Roadmap for a UK Virtual Research Environment

Report of the JCSR VRE Working Group

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Appendices

Contributors

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1. The need for a VRE

e-Science is a new paradigm of research, often characterised by a “deluge” of data analysed by massive distributed computing power. e-Science research collaborations are frequently large, distributed and multidisciplinary involving hundreds of institutions across the globe. Grid technology, emerging in response to these challenges, is enabling exciting possibilities for better research, even creating new disciplines like astro-informatics. In this context, a wide range of national and international initiatives are under way.

The concept of e-science is now broadening and evolving into e-research generally, to encompass the social sciences and the arts and humanities. At the same time it has to be recognised that different communities are at very different stages in their awareness of the new technologies: thus the current needs of a large international scientific collaboration are likely to be much more complex than those of the lone humanities researcher, wishing to collaborate more effectively with a handful of colleagues world-wide in the same field of interest. In our thinking we have tried to keep the whole range of requirements in view.

At the high end, the new developments are making the process of carrying out research more complex and demanding. The aim of a Virtual Research Environment (VRE) is to help researchers manage this complexity by providing an infrastructure specifically designed to support the activities carried out within research teams, on both small and large scales. JISC has recently been allocated £3.2 million as part of the Comprehensive Spending Review to develop a VRE.

The challenge is to create and sustain an infrastructure, ideally usable on a routine basis by researchers from all disciplines to enhance their productivity and effectiveness. Meeting this challenge is a task for those building the infrastructure, its potential user communities, the institutions to which users belong, the organisations which fund research and other stakeholders in the research process. These developments should not happen in isolation but will need to interwork with other components of the infrastructure being provided by JISC, Research Councils and HEIs themselves such as learning environments, digital libraries and national research facilities.

It is unclear, *a priori*, what type of framework a VRE should adopt, on which technologies it could be based, how it can be developed sustainably and how usability and take-up can be ensured. This document outlines a roadmap for developing a VRE. The target user community is all those engaged in research.

Disciplines, and communities within disciplines (especially in non-scientific subject areas), will have to identify the possibilities for them in the technology; may have to overcome cultural obstacles to collaboration; and may need training in relevant skills. Associated legal issues will need to be understood and clarified, and formal and informal codes of practice updated, to reflect understanding of novel forms of collaboration.

Locally, institutions will need to understand the business case for supporting research collaborations and how they can be reconciled with continuing institutional competition. Wider impacts will be felt through changes in scholarly communication

and in the complexities of managing and sustaining long-term open access to data for reuse.

Additional background material and rationale for creating a VRE is contained in a report entitled *Building Collaborative eResearch Environments*, compiled for JISC by Andrew Cox, Department of Information Science, Loughborough University [1]. This summarises the proceedings and breakout group discussions from two workshops held in March/April 2004 at Edinburgh and Warwick universities. The report also contains a SWOT analysis. A brief summary of some of the main recommendations from these workshops is included as Appendix A.

Background material from the UK e-science Grid, compiled by the Architecture Task Force, is contained in the report [2] *UK Role in Open Grid Services Architecture* by Malcolm Atkinson et al. This vision is being realised through the work of the Engineering Task Force and is be introduced onto the production National Grid Service (including the JCSR-funded computing and data clusters) during 2005.

Related JISC work on e-learning frameworks and tools is described at http://www.jisc.ac.uk/index.cfm?name=elearning_framework [3]. Work on developing a distributed architecture as part of the JISC Information Environment is described at http://www.ukoln.ac.uk/distributed-systems/jisc-ie/arch/ and in reference [4].

2. Capabilities of a VRE

The nature of a VRE means that it is more realistic to describe it in terms of its intended capabilities rather than its component parts as the latter are likely to evolve over time, depending on contemporary standards.

In our view, a VRE should:

1. Support the processes of conducting research, including marshalling of resources, scholarly discourse and publication, and the creation and maintenance of collaborations, across disciplines, institutions and countries, including support for meetings and organisational processes.

2. Be based, as far as possible, on loosely-coupled, distributed, interoperable tools, rather than a monolithic piece of software.

