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IMPROVING SERVICE MANAGEMENT FOR FEDERATED RESOURCES TO SUPPORT VIRTUAL RESEARCH ENVIRONMENTS

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Abstract. Virtual research environments provide an easy access to e-Infrastructures for researchers by creating an abstracted service-oriented layer on top of the available resources. Using the portal, researchers can focus on the research workflow and data analysis while being provided with a consolidated unified view of all tools necessary for their activities. The sustainable lifecycle of a virtual research environment can only be achieved if it is going to be used with high quality of experience by a large body of users. Aiming for this goal, in this paper we analyse the requirements and implementation of a cross-community virtual research environment that brings together researchers from three different domains. Promoting interdisciplinary research and cooperation, the federated virtual research environment is based on the service orientation paradigm, offering anything as a service solutions. Thus, the main pillar for a successful implementation of this solution is the careful design and management of the underlying elementary services and service compositions. The rest of the paper discusses the challenges of the service management implementation focusing on interoperability by design and service management standards.

Key words: e-Infrastructures, federation, service management, virtual research environment

AMS subject classifications. 68M14

1. Introduction. The vision of European Open Science towards pursuing excellent science sustainable in the long-term needs to be developed as a common research infrastructure serving the needs of scientists [1]. The European Open Science Cloud (EOSC) emphasizes the reusability of the existing e- and research infrastructures, and it should be a mixture of infrastructures, tools and services presented as interoperable virtual environments, "cloud of services", available to the researchers Europe-wide to store, manage, process, analyse and re-use research data across border and domains. This infrastructure should provide both common functions and localised services delegated to community level, where the EOSC will federate existing resources across data centres, e-Infrastructures and research infrastructures. In this context, e-Science is a paradigm for distributed networked, computationally- or data-intensive science, aimed at research problems that require collaboration using computational tools and infrastructures [2]. However, the future infrastructure landscape is developing into a high complexity entity: data systems of larger scale, cloud computing services, and highly heterogeneous technologies including new networking technologies (including software defined networks). Hence, performing research and experimentation has become ever more challenging and there is a growing need to lower the barrier for accessing and using the available infrastructure.

Different models have been proposed for providing shared access to the e-Infra-structure, where Grids and Clouds paving the way for solving the virtual environment sharing problem. A Grid is defined as an infrastructure that enables flexible, secure, coordinated resource sharing among dynamic collection of individuals, institutions and resources [3], where institutions that agree to share the resources are forming Virtual Organisations (VO) [4] and coordinating resource allocations based on agreed resource management rules within the VO domain. The problem with this model is that it places the resource requesters and providers in the same VO. The designed workflows in these systems are not always adapted to the methods of work preferred by the domain scientists making them hard to take advantage of. Cloud computing provides a different solution to these concerns, by separating scientists as resource requesters from cloud providers, and by allowing service owners to create user groups and manage access to deployed services. The on-demand, pay-per-use resource consumption model of cloud services, enables efficient use of equipment and flexibility for scientists [5]. The problem with cloud providers is that each provider has its own platform for accessing the services, which makes it hard for scientists that are in need of a uniform way of requesting services so that they can focus on their primary research activities, not wasting time on learning how to access and provision the services that they want to use.

Virtual Research Environments (VRE) [6] are innovative, web-based, community-oriented, comprehensive,

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flexible, and secure working environments conceived to serve the needs of modern science. Despite of their location, scientists should be free to use their browsers to seamlessly access data, software, and processing resources that are managed by various systems in different administration domains via Virtual Research Environments. The major challenges that need to be resolved to fully achieve a transparent VRE include large-scale integration and interoperability, sustainability, and adoption.

Service management in this complex VRE landscape becomes of great importance in order to provide users ease of access and use in a collaborative federated environment. With the growing demand for ever more complex e-Infrastructures, there is a strong requirement to sustain federated cross-domain experimental facilities ensuring the latest cutting-edge technologies are available to a large and experienced set of established research communities offered via centralised services.

