Virtual Research Environments: Sakai VRE Demonstrator

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Abstract

Because of its agile architecture, rich tool sets and ease of use, the open-source framework Sakai has been adopted to build up a generic Virtual Research Environment (VRE) system in a project supported by UK JISC, the Joint Information System Committee. This VRE Demonstrator uses the Sakai framework which was originally aimed at the higher educational market, but has also been used in the US OGCE, Open Grid Computing Environments, and has its origins in CHEF which was widely used for e-Learning and Grid projects in the USA. Sakai has a set of useful integrated tools, such as Chat, Blog, Discussion, e-Mail and Wiki for supporting collaborative activities in the e-Learning scenario which equally meet requirements for collaboration in e-Research. In this paper, we are going to share our experience in extending Sakai to fulfill the complex demands of e-Research, in particular enabling access to "hosted" services through Web Services for Remote Portlets (WSRP) and illustrating how Web 2.0 can be used to enrich interfaces and user experience. We also discuss how such a VRE system can be used for co-operative working in a Virtual Research Community or VO and to simplify management of research projects.

1 Introduction

The concept of a Virtual Research Environment or Collaborative Research Environment (CRE) has grown from the activities of the UK e-Science Programme, JISC Development Programme [20] and work on the Sakai Project [16] in the USA. A VRE is defined as a distributed way of working using a Web-based portal and for linking into users' desktop applications to access a wide and growing range of on-line tools. These include access to Grid-based computing and data management systems as well as collaboration tools, some based on Web 2.0. It is both a "one-stop shop" for academic users and a "turnkey solution" for commercial users.

These emerging characteristics of a VRE are increasingly overlaid with a requirement to provide support for the creation, further development, or enhancement of a research community in virtual space – a "Virtual Research Community". The OST report of March 2006 indicated that VRCs have *the potential to open exciting new opportunities to collaborate in research and thus realise significant gains at institutional, national and international levels*. Support for a rich variety of these interlocking communities is likely to remain a significant national and international objective for e-Research development for the foreseeable future, whilst noting that this will most likely be influenced by both planned and emergent developments. The increased use by researchers of social networking applications, for example, adds urgency to the requirement for VREs to adhere to open and published standards and specifications.

By using, adapting and integrating largely predeveloped components into a flexible VRE we can minimise time to implementation for a great many communities and projects, and act to ease problems associated with integration with institutional systems. Most importantly, by underpinning technical work with a detailed and thorough understanding of the needs of real researchers in a variety of discipline-based, institutional, and organisational contexts, the VRE will significantly reduce time to adoption and advance our collective understanding of the requirements of environments to support research and how to embed the Grid into complex and collaborative research processes.

In this paper, after related work is introduced, we are going to describe how a Sakai-based VRE system can meet the complex requirements of e-Research. Sakai contains a number of useful pre-built collaboration tools, such as Chat, Blog, Discussion, e-Mail and Wiki in addition to its extensive suite of scalable e-Learning tools. Among the technical extensions we have applied to Sakai for researchers, Web Services for Remote Portlets is discussed which highlights a promising way of integrating existing remotely-hosted portlets, e.g. those maintained for the National Grid Service. This contrasts well with the use of remotely-hosted Web 2.0 "mashup" technology which is also illustrated in a mapping application. As a VRE system, Sakai has also been extensively utilised for project management inside the Sakai VRE Demonstration Project [27] which has some 400 users in 20 projects. Evaluation and development of additional tools is funded by JISC and led by the Lancaster University with three other partners: Daresbury Laboratory and the Universities of Oxford and Reading (previously Portsmouth). Finally we give concluding remarks and describe ongoing projects which sustain this activity.

2 Related Work

Lawson and Butson [29] describe e-Research as a vague concept, but point out that it *covers the entire general area of information and communication technolo-*

gies (ICT) aiding researchers in their research process. In their report, they give a review of the current status of e-Research in the USA, UK, Australia and New Zealand, co-incidentally some of the partners in the JISC e-Framework for Education and Research [7]. Whilst the USA and the UK are today leading research in the e-Research field, Australia, New Zealand and also China are catching up. In summary, Lawson and Butson list six points that e-Research adds to today's research activities (see [29] for detailed information):

1) new fields of study;
2) increased quality of research;
3) savings in cost and time;
4) multidisciplinary and inter-institutional research;
5) increased impact of research output; and
6) comparative benefits.

