Semantic Service Integration for Water Resource Management

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Abstract. Water resource management is becoming increasingly difficult due to the interaction of conflicting factors such as environmental sustainability and economic constraints. In Australia, the introduction of a water rights management framework is an administrative attempt to facilitate the resolution of this complex and multi-faceted problem. Policies relating to water allocation and trading have already advanced beyond our abilities to monitor, measure, report and enforce these policies. Mismanagement of this valued resource can have severe damaging long term environmental and economic effects. We believe that Semantic Web Services technologies will help decision makers minimise the risk of mismanagement. In this paper, we discuss the potential application of our dynamic service composition approach and its compatibility with other solutions. We identify the benefits for the different categories of users and discuss how ontologies can help to bridge the gap between specialists and non-specialists, or specialists focusing on separate aspects of the overall problem.

1 Introduction

Water is becoming a highly valued resource not only in Australia but in many countries around the world. This value is driving the need for improving the efficiency of water management practices. In the Australian context, water management is a complex relationship between demand and supply, moderated by water rights trading. Intelligent water allocation, extraction and trading are essentially a process of economic optimization integrated with hydrologic network modelling. Decisions need to be made at both the micro (irrigator on farm) and macro (government policy making) levels. Water resource allocation is driven by a variety of environmental, economic and social factors, as well as physical constraints of the distribution systems. Decisions on water usage are based on data from information sources that include historical datasets, policy information, real time data and predictive simulation models that need to be executed at the time of decision making and evaluated on an ongoing basis.

Decisions are made by a variety of stakeholders, each operating on a different time horizon (from days to years) at different geographic extents, with different decision

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making goals and from very different contexts. For example, an individual farmer makes decisions about ordering water from a reservoir for extraction from the river in a matter of days. A regional water management agency may allocate water to consumptive users within a large catchment on an annual or seasonal timescale.

In this paper, we examine issues associated with water resource management in Australia in the context of allocation and trading. We then look at current information systems used by decision makers and the need for improved model data fusion. We introduce the need for a framework in which a new class of applications can exist and show how semantic technologies are a critical component to this framework in order to improve present approaches for linking data and models together. We characterise the data management and model integration problem to be addressed within the Australian context. We discuss how our approach to service composition can complement the existing approaches and identify the potential benefits.

2 Water Resource Management in Australia

The Australian climate is dry and highly erratic with long droughts alternating with periods of intensive and localized flooding. Additionally, water use has increased dramatically over the last two decades due mainly to the increase in irrigated agriculture. Producers are continually planning to avoid losses by protecting themselves against drought, as well as capitalising on high rainfall years. Water management is defined and regulated by each of the State and Territory Government authorities and in most states a licencing system regulates water access and distribution [3]. In most cases, a water licence is no absolute, but gives a right to use a specified amount of the available resource for a given time and within a given region. Water rights can also be withdrawn or altered at any time without any statutory guarantee of compensation. Water rights are defined in volumetric terms with several classes of rights. The two broad categories of water rights are surface water rights (access to streams and rivers) and groundwater rights (access to artesian aquifers). Within these categories water rights are classified into several priority classes that entitle the holder access to a share of the water available to each class.

2.1 Water Allocation

Allocation is the process of establishing and enforcing water demand. Planning for both environmental allocation and irrigation demand is undertaken by the relevant agencies within each state or territory. Unfortunately there have been a number of instances of over allocated systems, where too many licences have been issued for consumptive use such that the extraction of the total licenced volume would threaten the minimum reserve required for environmental sustainability. These situations are not necessarily the result of poor planning but more an indication of the complexity of the interaction between economic, social and environmental benefits and costs at different levels of geographic scale.

In an attempt to alleviate the situation of allocation errors, agencies are adopting adaptive management practices where they can respond more rapidly to changing circumstances such as unpredicted climatic change, new scientific evidence, changing community values and so on. The downside of this approach is that increased government intervention can have an adverse affect on financial investments that rely on water allocation. We are currently faced with the difficulty in determining whether the environmental allocations are actually achieved, due to the limited measuring and reporting that takes place, especially where a distributor provides water to users on a commercial basis.

