Secure data sharing across portals: experiences from OneVRE

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Research and higher education are facing an on-going transformation of practice resulting in the need for effective collaboration and sharing of resources within and across disciplinary and geographical boundaries. Portal technologies and portal-based virtual research and learning environments (VREs and VLEs) already have become standard infrastructures within a large number of research communities and institutions. From 2004, a series of research and development projects began to ask the question whether an open source videoconferencing and collaboration system could be used as a complete, or as a part of, VRE. This study presents the evolution of these projects and at the same time, describes the definition of a VRE and their future possible integration. The OneVRE portlet integration project attempted to create missing components, including adding secure and universal identity management. This moves the idea of shared data to a different level by creating a new administrative domain that is outside the control of a single local institution portal and resolves certain administrative virtual organizations problems. We explain some of the hurdles that still need to be overcome to make this venture truly successful, when a complete toolkit can be designed for the researcher of the future.

1. Introduction

The Access Grid (AG) environment and development toolkit, which was originally termed videoconferencing on steroids (http://www.accessgrid.org/), has been used within the UK academic sector for over a decade. From installing, the first UK large physical room-based node at the University of Manchester...
in 1999, the technology has shown itself as not just a system for synchronous multiple video and audio communication, but also as a method for sharing data, files, control streams and applications. The system was designed to be scalable, using multiple forms of communication methods and networking tools. The AG toolkit allows for these streams to be exchanged using encryption, and this is one of the reasons why it has been proposed in itself as part of a self-contained virtual research environment (VRE) [1]. Combined with the ability to add plug-in applications and for the core toolkit to be open source, this makes it a suitable development platform.

During this same time period, over the last decade, there has been a proliferation of portal-based and portal-like environments, for example Liferay, GridSphere, Sakai and uPortal, that have all enabled collaboration and data storage between various disparate research groups within the UK and beyond. These systems also allowed plug-in applications and with open standards, Java Specification Request 168/286 and Web Services for Remote Portlets 1.0/2.0, enable developers to create their own portlet and portlet to portlet communication.

Without central control, these portal-based VRE type systems have flourished but rarely did they cross-communicate with each other or link with other systems. If they did include linked information, this was often in the simplest of ways. This had the unintended consequence of reinforcing a new kind of silo mentality for research groups reducing the ability to cross-link with other group’s VREs or for individuals to play a cross-role in multiple groups with the same data and information exchange.

The Joint Information Systems Committee (JISC) VRE phase-three programme funded the ‘One VRE to Join Them All’ project [2] that is based on code modified by the Open Middleware Infrastructure Institute (OMII-UK)/ (http://www.omii.ac.uk/; ‘Software Solutions for e-Research’) funded Portlet AG project [3] as well as a range of experimental development projects. This was used to satisfy four requirements: to be a cross-site repository being a portlet; join portal environments keeping the researcher within their familiar environment; reduce administration overheads; and automatically creating virtual venues (VVs) based on virtual organization (VO) attributes.

OneVRE moves the idea of shared data to a different level by creating a new administrative domain, which is outside the control of a single local institution portal. This resolves certain administrative problems as the VO is controlled by local administrators that should know the people in their institution and can provide access to a collaborative environment on a by-venue basis. The local institutional administrator can now provide a tool to the researcher that is similar to the external VRE in the sense that there are no local resources exposed, but which lives inside the institutional VRE. Section 2 describes part of the history of a VRE definition and test development process as defined by various funding agencies. Then, the following sections describe the AG environment with examples from ‘add-on users’ who are the pioneers, the user specification process and finally the development process for the OneVRE project.

