Regional Integrated Management Information System

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Abstract: Landholders, departmental agencies and other stakeholders have long been involved in knowledge building of the physical elements affecting land use. Often, however, this has been without any accompanying information on social and economic impacts, or systems for exploring catchment trade-off decisions. RIMIS is the concept of a regional management system designed for landscape managers. It has a web-compatible interface allowing multiple users to access distributed data sources (including spatial databases) and run distributed bio-physical and socio-economic models to explore catchment management problems i.e. ask *'what if?'* questions. Its models bring together science, sociology and economics, to explore interactions and show the impact of management decisions in one place on the rest of the catchment and end-of-catchment targets. RIMIS is being deployed in the New South Wales Department of Land and Water Conservation (DLWC) for their TARGET project.

Keywords: Integrated Catchment Management; Problem Support System; Interoperable Information Infrastructure; Model Flow

1 INTRODUCTION

RIMIS aims to provide landscape managers, from diverse disciplines and organisations, with both an application and a re-useable information infrastructure that together enables systematic investigation of social, economic, water quality and salinity trade-off issues for the Lachlan and Macquarie catchments in NSW, Australia. Catchment management is a complex real world problem, usefully characterised as an ill-structured [Simon, 1973] or wicked problem [Rittel and Webber, 1973] because of its broad range of stakeholders (both individuals and organisations), problem scope (covering social, economic and bio-physical processes) and evolving problem definition (such as the structure of the physical processes under investigation, constraints on feasible solutions and investigation objective). Formulation of a system to successfully support landscape managers and other stakeholders involved in the catchment management problem requires elicitation and understanding of stakeholder wants and needs. The design and subsequent structure of RIMIS recognises the requirements of the principal stakeholders in salinity and water quality management: primarily *Catchment Management Boards* (CMB), but also *Primary Producers*, *State Government Departments*, *Local Governments*, *Domain Specialists* drawn across organisations from several discipline areas, and *Interested Public*. In Sect. 2 we present major stakeholder requirements addressed by RIMIS. Sect. 3 describes the major components of RIMIS and identifies how these components meet stakeholder needs. A common theme of organisational stakeholder requirements is interoperability–in terms of data, information and knowledge re-use. Sect. 4 highlights how RIMIS uses an inter-enterprise information infrastructure to achieve interoperability. RIMIS uses a

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workflow system to co-ordinate distributed data access and process model execution. We briefly describe our workflow approach to managing cascade networks of social, economic and bio-physical models in Sect. 5. RIMIS, through its Evolutionary Problem Support System (EPSS) interface, distinguishes itself from other work by adopting a problem definition model as the underlying theme for organising and presenting information and knowledge about the problem at hand. Sect. 6 describes the RIMIS problem definition model and the EPSS interface. We identify related work in Sect. 7 and present conclusions in Sect 8.

2 STAKEHOLDERS AND REQUIREMENTS

CMBs have statutory obligations to establish interim catchment targets for salinity, water quality, soil health, vegetation management and so on. The primary requirement of CMBs with respect to RIMIS is to broadly define catchment-wide landscape management problems and set scenarios for further detailed problem exploration. *Problem Solvers*, *Decision Makers* and *Domain Specialists* assist the CMB in defining catchment management problems and subsequently exploring the effects (outcome) of various action plans under a scenario. The model of problem definitions embedded within the EPSS component of RIMIS is crucial to enabling these stakeholders to systematically explore potential landscape futures. *Domain Specialists* are people and systems that answer questions about relationships among problem variables. *Domain Specialists* wish to provide expert input (usually in the form of models and specialist data) on the causal relationships among problem variables. Interoperable access to models and data forms a major requirement for *Domain Specialists*. *Domain Specialists* typically have significant existing investments in knowledge and expertise on using and calibrating process models. This investment in legacy models is often coupled with an unwillingness to re-implement that knowledge in another modelling framework. We see *Primary Producers* and *Interested Public* as major information consumers for RIMIS, demanding easy access to CMB strategy and implementation progress documents and interaction with a more concise problem-scenario-action-outcome representation than used by CMB. *State Government Departments* and *Local Government* would like to see increased data and information sharing together with broader access to domain expertise. An important constraint on information sharing is that organisations wish to retain custodianship of data and systems.