3. Be designed to meet user requirements and address usability and accessibility, with appropriate evaluation mechanisms and benchmarks for new tool development.

4. Include modes of access which (almost) any user can download and install on their laptop/ desktop/ PDA/ home computer, with “servers” that can easily be installed by system administrators without specialist knowledge and national JISC-provided servers as appropriate, so that tools work “straight out of the box”. Some tools will be integrated with domain-specific facilities (and *vice versa*).

5. Adopt and use appropriate open standards wherever possible.

6. Be secure and trustworthy. Hence the VRE components should interoperate with federated cross-institutional authentication and authorisation mechanisms.

7. Be accountable, by providing adequate logging and probity including supporting queries about provenance.

8. Be compatible with other widely used and deployed systems, including at least: web, email, instant messaging, SMS, Wikis and videoconferencing tools from lightweight desktop applications through to high-end videoconferencing via Access Grid. This means that the VRE should be accessible via web browsers and 3G mobile phones among other modes of access.

9. Support creation, sharing and curation of resources, through ease of authoring, publishing, discovery and access. This implies adoption of appropriate metadata schema and support for automatic generation of metadata. Resources to be described will include data, computation and potentially humans.

10. Be extensible with enhanced or new tools by any developer, through use of published standards and provided software development kits, software libraries etc. It should be as easy as possible to make existing software and services (e.g. e-print repositories, portals), including proprietary software, compatible with the VRE.

11. Be open source and standards-compliant wherever possible. The licensing of the tools should encourage and support improvements to the tools and development of new tools through open source development by the community.

12. Support tailoring of the environment by individuals or groups to reflect their interests and preferences.

13. Support the delegation of routine tasks to intelligent personal agents where the means to realise these exists, e.g. by incorporation into workflow processes.

3. Developing a VRE

Based on the background and examples summarised above, a VRE can be considered as a set of applications, services and resources integrated by a standards-based, service-oriented framework which will be populated by the research and IT communities working in partnership. The scope of the components needed to build this framework is further discussed with examples in Section 5.

Multiple domain-specific or community-specific gateways to the VRE will exist, in parallel serving the needs of different communities but achieving maximum synergy and cost-effectiveness by being based on a common framework which enables reuse of generic open-source components, referred to as services. The example of portals given above is just one example; lightweight programming libraries is another, permitting integration into “heritage” codes.

It is not the intention of JISC's VRE programme to produce a complete VRE, but rather to define and help to develop the common framework and its associated standards and to encourage others to work within this framework to develop and populate VREs with applications, services and resources appropriate to their needs. The intention is to maximise the value and benefit of future investment in this area by both JISC and the Research Councils, to secure community contributions and to promote sustainability.

VREs must cater for a wide range of scale and complexity of research activities, from small research collaborations with a few partners to large teams with many partners in many institutions. Examples of the latter include projects within the current e-science programme. A balance must be achieved between meeting the needs of specific disciplines and developing capabilities of widespread utility. The wide variety

of research activities means that a judgement must be made in each case on the appropriateness of including specific capabilities for the application in question.

In the long run, VREs will have to become self-sustaining within their user communities and service providers. They will therefore have to be seen to provide sufficient additional benefit to motivate this effort. Whilst VREs, gateways and resources will "belong" to their user communities and will respond to and track these communities' evolving requirements, it is expected that there will be mutual benefit in coordinating these separate VRE activities through a common framework with re-useable services and associated standards. JISC, in its closer relationship with the Research Councils, may continue to provide a suitable common reference point for this coordination. There is potentially a role for the Open Middleware Infrastructure Institute (OMII) in providing ongoing support for VRE middleware.

It is important that the VRE development activity has strong links with other related activities such as JISC's VLE and MLE programmes, the research programmes and communities supported by the individual Research Councils, and international developments such as Sakai in the US. It will have many components and services in common with these.

4. A Service Oriented Architecture approach

A Service Oriented Architecture (SOA) is an approach to joining up services to provide integrated capabilities. It is a relatively new approach, but is rapidly gaining popularity because of the lower costs of integration coupled with flexibility and simplified configuration. This is becoming best practice for commercial distributed software development, see recent reviews e.g. [8-12]. An SOA builds upon the use of web services, the emerging industry standard for building and integrating distributed systems. The rationale for using an SOA in the JISC context for MLEs/VLEs is given in [3]. Other relevant projects worldwide are considering and indeed beginning to deploy similar approaches and architectures. One worth noting is Arda, the next generation framework for distributed analysis of Large Hadron Collider data [13].

