRC has developed a system for a representation of aspects of local structural geology based on kinematics (Jessell *et al.*, 1994), methods for encapsulating geodynamic interpretation symbolically are not yet available. The conventional presentation is discursive prose with accompanying graphics.

Finally, the staff of the AGCRC are based in conventional earth-science departments in two universities, in the Australian Geological Survey (AGSO), and in CSIRO. They are a largely academically focussed group of researchers. The traditional reporting methods, for which the most recognisable institutional rewards are received, are largely confined to archivable research papers in learned periodicals, conference papers, books and chapters, printed maps, and open-file and restricted circulation reports.

Thus, the most important way of presenting the results of the research projects being carried out within the AGCRC will bear a strong resemblance to conventional journal articles. A major challenge for the AGCRC, therefore, is devising a way to manage the delivery of the results of its research in appropriate ways within a web framework.

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WEB ACCESS TO HETEROGENEOUS INFORMATION

The capability for integrated presentation of heterogeneous modes of information is perhaps the web's \most outstanding attribute. In particular:

1. Hypertext provides a very natural medium for delivering technical material. As well as the well-known graphics capability, particularly important is the provision of direct access to detailed supporting or reference material, but only to interested clients. Furthermore, while technical papers presented in the hypertext used on the web (hypertext markup language or HTML) (e.g., Cox *et al.*, 1994) may resemble a printed paper, they allow the reader access in a natural sequence, rather than the one imposed by convention and print technology. Colour and movement can be made available easily. Furthermore, given the low cost of disk-space, there is essentially no limit to the quantity of information that can be posted.
2. Multiple information servers on the world-wide-web can be linked together. This delivers resources that are incomparably richer than can be provided by any single agent.
3. Much valuable information on the web is ultimately stored in static files. Compilations and extractions from this can be made automatically for the reader, through customised searches of hypertext archives. These methods allow resource discovery independent of document maintenance.
4. Dynamic and interactive access to structured data can be provided within the same basic interface, through specific server-side applications. A graphical user interface (GUI) incorporating menus, check-boxes, clickable images, text-entry etc. runs within the browser on the client's computer, and causes jobs or queries to be run on a remote host.
5. Powerful applications which run fully on the client-side, on any platform, can be written using the *Java* language. This has great potential in the context of modelling.

We are taking advantage of each of these features in the construction of the AGCRC-Web (http://www.ned.dem.csiro.au/AGCRC/). The goal is to combine them in a system structured to support geodynamic inquiries.

ACCESS TO STRUCTURED SERVER-SIDE DATABASES AND INFORMATION SYSTEMS

Perhaps the most straightforward component of such a system is produced through the construction of web interfaces onto legacy information systems on servers maintained by the AGCRC's participants. Examples of these include:

1. AGSO is permitting public access to some of its ORACLE hosted databases. The first database to be made available in this way was the *Stratigraphic Names Database* (http://www.agso.gov.au/information/structure/isd/database/stratnames.html). This has been constructed within the standard http-client interface using the html-forms/cgi (Common Gateway Interface) method (e.g., Boutell, 1996). More sophisticated versions may be possible in the future since ORACLE is planning extensive use of web technology, including Java, in its future application development environment.
2. Our compilation of broad-scale geoscience data sets is stored in a GRASS GIS database at CSIRO in Western Australia. Display and query access to much of this is provided through an installation of the *GRASSLinks* interface, customised from the original version developed at University of California Berkeley (Huse, 1995), at http://www.ned.dem.csiro.au/AGCRC/4dgm/grasslinks/.

These systems each access a database housed on a single host. Although the functionality provided by their interfaces is limited compared with the native interface for these applications, the restrictions are useful for the target audience, who are non-expert and for whom the browser's standard look-and-feel is a great benefit.

Access may also be provided to data housed on more than one host or server. For example, the *ImageNet* system example from Core Software Technology (http://www.coresw.com/) acts as an interactive multi-vendor catalogue. Geospatial data-providers publish metadata (data about the data) for their holdings in a format that allows the system to locate data sets of potential interest through structured queries. Although *ImageNet* was designed to particularly cater to catalogues of remote-sensed imagery, some providers of GIS data sets are using the system, e.g., the National Directory of Australian Resources (NDAR).