3 RIMIS STRUCTURE

Stakeholder requirements are met through a Web-based software system that integrates data and process models in a highly interactive and problem-focussed way. This encourages unconstrained exploration of information resources and management options. Extensibility of the design enables it to be reconfigured to vary process models and data availability from time to time through reconfiguring rather than recoding. Embedded in a static Web site aimed at advancing knowledge and communication amongst stakeholders, the RIMIS offers two kinds of distinct end-user interfaces. One, intended for CMBs and their advisers, provides an evolutionary problem support interface (EPSS). This offers a problem-directed interface to integrated datasets, contextual data and process models calibrated for the problem: social, economic, water, salinity and vegetation models. A problem space is established through customisation of initial problem templates. Users explore the problem space through interaction with hypermedia maps, scenarios and action plans that describe possible futures and management options in a spatially-explicit manner, based on underlying biophysical management units. Simulated action plan outcomes are summarised through a pentagonal icon, but drill-down to underlying quantitative measures is available. The other end-user interface is offered through system tools that extract selected contextual data and management options from the problem support system and publish these to a technically simpler display-based system. RIMIS is built on an interoperability infrastructure developed by the Internet Marketplace (IMP) group [Abel et al., 1999]. Local government councils in Sydney have successfully used this infrastructure to share and access data and other information distributed across a number of organisations [Cameron et al., 2001]. The IMP infrastructure permits system extensibility, including dynamic access to custodian-sited datasets, legacy models and image processing services [Devereux and Power, 2001]. Interoperability is achieved through a declarative request language, specialised software components to interface with data and model sources, a workflow definition and management tool, and extensive internal metadata management.

3.1 Key System Components

Figure 1 sketches major components of RIMIS. The **RIMIS Web Site** is the entry portal for Public and CMB access to the Lachlan (LIMIS) and Macquarie (MIMIS) Web sites, each containing strategy documents relevant for their catchment. The portal allows public access to the **RIMIS Scenario Action Outcome Exploration Interface** enabling the Public to gain exploratory access to published scenario-action-outcome data. Other RIMIS Web Interfaces require security clearance for access.

The **EPSS Interface** enables the CMB and Domain Specialists to partially define a problem and establish a problem scenario. Problem Solvers use this component to build and simulate an action plan, while Decision Makers use this component to compare and evaluate the scenario-action-outcomes tied to a problem definition. The **RIMIS Scenario Action Outcome Publisher** enables the CMB to publish selected scenario-action-outcomes for use through the scenario action outcome exploration interface.

The **RIMIS Problem Definition Service** is a data store of the problem-definition focused representation of landscape management problems germane to RIMIS. **RIMIS Query Services** provide interoperable access to contextual data sources. **RIMIS Modelling Function Services** provide interoperable access to process models; primarily used by the IMP Workflow Request Execution service, to simulate a scenario-action-outcome on behalf of the EPSS Interface. The **IMP Workflow Request Execution Service** executes process model networks on behalf of the EPSS Interface. This service and its workflow definitions enable Domain Specialists to establish and configure process model networks for biophysical and socio-economic modelling.