The VI-SEEM H2020 funded project (VRE for regional interdisciplinary communities in the Southeast Europe (SEE) and the Eastern Mediterranean (EM)) focuses on bringing together the regional e-Infrastructures to build capacity and better utilise synergies, for an improved service provision within a unified Virtual Research Environment for the inter-disciplinary scientific user communities in the combined SEE and EM regions (SEEM) [7]. The main objectives of the VI-SEEM project include providing scientists with access to state of the art e-Infrastructure - computing, storage and connectivity resources - available in the region, and integrating the underlying e-Infrastructure layers with generic/standardised as well as domain-specific services for the region. The latter are leveraging on existing tools (including visualisation) with additional features being co-developed and co-operated by the Scientific Communities and the e-Infrastructure providers, thus proving integrated VRE environments.

In this paper, we present the VI-SEEM effort in the creation of the targeted communities VREs focusing on the establishment of an integrated service oriented approach in a federated interdisciplinary environment enabling end users to browse, access and use common and specific domain services in a unified manner. One of the main challenges in the project has been the development of a service management approach from defining the foundations of policies and practices to the implementation of a fully functional service catalogue and portfolio.

The paper is structures as follows: section 2 reviews the challenges and approaches in federated environments, while the section 3 describes the building blocks of service oriented VREs. Section 4 is dedicated to the service management with focus on the federated approaches in service management, along with the design and implementation of the management of the service lifecycle in the VI-SEEM VRE. Section 5 overviews the related work, while the conclusions and future work are provided in the section 6.

2. Challenges in virtual research environments. The main issues when aiming to implement a sustainable Virtual Research Environments are large scale integration and interoperability, sustainability, and adoption.

Since VREs are built as a collection of existing systems and resources, interoperability is a must in order to fully utilise the potential of all available resources. It is fundamental to rely on a rich array of systems and resources, both in terms of variety and size, that can be seamlessly accessed and combined in innovative ways to satisfy the evolving needs of the targeted community. The challenges affecting Virtual Research Environments are very broad and include every aspect of an e-Infrastructure as they represent the application layer that is built on top of one or more layers offering at raw resources, communication and authentication protocols, protocols for publication, discovery, negotiation, monitoring, and accounting of services. The infrastructure itself should address most of these challenges. Through a collection of mechanisms put in place, it should enable interoperability with existing systems to build a federated space of services. To address this issue, VI-SEEM has developed a set of open APIs for managing the service offerings in an unified manner that can then be integrated with additional systems and partners. In this way, all targeted communities are treated in a uniform federated way creating a completely transparent federated VRE.

Sustainability is another major challenge when aiming to develop a federated Virtual Research Environment. VREs require effort and money to be built and maintained according to the needs of the targeted communities. As proposed in [8], there are three key strategies for sustainability that can be put in place: (i) acquire further funding from diverse research bodies; (ii) develop business models aiming at self-sustainability; and (iii) rely on community support. Given the volatile nature of communities of practice the sustainability issue remains a challenging problem for singled out targeted communities. However, pursuing an interdisciplinary approach as fostered in VI-SEEM not only enables deeper research collaboration putting in place the initial tools needed for innovation, it also ensures a long term community support due to the increased coverage. The VI-SEEM exploitable assets including data management services, application specific services, computational and access services, and knowledge-based services, form a base line for the project sustainability.

Although several Virtual Research Environments have been developed in various application domains, the majority of these systems are not yet fully integrated into standard practices, tools, and research protocols daily used by real life communities. One of the hardest obstacles to cross is the unwillingness of the scientists to migrate from traditional and consolidated research practices and facilities to the novelty ones promoted by VREs. As recognised by [8], among the factors causing this issue are: (i) the lack of support of both technical and educational nature; (ii) the gap between the target community needs and the actual service implemented by the VRE; (iii) the reliability of the technology; (iv) legal, ethical, and cultural issues; and (v) internationality. All of these identified problems are addressed within VI-SEEM by organising educational training events that target all communities of interest, liaisoning with research communities representatives that provide input on their specific needs in terms of resources and services, and by working in a highly international environment that acknowledges different national issues and practices.