AUTOMATIC SEARCHING AND INDEXING OF WEB-HOSTED DOCUMENTS

As discussed above the bulk of the information in our system will be stored outside of Database Management Systems (DBMS) or similar structured information systems. The most significant format, at least in the short term, is likely to be static HTML files on http-server systems, as for most of the web. Indexing these to provide information relating to questions about Australian geodynamics and exploration is the main challenge for our system.

Private digital document management systems have been developing particularly in the corporate sector for a number of years. These have generally involved metadata systems designed for entry by professional indexers.

This technology cannot be applied *generally* to the web, because of its volume and distributed nature, and the variety of documents available. However, the increase in processing power and communications speed has allowed automated systems of resource discovery to become viable. Well-known public systems include *Lycos* (http://lycos.com/), *AltaVista* (http://www.altavista.com/) and *HotBot* (http://www.hotbot.com/). In these systems, primary indexing is based on the text content of the body of the html files.

Some of the services can be refined, by targeting a search at particular servers and domains, and versions are available for private use, including for restricted access servers ("intranets").

Although indexing based on processing of the body text is powerful, it is poorly controlled, and (despite developments in fuzzy matching and searching methods) will always have significant limitations compared to more traditional structured indexing or cataloguing. A general system should include both approaches. However, this requires structured indexing terms to be provided within or in association with the HTML documents.

INDEX TERMS AND IMPLEMENTATIONS

The *Dublin Core* (DC) (Weibel *et al.,* 1995; also see http://purl.org/metadata/dublin_core) is the most widely supported general purpose resource description proposal for digital documents. It includes descriptive catalogue information, with additional items *Subject* (the topic addressed by the work), *Object type* (the genre of the object, such as novel, poem or dictionary), and *Coverage* (the spatial location and/or temporal duration characteristics of the object) which provide information relating to content. The *Warwick Framework* (WF) (Dempsey and Weibel, 1996) is a flexible method for extending this by aggregating "packages" of metadata, potentially incorporating sets of domain-specific terms.

In order to service client queries fully, sets of index terms and permitted values (vocabulary, range), and agents that use these, must be established for each domain of interest. Although no existing standards specifically cater to Australian Geodynamics, a number have some relevance, including some specifically for geospatial data. Some of the indexing systems are also connected with functioning directories or access systems.

Of particular interest are the *Spatial Data Transfer Standard* (SDTS) (USGS, 1996), the U.S. Federal Geographic Data Committee's (FGDC) *Content Standards for Digital Geospatial Metadata* (FGDC, 1994), the U.S. *Government Information Locator Service* (GILS) (Christian, 1996), the Australian *National Directory of Australian Resources* (NDAR) (Shelley, 1995), the Australia New Zealand Land Information Council (ANZLIC) *Guidelines for Core Metadata Elements* (ANZLIC, 1996), the Australian Mineral Foundation's (AMF) *Australian Geoscience, Minerals and Petroleum Thesaurus* (AMF, 1996), and the American Geological Institute's *GeoRef Thesaurus* (Goodman, 1994). I have reviewed these at greater length elsewhere (Cox, 1997).

The next consideration, given an appropriate metadata or indexing standard, is how the data conforming to this can be attached to the document, and the related question of how this is made available automatically to a discovery engine.

The <meta> element in the HTML document <head> provides a general purpose (name,value) syntax which is available to store descriptive information under the current HTML standard (see http://www.w3.org). And since the <head> information from a HTML document is returned by a http-server in response to a HEAD request, the metadata may be included in the same file as the document that it describes, but made available at lower cost in performance or bandwidth. Including it in the same file often makes maintenance simpler than if additional files are involved.

A number of proposals for instantiating the Dublin Core metadata in this way have been developed. Miller (1996) gives an interesting example which uses Warwick Framework extensions for the Archaeology Data Service, with the protocols being used indicated via the <link> element.