2.2 Water Trading

Now that availability of water is becoming increasingly scarce, water trading is emerging as a means of efficiently allocating rights. In moving toward free trading of water rights, market based solutions for water management will be difficult to implement. Long term commitment is needed by governments and the private sector and the dynamics of a market system for a natural resource such as water include some unique difficulties, such as:

- Long distance trading – losses that occur between original and new locations;
- Exchange rate is difficult to calculate due to hydrological differences when trading occurs across catchments;
- Wide variety of transaction costs;
- The drivers for permanent and temporary water entitlements are different.

Water trading has been in existence in Australia for some time and tentative steps have already been taken with trial systems for interstate water trading [4], [16]. The success of these trials has resulted in the creation of water markets now covering larger geographic areas and involving a greater number of traders and brokers.

Water management, in particular allocation and trading, is essentially a process of optimization that involves the integration of water balance models, climatic models and economic models. Traditionally, the process has comprised the selection and development of appropriate modelling tools to support policy development and decision making processes by water authorities. While the tools themselves may originate from different domains (hydrologic and economic) there also exists a broader community of potential users that could benefit from access to these tools.

Irrigators and allocators (authorities responsible for establishing and regulating water allocation limits) require access to the same information and services although they are engaged in addressing problems at differing geographic and temporal scales. Allocators need to consider the conflicting interests of the different stakeholders which include environmental interests as well as economic [13].

Water trading has been available to land holders with water entitlements in the Southern NSW and Victorian regions of Australia since the completion of the Murray-Darling pilot project[1]. Watermove[2] is one example of an online web based water exchange facility operated by Goulburn-Murray Water Authority. An irrigator's decision to trade water will be sensitive to water prices as well as current and future farm product prices [18] and seasonal conditions [1]. As the Watermove web site

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[1] http://www.mdbc.gov.au/naturalresources/watertrade/pilot_watertrade.htm

[2] http://www.watermove.com.au

suggests, there are a number of factors a trader should take into account when considering an offer. These include: seasonal allocation compared with previous seasons, water use in current season compared with previous seasons, cost of alternatives. (e.g. dairy farmers buying feed), prices paid for temporary water in the region, price trends, price volatility, water volumes available, tariff structures and whether any delivery charge will apply to water purchased and used. Although the establishment of zones, trading rules and exchange rates are fairly static compared with other trading systems such as energy and finance, it becomes increasingly difficult to predict outcomes as the geographic scale increases. For example, the trading variations occur across zones which contain separate tributaries that may impact down stream water balances. Add to this unpredictable climatic conditions and the dynamics of the system become much more interesting to all parties. To define long term policies for catchment or basin level regions, we need appropriate data and predictive models for all types of water use that allow analysis at a whole of system level in order to support the next round of water reforms.

It is clear that an environment that can provide requirements based problem expression, resource discovery, service composition and iterative problem execution, will potentially benefit a broad community of users.

3 Current Approaches in Model and Data Integration

There has been an increasing emphasis in recent years on providing more integrated information services to Australian natural resource managers. However these initiatives have typically focused either on data delivery or on simulation modelling and rarely on both. These new services have introduced considerable flexibility to their consumers, but are still based on relatively rigid models of interaction, and each are configured to answer a limited set of questions at very specific spatial and temporal scales.

3.1 Data Services

Natural resource managers regularly require access to spatial and temporal data, which in Australia is held by a variety of organizations in each jurisdiction. This data is gradually being made available through online data portals, such as the Victoria Water Resource Data Warehouse[3]. The range of natural resource data available online in Australia includes hydrologic data[4], climate data[5], soils information[6] and various derivative products, such as Sentinel Hotspots[7] used for bushfire detection. CANRI[8] and the NSW Natural Resource Atlas[9] are good examples of web based access to natural resource datasets available to a broad user community.

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[3] http://www.vicwaterdata.net

[4] Ibid

[5] http://www.nrm.qld.gov.au/silo/, http://www.bom.gov.au

[6] http://www.asris.csiro.au

[7] http://www.sentinel.csiro.au

[8] http://www.canri.nsw.gov.au

[9] http://www.nratlas.nsw.gov.au

While these and other services represent an improvement over previous, more manual forms of data provision and exchange, they still suffer from a number of problems, particularly a lack of integration with models. Many users of data services expect to use the data as input to models, although often significant and time consuming pre-processing must occur before the data can be used.