The federated approach taken in VI-SEEM in terms of multiple target communities is seen as a means to ensure the creation of an interdisciplinary virtual research environment that can be used as a blueprint for expanding to additional target communities thus expanding the user base and providing a tested environment that can further grow and follow the concept of a truly unified virtual research environment.

3. Service oriented VRE. All underlying e-Infrastructure can be offered to the VRE end users via a set of well defined services that are constructed in a way that enables the end users to achieve their requirements with minimum additional overhead in terms of service management and workflow definition.

In this context, a service offered in the VRE is a means of delivering value to end users by facilitating outcomes end users want to achieve without the ownership of specific costs and risks [9]. As long as the task or function being provided is well defined and can be relatively isolated from other associated tasks it can be distinctly classified as a service.

In the South East Europe and Eastern Mediterranean area, the established regional e- Infrastructure resources and application support enable the foundation for building service oriented VREs that will foster high-quality research and help reduce the digital divide and brain drain in Europe.

The VI-SEEM consortium brings together e-Infrastructure operators and Scientific Communities in a common endeavour: to provide an improved service provisioning for researchers within a unified Virtual Research Environment. One of the major features of the project is that it targets inter-disciplinary scientific user communities, building a single VRE platform for the Life Sciences community, the Climate community and the Cultural Heritage community that aims to support multidisciplinary solutions, advancing the community research, and bridge the regional development gap with the rest of Europe.

In other words, the project objective is to provide user-friendly integrated e-Infrastructure platform for regional cross-border Scientific Communities in Climatology, Life Sciences, and Cultural Heritage for the SEEM region. The resulting VRE portal provides access to computing infrastructure, data sets and data storage facilities, and cloud applications, as well as supporting services, models, software and tools, see Fig. 3.1.

The VRE supports the full lifecycle of collaborative research: workflows that provide support for simulations, data exploration and visualisation, possibility to access and share relevant research data, provided code and tools that can be used over the data sets to carry out new experiments and simulations on large-scale e-Infrastructures, optimized applications and libraries used for specific purposes. The newly produced knowledge and data can be stored and shared in the same VRE.

Moreover, the potential VRE users are not only researchers, but also students and SMEs that can benefit from using the services provided in the portal, see Fig. 3.2. For students, the VRE portal can be seen as a starting point to join the research communities by accessing training information and material and applying to participate on various related events. Also, the access to data sets, scientific workflows and source code repository enable students to familiarize with the state of the art research and analyze the results. For SMEs, on the other hand, the VRE platform can be seen as a place that provides possibilities for collaboration with the academic research institutions. The joint proposals are also provided with access to the infrastructure, data and