Fraser [28] gives an overview of a VRE and three JISC funded VRE projects: Integrative Biology VRE, IBVRE; Building a VRE for the Humanities, BVREH; and Sakai VRE Demonstrator with end-users at the University of Oxford. Although focusing on different disciplines, these projects all keep user requirements and technical open standards in mind. VRE is defined by Fraser as *a framework into which tools, services and resources can be plugged*, a philosophy which we endorse.

While people may give various definitions of VRE, we argue that the core of VRE is collaboration. VRE can be treated as an implementation of e-Research. Through a VRE system, researchers should be able to work collaboratively, share data and other artefacts and use many of the tools specific to their research domain; hence such a system should provide services for communication and resource integration. For example, NEESit [9] tries to link earthquake engineers together across the United States by providing them with software and services so that they can easily organise and share data, participate in remote experiments, and perform hybrid simulations. NEESit is one of the TeraGrid Science Gateways and NEES has used both the CHEF and Sakai frameworks for its evolving VRE.

The idea of portals has been around for a number of years. We organised the Portals and Portlets 2003 Workshop [26] just at the time when two significant pieces of technology, the JSR-168 portlet standard and WSRP 1.0, Web Services for Remote Portlets standard, were being agreed. Since then a number of open-source and commercial portal projects have been launched and are in use for a variety of purposes. One example in the UK is the portal for the National Grid Service [10]. This evolved from HPCPortal which was initially a Perl/ C based environment for launching and monitoring Grid jobs similar to the US GridPort and HotPage portals from San Diego Supercomputer Centre [6]. After briefly using PHP technology we have now evolved to using JSR-168 portlets firstly in the GridSphere and StringBeans frameworks and more recently in uPortal.

A VRE is however more than just a portal. Whilst NGS Portal has a number of tools to encourage people to share artefacts, e.g. descriptions of computational tasks or workflows, it has very little built-in community support. It is important to address this if e-Science technologies and the Grid are going to be taken up more widely. In the USA this is done through the concept of "Science Gateways" such as NEESit. A number of other science gateways are listed on the TeraGrid Web site [19]. Many of these are home-grown Web applications rather than fully-functional portals or VREs. However a few such as DOE Fusion, QuakeSim, NEES, TeraGrid User Portal, NVO, LEAD, BIRN and SCEC go much further and some are based on the OGCE: Open Grid Computing Environment portal components [13, 25] which has many of the characteristics of a VRE (see screenshots on the Web site).

2.1 Sakai and Science Gateways

The TeraGrid Science Gateway Primer [19] says:

Science Gateways signal a paradigm shift from traditional high performance computing use. Gateways enable entire communities of users associated with a common scientific goal to use national resources through a common interface. Science gateways are enabled by a community allocation whose goal is to delegate account management, accounting, certificates management, and user support to the gateway developers.

Science Gateways take three common forms:

- *A gateway that is packaged as a Web portal with users in front and TeraGrid services in back;*
- *Grid-bridging Gateways: often communities run their own Grids devoted to their areas of science. In these cases the Science gateway is a mechanism to extend the reach of the community Grid so it may use the resources of the TeraGrid;*
- *A gateway that involves application programs running on users' machines (i.e. workstations and desktops) and accesses services in TeraGrid (and elsewhere).*

Scientific gateways can have varying goals and implementations. Some expose specific sets of community codes so that anonymous scientists can run them. Others may serve as a "metaportal", a portal that brings a broad range of new services and applications to a particular community. A common trait of all three types is their interaction with the TeraGrid through the various service interfaces that TeraGrid provides. Although the gateways may be instantiated on TeraGrid resources, it is expected that many will be instantiated on community resources and be administered by the community itself.

We would envisage a VRE for computational science to be capable of doing many of the things described here, such as submitting jobs to remote Grid resources in another institution or managing resources on a Campus Grid within the user's own institution. We also consider that a VRE should contain a comprehensive suite of community-building tools [24].