Additionally there is increasing need to use real-time data sourced from sensor networks that allow monitoring and control of water use. To meet this need, such data must be provided dynamically and in a form to support its ready integration with a wide variety of other information resources.

3.2 Model Services

Predictive modelling is becoming central to natural resource management for purposes such as considering the impacts of a new policy, or performing a priority allocation of restoration funding in order to achieve a desired outcome. There is a need for models to become more accessible, for use by a wide range of stakeholders, and more integrative, by including a range of biophysical considerations. Several large modelling initiatives have, in recent years, addressed these issues of accessibility and integration of models developed to match the requirements of different categories of users [6], [12].

3.3 Model Integration Services

Model integration frameworks have been designed to facilitate the integration from broad scale water quality models[10] to complex models examining water allocation scenarios in circumstances ranging from 'what-if' analyses in public stakeholder workshops to seasonal water allocations by legislative authorities. The Catchment Modelling Toolkit[11] is a suite of environmental modelling products, engineered with high level user interfaces delivered through an online community and supported through regular training workshops. The toolkit has made its suite of catchment models available to a wide range of industry stakeholders and consultants. Central to the Toolkit is a framework, TIME [14], that supports toolkit model development and integration. TIME is based on the Microsoft .NET[12] platform and supports the development of spatial and temporal models in standard programming languages.

The Harmon-IT[13] project focuses on integrating existing catchment models by defining a standard protocol for communications between models called openMI[14]. Using this approach, wrappers can be created for legacy models, while models under active development can have the protocol embedded directly.

The Dynamic Information Architecture System DIAS[15], is designed for the simulation of complex dynamic systems and supports both the development of new models and the integration, through wrappers of legacy models.

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[10] For example, CMSS: http://www.clw.csiro.au/products/cmss

[11] http://www.toolkit.net.au

[12] http://www.microsoft.com/net

[13] www.harmonit.org

[14] http://www.openmi.org

[15] http://www.dis.anl.gov/DIAS

RIMIS [7] is a Web Services based system designed to support regional landscape managers in posing 'what if' questions for catchment-scale salinity and water quality problems. RIMIS integrates hydrological, economic and social simulation models and is built on an infrastructure that enables distributed data and service coordination across organizations. This allows catchment managers to describe their problems and scenarios using data and modelling services from participating state government and local council organizations. RIMIS uses workflow technologies to provide a solution to the problem of obtaining data and coordinating model execution. However, the construction of workflows is not based on semantic descriptions of data and services, making it a difficult task for domain experts.

Hydra3 [15] is an older model integration technology which lacked the modern advantages offered by Web Services for interoperability but attempted to drive model-data and model-model integration through the use of declarative specifications of mapping relationships. This approach to interoperability is now driving much of the semantic web services research agenda.

3.4 Limitations of Current Systems

Water resources management is dependent on information about water distribution, utilization and knowledge of water quality and availability. Improvements in water resource management will be driven by our ability to improve access to environmental data integrated with predictive models. Data and models currently exist in abundance as isolated self contained systems that make integration across these systems problematic. Recent advances in environmental sensing technologies provide an opportunity to collect information about our environment at much higher spatial and temporal resolutions. However, without an underlying framework to facilitate intelligent integration of models and data there will be little benefit gained in generating orders of magnitude more data from real time sensor networks.

Environmental Modelling Frameworks like TIME and OpenMI are an improvement over product-centered integration approaches such as Arc Hydro[16], and HEC[17], but they do not solve all the issues linked to model complexity [11] and component interoperability over multiple frameworks [2] for which Web Services with richer semantics are seen as a viable option. Semantic technologies will mean that integrated, problem based software applications will no longer need to "hardcode what to do with each data item" [17], so that the task of investigating problems and making decisions can be placed in the hands of key information users, without the mediation of software technologists.