Furthermore, because HTML is an implementation of the Standard Generalised Markup Language (SGML) (e.g., Turner *et al.,* 1996), usage of an indexing protocol can be formally and rigorously defined with a Document Type Definition (DTD) (e.g., Maler and El Andaloussi, 1996). Using the latter, which can be made publicly available through http (i.e., on the WWW), the metadata can be extracted into a structured framework by (existing) general SGML parsers. Metadata registries could be used as a means of publishing arbitrary domain-specific packages. This collection of tools and protocols then provides a basis for automatic construction of indexes and search engines based on publicly accessible archives of compliant documents.

Alternative implementations of DC in Multipurpose Internet Mail Extensions (MIME) syntax (Knight and Hamilton, 1996) and Common Object Resource Broker Architecture (CORBA) environments have also been proposed.

PROPOSAL FOR A SYSTEM FOR INDEXING AND MODELLING GEODYNAMICS DOCUMENTS

The most important consideration in designing a structured index system is to ensure that it supports the queries that users are likely to make. This is a non-trivial issue, particularly for domain-dependent thematic queries and when the information may be used in research for which the guiding models (or fashions ...) are not necessarily stable. Nevertheless, the starting point must be based on understanding the current modelling framework.

The AGCRC's version of Geodynamics primarily concerns tectonics and structure in the earth's crust, particularly as it affects the emplacement, and therefore present location, of resource deposits. Thus, as well as determining the present-day disposition of the geology through various methods, there is a strong emphasis on the geo-historical sequence of events and in deformation kinematics and mechanics. Linking together evidence of contemporaneous activity from study areas which may now be spatially distinct, and recognising patterns of geological activity recurring in different sites and eras, are the critical evidence used in developing broad scale tectonic models. Note that simple geometrical information is often *not* the major element of a structural geology model.

Geographic elements of the spatial information, and possibly key words, may be covered by other metadata systems (e.g., ANZLIC, DC). All the rest—including the depth or vertical extent of the spatial information—are specialist terms for which we would need to develop our own syntax. A minimal set of additional index items might include:

1. Present-day spatial extent of the information
2. Methods used for the study
3. Pointers to any primary data sets available as an outcome of the study
4. Stratigraphic units present
5. Geochronological determinations, including method with results
6. Stratigraphic inferences (i.e., relative time)
7. Results of geothermometry/geobarometry—e.g., peak metamorphic conditions
8. Structural events, including principal direction (azimuth, dip) and style (e.g., compression, shear)
9. Key search words, controlled by an authority table or thesaurus.

These topics essentially provide a *structured abstract* of the document content. This may be aggregated with catalogue data and metadata using the Warwick Framework (Lagoze, 1996). An AGCRC HTML document containing such indexing terms might be constructed using the <head><meta ...> ... </head> approach as shown in Figure 1.