2.2 Sakai and Collaborative Working Environments

According to Wikipedia [2], *a Collaborative Working Environment (CWE) supports people (e.g. E-professionals) in their individual and cooperative work. Research in CWE involves organisational, technical, and social issues*. It lists tools or services which may be considered elements of a CWE including e-Mail, instant messaging, application sharing, video conferencing, collaborative workspace, document management, task and workflow management, Wiki and Blog. Access Grid is mentioned as being a particular type of CWE. It will be seen below that many of these tools have also been recognised as being important in our VRE development and are now available via Sakai. Not all of this work is described in this paper however; in particular the important work on the Agora conferencing and desktop sharing tool from University of Lancaster, which initially funded as part of the VRE Demonstrator, is described separately [1]. This tool addresses the requirements of desktop-based video conferencing.

Agora makes it simple to have online meetings with full video conferencing, desktop sharing, whiteboard, instant messaging, meeting recording and moviecasting functionality. A Sakai Web tool is used to create conferences and invite the users; this conference information is then passed onto the Agora client software. In the future it will address participating from desktop client systems with Access Grid conferences. This will involve the creation of an Access Grid bridge to allow simple lookup and connection of Agora meeting rooms and Access Grid venues. Figure 1 gives a screenshot of Agora.

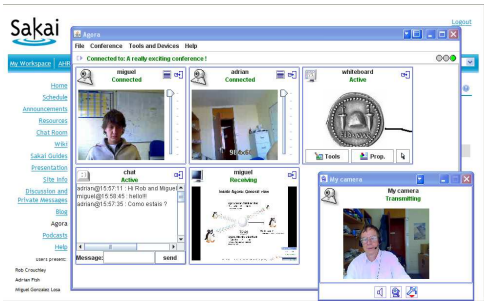

Figure 1: Agora used for discussing Historical Artefacts

We believe that combining existing Sakai collaboration and learning tools with additional collaborative working and Web 2.0 tools and Grid computation and data management tools has yielded a very powerful Web-based VRE. Enhancements to the toolset, the way researchers from different domains use the VRE and what combination of tools they prefer is still being investigated.

3 Sakai and the UK VRE Demonstrator

Sakai is a Java-based open-source and open-standards based e-Learning system from the USA with developers at University of Michigan and elsewhere [16]. It targets the higher education market but draws on earlier experience from CHEF so comprises a rich framework for tool integration. It has an agile architecture which consists of four layers, see Figure 2: services, tools, presentation and aggregator. In general, the services layer manages data held in a database which can then be called by other services or tools. The tools layer aims at bridging data (services) and user interfaces (presentation layer). The aggregator works with the presentation layer to render interfaces in a way which is accessible and customisable by end-users.

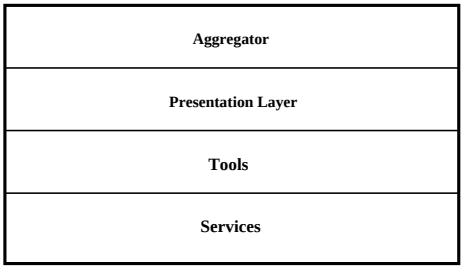

Figure 2: Sakai Architecture

The key benefit of such an architecture is that Sakai can be extended on demand to fit particular research requirements [30]. Normally, services and tools are developed to plug new functionalities into Sakai without affecting the remainder of the system. This has been referred to as a "service oriented approach" but that terminology is at odds with the concept of the SOA which is a popular software development pattern adopted by the International e-Framework and others [7]. It could perhaps be called a component-oriented approach. This feature is vital to VRE systems as new demands are raised by users based on their growing experience [1]. This is in fact one of the key reasons Sakai has been selected for building up a VRE system in several large projects. The Sakai-based VRE architecture has been discussed in [32]. The core underlying technologies of Sakai are Spring, Hibernate and JavaServer Faces (JSF). The use of open standards and particularly the use of Web services in the service layer means that Sakai can indeed form part of a wider SOA as we have investigated using WSRP as will be discussed below.

Sakai as a VRE is therefore being deployed as a flexible integration framework for multi-institutional research and research-related administrative services, validating this framework and its components against the requirements and practice of several discrete end-user research communities. This acts to both guarantee existing investment made in components – particularly the significant

[1] We note that the National Centre for e-Social Science is studying the uptake of e-Science technology by end users, particularly but not exclusively in the social science community.

range of available portlets – by the broad UK and international e-Science community, and to reduce the time to implementation of potential solutions for new research communities. Further iterations of environment instantiations for particular research communities will be provided according to the needs of those communities.