The following figures highlight some aspects of an SOA relevant to deploying a VRE with appropriate user interfaces such as portals, online commands, drag and drop desktops and programming libraries. A key aspect of the architecture is to maximise the re-use of common services and middleware including portlets.

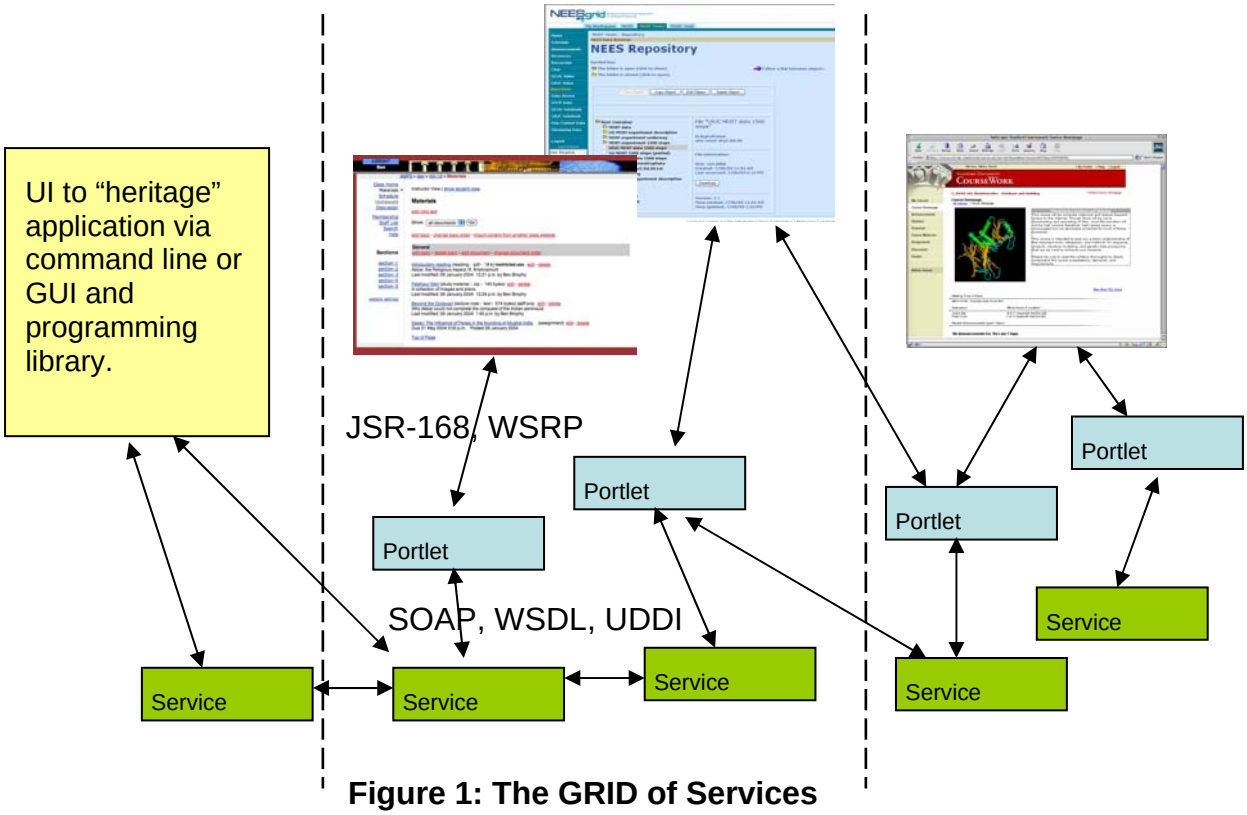

Figure 1: The GRID of Services

Figure 1 shows how an SOA approach would be of benefit in exposing a common set of services and middleware through a variety of user interfaces including web portals. It indicates how this architecture can be used to facilitate the horizontal aggregation that can occur for specific groups, e.g. the National Centre for e-Social Science (NCeSS) which is working alongside the Lancaster node for Quantitative e-Social Science (CQeSS) and the JISC/ ESRC training and awareness programme ReDRESS, see *http://redress.lancs.ac.uk* .