4 A Framework for Water Resources Monitoring and Management

The Water Resources Observation Network (WRON) is a concept envisioned by CSIRO as a distributed network integrating a range of technologies for acquiring,

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[16] http://www.crwr.utexas.edu/giswr/hydro

[17] http://www.hec.usace.army.mil

storing, analyzing, visualizing and interpreting environmental and economic data relating to water resource management at a national scale. WRON will require collaboration and participation by many agencies and stakeholders within Australia. The goal for WRON is to facilitate the development of next generation modelling and decision support tools and be able to deliver those tools to a much wider range of water resource users utilizing dynamic model-data fusion techniques. Essential to WRON will be the efficient and seamless linkage of the following elements:

- Legacy databases held by various custodians. These are typically spatial databases such as terrain, soil and land cover datasets, also time series hydrometric data (eg: climate, water levels and physio-chemical parameters);
- Field based sensor networks that measure climatic, in stream, groundwater, landscape and ecosystem parameters in real time at much higher resolutions (both spatially and temporally) than currently available;
- Remotely sensed data sources such as soil moisture, soil temperature, evapotranspiration, vegetation indexes and land use activities, reported in near real time;
- Predictive models and decision support tools for uncertainty estimation, optimization and multi-criterion analysis available as re-useable building blocks rather than self contained systems;
- Computational resources that automatically enable the execution of compute intensive applications deployed across the network.

We identify three categories of users for the WRON. These are: users with an administrative role in charge of reporting water usage on the basis of the presently available data and knowledge; users with an operational role, in charge of day-to-day management of some parts of the system; and users with a planning role, preparing decisions affecting the future on the basis of ‘what if’ models.

The common theme among these users is that they are all working within a scenario driven environment where problem expression capabilities would range from specification (*how much water should I buy/sell today?*) through simulation (*what is the effect on diversion limits if demand increases by 20%*), analysis (*given current climatic conditions, and my usage profile, actions recommended include …*), monitoring (*I need to know when consumption is exceeding diversion limits*) and evolution to reiterate the problem definition. Enabling flexible and efficient problem management is a key component in translating WRON’s technological underpinnings into domain specific problem focused tools that have meaning and impact for users.

5 Semantic Web Services Composition

There are many desirable features of current and emerging semantic web tools that can provide solutions to the WRON needs, especially those tools developing around Semantic Web Services. It is particularly attractive to leverage the high-impact Web Services standards together with the emerging descriptive and inferencing capability of the Semantic Web. Our work is adopting these tools for resource description, workflow enactment, and service interoperability, together with declarative data integration technology, to address the WRON needs. In this section we emphasise the need for machine interpretable resource description, and outline how this can be used, together with other intelligent technologies, to realise the WRON.

5.1 Why We Need Formal Resource Descriptions

In order to support the wide diversity of rich data and processing resources required for water resources management, as well as the wide diversity of expected users, it is important to have declarative, computationally-interpretable resource descriptions.

A traditional approach to resource descriptions would have a body of like-minded people recognising a common information need to meet and establish a data format standard for information exchange. Nowadays, such a format would certainly rely on XML. Once a resource can be encoded in a standard format it can also be described with external metadata in a fairly simple way following another standard such as ANZLIC[18] or Dublin Core[19]. Inevitably, any previous standard for data format encoding or metadata will be either too broad (requiring coverage of areas that are of no interest to the current problem) or too narrow (not supporting sufficiently specific description for the current problem). Large scale attempts to standardise a common information model for frameworks such as the WRON, either in terms of data formats or metadata formats, are doomed to fail [17]. They will be expensive and slow and will surely hinder development in a multi-party environment that requires infrastructure development to proceed within widely varying time, budget and goal constraints of participating organisations and application needs.

A computationally interpretable resource description has many advantages in making software components more generally applicable over a range of evolving, different, flexible resource types. This capability is a much more natural fit with the nature of feasible WRON development. For example, the use of hierarchical classifications to support discovery of modelling components has been established in the natural resources domain [10] and using the added value of OWL[20] to support contextually-based discovery of resources of software modules, has been demonstrated in [9].

An important feature of formal resource descriptions is that there is no reason for any particular classification to be authoritative: multiple independent or co-dependent ontologies may be created to meet community needs as they arise. Software tools to navigate, select, and manipulate data may be entirely independent of any particular ontology because the ontology itself is manipulated as a data object with well defined semantics, amenable to semantic inferencing.

What can this semantic inferencing offer? Firstly, it offers an advantage for rapid ontology design through acquisition and merging of multiple pre-existing ontology resources. Information sources containing the standard knowledge shared by specialists in their domain of expertise are readily found and can be converted into formal domain ontologies. Semantic inferencing assists in the construction of sound and non-trivial ontologies.

