Title: **MONET – Imagining a Math-Savvy World Wide Web**

Summary: The introduction of Web services and the semantic Web promises to transform access to powerful computational resources and consequently the way the world does business. Imagine the benefits of a Web service where a user could describe an analytical problem and data through relatively simple parameters and enable an agent to seek out and negotiate the best method available anywhere in the world. This paper describes how the MONET project is investigating mechanisms for describing mathematical Web services.

The introduction of Web services and the semantic Web promises to transform access to powerful computational resources and consequently the way the world does business. These technologies are likely to have a significant effect on the use and delivery of mathematical software, particularly affecting how business analytics applications evolve.

Imagining the not-so-distant future when Web services are more developed, one can envision that whenever users need to access a service or solve a problem they can employ the most appropriate technology located anywhere in the world. This is especially important with mathematical computations, because there are often specialist algorithms that are particularly suited to some well-defined class of problem, but users sometimes lack the expertise and time to identify and apply them. Imagine the benefits of a Web service where a user could describe an analytical problem and data through relatively simple parameters and enable an agent to seek out and negotiate the best method available anywhere in the world.

Unfortunately the currently available Web service toolkits aren't sufficient to support this process. Although current Web services publish descriptions of their interfaces, there are no facilities for describing what they actually do. The semantic Web is essential if automatic service discovery is to be supported.

SEMANTIC WEB

The semantic Web is an extension of the existing Web where the meaning of information and objects is well defined. Today, an existing Web page consists of plain text, formatting information and embedded objects such as JPEGs, MP3 files, PDF documents, etc. A semantic Web page is structured according to a particular ontology designed to convey information in a given application area. An ontology is a vocabulary where each term has an agreed meaning, along with some kind of grammar, to allow unambiguous statements to be constructed.

For example, we could distinguish between the different meanings given to the word "derivative" by a mathematician, a chemist and an investor in the stock market. In practice, ontologies also support some kind of inference mechanism so a piece of software can reason about statements it discovers on the Web.

There are a number of different frameworks in which to construct ontologies. Currently the most widely used is the Resource Description Framework, originally designed to encode meta-data (e.g. the statement "the author of this article is Mike Dewar") in documents on the Web. A more powerful mechanism, the Web Ontology Language, is currently being developed to underpin the semantic Web.

Using some kind of ontological framework it ought to be possible to describe mathematical Web services and identify those with the correct capabilities to solve a user's problem.

OpenMath

OpenMath is a mechanism for the semantic representation of mathematical objects and statements in XML. At the heart of OpenMath is the idea of a content dictionary, which defines a collection of related symbols and their meanings. Effectively a content dictionary is a small, specialized ontology, and, since anybody can write new content dictionaries, OpenMath is both flexible and extensible. It can be used on its own or in conjunction with W3C's MathML language, which provides facilities for presentation markup and supports the use of external mechanisms such as OpenMath for describing the semantics of symbols and objects.

When building a mathematical Web service, developers can use OpenMath in two ways. First, it can be used to encode the mathematical part of the problem being solved (for example a set of differential equations or an integral), and of the solution. Second, it can form part of the description of what the Web service does by defining the sets of symbols "understood" by the service (i.e. which may appear in the input) and used to represent the result. On its own this does not provide a complete description of a service, but it is a significant portion of it.

MONET

The Mathematics on the Net (MONET) project is a two-year investigation into building mathematical Web services funded by the European Union's Fifth Framework Programme. As part of this activity, the MONET Project is investigating mechanisms for describing a mathematical Web service that on the one hand provide sufficient detail to allow for automatic service discovery, while on the other hand are not too complicated for practical use. Broadly speaking, the project has identified the following components that together comprise a usable service description:

- The precise language used to describe the problem and return the result
- A broad categorization of the problem area(s) handled by the service according to some agreed taxonomy
- More detailed specification of the problems the service can handle in some suitable ontology
- A description of the role played by each parameter in the interface to the service

OpenMath can address the first of these issues, as discussed above. The second point allows for easy matching of a problem to a service without the need for any deep mathematical analysis. An "expert" broker can use the third set of criteria. The fourth piece of information is needed to explain how the interfaces described in Web services description languages are to be used.

The kind of interaction that might take place in the MONET framework is as follows. A user, working in some well-known package, generates a problem that is beyond the package's capabilities to solve. The package sends that problem to a piece of software running somewhere on the Internet called a broker and requests the details of a service that can handle it. The broker identifies the problem area using a set of heuristics and matches it to a service. It returns a Web services description language document describing the service plus details of how to construct the simple object access protocol messages recognized by it. The client package then generates a local proxy for the service on the fly and invokes it to solve the original problem.

Of course this is a simple example; much more complex interactions are possible. For example, solving a problem might require not one but several services, and the choice of some of these services might depend on intermediate results. There might also be scheduling issues involved as the most suitable service might not be available immediately.

Practical Issues

The most obvious difficulty with this approach to problem solving is trust. How can we be sure the service does what it says it does, and do we really want to send our data to a third party? The MONET Project anticipates the brokers and services an individual or organization uses most frequently will be installed locally and that only external brokers and services from trusted and reputable sources would be employed. Established companies such as The Numerical Algorithms Group (NAG) and other mathematical software vendors could well offer brokers for their own products, and professional bodies such as the American Mathematical Society might offer a neutral brokering service.

Another set of issues that will arise involves the commercial model for Web services in general and mathematical Web services in particular. Should a vendor charge a subscription fee or offer a pay-per-use service? What happens if the service fails to solve the problem or determines that there is no solution that fits the user's requirements? At the moment most real applications of Web services are used within organizations so these issues don't apply, but in the future they will become important.

The semantic Web won't replace the existing Web but will exist alongside it. Similarly, Web services will augment rather than replace existing software packages. Having said that, the technology for constructing Web services is now widely available and offers a relatively simple, open mechanism for building distributed, scalable applications. The big benefit will come, however, when we can add facilities for advertising and discovering services so that software agents are able to combine services to create custom applications as and when required.

Finding the right level of service description is not straightforward. Require too much detail and the process of service deployment and service discovery will become too onerous, require too little and it won't be possible to discriminate between similar services. Mathematics is relatively formalized compared with other application areas; thus, it ought to be easier to describe services in this domain than elsewhere. On the other hand, mathematical users' requirements are often more specialized than is generally the case. The MONET Project's experiments so far suggest it's possible to define a flexible framework that can accommodate both extremes.

Anyone with an eye on the future of the digital economy is advised to pay attention to MONET's progress. Mathematics is one of the easier ontologies to define on the emerging semantic Web and how it takes shape will have much to do with how e-commerce evolves with a fully endowed semantic Web.

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Internet References

MONET: http://monet.nag.co.uk
Resource Description Framework: http://www.w3.org/RDF/#specs
Web Ontology Language (OWL): http://www.w3.org/TR/2002/WD-owl-ref-20021112
OpenMath: http://wwwopenmath.org
W3C's MathML Language: http://www.w3.org/TR/2001/PR-MathML2-20010108

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