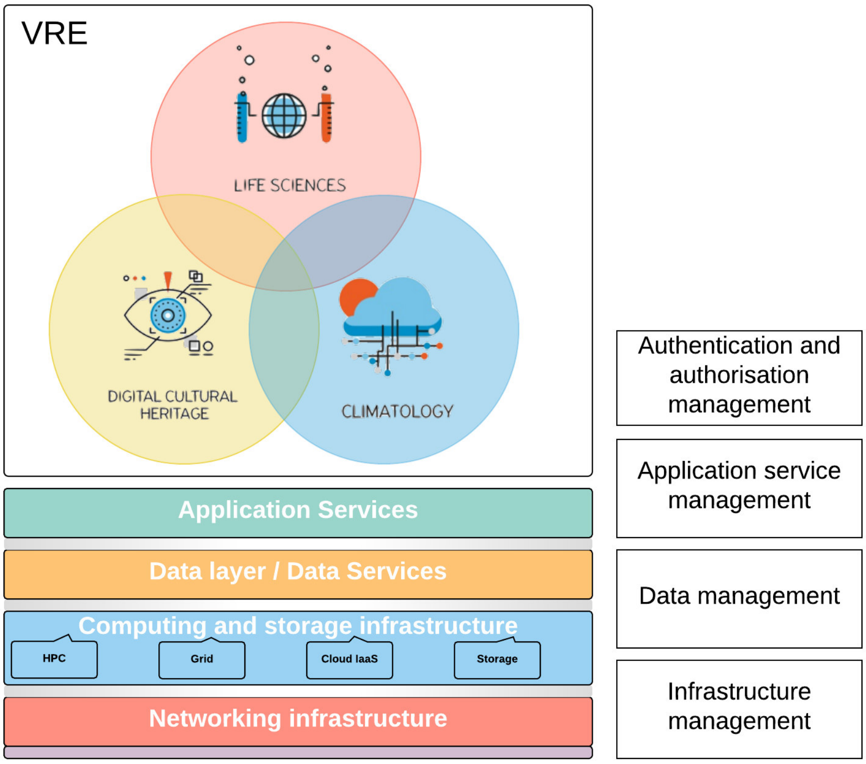

FIG. 3.1. *Cross-community VRE in VI-SEEM*

application services. The presented use cases can be used as successful examples that illustrate the potential and benefits from the joint academic/industrial efforts, representing one of the pillars for future sustainability of the VRE portal.

One of the major principles when developing VREs is the concept of service orientation. Service orientation is the ability and desire to anticipate, recognise and meet others' needs, sometimes even before those needs are articulated. This essentially means that the VRE needs to be developed so that is contains all of the required services by the target community in order to further empower endusers. Service orientation is based on a number of principles with the most important ones being [10]:

- Services are loosely coupled..
- Services abstract underlying logic.
- Services are autonomous.
- Services can be composed.
- Services are reusable.
- Services are stateless.
- Services are discoverable.

The service orientation principles are incorporated into the developed VI-SEEM VRE from several aspects. The federative type of organization implies loose coupling of the offered services. Similarly, all services are abstracted on a higher level so that the federated partners can deal with the local details. While the federated VRE presents a high level view of the available resources and services, the federated management tools still maintaining a more in-depth information about the way the services are implemented in order to provide high service availability via efficient service management, as it is discussed in the next section. The federated service management approach also takes into account the need for autonomy of services by maintaining a detailed level of service composition and tracking the status of all service components and interdependencies.

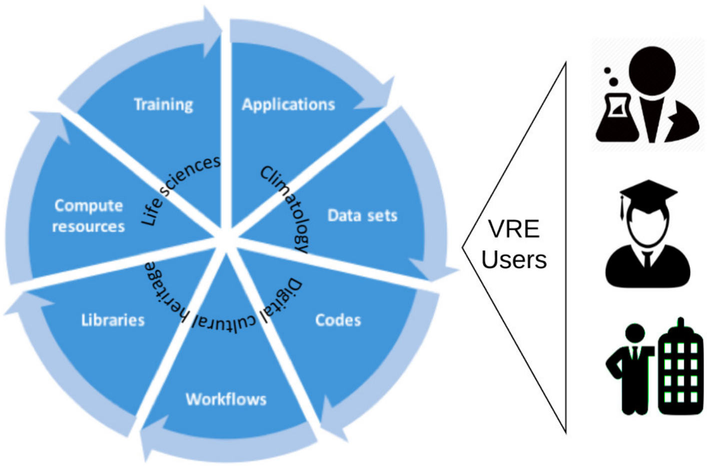

Fig. 3.2. *VRE content and users*

Furthermore, the scientific workflows section in the VRE provides information on how to compose the elementary services, reusing the same service in different ways for different workflows and scientific processes. The stateless nature of the services is a requirement when building scientific workflows where services can be reused in different settings for various users and domains.

There are multiple aspects of service discoverability that are implemented in the VI-SEEM VRE:

- Services are discoverable by the VRE users via the VRE portal - these are the end user services that can be elementary or composed complex workflows of services.
- Services are described in a service catalogue and portfolio - the catalogue component not only provides detailed service description, but also supports further discovery and integration of the services into a common European e-Infrastructure Services Gateway [19] using open APIs
- Services are internally enumerated in a service registry - enabling a coherent approach to service quality monitoring, accounting and support

4. Service management. It is evident that when implementing a service oriented VRE, one of the the key elements for a successful service orientation are the underlying components for service composition, management and monitoring encompassed in the IT service management.