Note that the usage illustrated is strictly incomplete in relation to any of the standards. Nevertheless, the example given is a long and complex HTML header by normal standards. Thus, notwithstanding the fact that many elements have been treated as optional, compliance and

```
<HTML>
<HEAD>
<TITLE>Some important research results about Australian Geodynamics</TITLE>
<META NAME="DC.Title" CONTENT="Important Australian Geodynamics Research Results">
<META NAME="DC.Author" TYPE="name" CONTENT="Simon Cox">
<META NAME="DC.Author" TYPE="e-mail" CONTENT="s.cox@dem.csiro.au">
<META NAME="DC.Author" TYPE="name" CONTENT="Barry Drummond">
<META NAME="DC.Publisher" CONTENT="AGCRC">
<META NAME="DC.Subject" CONTENT="Australian Geodynamics">
<META NAME="DC.Date" SCHEME="ISO31" CONTENT="1997-01-16">
<META NAME="ANZLIC.Dataset.TITLE" CONTENT="Important Australian Geodynamics Research Results">
<META NAME="ANZLIC.Dataset.CUSTODIAN" CONTENT="AGCRC">
<META NAME="ANZLIC.Dataset.JURISDICTION" CONTENT="Australia">
<META NAME="ANZLIC.Description.ABSTRACT" CONTENT="A paragraph of text here">
<META NAME="ANZLIC.Description.SEARCH_WORDS" CONTENT="GEOSCIENCES Geology">
<META NAME="ANZLIC.Description.SEARCH_WORDS" CONTENT="GEOSCIENCES Geophysics">
<META NAME="ANZLIC.Description.GEOGRAPHIC_EXTENT" TYPE="polygon" CONTENT="112 -9, 154 -9, 154 -44, 112 -44, 112 -9">
<META NAME="AGCRC.keywords" SCHEME="amf-aesis" CONTENT="structural geology, tectonics, proterozoic">
<META NAME="AGCRC.method" CONTENT="field_mapping">
<META NAME="AGCRC.method" CONTENT="aeromag">
<META NAME="AGCRC.method" CONTENT="computer_modelling.geometry">
<META NAME="AGCRC.D.1.azimuth" CONTENT="315">
<META NAME="AGCRC.D.1.style" CONTENT="overthrust">
<META NAME="AGCRC.D.1.date" CONTENT="1862.Ma">
<META NAME="AGCRC.D.2.azimuth" CONTENT="270">
<META NAME="AGCRC.D.2.style" CONTENT="extension">
<LINK REL="SCHEMA.DC" HREF="http://meta.org/meta-reg/Dublin-Core.html">
<LINK REL="SCHEMA.ANZLIC" HREF="http://www.auslig.gov.au/pipc/anzlic/anzlicma.htm">
<LINK REL="SCHEMA.AGCRC" HREF="http://www.ned.dem.csiro.au/AGCRC/4dgm/meta/AGCRCschema.htm">
</HEAD>

<BODY>
This is the body of the sample document
</BODY>

</HTML>
```

Figure 1: *Example of a HTML document incorporating catalogue information, metadata and structured abstract terms, following the Warwick Framework method.*

maintenance is certain to remain an issue. Metadata is most easily provided at publication, by either the author or a local information custodian. Furthermore, because of the technical nature of many of the terms, the author or content provider is best qualified to supply it. They must perceive a significant value from the effort required to understand the system and populate the metadata fields. Clearly it would be desirable to enter a number of the elements automatically, and for the rest use a (web) form to assist authors choosing values and generating a valid document header.

A further, and potentially important, use of the metadata that has not been illustrated here is to use it to provide links to actual data sets. This could enable the document archive information system to integrate with remote and local modelling tools and applications. An indication of file and record formats for datafiles would be required, probably by reference to the application(s) which were used to create the data set. MIME syntax is a good example of how this might be achieved (Knight and Hamilton, 1996).

SOME AGCRC PROTOTYPES

The AGCRC's implementation of a web-based geodynamics information system has proceeded through the development of a number of prototypes. This has allowed experimentation and refinement of components with the involvement of a large base of client users. These are being continually refined and enhanced, so the description here relates to the date of writing (January 1997) and I would expect to report additional developments at the time of the conference.

Document archive

Some of the standard web-search engines index terms from <meta> elements. However, since use of these in searching depends on knowledge of the schema, this part of the index is not normally visible on the public search engines. It may be used in customised interfaces.

For prototyping purposes for document searching we have developed a HTML-form and CGI script *Search-AGCRC* (see Figure 2) (http://www.ned.dem.csiro.au/AGCRC/search.html). In addition to searching for text in the body of HTML documents, *Search-AGCRC* can alternatively search for text in the HTML <title>, or in keywords stored in <meta> elements. The search can be further restricted to find documents which include a particular location, determined by a point-in-rectangle test on bounding coordinates given in <meta> elements. The position of the search location is entered on the main search form either by typing latitude and longitude, or by selecting a point on an image map. The boolean logic governing the combination of the various criteria submitted from the main search form has a default state optimised from experiments involving casual users.