Moreover Sakai is an "enterprise level" Web-based tool integration framework with comprehensive underlying services, including role-based access control (RBAC) and database management support. Its major open-source competitor as a framework for both e-Learning and e-Research is uPortal. Nevertheless the two projects are closely aligned with a common management board and shared input into JA-SIG [8]. Smaller research projects have often adopted other JSR-168 Java portlet compliant frameworks such as eXo Portal, GridSphere, LifeRay, Pluto, StringBeans, etc. For an early evaluation see [23]. Superficially these are easier to use; if you have a domain-specific project with a handful of end-users, and loosely-coupled JSR-168 portlets are sufficient, then any of the frameworks has been shown to be adequate. They however do not support the rich integration framework and scalability that we expect in a VRE which may support many projects and hundreds or thousands of users.

Deployment and evaluation of such a VRE tests and extends our understanding of practical IT-based support for research in the following areas:

- How can portal frameworks be configured to best suit the expectations and work practices of different research user communities and institutional or organisational contexts?
- Can tools from multiple institutions and organisations be brought together coherently to enable sharing of information, processes and collaboration?
- Can community-specific tools be integrated meaningfully alongside generic and remotely-hosted Web tools?
- Can a portal based approach provide the flexibility to enable effective use by both researchers and administrators?
- At what points are desktop tools or those provided by a mobile platform, more effective?
- How might these be best integrated within a meaningful user experience?

3.1 Sakai as a VO Enabling and Management Tool

Sakai has been adopted by several UK e-Science projects including the JISC-funded Sakai VRE Demonstrator Project [27] and the VRE for Research in Teaching and Learning [17]. Besides functionalities like project management, Sakai is an ideal candidate for building up community portals. We are therefore using Sakai as an e-Research environment to support users in a multi-institution VRE.

The Grid and associated middleware which accesses distributed services exist to enable multiple institutions to share resources, collaborate and avoid duplication. Sakai adds to such middleware which manages computational and data services and security by providing a user interface and a useful range of collaboration and administration tools. It also has the built-in capability of managing groups of users and therefore supports the concept of Virtual Organisation (or VRC in the language of the OSI). Sakai is therefore an ideal candidate for building community-driven VREs for Grid and other e-Research projects.

In the terminology of Sakai, a VO maps onto a "worksite". Through their worksites, bespoke tools can be made available to the VOs that require them. Each worksite can be customised to have a specific look-and-feel and configured to contain just the tools that are required by its members. This can include Web interfaces to distributed services managed by a particular project or hosted as part of a Grid resource.

Sakai's internal VO management is through role-based policies. Users can be allocated roles within each worksite. Roles can be extended by administrative users from the small number of defaults like "admin" and "maintain".

Permissions allow users to access features of a worksite. Roles are simply collections of permissions. For each worksite tool, permissions can be set to allow or prevent users from seeing it or performing certain tasks depending on their roles. Some closely-integrated tools will share roles. Permissions apply to the tools rather than the content that they create since the tool always acts as the interface. Each tool can have a different available set of permissions, such as "new", "delete", "import", "read", "revise".

A "type" is a broad user designation within Sakai. Each user can be allocated to be of a specific type. There are a small number of default types such as "guest" and "registered", the latter has a role which includes the permission to create new work sites. This could for instance be useful for a project manager who wishes to set up a related worksite for a conference or sub-project. Worksites themselves can also have types such as "course" or "project" which mean they take on a specific template, we could for instance add one for "conference".

Sakai also includes the concept of "realm". A realm is a set of Sakai security definitions; defining roles and grants of roles and specific abilities to users. Grants in a realm do not apply to any particular resources. Instead, a realm is programmatically associated with one or more resources. The grants of abilities to users in a realm apply to all the resources associated with the realm. A realm is really a set of default configurations stored in a template file. For instance a registered user type has the realm `!user.template.registered` and a project type worksite has a realm defined in `!site.template.project`.