Secondly, it offers a degree of automation in classification of resources, described using ontological terminology. This classification is valuable for software components, data types, data models, and structured data sets, including databases. It can

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[18] http://www.anzlic.org.au

[19] http://dublincore.org

[20] http://www.w3.org/TR/owl-features

assist in both resource discovery (through support for classification, browsing and querying ontological structures), and resource assembly (through machine assisted goal seeking and data type inference). For example, it will be possible for a WRON user to describe their problem domain in terms of an ontology, rather than in terms of WRON resources. Good resource descriptions will enable the expertise embedded in models to be exposed: constraints relating to time, location, and physical parameters can be interpreted by software to validate their use in a user problem context. Data format translation services will be invoked automatically as necessary.

Thirdly, it offers some resilience to change in domain applications assembled from underlying resources. If the assembly of resources to meet application goals is specified at a conceptual, abstract level, and machine processable inference can be employed to ground the specification to concrete resources, then the abstract specification will be isolated from many of the changes at the resource level. This is analogous to the value gained from interpreters and compilers for high level programming languages—they enable a machine recompilation step to translate a high level specification to work for different platform architectures.

Fourthly, and perhaps most importantly, semantic inferencing is crucial to avoiding death by standardisation. Where community standards can be developed or pre exist for data formats and terminology, they are very valuable community assets. But where they don't exist, semantic descriptions, coupled with machine interpretable mapping rules and semantic inferencing can be used to relate pre existing WRON resources to an application domain model of choice at run time. For example, provided that a water quality time series dataset description formally identifies that the "BOD" element corresponds to "bio chemical oxygen demand" and that it is measured in "milligrams per litre", on a "daily timestep", at a fixed geo-location, the integration of this information with another biological oxygen demand measurement data set, recorded and labelled in a different format, but described in a consistent terminology, is straightforward machine processing. Furthermore, appropriate machine generated metadata (itself amenable to semantic inferencing) should be attached to generated information products by this method, so that there is also the potential to explain any deficiencies or assumptions made in creating the new information for scientific scrutiny.

The need for the WRON computational infrastructure to support heterogeneity in data resources is only exacerbated by the desire to provide data access for real time sensor networks. Autonomous water quality sensors are themselves an emerging technology: their capabilities for measurement parameters vary widely already and divergence will continue over time as legacy sensors will co-exist with modern types. This makes it very important to capture descriptions of sensor capability and limitation within the computational infrastructure, so that machine reasoning, as before, can be used to match sensor data to the requirements of an application problem.

5.2 How the WRON Might Work

Our vision for the WRON comprises basic resources, reference ontologies and mappings, a problem definition tool, and a sophisticated Web Services based run time environment. Basic resources are published to the WRON with Web Service interfaces. These resources comprise data as files, databases, sensors, and complex software components embedding expert knowledge such as model algorithms. These resources are enriched with extra information as resource descriptions in terms of a reference ontology and mappings that permit computational interpretations. For data resources such as databases, this description is centred on the data model itself. For services exposing software components such as hydrological models, it also provides an understanding of the functional meaning to assist the selection of the right model and capture knowledge on how to link models from various origins together. This approach is workable if and only if resource specific concepts are managed independently of each other.

Reference ontologies, like “neutral ontologies” [17], capture domain knowledge in a resource independent manner. Basic resources are related to one or more reference ontologies through machine interpretable, declarative mappings. Logical languages provide a very good basis for this purpose [5], [8] but closer integration with ontology languages is still needed. While there may be considerable effort in establishing the semantic content, especially to generate large reference ontologies, this activity is useful in more than one way. The information collected can also be used to generate metadata to document and complete the translation done at the various stages of the service composition. That is, much of the metadata for problem specific composed services may be produced for free.

Specification of application problems proceeds through user interaction with the resources and ontologies in an “ontology based specification” approach as described in the following section. This interaction produces an artefact which we call a problem definition. Queries expressed in terms of the problem definition are answered in a run time environment that dynamically interprets the definition and coordinates services to respond with an integrated result.