2. Visions for a virtual research environment

The purpose of a VRE is to help researchers from different disciplines to work by managing and reducing tasks in carrying out research at various scales. Over the last 10 years, JISC, in the UK, has created various definitions, and currently a VRE ‘helps researchers from all disciplines to work collaboratively by managing the increasingly complex range of tasks involved in carrying out research’; this has been classified as ‘shorthand for the tools and technologies needed by researchers to do their research, interact with other researchers (who may come from different disciplines, institutions or even countries) and to make use of resources and technical infrastructures available both locally and nationally’. When building a VRE, JISC specifies that this ‘also incorporates the context in which those tools and technologies are used’. This means it can be dependent on ‘discipline, context and security requirements’ (http://www.jisc.ac.uk/whatwedo/programmes/vre.aspx).
The DFG (Alliance of German Research Organizations) has a similar but modified definition of a VRE (Virtuelle Forschungsumgebung) as a ‘platform that allows multiple researchers in different locations work together in real time without restrictions’, and they specify that in ‘terms of content, VREs potentially support the entire research process—from the collection, discussion and further processing of data right through to the publication of results. From a technological perspective, virtual environments are based primarily on software services and communication networks. VREs are essential components of state-of-the-art research infrastructures’. The Dutch SURF foundation defines the VRE in terms of a ‘collaboratory’ as follows: ‘a web-based collaborative electronic environment that enables researchers based in different locations to work together and share their knowledge and facilities, thus enriching and speeding up both national and international research’. From the UK e-Science programme and European Union (EU) involvement, various tools have, in the last few years, been created that have informed both the Australia and USA developments of VREs as cyberinfrastructure tools. In parallel, commercial developments have emerged from the virtual learning environment developers as well as larger enterprise solution organizations including Microsoft and IBM.

It should be noted as described in §3 that bespoke systems have been built, and VREs have been successful when they allow access to certain physical devices and resources; for example, computation or data gathering purposes, telescopes or other image capture devices. This means the data workflow from capture to analysis and then presentation all have a part in a VRE and have been shown to be ‘useful’ to communities. Carusi & Reimer [4] define a good version of the current landscape, and the EU Knowledge Exchange VRE working group further improve the dialogue between developers and users [5], http://www.knowledge-exchange.info/.

3. Access Grid as a virtual research environment

The AG is an open source collaboration and resource management architecture, and we propose that it provides some of the capabilities defined for a VRE. AG provides an environment that is used as an advanced collaborative framework and is based on the metaphor of persistent virtual spaces where just as in face-to-face collaborations, which take place in a physical room, laboratory, lecture theatre, etc., so collaborations between participants who are geographically distributed take place in VVs. The aims of the original inventors of AG (at the Futures Lab, Argonne National Laboratory) have been met using commodity hardware.

Currently, the main usage of AG is as an advanced videoconferencing environment that is a subset of a fully collaborative environment. It is very effective in this role because of features such as high quality audio, Internet Protocol multicast to make efficient use of network bandwidth allowing dozens of simultaneous video and audio streams to be received, room-based active echo cancellation and using large displays that enable many remote participants to take part as life-sized images, which enables the full use of body language and other non-verbal cues, just as in face-to-face meetings. This technology has provided productivity gains across the e-Science community resulting in the fact that in 2004, there were about 20 AG nodes in the UK and many hundreds worldwide, and now in 2012, 150 UK institutes have nodes, many multiple. Figure 1 shows the three main types of uses: as a main room-based node, as an office node and as a personal desktop session; and the graph shows the steady increase in registered users of both room and desktop nodes within the UK.

However, as stated above, the AG has the potential to be much more than advanced videoconferencing. Recent releases of the toolkit enable integration with Grid resources via the use of X.509 certificates and the framework to incorporate a wide range of collaborative software. AG allows third parties to integrate complex collaborative tools enabling at present simple document sharing and cooperation, but the process can be made secure and trustworthy by reusing X.509 certificates.

As stated in the UK, there are over 150 institutes with AG technology, and the system is stable with support provided by the Joint Academic Network (JANET (UK)). To support this, the JANET (UK) funded the Access Grid Support Centre (2005–2010) and afterwards Video
Figure 1. (a) Access Grid system being used in its three main modes; in a large room-based node with three projectors covering a complete wall, as a portable three liquid crystal display screen room-based node and as a single user desktop implementation. (b) The graph shows the increase from April 2004 to April 2011, of registered nodes that are on the JANET online booking system. As shown in the last few years, registered desktop and office nodes have exceeded the number of registered, large room-based nodes. (Online version in colour.)

Figure 2. (a,b) Monthly statistics from 2005 to 2011 for the combined AG Toolkit v. 3.2 and the IOCOM IGI2 software. (a) The number of meetings held each month, indicating a slight increase and also a change in use towards semester-based taught courses. (b) The average length of a meeting within each month, which has also increased in this time period. (c) All the individual meetings of these two services over the period of a single academic year (September 2010–September 2011), with the vertical axis showing the time from midnight to midnight. These data are used for visual analytics purposes, allowing data mining to occur in order to gain extra knowledge from the activity data statistics, with some specific uses outlined in the main text. (Online version in colour.)
Figure 3. The use of the facilities by performance artists. The key facilities used included portable systems with the Access Grid enabled for stereoscopic video streams. (Online version in colour.)