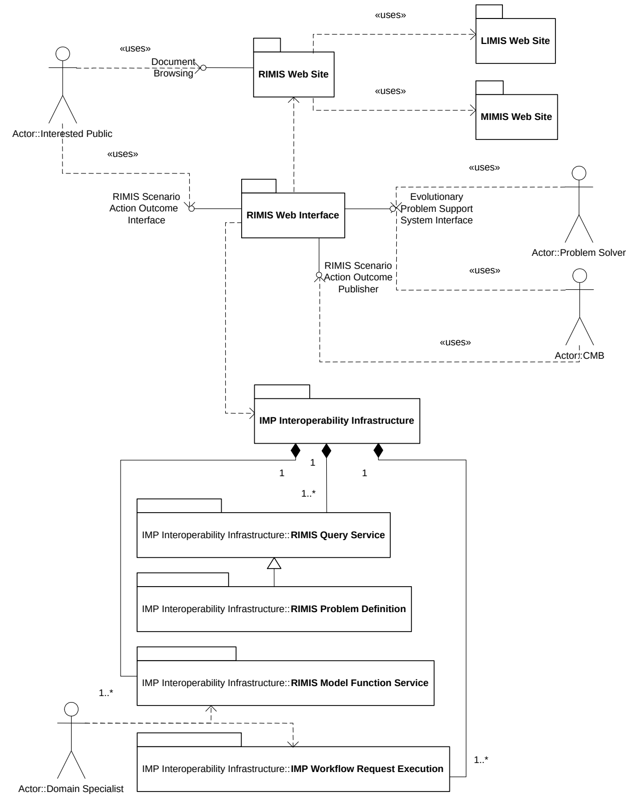

Figure 1: RIMIS Architecture

4 Interoperability Infrastructure

In IMP terminology, a *request service* can be either a *query service* (such as that provided by a database) or a *function service* (such as a simulation model). The IMP infrastructure enables interoperability through use of a declarative request language. This language is extensible, allowing services to differ in their capabilities, but has a fixed structure. Each *request service* has an IMP interoperability wrapper, enabling the service to interpret and act upon the declarative requests sent to it. Services establish an export schema (i.e. data structures and their operators for those structures) in a registry service [Cameron et al., 2001].

RIMIS uses the HTTP binding of the IMP infrastructure as a transport layer, enabling services to respond to web-requests from browsers, web-forms as well as applications. The declarative request submitted to a query service results in the service returning data in the required structure and format. The contextual information available to RIMIS, such as spatial data for the region of interest and model input data, comes from IMP query services. Function services use multi-part mime messages, enabling services to operate on data delivered as part of the request. All of RIMIS' simulation models are IMP function services.

A significant implication of using a declarative language to invoke services is that the engineering challenge in coordinating and controlling services moves away from the complexity of establishing interoperability with many different object interfaces, to establishing interoperability at a declarative request language level. Since the structure of the request language is fixed and the data structures and operators a service supports known, it is possible for applications to 'template' their requests to services [Cameron et al., 2001]. We expand on this technique in Sect. 6.

5 Model Flows

RIMIS has key biophysical process models wrapped by IMP interpreters available to simulate potential outcomes arising from landscape actions. Biophysical processes of interest in a catchment are surface (flow) and ground water (recharge) movement, as they relate to water quality and salinity. In modelling terms, each catchment is broken into a number of contiguous regions, termed Biophysical Modelling Units (BMU), having similar hydrogeomorphic features.

There are three models that support derivation of flow and recharge, as depicted in Fig. 2. The HYDRO model derives surface water components for flow and recharge from combinations of rainfall data and up-stream surface flow. The GROUND model derives the subsurface discharge and storage (groundwater level along the hydrogeological unit (HGU)) using the recharge derived from the HYDRO model. The recharge from each contributing BMU is summed (weighted by contributing area) to give the recharge to each HGU. The NETWORK model simulates transport of surface or subsurface flow and recharge, linking HYDRO and GROUND components together and to downstream process networks. A biophysical cascade, consisting of linked NETWORK, HYDRO and GROUND models, operates within each BMU. The bio-physical cascades operating in each BMU within a catchment are linked together through NETWORK models.

Workflow technologies, together with an inter-enterprise infrastructure, enables service composition, which is an important aspect of flexible service re-use [Bond and Sud, 2001]. IMP uses workflows to connect logical data flows from query services through function services. *Domain Specialists* can construct a network consisting of data and models that generate and transform simulation data, possibly originating from different organisations.

RIMIS uses a workflow tool to link together models and data into a model flow. Fig. 2 is an example model flow. It links together land-use changes for localised BMUs (ovals), biophysical models for surface, subsurface, and stream flow processes, and a social model. The run collector of the model flow assembles the resultant output for subsequent interrogation.

6 A Model of Problem Definitions

Smith [1992] argues that problem formulation is a particularly appropriate activity in resolving ill-structured problems. The heart of a problem is a discrepancy between *what is* and *what might be*. The RIMIS Problem Definition Model is a simplification of the 6-Component Problem Definition Model [Cameron, 2000]. For our purposes, a problem definition is a representation of what a problem stakeholder believes *what is*, *what might be* and their *perceived difference* between them. RIMIS adopts a modelling perspective for establishing a problem definition. The EPSS characterises *what is* in terms of a model network, together with scenarios and action plans. *What might be*, is then a simulation of an action plan in the context of a scenario and model network. The EPSS enables exploration of the *perceived difference* through scenario-action-plan comparison graphs.