Realms are used in many ways in the Sakai services. Each site has an associated realm. The grants to users in

the site's realm apply to all the resources associated with the site. Content hosting collections (folders) optionally have realms. The grants of abilities in collection realms apply to the files and folders within that collection. Since a realm can be defined for any collection, a particular file resource may have many realms defined along its folder path.

When multiple realms apply to a resource, they are cumulative. The user is permitted the function on the resource if that user has a grant of the ability or a role that includes that ability in any applicable realm. There is no "deny" grant, which would undo the effect of a grant in another realm.

This gives sufficient flexibility to meet most of our requirements. We note that Sakai also has the capability to apply "skins" and "preferences" to worksites to give them a unique look-and-feel. We do not have space to discuss that here however.

3.2 Project Management and Administration Tools

Existing Sakai tools can be immediately available to any new virtual community. Once a worksite is created the required tools are selected from the "worksite setup" tool. Tools such as Announcement, Resources, Calendar, Discussion, Wiki and links to Web Content are already being used for management and administration around projects such as NW-GRID, a computational Grid for academic and commercial users in the North West of England [12]. Each board (Project Board, Technical Board and Operations Board) has its own worksite with members able to see one or more as appropriate. These sites are typically managed by secretarial staff who can administer users, add working papers, etc. The most commonly used tool is Resources which enables site members to upload and share documents. Throughout the project, nearly all working documents have been uploaded to Sakai using its Resources tool which greatly improves quality of the whole project.

Adoption of the current production portals focusing on institutional/ research tools can take place immediately with integration of new tools to meet the emerging requirements. A new project wishing to join an established Sakai community can have a worksite set up on the fly. Participants can be invited to join or it can be moderated with roles assigned to individual members.

Links into institutional administrative processes still have to be explored as do potential links into Research Council administrative processes and the regional agencies such as NWDA. Simple tools like RSS can be used to consume news feeds and publish notifications. In the longer term we can investigate bridges to systems such as MicroSoft Exchange Server. We will investigate commercial solutions first, e.g. BEA Weblogic or SyncEx portlets (a preliminary evaluation document is available). An interim solution is to export to a common Web 2.0 platform such as Google calendar and mail [5].

3.3 Collaboration Tools

As an e-Learning platform, Sakai naturally has a set of collaboration tools for groups of peers, such as students, to work together or for communications between students and teaching staff. For example, it has Announcement, Blog, Chat, Discussion, Wiki (see Figure 3 and many other tools available. These tools provide users with the various modes of communication. As mentioned in [32], e-mail is still widely used but insufficient to meet the demands for today's communications. Quite often, researchers require writing proposals, technical reports, and papers jointly. Today, e-mail still dominates this process, although online Web 2.0 editing tools like Google Docs and Spreadsheets [5] are beginning to be explored. In Sakai, the Resources tool can be used to easily share documents during such collaborative work. Permissions and roles can be applied to a document so that only selected users are able to access or edit it. A useful addition to the Resources tool would be the ability to manage versions of documents.

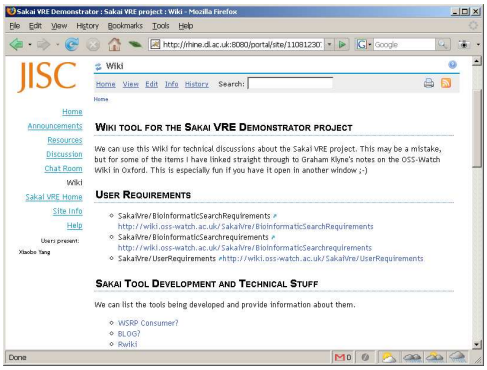

Figure 3: Screenshot of the Wiki Tool inside Sakai

4 Extensions to Sakai

As mentioned above, the beauty of Sakai is that it is very flexible, and highly extensible. Several tools and services have been developed at Daresbury and Lancaster for the Sakai VRE Demonstrator Project. For example, a document management tool has been written to help to organise conferences and workshops [31]. Besides native Sakai tools and services, external Web sites can be easily added to Sakai which under some circumstances is very useful.

Here we are going to describe how Sakai has been extended to provide users access to Grid, Web 2.0 and external information resources.