Technology Advisory Service roles, to build and maintain a network of primary and secondary servers across multiple geographically spaced locations. This allows a multicast backbone to connect different types of related services; the open source AG Toolkit, spin-off IOCOM IG2 and visimeet services, as well as Caltech’s Enabling Virtual Organization servers; including multiple dedicated bridges between these servers and multiple test room clients. Figure 2a shows the usage of two of the software products (AG Toolkit v. 3 and IOCOM IG2) showing a gradual trend from research administration to semester-based training. A trendline of the monthly statistics indicates a gradual increase in the number of meetings held, and figure 2b indicates an increase in the average length of an average meeting. Figure 2c shows all the meetings that took place over the academic calendar year, in the UK, from September 2010 to September 2011, highlighting certain features. Recording activity data enables better planning for infrastructure; for example, certain physical nodes had different usage patterns, with some being used mainly in the morning, and others in the afternoon. Hence, there is scope to make more efficient use of existing facilities; it is hypothesized and there is some evidence that there were fewer complaints about technical issues in the period after full quality assurance testing; through continual training, this has meant that the average meeting length has increased owing to extra experience gained and practice; and it is also possible as a service to quantify the CO₂ savings that individual physical room nodes have made.

(a) Example add-on users

Allowing dozens of video streams, full-size interaction and simple document sharing does not make a VRE as has been specified, but as the system is open source, it is expandable and certain ‘add-on users’ have exploited this potential. Figures 3–5 show examples of various ‘add-on users’ using the AG by augmenting specialized tools. The first screenshot (figure 3) was taken during a playback of a recording to add a ‘director’s commentary’ as an extra soundtrack, on top of a stereoscopically projected dance performance, which occurred across two geographic locations [6]. The performance was time stamped into separate phases shown within a graphical timeline, representing the sub-parts, and a nonlinear time-stamped mind mapping tool was used to annotate the complete session [7]. Extensions to this work termed ‘dancing on the grid’ are described by Bailey et al. [8].

The second screenshot (figure 4) shows a multi-site mixed media seminar involving separate desktop sharing utilities designed for computer graphics visualization transmission across poor networks, as well as offering a text chat system and weblink sharing. The user group was the Manchester UK Association for Computing Machinery (ACM) Special Interest Group on Computer Graphics and Interactive Techniques (SIGGRAPH) Professional Chapter.
Figure 4. Prof. Ken Perlin gave the inaugural Manchester UK ACM SIGGRAPH Professional Chapter talk, one of 76 monthly meetings between 2005 and 2012, involving 1058 local attendees, and 61 unique external sites. These were also recorded and semantically tagged for later searching. (Online version in colour.)

Figure 5. Postgraduate lecture series and cross-institutional facilities allow large networks to form and require support structures including website repositories and social annotation and commentary. (Online version in colour.)

(http://manchester.siggraph.org/), and their sessions were recorded with meta-data tags, including location, abstract and speaker details for future intelligent semantic web-searching. The semantic recording and searching system is described by Daw et al. [9].

The third screenshot (figure 5) is from the Mathematics Access Grid: Instruction and Collaboration (MAGIC) group that runs a wide range of postgraduate-level lecture courses. Lecture materials are freely available from a website, and a key issue is to synchronize many high-definition video streams from multiple sites, with audiences across 19 different institutions. Transmission includes video streams from electronic whiteboards, as well as hand-written capture devices. MAGIC is one of six Engineering and Physical Sciences Research Council funded Taught Course Centres, and future plans include the ability to edit snippets of video that can be inserted into the lecture notes. Also shown on the far-right-hand image is an example of social network annotations linked to the video streams.

These have created specific tools for bespoke VRE-type user groups, but even combined, these do not create a complete toolkit for a VRE. A missing component and a key request was the ability for cross-institutional access and identity management.