Problems have a number of major structural components, such as the network of models, data sources, variables and the dependencies among them. Typically these structural components change infrequently during the process of establishing feasible solutions to the problem for a given scenario, however they are likely to change over the entire life-cycle of a problem investigation.

A **Problem Template** is a pre-specified organization of structural components that are typical for a problem within certain contexts. Problem scale (such as sub-catchment or catchment scales), problem location (within the Little River sub-catchment, for example) and problem theme (such as biophysical or social or integrated biophysical social and economic) are all examples of problem contexts suitable for pre-configured problem templates. Each problem template has associated documentation about the sort of problems for which the template might be useful. Templates provide a certain degree of parameterisation, where scenarios provide the 'missing problem invariants'. The selection of models of appropriate temporal and spatial scales and their interconnectivity is expressed as a workflow within the problem template, established by *Domain Specialists*. A problem template establishes an outline of *what is* for stakeholders. A working problem arises through selection of an appropriate problem template by stakeholders. We currently see the construction of template model flows as an activity performed by domain specialists (perhaps with help from productivity tools such as those described by Christophides et al. [1999]).

A **Scenario** identifies a set of common assumptions or themes that group subsequent problem solving investigations for the working problem definition.

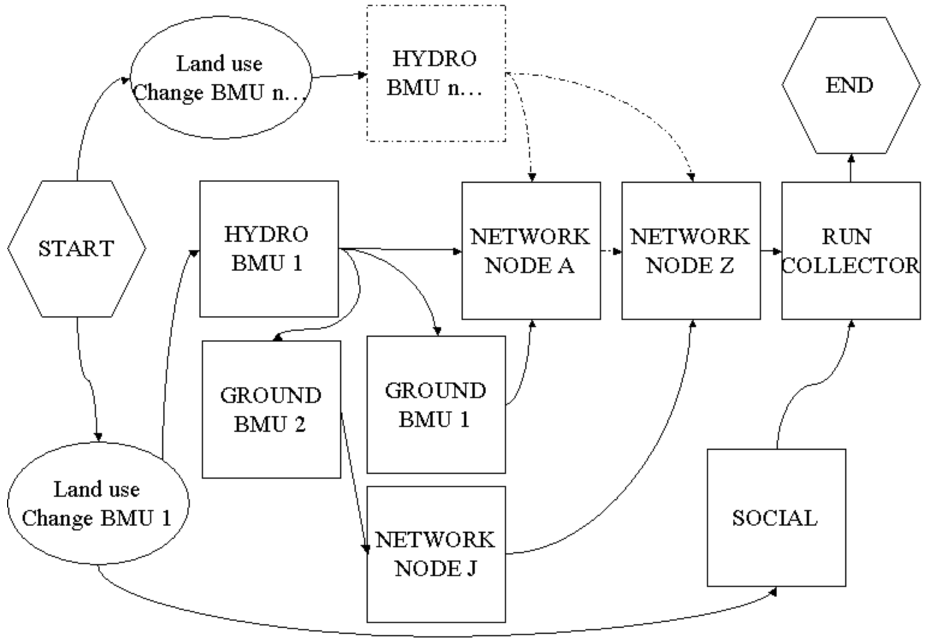

Figure 2: Model Flow

A scenario is a set of 'problem invariants' that apply to a working problem definition. A scenario and problem template together complete the definition of *what is* for stakeholders.

In modelling terms, an **Action Plan** is a specification of a series of value assignments that effectively modify values of model input variables. Workflows contain parameters that are rewritten by action plans. In terms of our working problem definition, application of an action plan will result in the action plan substituting values into the parameterised workflow, completing the workflow definition in readiness for execution.

Outcome *Problem Solvers* may simulate the virtual changes specified by an action plan and record outcomes of one or more simulation(s).

The Catchment Management Board and their intermediaries primarily interact with RIMIS through the EPSS. The EPSS enables the CMB to define problem contexts, construct scenarios, develop action plans and simulate outcomes for the purpose of making catchment wide trade-off decisions. The problem definition model, consisting of a working problem definition, scenario, action plan and outcome, provides a unique framework for formulating, evolving and answering questions of the form: *'when faced with* <***problem***>*, what* <***outcome***> *might happen if we do* <***action plan***> *assuming* <***scenario***>*?'*.