IT Service Management (ITSM) [11] are the activities that an organisation performs to plan, deliver, operate and control IT services that are offered to customers. Such activities facilitate the offering of quality IT services that provide value to customers meeting their needs. IT Service Management provides the necessary guidance for an IT organisation to plan, design, develop, deploy and support business aligned IT Services. These services include the hardware, software and other IT assets necessary as well as the overall guidance for the IT organisation in the provision of these services.

In terms of federated environments, such as the ones that are fostered by the VI-SEEM project, the term IT organisation translates to a loose federation of the project partners, which makes the whole process of IT service management much more complex to define and implement. Thus, the first steps towards implementing service management in the federated VRE is choosing a suitable IT service management standard that will be used as a guidebook.

4.1. Service Management Standards and Best Practices. To successfully implement the service management process into an e-Infrastructure, there are several systems and processes that have to be put in place. The key elements are:

- Service management system, consisting of service catalogue and portfolio - the Service Portfolio is used to manage the entire Lifecycle of all services, and includes three Categories: Service Pipeline (proposed or in development); Service Catalogue (live or available for deployment); and Retired Services.

- Service registry - The service registry is a database populated with information on how to dispatch requests to service instances.
- Monitoring system - real-time observation of and alerting about health conditions (characteristics that indicate success or failure) in an IT environment, ensuring that deployed services are operated, maintained, and supported in line with the service level agreement (SLA).
- Operational and service level definitions SLAs define what the organisation as a whole is promising to the customer, while OLAs define what the functional internal groups promise to each other.

The most important role of IT service management processes is to support the delivery of IT services. In many cases, the provisioning of one IT service requires several processes. All of these processes need to be successfully operating and interacting to deliver an IT service. This requires that each IT service management process, is defined using its standard elements, including:

- Goals and objectives
- Clearly defined inputs, triggers and outputs
- Set of interrelated activities
- Roles and responsibilities

There are many standards and best practices that cover the area of IT service management defining in details the common systems and processes that need to be put in place. ITIL [12] is one of the most frequently used, especially in the large enterprises. The IT Infrastructure Library (ITIL) provides a descriptive framework of best practices for the delivery of the components of the IT infrastructure as a set of services to the enterprise. Although ITIL is being used by a large number of IT organizations for efficient delivery of services to their users, it cannot be as successfully implemented in a case of federated environment, similar to the one built by most of the e-Infrastructure international projects including VI-SEEM. The latest efforts toward addressing these issues led to the establishment of a new, lightweight standard, with special focus on the federated environment, FitSM (federated ITSM).

The goals and activities of the FitSM standard series [13] are aimed at supporting effective, lightweight implementation of IT service management processes in an organization (or part of an organization delivering IT services to customers), and harmonizing ITSM across federated computing infrastructures. The main goals of FitSM are:

- Create a clear, pragmatic, lightweight and achievable standard that allows for effective IT service management.
- Offer a version of ITSM that can cope with federated environments, which often lack the hierarchy and level of control typical for enterprises.
- Provide a baseline level of ITSM than can act to support management interoperability in federated environments where disparate or competing organisations must cooperate to manage services.

Having in mind the federated nature of the VI-SEEM consortium, the FitSM was the clear choice for governing the IT service management of the offered services.

The IT service lifecycle is governed in FitSM using a set of 14 processes, where the standard defines the specific models for implementing them into the service management system. The process models are listed in Table 4.1.

4.2. Implementing VI-SEEM Service management. As described in the previous section, a service management system is an overall management system that controls and supports management of services within an organisation or federation. According to FitSM, the first process model that is the key element of the service management system is 1: Service portfolio management. This process model addresses the activities necessary to define and maintain a service portfolio.