An SOA clearly does not preclude also using portals or data warehouses, and is in fact agnostic about how the rest of the enterprise is configured, which is why it makes a good approach for a framework. In addition, because integration occurs in this fashion, it becomes a simpler task to replace the systems that provide services within the architecture or to look up new ones via a registry such as UDDI. Because service consumers are configured to access a service without any knowledge of the system that provides the service, we can replace the underlying system without affecting systems dependent on its capabilities.

Figure 2 shows how services are used in a typical 4-layer architecture for portals and other client tools.

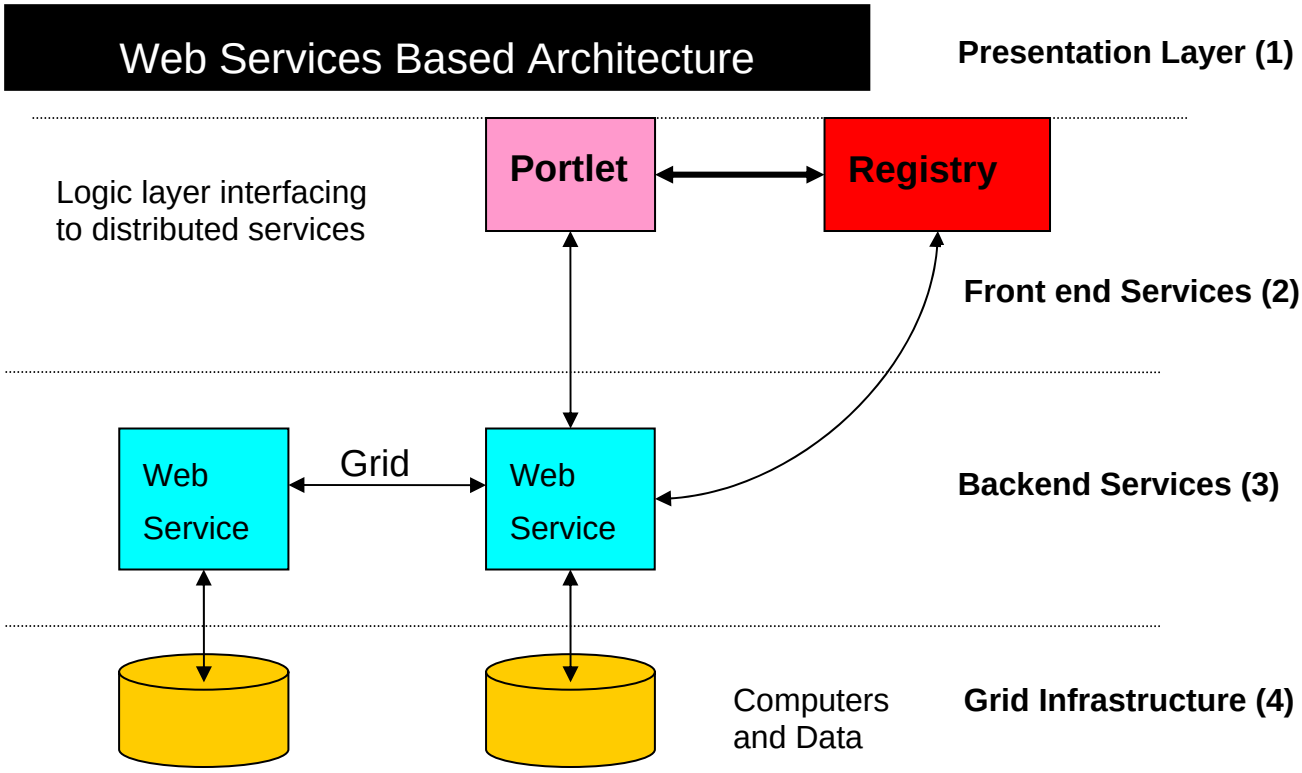

Figure 2: 4-layer Portal Architecture Employing Web Services

Notes:

(1) Presentation layer, e.g. uPortal, Jetspeed or similar integration and rendering framework. Tools such as Sakai/CHEF add value to this by providing a content management system and additional service interfaces.