Map builder and query system

The second part of the AGCRC information system is the map-data viewing and query system GRASSLinks (http://www.ned.dem.csiro.au/AGCRC/4dgm/grasslinks). This is a HTML-forms and image-map based GUI which offers a subset of the functionality of a full GIS, but provides it remotely over the web (Figure 3). It is also written as a CGI application in the perl language (Wall *et al.,* 1996; Boutell, 1996). Data sets are stored in a GRASS database. Those data sets that are available are listed in tables, with user selection defining what is desired on the map. Maps may be generated by selecting an arbitrary combination from these, covering a location and at a scale which is selected interactively. The maps may be queried to discover the value at locations chosen by

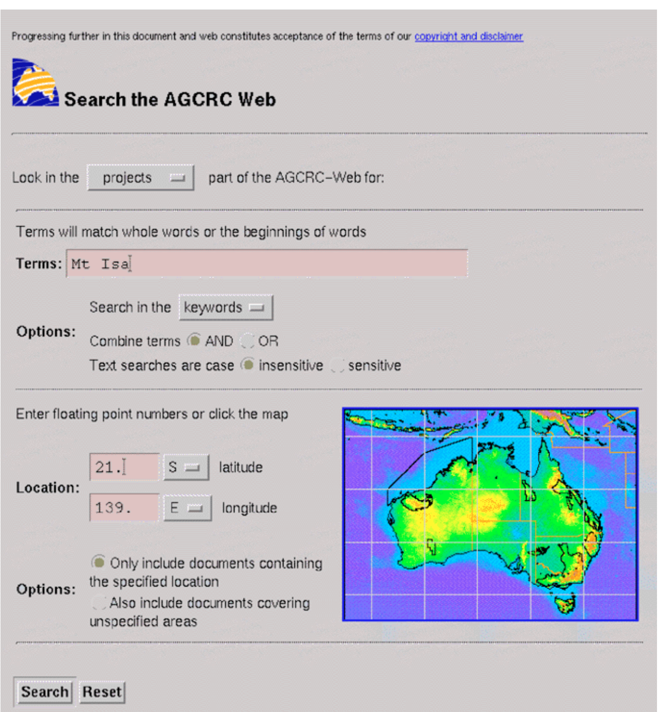

Figure 2: *The Search-AGCRC form.*

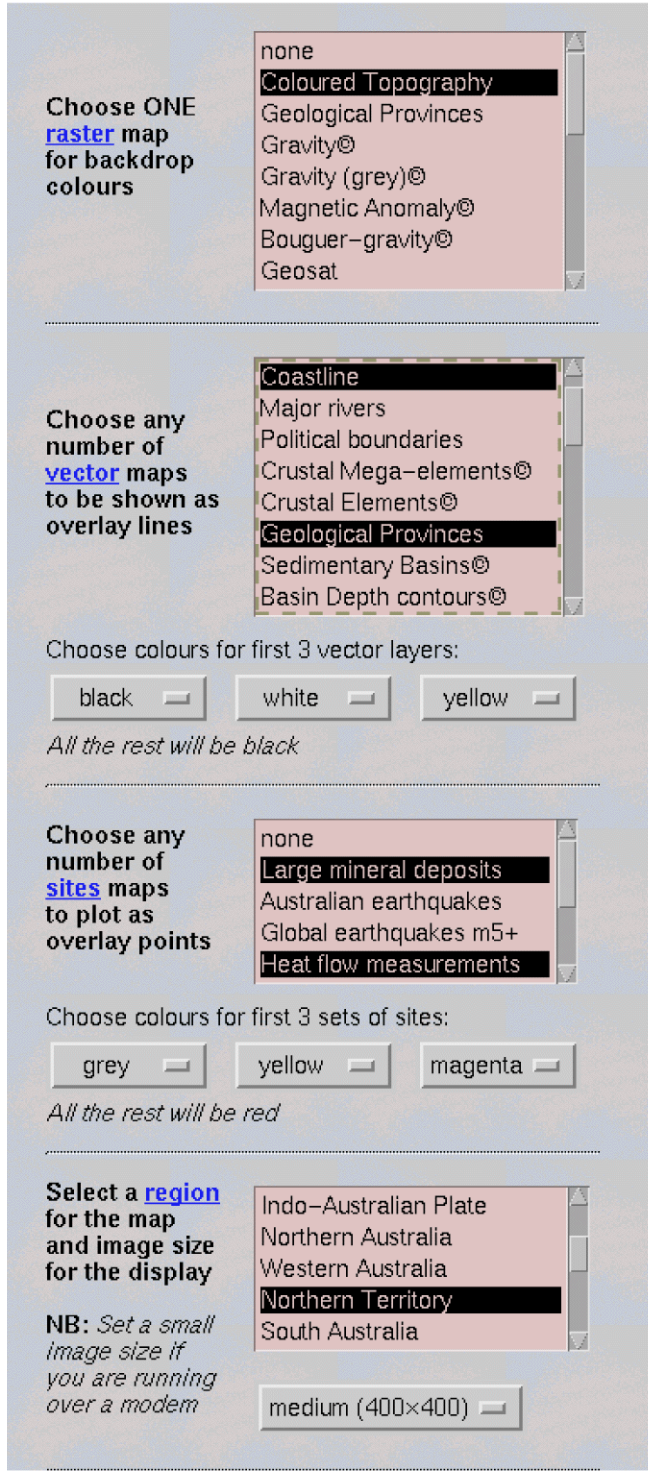

Figure 3: *GRASSLinks menus for designing a map.*

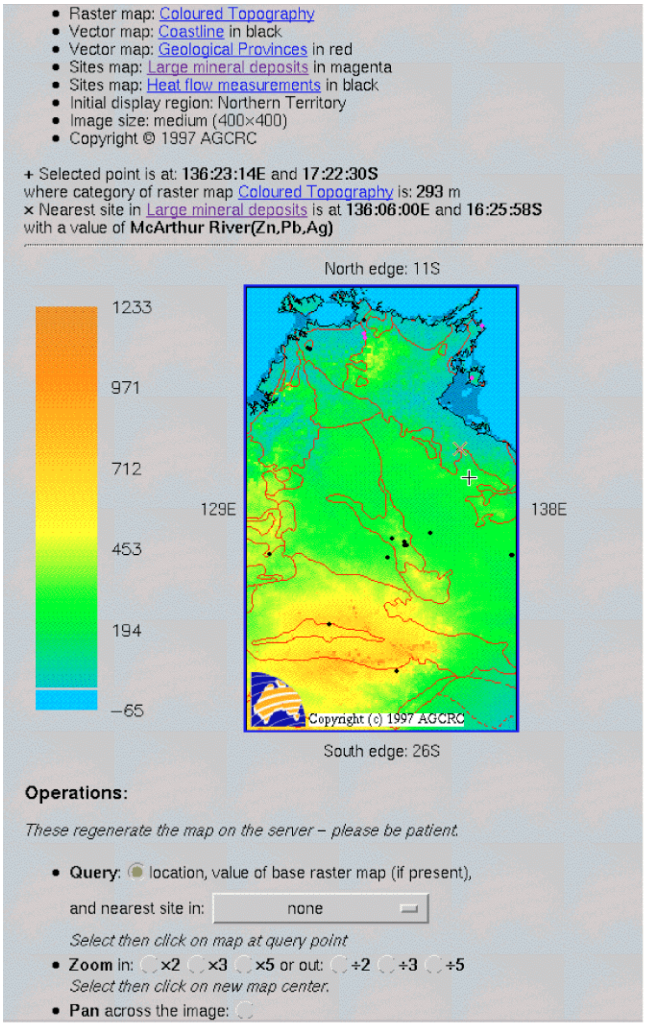

Figure 4: *GRASSLinks map-query form.*

clicking on an image (Figure 4). Descriptions of all the data sets are provided in associated web-pages, which include links back to the primary information custodian where appropriate.

Integration with other modelling systems

The GRASSLinks system does not, however, solely run GRASS functions. For example, a Cross-Section operation retrieves data from the GRASS database, but then passes this to external software to produce the visualisation. This demonstrates the principle of using one private database system to feed data automatically into another, arbitrary modelling system. We expect to extend this into other applications: 3-D viewing of multiple data sets is a high priority.

A second example of integration is calling the document search facility from within GRASSLinks. In this case, the results of a GIS process are used to generate the interface to the second application.

Extensions to the AGCRC system

A number of improvements and extensions to the AGCRC Information and Modelling system are planned.

1. Refining the geodynamics metadata system, and implementing a document maintenance system and a document search system based on this.
2. Adding additional visualisation applications for data stored in the GRASS database.
3. Developing a generalised metadatabase of available data sets. This would replace the set of tables used by GRASSLinks, and will be extensible in order to support other modelling applications.