The Service Portfolio (SP) is an internal list that details all services offered by a service provider including those in preparation, live and discontinued. The service portfolio includes meta-information about services such as their value proposition, target customer base, service descriptions, technical specifications, cost and price, risks to the provider, service level packages offered etc. The Service Portfolio is the basis for the Service Catalogue. The Service Catalogue (SC) is a customer facing list of services that are in production and provide value to the customers of the service provider. The SC, among others, provides also information on service

Table 4.1
FitSM requirements for a service management system

#	Process model
1	Service Portfolio management (SPM)
2	Service Level Management (SLM)
3	Service Reporting Management (SRM)
4	Service Availability & Continuity Management (SACM)
5	Capacity Management (CAPM)
6	Information Security Management (SM)
7	Customer Relationship Management (CRM)
8	Supplier Relationship Management (SUPPM)
9	Incident & Service Request Management (ISRM)
10	Problem Management (PM)
11	Configuration Management (CONFM)
12	Change Management (CHM)
13	Release & Deployment Management (RDM)
14	Continual Service Improvement Management (CSI)

options including the various SLAs available for each service. At a high level the service catalogue is a subset of the service portfolio, both in terms of the number of services that they contain and also in terms of the number of fields or attributes each one holds.

4.2.1. Requirements. The VI-SEEM service portfolio management system has been developed to support the service portfolio management process within VI-SEEM as well as being usable for other infrastructures if required. The main requirements for the creation of this tool have been collected from the service management process design that includes the infrastructure services, storage services and application level services. The service management system has been designed to be compatible with the FitSM service portfolio management. Requirements gathered in the context of EUDAT2020 [14] project have also been considered for compatibility and completeness.

The main functional requirements that were used as a foundation of the service portfolio management system development are as follows:

- The user roles that should have access to the tool functionalities are:
  - The potential customers or end users of the services listed in the service catalogue.
    These users should be able to see the list of the services that are currently in production or beta stage and are offer for use. Public details about each offered service should also be available. These users should be able to order and use the services listed in the service catalogue, as well as interact with the help desk or any other dedicated support channel for that service. The specific services features and use cases of using the service should also be available to the users.
  - The service managers within the VI-SEEM environment.
    These users should be able to see all service details about service that can be found in the service portfolio. This includes services that are not offered to the end users, as well as additional service information that is stored for management purposes only.
  - The service owners.
    Service owners are the persons responsible for each service listed in the service portfolio. Users with this role have the full responsibility for the content that is provided within the service catalogue and portfolio regarding the services under their responsibility. The service owners are assigned by the service providing partner institution.
- The service catalogue contains only public information about services that are to be provided to the potential customers and end users of the services. The service portfolio contains all services, including the ones not currently offered to end users, together with detailed information about each service (public details and management details).

- Each service can have multiple versions in the service portfolio. Each version can have a different readiness status i.e. concept, under development, beta, production, retired etc.
- The service owners and the service managers should be able to state which service versions should be available in the service catalogue.
- The service can be either customer facing or resource facing, internal to the organisation.
- The dependencies between services should be modeled in the service portfolio in order to facilitate efficient implementation of the SLA management process.
- The components that are required for deploying each service should be detailed in the service portfolio providing information needed for operations to deploy such services.
- The service portfolio should be accessible via a RESTful API to accommodate 3rd party application development and different views of the service catalogue depending on the needs of the consumer of this information (organisation, federation, external party, global e-Infrastructure catalogue).
- The service portfolio/catalogue should have a default web UI providing the main service catalogue view for the VI-SEEM project end users as well as to be used as a management UI for adding and editing information by service managers and service owners.

4.2.2. Design. FitSM defines a set of activities for the initial setup and maintenance of the service portfolio and the corresponding catalogue. For the service portfolio such activities are:

- Initial Process Setup
  - Define a way to document the service portfolio;
  - Define a way to describe / specify a specific service;
  - Set up an initial service portfolio (including service specifications) covering at least all live services provided to customers, as far as they are in the scope of the service management system;
  - Create a map of the bodies / parties (organisations, federation members) involved in delivering services.
- Ongoing process execution
  - Manage and maintain the service portfolio;
  - Manage the design and transition of new or changed services;
  - Manage the organisational structure involved in delivering services.

For the service catalogue the defined activities include:

- Initial Process Setup;
  - Define the structure and format of the service catalogue, and create an initial service catalogue based on the service portfolio;
  - Define a basic/default SLA valid for all services provided to customers, where no specific/individual SLA are in place;
  - Define templates for individual SLAs, OLAs and UAs;
  - Identify the most critical supporting service components, and agree OLAs and UAs with those contributing to delivering services to customers;
  - Agree individual SLAs with customers for the most important/critical services.
- Ongoing process execution;
- Maintain the service catalogue;
- Manage SLAs;
- Manage OLAs and UAs.