(2) Front end services, logic layer interfacing with (1) through the JSR-168 portlet API.

(3) Back end services, accessed via web service or other well-known protocols: could be distributed, and/or could interact with other web services forming a Service Grid.

(4) Remote resources on a Grid infrastructure, e.g. computers and data bases, such as the JCSR clusters.

5. Technical framework

This section briefly outlines technical aspects of a VRE which may indicate the scope of work required. This discussion arises directly from the identification of an SOA as the preferred architecture for the VRE and the community input which has led to the workshop recommendations. It is easy to be all-inclusive in a theoretical approach, but a more carefully chosen set must be suggested for pragmatic reasons. The following sections therefore attempt to suggest an initial preferred set.

5.1. Frameworks/interfaces

Following discussions among interface providers, such as those writing 2nd Generation Portals and web services based middleware, we suggest adopting the following standards:

- JSR-168 (Java standard for portlet interface);

- Web Services (WSRP, WSDL, WS-I) which may extend to such things as WSRF in future (SOAP over HTTP is mainly implied as a request/response protocol but other delivery protocols may be needed, e.g. for large datasets, see below);

Frameworks should therefore be able to support these interfaces, e.g. in the case of portals Websphere, uPortal, Jetspeed, GridSphere etc. are possible candidates. For further discussion on JSR-168 and WSRP see [5]. There will be multiple solutions for access to the VRE and standards and inter-operability are key issues. In addition to frameworks such as portals, services must be able to be incorporated into “heritage” applications and GUI interfaces such as those developed and maintained by the long-standing Collaborative Computational Projects (CCPs), which are a unique contributor to UK research output.

5.2. Generic services

These generic services are an abstraction of actual services, some of which might be made available via the VRE. Appendix B provides a fine-grained, but still evolving, list of services from areas such as:

- AAA, Grid Services, Semantic Services, Resource Discovery, etc.
- E-Collaboration;
- Support and Management Services.

This is an attempt at an initial classification and description of these services based on work of other groups such as JCLT, ETF and GGF. Further work is required to identify how services can be broken into methods (functionality) and if appropriate where existing middleware provides such functionality. See http://www.grids.ac.uk/ETF/public/WebServices/classes.html .

5.3. Real resources

Services must clearly be mapped onto real resources to be of value. In Appendix C we have listed some resources and services already available to the UK academic research community which could be accessible. This list is also not exhaustive, but we should identify the main resources and facilities which are likely to be available via the VRE. It may be the case that some of these resources need extra effort to provide interfaces or full availability. Gaps may also be identified as we analyse these resources and services.

5.4. Requirements and use cases

Development of requirements is an ongoing process and the awareness days and demonstrations which have taken place so far have informed this document. Following further demonstrations of VRE prototypes additional requirements will emerge as people change their ways of working, just as the invention of the elevator by Otis made the upper floors of skyscrapers into desirable real estate.

As an example of how requirements could be used to inform the list of services and identify workflows we give one sample use case:

- User specifies required topic;

- Uses search to discover location;
- Uses authentication and authorisation to access source;
- Downloads material using appropriate protocol;
- Interacts with it using appropriate tool(s);
- Does research;
- Writes paper;
- Publishes content;
- Attends international conference.

5.5. Protocols/standards

To make use of resources within the VRE additional protocols and standards are required over and above the access protocols identified above (e.g. Web services). Obvious examples include the transfer of large quantities of data between data stores and computers, which requires optimal utilisation of bandwidth via a tuned FTP service. The following list may need to be extended, but should be contained to a manageable set:

- **Protocol examples:** FTP, VIC, RAT, Z39.50, SRW/ SRU, OAI-PMH, RSS, OpenURL;
- **Standards examples:** IMS, Dublin Core, LOM, OAI, OKI, etc. including those as appropriate from W3C, IETF, OASIS, GGF.