The first item has been discussed at length, and the second briefly above. The third is like a local version of NDAR (Shelley, 1995), but would support automatic retrieval of data. A number of technologies might be used.

Populating the AGCRC system

The most important aspect of any information and modelling system is its content. A beautiful and elaborate structure has no value without information to operate on. The AGCRC web site has received kudos for delivering actual information and research results, rather than simply being an elaborate brochure or advertisement, or administrative tool. The main information that is currently available is:

1. The map data sets accessible through *GRASSLinks* (http://www.ned.dem.csiro.au/AGCRC/4dgm/grasslinks)
2. A comprehensive set of project descriptions (http://www.ned.dem.csiro.au/AGCRC/projects)
3. Abstracts of all reports and publications (http://www.ned.dem.csiro.au/AGCRC/publications/).

Approval of the AGCRC Director is a condition of publication of reports and papers resulting from AGCRC projects. A component of this is the electronic submission of an abstract. The AGCRC secretariat posts these abstracts on the web in HTML form.

However, until now few AGCRC research staff have used the AGCRC's web to report their results directly. This is partly due to the normal logistical and skills reasons, but more important is the change in culture that reporting on the web involves. Given our immature understanding of how to use the web effectively for reporting, and particularly given the nature of the participants, discussed previously, we have largely relied on informal means to encourage posting on the web by AGCRC staff. The process of enhancing our existing document archive with metadata of the form indicated previously, and of including the metadata at time of publication for future postings is a particular challenge.

With the increasing profile of the AGCRC's web site, and widespread availability of HTML authoring and conversion software, we expect that this situation will improve naturally. Furthermore, AGCRC staff are the biggest users of the map database, and are beginning to investigate how to get their information included into the same framework. Improvements to the modelling tools will serve to increase this tendency.

Finally, there are significant concerns in developing robust arrangements for archival management of documents and other information. For example, it is common for material to be moved to a new location. Although there are methods of managing this so that links are not lost, no consistent procedures are in widespread use. A number of proposals have been made, such as replacing URLs (Uniform Resource Locators—those address strings that start e.g., http://...) with URNs or PURLs (Uniform Resource Names or Persistent Uniform Resource Locators—which get mapped to URLs by registries similar to the Domain Name Server system), but implementation of these appears to be some way off. Furthermore, one of the strengths of electronic documents—the ability to easily edit and update them—also introduces hazards. For example, particular content in a document may change or even vanish, making references to this invalid. In the most extreme cases, this could have legal implications.

CONCLUSIONS

The AGCRC is committed to using the WWW as the main route for publishing its research results. The advantages are clear—hypertext is a rich and flexible medium, the WWW provides a simple and effective delivery mechanism, and the possibility of including interactive modelling tools is very appealing. All of these benefits have been used in the prototype implementation. The AGCRC web site has become one of the most used on-line resources for exploration information in Australia. However, we have encountered a number of challenges. These include:

1. Adding more material to the site, by enabling our staff to create material for the new medium—this is a matter of both technical skills and encouraging a shift from traditional modes of reporting;
2. Developing systems for encoding interpretative information so that documents relevant to a particular technical question can be easily discovered from within our archive.

A number of developments in the area of information management are pointing the way forward on the latter. However, extensive customisation of these is needed in order to incorporate them in our system.

Overall, we believe that the AGCRC's experience with WWW is a valuable experiment in the development of flexible networked information systems for the delivery of very general exploration information.

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REFERENCES

AMF, 1996, Australian Geoscience, Minerals and Petroleum Thesaurus, 4th Edition, Australian Mineral Foundation, Glenside, South Australia.

ANZLIC, 1996, ANZLIC Guidelines: Core Metadata Elements for Land and Geographic Directories, Version 1, Australia and New Zealand Land Information Council, Belconnen, Australian Capital Territory.

Boutell, T., 1996, CGI Programming in C & Perl, Addison-Wesley, 402 pp.