4. Approach and user groups

In most of the VRE research and development projects, our approach has been to integrate user engagement and evaluation as a continuous activity throughout the project lifetime to feedback the pilot users and user community requirements properly into the iterative, user-driven development process (previous, similar endeavours include the JISC VRE2 funded Collaborative Research Events on the Web (CREW) project; see Poschen et al. [10] for a detailed overview of this approach). Owing to their remit and resources, some smaller development or prototyping projects did not allow involving a user community or pilot group to that extent on a regular basis; they still contributed immensely to the work done in this context via establishing contacts with researchers, users and other developers and providing new insights, tools and developments. It is evident that users’ (researchers’) time is scarce, and it is important to establish some mutual benefits, give them something useful in exchange for their commitment.
On the basis of our experiences, the modes of user engagement have been refined over time, starting with CREW, which from the outset made an effort to ensure the best possible exchange and collaboration in formalizing the involvement and then integrating the user groups within the core activities of the project. In OneVRE, we have followed the same avenue, engaging with research groups selected from a number of user stakeholders who were also part of and provided advice in the steering group and were supporting OneVRE from the proposal phase onwards. Research groups involved the nodes Administrative Data: Methods Inference and Network (ADMIN) and Simulation Innovation: a Node (SIMIAN) of the Economic and Social Research Council (ESRC) National Centre for Research Methods (NCRM) and the GENeSIS (Leeds side) and Data Management through e-Social Science (DAMES) nodes from the ESRC National Centre for e-Social Science (NCeSS). We also included additional project-related cross-institutional activities with overlapping research communities based on the use of an instance of the Sakai portal used for collaboration in the NCeSS, National e-Infrastructure for Social Simulation (NeISS) and Manchester eResearch Centre context. NCeSS and NCRM nodes also used their own collaborative environments, sometimes exclusively. These related, but separate, communities and research groups saw the benefit in the aim of OneVRE to foster existing collaboration in a disparate landscape by improving or introducing data and application sharing. This set-up of user stakeholders enabled OneVRE to establish a test bed for use in cases involving different collaboration modes between research groups. Engagement with portal development teams across the NCeSS and NCRM infrastructures as well as locally at the University of Manchester further helped to inform and develop the technological framework of the project.

5. To portal or not to portal

In the light of the vast number of different portals and VREs used by research groups, an increasing challenge lies in managing VOs, which have to operate across multiple institutions and technical boundaries over many different administrative domains with various institutional policies. The OneVRE project addressed these challenges in creating an infrastructure to join...
up VOs collaborating via portal-based VREs using AG technologies, with integrated user engagement (described by Poschen et al. [11]). OneVRE integrates technologies produced by the OMII-UK funded Portlet AG (PAG) project [3] into a web-based portal environment accessible from within any VRE or portal already used (the focus during the project’s lifetime lies on Sakai, Liferay and GridSphere portals). PAG enables collaboration through a videoconferencing and data-sharing utility that is enhanced through the AG concept of the VV, allowing the sharing of both data and applications in an augmented videoconferencing meeting space. As shown in figure 6, OneVRE generates a new administrative domain controlled by the members of the VO. New venues can be created as required by a member of any of the local VREs and can be used across sites. This venue is secured by the VO attributes a user holds in a Virtual Organization Membership Service (VOMS) server that is accessible through the UK Access Management Federation. The service is accessible across the VRE portals, as the service is located on an external OneVRE venue server that can be installed outside the administrative domains of all the VREs involved. The portal infrastructure was a good basis to start, as OneVRE was not designed to replace but to enrich the existing VRE structures. OneVRE is an additional tool in the toolbox of a researcher that allows data exchange in a well-controlled fashion between different VREs collaborating researchers use. The aim was to stop forcing researchers to create yet another VRE in an independent location for a new collaboration just because their institution does not support ‘external users’ on the institutional VRE.

6. Putting the grid back into the Access Grid: identity management

The main reason institutions do not like to support ‘external users’ on the institutional VRE is that there is a loss of control and no way of enforcement of institutional rules with users not used by the institution. The ‘external user’ is not known to anyone in the institution and cannot be traced. There is also a huge overhead involved with keeping external users joined and separate for no apparent gain to the institution. To overcome these issues, OneVRE looked at the tools, authentication and collaboration systems provided by the National Grid Service (NGS) ‘connecting infrastructure, connecting research’ (http://ngs.ac.uk/).