6. References

1. *Building Collaborative eResearch Environments*, Final report compiled for JISC by Andrew Cox (University of Loughborough, March 2004)

2. *UK Role in Open Grid Services Architecture,* draft report v0.7 from the Grid Architecture Task Force (12/3/02)

3. *The Distributed National Electronic Resource Technical Architecture: Scoping the Information Environment* Liz Lyon and Andy Powell (UKOLN, University of Bath). See also http://www.ukoln.ac.uk/distributed-systems/jisc-ie/arch/

4. *A Technical Framework to Support e-Learning*, report to JCLT from S. Wilson, B. Olivier, S. Jeyes, A. Powell, T. Franklin (2003)

5. *Portals and Portlets 2003*, proc. NeSC workshop 14-17/7/03 Rob Allan, Chris Awre, Mark Baker, Adrian Fish (CCLRC and NeSC, 2004) http://www.grids.ac.uk/Papers/Portals/portals.pdf

6. *A Service-Oriented Architecture for VRE/ VLE building on the Sakai Framework*. Report to JCLT by R. Crouchley and R.J. Allan (2004)

7. *A Comparison between the JISC and Sakai Frameworks,* Mark J. Norton (24/3/04)

8. *The Benefits of a Service-Oriented Architecture,* Michael Stevens, Developer.com, http://www.developer.com/services/article.php/1041191

9. *Service-Oriented Architecture Introduction (2 parts),* Michael Stevens, Developer.com, http://www.developer.com/services/article.php/1010451

10. *Web Services and Service-Oriented Architectures* http://www.service-architecture.com/

11. *Service-Oriented Architecture Explained,* Sayed Hashimi, O'Reilly http://www.ondotnet.com/pub/a/dotnet/2003/08/18/soa_explained.html

12. Succeeding at Service Oriented Architecture, Bill Ruh, (ZDNet) http://www.zdnet.com.au/builder/architect/work/story/0,2000034884,20276810,00.htm

13. The Arda Project – a Realisation of Distributed Analysis for LHC. See *http://lcg.web.cern.ch/LCG/peb/arda/Default.htm*

Appendix A

Building collaborative e-research environments - issues and recommendations

JISC held two public awareness-raising workshops (23 February, National e-Science Centre (NESC), Edinburgh and 5 March 2004 University of Warwick) at which presentations were given illustrating possible environments and use cases. Delegates were then asked to separate into smaller groups to discuss the four topics:

1. Technical infrastructure, standards, interoperability, security, middleware;
2. Management and organisational issues;
3. Sharing of and access to resources between institutions and subject disciplines, preservation, IPR, licensing;
4. User and community needs.

Issues

A number of key issues emerged from these discussion sessions, which are listed by title below. More detailed accounts and conclusions of the discussion groups can be found in the Workshop Summary [1].

1. Positive incentives
2. Barriers
3. Institutions
4. Disciplinary communities
5. User needs
6. A Virtual eResearch framework
7. Usability
8. Awareness
9. Threats
10. IPR and legal issues
11. Rhetoric of ‘collaboration’
12. Scholarly publishing and open data

It is expected that components of a VRE should address these issues in a technical sense.

In its search to find the best way to support the development of a virtual e-research environment – or whatever it might be called – JISC faces a number of difficult questions. Should there be one framework or several? What functions should it encompass? What technology or standards should such a framework be based on? Who should develop it as a system and how can that be sustainably funded? What would be its relation to online learning systems and digital libraries?

Recommendations

Recommendations which emerged from these discussions and will help to inform a VRE programme include:

1. Establish services to increase awareness of tools and support their use

2. Explore how one or a number of frameworks could be developed as a virtual e-research environment that encompasses the variety of all disciplines

3. Explore the nature of such environments: what is the nature of the framework, what technologies and standards should it be based on, what business case could be developed to build and sustain it. Determine its relation with MLEs and digital libraries

4. Produce a framework that encompasses research administration and project management

5. Produce a description of the technology support function institutions should have

6. Fund user studies that are cross disciplinary, longitudinal and encompass current non-users

7. Explore the implications of expanding a collaborative framework to include people outside JISC's usual constituencies, such as members of the general public and foreign nationals