5.3 How a User Works with the WRON

At one level, a user may interact with the WRON in a very traditional way - to use the rich resource descriptions to locate web services and data resources to meet their needs. A simple application would provide a search based interface for a web user to discover datasets based on metadata keywords for example. However, much of the perceived benefit for WRON relies on providing the capability to create new resources or services out of the basic resources. These new resources would be available for reuse just as basic resources are. To describe how this works, we focus on a scientific expert WRON user – someone aiming to offer their expertise into the community through development of a specialist application, perhaps to assist irrigators in water allocation decisions.

We envisage the development of a new application to proceed as follows. A domain expert works with a specialist tool (we call it the “Composers Workbench”) to browse reference ontologies as sources of knowledge about the target application domain concepts. In doing so, the expert selects domain concepts and defines a problem specification for the application in mind. By virtue of the fact that network resources have been previously linked to reference ontologies, the domain expert is also simultaneously selecting an assembly of resources to satisfy the specification. By employing rich semantic descriptions to the full, the expert is free to be only as specific about the exact resource selection as desirable for the problem at hand. The expert may supplement the definition with specific calibration or parameter data appropriate to the problem. The problem itself will certainly evolve as the expert redefines and tests the automatically generated service implementation. When complete, the expert may deploy the service composition as a first class resource, the interface of which is exposed as yet another web service. The service conceptual description (as OWL) and interface (as WSDL), together with a computational implementation of the service may be automatically derived from the specification. That is, the service now becomes a WRON accessible Web Service resource available to the wider community of users. Depending on the application needs, the Web Service may need to be supplemented with a specialist GUI for presentation and user interaction, such as that offered by the Catchment Modelling Toolkit for example.

When using the service, a specific run time query is combined with the abstract specification of the service and transformed at run time to an executable workflow. We use an automated planner to derive an optimal, executable process specification with temporal relationships between component execution derived automatically. Declarative constraints on component applicability are interpreted in the context of the run time data. The workflow may be generated in a choice of languages, including the Web standard BPEL4WS[21]. A workflow engine is used to orchestrate the calls to each individual resource in an asynchronous manner. These workflows may coordinate tens or hundreds of activities, including activities for authorisation, multi database semi joins, translations of data types and units of measurement, data chunking to match service capability, computational and data intensive models, and managing temporary storage of intermediate results.

6 Conclusions

To improve our understanding of the impact of Water Reforms and monitoring the state of catchments with a range of multi disciplinary focuses, we need to keep pace with the rapidly increasing volume and availability of data and the increasing richness and sophistication of models available. Environmental Modelling frameworks are now adopting appropriate standards and common software engineering practices which will facilitate the move to Web Services. It is for this reason we believe the timing is ideal to consider the adoption of Semantic Web technologies. We believe the semantic richness required to work on hydrological problems is already expressed in "de facto standards" from collaborative projects (Arc Hydro, HydroML[22], HarmonIT, Harmoniqua[23], CUAHSI[24]) and further refined in the work to develop the Upper Ontology for Hydrology[25] developed at Drexel University and other projects such as SWEET[26].

A large part of our work to date has been in building domain-independent infrastructure tools for ontology engineering, problem definition, query planning, work-

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[21] Developed by Microsoft, IBM, and BEA http://www.oasis-open.org

[22] http://water.usgs.gov/nwis_activities/XML/nwis_hml.htm

[23] http://harmoniqua.wau.nl

[24] http://www.cuahsi.org

[25] http://loki.cae.drexel.edu/~how/upper/2003/12/upper.html

[26] http://sweet.jpl.nasa.gov/ontology

flow generation and workflow execution. Prototype versions of our tools now exist and the next stage will be the deployment and evaluation of these tools in variety of application domains. Our work permits a fine grained approach to service interaction whereby process-oriented workflows are automatically generated from declarative specifications. This means the resulting workflows may be more complex and better optimised than those created from flow-based specification tools. For example, Oracle's BPEL Designer[27], which provides a neat graphical user interface to describe a workflow, is inappropriate for editing and maintaining workflows that invoke hundreds of services. We are also developing tools that can assist domain specialists in the creation of ontologies from content available in a range of existing formats. Many sources of knowledge rich content are presently under exploited and we hope to improve what is often seen as a tedious and timely process. We believe the increased level of automation these semantic tools can provide has the potential to significantly reduce the effort required in building applications and to enable knowledge specialists to effectively build their own applications without the need for the software specialist.

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[27] http://otn.oracle.com/bpel

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