These processes for the Service Portfolio and Service Catalogue management have been implemented in VI-SEEM by developing a specialised service management component. The design model of the component takes into consideration similar approaches on service portfolio management and service catalogue that are being performed in projects such as EUDAT2020 and PRACE-4IP [15]. The information model of the component is presented in Fig. 4.1.

The central element of the information model is the service. Each service can be dependent on other VI-SEEM services, or external services. This relationship enables the construction of complex services that are designed as a composition of multiple elementary services. Each service is defined using a number of attributes that describe the services internally for the federation and externally for users. Service area and service type

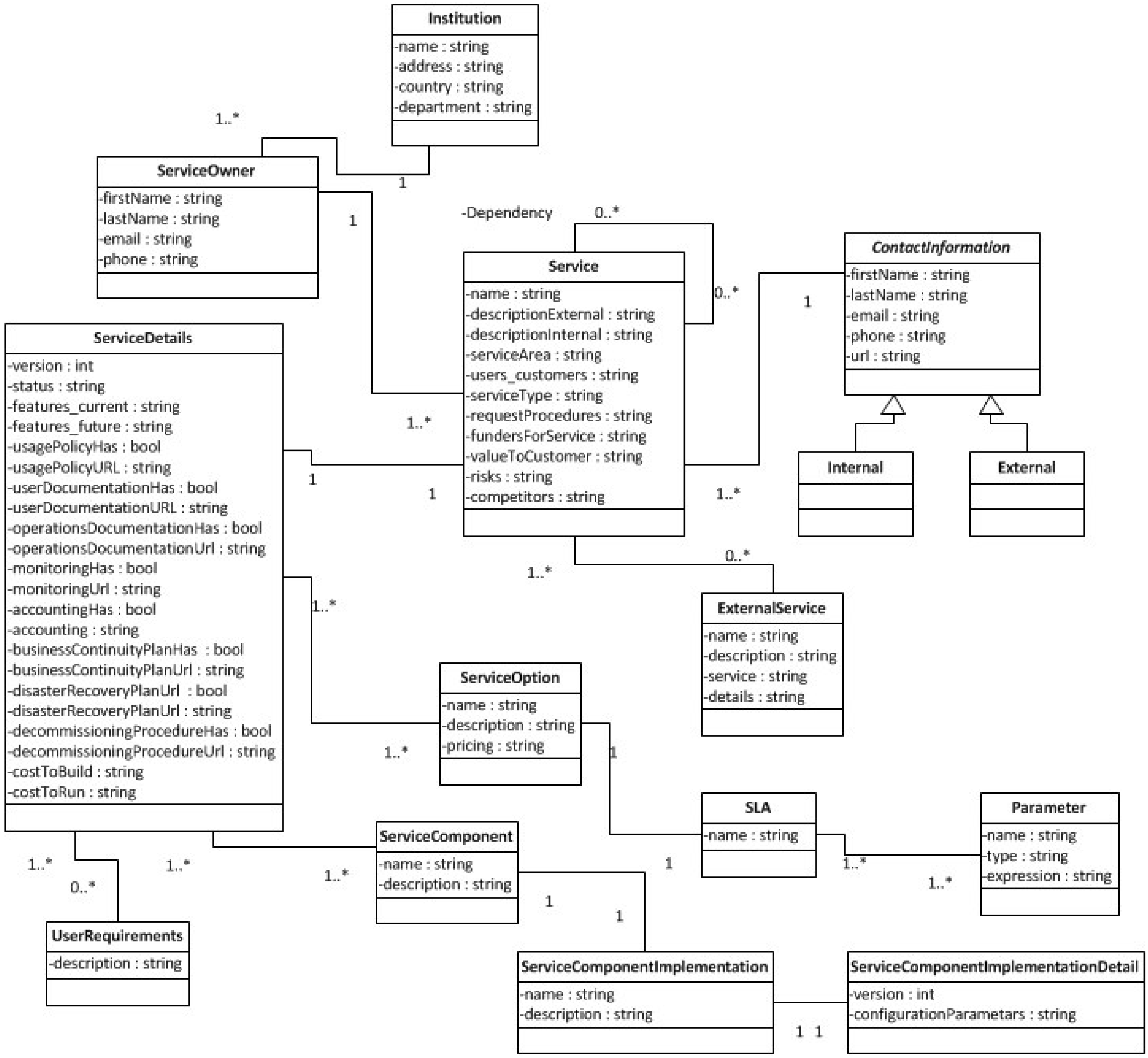

FIG. 4.1. *Information model for the VI-SEEM service catalogue and portfolio*

attributes are used for service grouping on the public UI. Each service is linked to a request procedure for the service. The service is associated with a service owner and service contact information (ex. help desk for the particular service). The service version is part of the service details attributes. The service status is used to filter the active services that are presented in the service catalogue. Additionally, attributes such as current and planned features, as well as, the policies, user documentation, and management information (monitoring, accounting, business continuity plan, disaster recovery) links are stored for each service version.

The service is built using multiple service components that represent the elementary resources needed to run the service. Each service component can have multiple service component implementations represented with different versions and parameters. In example, the VI-SEEM simple data storage service version 1.0 is designed using the File hosting component implemented using OwnCloud version 8.1. Each service can be offered with different service options, where options represent the information about value models, and service levels and

Table 4.2
Roles and responsibilities

Role	Responsibilities
Service Portfolio/Catalogue Process Owner	To control the SPM and SLM processes, maintain the catalogue and portfolio and report to senior management
Service Technical Coordinator / Architect	Has the overall view of services being developed or operated in the organization from the technical point of view
Customer Relationship Manager	Gathers requests for new features from feature / service requestor, Initiates a new service / service change to the service portfolio, identifies services that need decommissioning
Service Portfolio Approval Committee	Review and approves new services or changes to services