8. Address the usability of collaborative tools. Provide 'idiot proof' tools, thus creating a critical mass of users

9. Address the usability of the Grid in general

10. Explore the potential in different disciplines: building common requirements and removing barriers

11. Encourage cross working between social science and humanities with computer science

12. Find ways to support an incremental process of getting communities to use tools or build on their existing preferred tools

13. Help transfer experience from successful projects and bottom-up initiatives through generic case studies. Look at tools and practices already being successfully used and support them

14. Take forward existing work on collaborative tools, in projects led by subject disciplines with 'real people'

15. Run studies to discover and map what tools are available; establish repositories of tools

16. Fill gaps in the taxonomic framework for cross-disciplinary collaborations

An important ground-clearing exercise is the clarification of the legal and ethical frameworks.

The impact of eResearch on scholarly publishing is another important issue, and the implications of this for institutions needs to be explored.

Appendix B

Service capability set

This appendix summarises ongoing e-service classification work which will be extended online at http://www.grids.ac.uk/ETF/public/WebServices/classes.html .

We list services which could form the basis for virtual environments for a variety of purposes. We specifically draw upon considerations of an information environment; virtual learning; and e-research. Reports and papers from which ideas have been taken are listed in the references. We thank the authors of these and also groups such as JCLT, JCIE and ETF whose members have been debating e-services for at least a year. Additional input has been taken from the various working and research groups of the Global Grid Forum which is currently identifying services, specifications and standards leading to an Open Grid Services Architecture (OGSA). In the UK, the recommendations of the Grid Architecture Task Force and the e-Science Gap Analysis carried out by Geoffrey Fox and David Walker have been taken on board.

We have attempted a rather broad and arbitrary classification of the services identified into the following areas: collaboration; e-research; e-learning; digital information; common infrastructure.

We do not consider these to be definitive lists of the services that can be provided, only examples, and we hope that additional services will be identified and developed in ensuing programmes, or identified services refined in the light of future requirements analyses – such lists are organic and will grow and shrink. The aim is to kick-start a programme whereby a framework can be deployed to enable community input and contribution of more specialised services and resources. There is a tendency at the start to list many small-sized atomic services for every function imaginable, later the need to optimise the large-scale distributed system may indicate that services have to be aggregated (federated) in different ways to improve performance. We expect any e-Environment to support only a range of the services listed here.

e-collaboration application services

Collaboration is about people working together, either as peers or in some more formally-defined relationship, such as researcher-supervisor. Collaboration extends to high-end technologies such as Access Grid.

Calendar

Collaboration Management

Content Management

Content Sharing

Group or VO Management

Peer Group Join

Peer Service Location

User Registration

e-research application services

Research services are specific to supporting research processes and tools, including the Grid. They should include collaboration with experts and peers, encapsulation of complex procedures for non experts to facilitate growth of inter-disciplinary sciences and aids for results publication and proposal writing. We aim for a holistic system-based approach!

Application Management

Deployment

Distribution

Fabric Management

Grid Information

Information Access

Information Aggregation

Information Content Registration

Information Query

Information Metadata

Information Presentation

Information Notification

Information Update

Job Management

Knowledge Extraction

Knowledge Syndication (Join)

Process Building

Proposal Writing

Resource Discovery

Resource Management

Scheduling

Security

Validation and Verification

Visualisation

e-Learning application services

Learning services are about supporting a Managed Learning Environment with particular relevance to teachers and students supporting both peer groups and training hierarchies. A variety of approaches to teaching can be included with also self learning and assessment. A training and awareness environment might be distinguished from a more formal teaching environment because the former may not require assessment but could have more interactive demonstration material (e.g. via

the Grid). There should be the ability to walk through material in various ways, log activities and attention to accessibility issues. Again the aim is to provide a holistic approach, but there must be access to humans if a student runs into difficulties, be they ones of understanding or personal. An electronic system cannot completely replace tutors!