7 Related Work

RIMIS has two themes with which it relates and distinguishes itself from other activities: the IMP infrastructure as an inter-enterprise interoperability infrastructure; and the EPSS as an evolutionary problem support tool.

There is a large body of research on the architecture and design of Decision Support Systems. Earlier research is based on a 'system component' view of the architecture–what components should a DSS have and how to connect those components (see for example Bonczek et al. [1981]; Sprague and Carlson [1982]). More recent work investigates distributed architectures based on Internet as middleware [Bhargava et al., 1997], federated information systems concepts [Abel et al., 1994, 2000] and mediation architectures [Houstis et al., 1998].

THETIS [Houstis et al., 1998] in particular shares with RIMIS a common goal of interoperability and application of workflow technology to process modelling problems, though THETIS focuses on coastal zone management. RIMIS and its EPSS interface distinguishes itself from other work by adopting a problem definition model as the underlying theme for organising and presenting information and knowledge about the problem at hand.

8 CONCLUSIONS

RIMIS is a system designed to meet specific requirements for regional landscape management. RIMIS supports the CMB in posing *'what if?'* questions for catchment-based landscape management. The IMP information interoperability infrastructure effectively enables RIMIS to access contextual data, information and modelling services from diverse data custodians and organisations. RIMIS builds upon this basic accessibility to offer interfaces and services crafted for its stakeholders.

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10 REFERENCES

Abel, D. J., V. J. Gaede, K. L. Taylor, and X. Zhou. Smart: Towards spatial internet marketplaces. *GeoInformatica*, 3(2):141–164, 1999.

Abel, D. J., P. J. Kilby, and M. A. Cameron. A federated systems approach to design of spatial decision support systems. In *SDH'94*, Edinburgh, Scotland, 1994.

Abel, D. J., K. L. Taylor, G. Walker, and G. Williams. Design of decision support systems as federated information systems. In *Decision Support Systems for Sustainable Development: a resource book of methods and applications*, Boston, 2000. Kluwer Academic.

Bhargava, H. K., R. Krishnan, and R. Muller. Decision support on demand: Emerging electronic markets for decision technologies. *Decision Support Systems*, 19:193–214, 1997.

Bonczek, R., C. Holsapple, and A. Whinston. *Foundations of Decision Support Systems*. Academic Press, New York, 1981.

Bond, A. and J. Sud. Service composition for enterprise programming. In *Working Conference on Complex and Dynamic System Architectures (CDSA-01)*, Brisbane, Australia, December 2001.

Cameron, M. A. *A Problem Model for Decision Support Systems*. Phd., Australian National University, 2000.

Cameron, M. A., K. L. Taylor, and D. J. Abel. The internet marketplace template: An architecture template for inter-enterprise information systems. In *CoopIS'01*, Trento, Italy, September 5-7 2001. Springer-Verlag.

Christophides, V., C. Houstis, S. Lalis, and H. Tsalapata. Ontology-driven integration of scientific repositories. In *NGITS'99*, Zikhron-Yaakov, Israel, July 5-7 1999. Springer Verlag.

Devereux, D. and R. Power. The image analyst's workbench. In *Proceedings of the 10th Australasian Remote Sensing and Photogrammetry Conference*, pages 623–635, Adelaide, Australia, 2001.

Houstis, C., C. Nikolaou, S. Lalis, S. Kapidakis, and V. Christopides. Towards a next generation of open scientific data repositories and services. Technical Report TR98-0219, 1998.

Rittel, H. W. J. and M. M. Webber. Dilemmas in a general theory of planning. *Policy Sciences*, 4:155–169, 1973.

Simon, H. The structure of ill-structured problems. *Artificial Intelligence*, 4:181–202, 1973.

Smith, G. F. Towards a theory of managerial problem solving. *Decision Support Systems*, 8: 29–40, 1992.

Sprague, R. and E. Carlson. *Building Effective Decision Support Systems*. Prentice-Hall, Englewood Cliffs, NJ, 1982.