The original AG software was based on Grid technologies to securely transfer data; with the development of AG to become more and more an advanced videoconferencing system and less and less a data exchange system (VRE), most of the Grid technologies wilted and were reduced to the bare minimum such as X.509 server authentication and Simple Object Access Protocol messaging. These stubs however created the idea to use the Grid features that were there and use them as a basis of joining VREs. As we were looking at using Grid Certificates, we looked at the NGS and the UK e-Science Certificate Authority (CA), but discarded the idea of using the standard UK e-Science Certificates as too high a barrier. The solution was in establishing the identity using an integrated Shibboleth infrastructure based on the Shibboleth Access to Resources on the NGS (SARoNGS) project [12]; a Shibboleth-based infrastructure for the NGS that enables higher education users (researchers) to access resources using their institutional identities. This is provided through membership of the Access Management Federation that authenticates users and provides VO attributes.

Through SARoNGS, the identity is established by a series of events that are all triggered from the VRE-portal login, as shown in figure 7. The login process forwards the request to the Credential Translation Service (CTS) a central service at the NGS that orchestrates a series of events; first, it establishes the identity through the Access Management Federation, which in turn triggers the Authentication and Authorization mechanisms of the users home institution. Once the identity is established locally, the CTS stores a proxy certificate for the user and starts querying VOMS servers to add VO attributes to that certificate. The result of this process is stored in a MyProxy server, which is made accessible to the portal server.

The OneVRE development collaborated with the NGS to move on some of the SARoNGS features to allow a central definition of the VO attributes to be looked for from each server. The authentication system of the portal talks to the CTS Application Programming Interface in order...
Figure 7. Cross-links for secure access showing the points of communication between the portlet and the SARoNGS service. (Online version in colour.)

to get a list of VO in which the user is a member. In the original version of the CTS user interface, the user had to select the VO attributes to be attached to the certificate, which seemed a tedious process to put users through. The new system allows this selection to be done by the VRE/Portal and OneVRE administrator, who only decides which groups can collaborate. The collaboration itself can be created by the end user, as he can decide which groups and roles he wants to grant access to the VV (data exchange space).

(a) OneVRE features

The OneVRE system provides five properties that were developed.

— New Skype-like interface that monitors sets of VO venues and the integration of new shared applications within the areas.
— Using SARoNGS, a Shibboleth-based infrastructure for the NGS that enables higher education users (researchers) to access resources using their institutional identities. This is provided through membership of the Access Management Federation that authenticates users and provides VO attributes.
— X.509 proxy certificates are used as the main secure authentication method. Specifically, these grid certificates are cryptographic tokens that contain details identifying an individual in a way that computing resources are able to understand and verify.
— Provides a VO-based access to documents stored in the venues. VOMS Attribute Assertions are cryptographic tokens, which are inserted into grid certificates. Each is a verifiable statement by a VO that the bearer (identified by the grid certificate) is a member of that VO, and may also indicate their role.
Figure 8. Screenshots showing a Liferay portlet interacting with the University of Manchester secure federated access before OneVRE and Access Grid virtual venue data stores are made available. (Online version in colour.)

— Documents can be added to the storage with extra properties, for example, an expiry date. This specific property means that a file can be stored and shared, but will be removed automatically when the expiry date is reached.

Federated management comes from the use of SARoNGS that implies some centrally managed higher/further education sector control. This specifies that the base structure by VOMS can be and is controlled elsewhere. We developed a system where new VOs can be created on-the-fly and then automatically used. The institutional VRE administrator only needs to install the OneVRE portlet to create a new OneVRE server that provides these tools and enables the collaboration with other VREs.

For users, an emphasis was based upon creating a system that was easy to use by both client users and server installers. Key features to enable this were inherited from PAG that implied no special installation was required on the client machine. The only minor requirement is for Java (v. 1.6 or higher), and all platforms are then easily supported (Windows, Linux, Mac OS X). The client can connect to any AG Toolkit v. 3 (AGTk3) server and allows free navigation of VVs as well as access to Jabber text chat and shared applications and data within the venue. Screenshots of its use are shown from a Liferay portal example in figure 8.

So shared resources, for example, data or applications, are stored and accessed within the VVs. These can be accessed, as in the original PAG by anonymous users if required, and are also now accessible via anyone with suitable access to the portal, or as is proposed here, also have access rights controllable through the VO attributes.

As described in §4, the development of OneVRE has been informed by a continued requirements gathering, system testing and discussion process driven by a range of users and stakeholders. Underlying topics that influenced current use and envisioned case studies include questions of access right policies and diverse issues around data sharing (simplicity of sharing; data expiry, control, security; confidential data sets and licensed data).