Activity Authoring

Activity Management

Assessment

Competency

Course Management

e-Portfolio

Grading

Help

Learner Profile Management

Learning Flow

Rating/Annotation

Resource List

Resource Management

Scheduling

Sequencing

Trails and Personalisation

View

Digital information services

These are services for digital information and data management, which will be informed by issues identified by the Digital Curation Centre. Special attention to database servers and large collections, some of which are of qualitative nature, will be required. Conversion to electronic format and data mining may be targeted too.

Archiving

Cataloguing/Curation

Data Access and Integration

Data Virtualisation

Data Replication

Data Management

Deposition

Dictionaries and Ontologies

Digitial Rights Management (DRM)

Resolver Services

Resource Discovery

Terminology

Common services

We have identified the following common services which may underpin many of the other services. They could in many cases be provided as part of the "infrastructure", and not directly visible to the users, maybe acting as "agents" to other high-level services. Session management is an example of this. Common services also give scope for system optimisation, e.g. through aggregation or federation in special cases and could be encapsulated in workflow for various scenarios. Some use cases are required here to extend and refine the list.

Accounting

Alert/Notification

Authentication

Authorization

Billing

Component Communication

Filing

File/Dataset/BLOB Management

Identifier

Logging

Messaging

Metadata Registry

Monitoring

Network Management

Packaging

Personalisation

Portal Services

Proxy Management

Search

Service Registry

Transaction

User Preferences

Workflow

Appendix C

Some resources and facilities available to the academic research community

- Access Grid Nodes (e-Science Centres);
- Course Content (University and Training Institutions);
- Condor pools of workstations (University and Teaching institutions);
- Resource Discovery Network resources (JCIE) http://www.rdn.ac.uk/. See the RDN Internet Resource Catalogue http://www.jisc.ac.uk/index.cfm?name=rdnipage
- AHDS (AHRB) and e-SS (ESRC) and related training and awareness material, e.g. REDRESS;
- Directories: Z-Directory (UKOLN), Z39-50 target directory (Index Data), RSS-express (UKOLN), OAI Data providers (OAI), IESR (JISC)
- Text mining service (BBSRC), Data Curation Centre and any other specific research resources funded in partnership with Research Councils;
- Resources referenced in the JISC subject resources guides http://www.jisc.ac.uk/index.cfm?name=resguides . These cover the seven subject areas: Arts and Humanities; Engineering, Mathematics and Computing; Geography and the Environment; Health and Life Sciences; Hospitality, Leisure, Sport and Tourism; Physical Sciences; Social Sciences. They include resources such as: Bibliographic, reference and research information; Publications online; Subject gateways; Data services; Learning and teaching; Support services.
- Tools referenced in JISC Collections publications list: collections of high quality online research tools, learning materials and digital archives for UK HE and FE institutions http://www.jisc.ac.uk/index.cfm?name=coll
- National Grid Service nodes (JCSR) http://www.ngs.ac.uk ;
- Supercomputing facilities such as HPCx, CSAR (managed by EPSRC): http://www.hpcx.ac.uk and http://www.csar.ac.uk ;
- Data Archive and MIMAS (ESRC);
- Protein Data Bank (Hosted by Wellcome Foundation at EBI);
- Large-scale facilities such as SRS, ISIS, Diamond (hosted at CCLRC) and associated scientific data collections;
- LHC Data Grid (PPARC);
- NERC Data Centres and CEH;
- Telescopes, e.g. via eSTAR services (PPARC);
- British Library, National Museums, etc. e.g. http://www.nmsi.ac.uk/
- Others such as British Geological Survey, UK Met. Office, Hadley Centre;

Appendix D

Criteria for success

In accordance with the discussion set out in the text, we suggest that a successful VRE would:

- Be applicable to all disciplines;
- Integrate e-research, e-learning and management of digital information to add value to all application areas;
- Be built to current specifications, standards and technology, in order to minimize development costs and time;
- Make UK services and resources available in familiar environments e.g. typically via a web browser;
- Have fast-track links into existing tools, services and resources – some of which have been costly to produce and thus should be re-used;
- Enable an open community process for producing and consuming services and tools;
- Offer choice in presentation, delivery, and service and resource provision;
- Provide maximum ease of use, especially to new users, to optimise take-up;
- Demonstrate added value with respect to existing workbenches, toolsets, portals etc.