Burnard, L., Miller, E., Quin, L., and Sperberg-McQueen, C.M., 1996, A syntax for Dublin Core metadata http://www.uic.edu/~cmsmcq/tech/metadata.syntax.html.

Carimati, R., Marini, A., and Potenza, R.G., 1982, The mathematical formalization of the geological relations identifying the basic structure of a geological data bank, *In* Quantitative Stratigraphic Correlation, J.M. Cubitt and R.A. Reyment, eds., 13-18.

Christian, E.J., 1996, GILS What is it? Where's it going? D-Lib Magazine, December 1996, http://www.dlib.org/dlib/december96/12christian.html.

Cox, S.J.D., Kohn, B.P. and Gleadow, A.J.W., 1994, Toward a fission track tectonic image of Australia: model based interpolation in the Snowy Mountains using a GIS, Geol. Soc. Aust. Abstracts, **37,** 72-73, and http://www.ned.dem.csiro.au/AGCRC/projects/2005LO/snowys/.

Cox, S.J.D., 1997, Using the web to build a domain-specific information and modelling system, Australian World-Wide-Web Tech. Conf., Brisbane, QLD, Australia. 7-9 May 1997.

Dempsey, L. and Weibel, S., 1996, The Warwick Metadata Workshop, D-Lib Magazine, July/August 1996 http://www.dlib.org/dlib/july96/07weibel.html.

FGDC, 1994, Content standards for digital geospatial metadata, ftp://www.fgdc.gov/pub/metadata

Goodman, B.A., ed., 1994, GeoRef Thesaurus, 7th edition. Am Geol. Inst. 842 pp.

Huse, S., 1995, GRASSLinks: a new model for spatial information access in environmental planning, PhD. Thesis, Univ. California Berkeley. http://www.regis.berkeley.edu/sue/phd/.

Jessell, M.W., Valenta, R.K., Jung, G., Cull, J.P., and Geiro, A.A., 1994, Structural geophysics, Exploration Geophysics, **24**, 599-602.

Johnson, B.D., Shelley, E.P., Taylor, M.M., and Callahan, S., 1991, The FINDAR directory system: a meta-model for meta-data, *in* Metadata in the Geosciences, Medyckyj-Scott, D., Newman, I., Ruggles, C., and Walker, D., eds., Group D Publications Ltd, Loughborough, UK.

Knight, J., and Hamilton, M., 1996, MIME implementation for the Warwick Framework http://weeble.lut.ac.uk/MIME-WF.html.

Lagoze, C., 1996, The Warwick Framework: a container architecture for diverse sets of metadata, D-Lib Magazine, July/August 1996, http://www.dlib.org/dlib/july96/lagoze/07lagoze.html

Maler, E., and El Andaloussi, J., 1996, Developing SGML DTDs from Text to Model to Markup, Prentice Hall, 525 pp.

Mann, C.J., 1977, Towards a theoretical stratigraphy, J. Math. Geol., **9**, 649-652.

Miller, P., 1996, An application of Dublin Core from the Archaeology Data Service, http://www.ncl.ac.uk/~napm1/ads/metadata.

Shelley, E.P., 1995, The National Directory of Australian Resources: current status and future directions, Proc. 3rd Nat. Conf. Mgmt Geoscience Information and Data, Australian Mineral Foundation, Adelaide, Australia, 18-20 July 1995, 24. 1-7.

Turner, R.C., Douglass, T.A., and Turner, A.J., 1996, Readme 1st: SGML for Writers and Editors, Prentice Hall, 272 pp.

USGS, 1996, Spatial Data Transfer Standard (FIPS PUB 173-1) http://mcmcweb.er.usgs.gov/sdts/standard.html.

Wall, L., Christiansen, T., and Schwartz, R.L., 1996, Programming Perl, 2nd Edition. O'Reilly, Sebastopol, Calif. USA. 648 + xxii pp.

Weibel, S., Godby, J., Miller, E., and Daniel, R., 1995, OCLC/NCSA Metadata Workshop report, http://www.oclc.org:5046/oclc/research/conferences/metadata/dublin_core_report.html.

Weibel, S. and Miller, E., 1997, Dublin Core metadata element set: reference description http://purl.org/metadata/dublin_core_elements.