The portlet code and a test server linked to the main UK federated access are now available online and downloadable for use on your own portal environment. We present here the main form of use. A secure space allows a OneVRE user to login via their federated access (SARoNGS).
user has to provide only some profile details (first use) to be acknowledged on the portal server, and then the VO is created on-the-fly, providing a secure space for file transfers and exchange. VO management functionality, awareness mechanisms and other features are then provided, e.g. the expiry date for files, and are immediately available.

Currently, there are some security caveats in that: storage on the server is not encrypted automatically; and in general, security is only as good as the weakest link, e.g. users’ machines and socio-technical factors.

7. Future case studies and conclusions

This study has shown that there is a user need for greater cross-VRE integration, and there are identity management tools available to help enable this to occur. From the definition of a VRE, these are still just parts of the disparate set of tools involved to create a complete VRE toolkit for the future researcher.

From the next stages of user evaluation, various extra modes are proposed. Researchers are increasingly using third-party-shared storage tools such as Dropbox, and there is a growing contradiction in usage. These tools are incredibly convenient, but are not always as secure or as integrated with university federated controls as they should be. Using OneVRE, we can now create an encrypted shared Dropbox account that has the best of both functions. Data are stored in encrypted format on a Dropbox account, together with a public key available via the standard login and authentication stored via the OneVRE data storage. OneVRE creates a certificate/private key(s) for access and decryption of the Dropbox data. Now the trust mechanisms between the users become the weakest link, but one that can be addressed by raising awareness via documentation and training (albeit such social issues will always be manifest).

A second requested dependency is linking OneVRE with popular systems for document creation, sharing and collaborative working, for example, Google Docs, but addressing the absence of authentication and security features.

An extra issue is with creating and managing ‘mini-VOs’. Current use with federated management access works only within a certain domain. With current test users, this is within the boundaries of the UK educational community. The concept of ‘mini-VOs’ has to be explored further for feasibility, creating a service to act as its own CA and handling certificates from international bodies. Users from different organizations, for example, industry and abroad now can simply login to their OneVRE, and the OneVRE server then issues a certificate using its own VOMs server, hence creating a secure and certified ‘mini-VO’. This will form the next level of networked interconnection, allowing multiple cross-linked circles of researchers to form. These cloud-based technologies bring issues of geographical location, trust and reliabilities that will need to be addressed.

8. Conclusions

From the definition in §3, there is still some way to go before a complete VRE toolkit is available, and the AG is likely to be only a part of this process. The collection of tools proposed and developed so far is not adequate to match the descriptions and is missing data management and internal review processes, and is lacking in links to many external sources. There are and have been specific pioneer users who have benefited from the current subset that is available.

To understand what will make the future research community embrace a full VRE, the British Library has been commissioned to study the ‘researchers of tomorrow’. This is a 3 year study tracking the research behaviour of ‘generation Y’ doctoral students. These are students born between 1982 and 1994, and so currently undertaking a PhD in the UK; http://www.researchersoftomorrow.net/. Initial results from Carpenter et al. [13] indicate that these researchers will embrace technology only when it has a clear benefit towards their research goals and are fairly unwilling to invest in time and effort unless this is proposed either by the researcher’s supervisors or more likely by their peers.
The uptake graphs of AG activity data that we have compiled indicate that we are still some way from this tipping point, but this gives developers time to further improve the toolkit and also an opportunity for new pioneer researchers to take advantage before it is ubiquitous.

We thank the involvement, as members of the steering panel, test users and dissemination and evaluation routes, of Manchester e-Research Centre (MeRC) with links to the GENeSIS simulation project, National e-Infrastructure for Social Simulation (NeISS), Data Management through e-Social Science (DAMES), NCRM Administrative data: methods inference and network (ADMIN), the Centre for Research in Social Simulation (CRESS), Simulation Innovation: a Node (SIMIAN) and OMII-UK (Software Solutions for e-Research). We acknowledge the support from all the related funding bodies, especially through the e-Research JISC theme, and the expertise from the NGS. Special thanks to the past, current and future ‘add-on users’ of the AG toolkit whose pressure will dictate new bespoke environments. A blog describing the University of Manchester VRE and AG projects is available at http://grace.rcs.manchester.ac.uk/AGProjects/. This blog also gives links to data and further resources.

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