4.1 Grid Resource Access Support

The computational Grid has been set up at various levels. In UK, the National Grid Service (NGS) has set up a core Grid with resources across the country integrated. To provide transparent access to these data and computational Grid resources, a Web portal is an ideal option as Web browsers today exist on nearly all computers and

many mobile devices. The NGS Portal [10] now provides researchers around UK with a central generic gateway for accessing NGS Grid resources. The NGS portal uses portlet technology to combine Grid portlets for executing tasks like credential retrieval, job submission, monitoring and file transfer.

At the start of the VRE Demonstrator project, one of our aims was to combine NGS portlets with Sakai worksite tools so that each worksite becomes a science gateway, similar to those on TeraGrid but using the more powerful Sakai framework. However while native JSR 168 support for Sakai is now being developed in USA, at the time this project started, there was no means to deploy these portlets inside Sakai.

Our answer was to investigate and use WSRP so that existing JSR 168 compliant Grid portlets can be re-used without modification and re-deployment. The OASIS standard, WSRP 1.0 makes use of Web services so that markup fragments generated by portlets are transferred from a producer to a consumer in response of consumer's request. A WSRP consumer has been developed so that Sakai is effectively extended to support the WSRP 1.0 specification through which Grid portlets can be re-used without modification. The portlets are typically produced in a Pluto container. See Figure 4 for an example portlet running inside Sakai through WSRP.

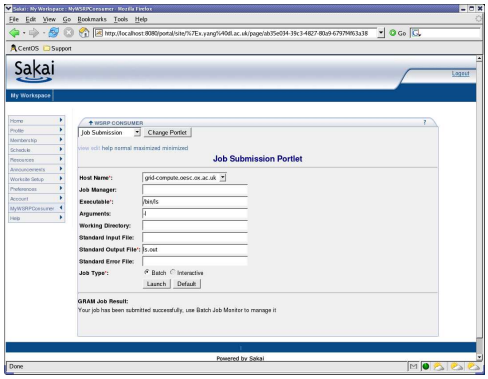

Figure 4: Sakai Job Submission Tool using WSRP

4.2 The Information Environment

Many institutions provide access to library services for information storage and retrieval. Work of the JISC Information Environment is providing a set of shared service such as OpenURL resolvers, cross searching, aggregators etc. which have portlet interfaces. For authentication, Shibboleth is used, which has been integrated with portals via the ShibGrid project [18]. CCLRC (now part of STFC) also has its own open-archive ePubs service which will be made accessible to large-scale facility users via the portal. Currently portlet access is provided using the JAFER cross search tool which was an output of the JISC-funded CREE project [3]. WSRP has been used again to integrate it with Sakai.

Information services are key to training and awareness activities around the Grid. The JISC/ ESRC-funded ReDRESS project at Lancaster [15] was set up to meet this need for social scientists and others wishing to understand and use e-Science technology. The JISC-funded Intute activity hosted at Manchester has a similar role for other areas and at one time had portlet-based interfaces developed in the SPP project.

5 Web 2.0 within Sakai

Web 2.0 does not have a precise definition. According to Wikipedia [21], this phrase emphasises "online collaboration and sharing among users". Technologies such as blogs, wikis, social bookmarking, RSS feeds and Web APIs from various vendors have significantly changed patterns of Web usage. Active participation is becoming more and more important on the Web. This agrees well with our requirements for a VRE – the core of VRE is about collaboration.

Sakai already has a set of tools which can be categorised as Web 2.0 services, in that they are hosted on the Sakai server and encourage active collaboration. The News tool supports displaying RSS feeds inside Sakai. The Blog tool developed at Lancaster provides users with a weblog, and the Wiki tool developed at Cambridge gives users opportunities to access editable Web pages.

5.1 An Experiment on Map Mashup

Recently we have investigated how to augment these built-in Web 2.0 services by making use of the Yahoo! Maps Web Service [22]. Such a Web API greatly alleviates the entry level of developing Web 2.0 for geo-spatial research applications. The services provide a set of APIs (AJAX or Flash) through which developers can easily access online maps around the world and overlay their own information (mashup).

What we have tested is to display a map of the Sakai Community similar to the one located at the Sakai Web site [16] inside our VRE. Because the Google Maps API was used at the Sakai Web site, we first retrieved the XML description of the locations of Sakai installation and brief descriptions from the project Web site. This information was converted to GeoRSS, Geographically Encoded Objects for RSS feeds, the format which Yahoo! Maps Web Services accepts. Finally the feeds are loaded in and displayed on a map (see Figure 5).

We expect this kind of mashup technology to be of use in a number of research fields such as archeology, flood monitoring and prediction, climate simulation and urban decision making in addition to supporting other forms of collaborative working, such as locating Access Grid rooms.

Whilst this preliminary work shows how mashup can be useful in a VRE, we have identified further developments from statements of users' requirements. For example, users may want to add or delete GeoRSS feeds on the map directly rather than having them managed by the administrator.

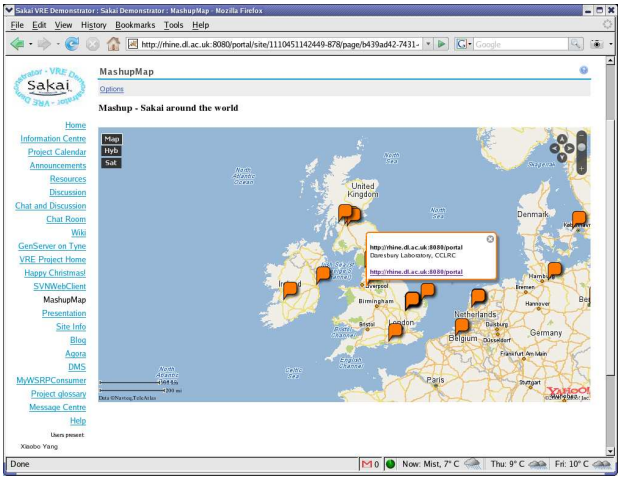

Figure 5: Mashup – Sakai instances in UK on Yahoo! Map

6 Conclusions and Ongoing Work

In this paper, the concept of a Virtual Research Environment has been discussed with Sakai used as the basis for a fully-functional and scalable implementation for multi-institution and multi-disciplinary e-Research. We have argued that the core of VRE systems is collaboration and shown that Sakai is a powerful tool for both managing users and integrating tools. Because of its agile architecture, rich tool set and ease of use, this open-source open-standards e-Learning framework has been adopted to build up a VRE system in the UK JISC funded Sakai VRE Demonstration Project. In addition to its bundled tools such as Chat, Blog and Wiki for supporting collaborative activities, we have extended Sakai to fulfill requirements in e-Research, in particular enabling video conferencing and shared applications, Grid resource access through WSRP and shown how Web 2.0 can be used to enrich interfaces and user experience. Our experience of using Sakai for project management has also been discussed and was found to be an early win as it can be administered by secretarial staff. In general, Sakai provides a flexible easy-to-use platform which makes it an ideal candidate for building VRE systems to support collaborative research projects.

There are still some issues to overcome. One is the capability to work off-line which has been noted a number of times in discussions with users. This is hard to achieve with Sakai, as is also the case with other Web-based systems. Another is the capability to integrate with other institutional environments such as Exchange server, however this can be overcome in future work.

In the VRE Demonstrator Project we have focused on integrating a suite of tools of interest to researchers and extending the capabilities of the Sakai framework. When we started this project, Sakai had a "tool portability profile" for integration of tools with internal services and had a basic WSRP producer. We have developed a WSRP consumer to allow for integration of remotely-hosted Java portlets and more recently have worked with the Pluto 1.1 developer [14], David de Wolf, to implement a native JSR-168 portlet interface within the Sakai framework.

We are now deploying fully-operational and supported Sakai-based VREs for the following communities:

NW-GRID: a community of computational scientists, both academic and commercial, using compute clusters in the North West of England.

ESRC e-Infrastructure: a community of multi-disciplinary social scientists though out the UK building a common infrastructure and adopting e-Science technology through the work of NCeSS and ReDReSS [11, 15]

Diamond e-Infrastructure: a community of experimental scientists using the new Diamond Light Source [24, 4] *the largest investment in science in the UK for 30 years*.

It will be interesting over the next couple of years to assess how these communities have used all the Web-based tools appropriate to research which are available as open source or Web 2.0 style hosted services and which can be integrated using the Sakai framework.

7 Acknowledgements

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