Service Owner	Has the overall responsibility for one specific service which is part of the service portfolio, Acts as the primary contact point for all (process-independent) concerns in the context of that specific service
Service Design Team	The team that is responsible for the design, implementation and maintenance of a service

associated parameters.

The definition of roles and responsibilities within the SPM/SLM processes is presented in Table 4.2.

4.2.3. Implementation / Current status. Fig. 4.2. illustrates the current state of the the service catalog, offering production services to the scientific communities. The services are grouped in 5 service areas: data storage, application level, computer, authentication and authorization and service provisioning. The data storage services include simple storage, archival, repository and data discovery services, covering the the full lifecycle of relevant research data. The services in the application level area include domain specific services, such as the ChemBioServer [16] for the Life science, LAS [17] for the Climate and Clowder [18] for the Digital Cultural Heritage scientific community. The computing services, including grid, HPC and cloud resources are enlisted under the computer service area.

5. Related work. IT service management has been recognized as the preferred methodology for the operations and sustainability of the e-Infrastructures. In [20], the authors propose a novel methodology for creating an assessment process of the capabilities of service management systems in federated e-Infrastructures, useful for introduction or improvement of service management in the relevant domains. Various IT service management standards and/or best practices are successfully engaged to enhance the service capabilities of the exiting or future e-Infrastructures. ITIL was successfully applied in the merging process of two large e-Infrastructures, as shown in [21]. The PL-Grid infrastructure employed ITSM to maximize the efficiency of its operations [22]. By following the FitSM standard, their federated infrastructure is able to implement all required processes and serve the scientific community in highly efficient manner.

6. Conclusions. The growing complexity of the research e-Infrastructures and various resources available have driven the need to support the next generation of researchers by providing them with a consolidated access to all resource at their disposal. Implementing a virtual research environment portal on top of the underlying resources provides the researchers with an easy access to the tools, data sets and workflows of interest, enabling them to focus on the research process alone. However, such facilities are typically difficult to sustain in the long term, particularly if they are focused on a small set of users. The VI-SEEM project is a cross-domain federation of e-Infrastructures from the South Eastern Europe and Eastern Mediterranean region that aims to support

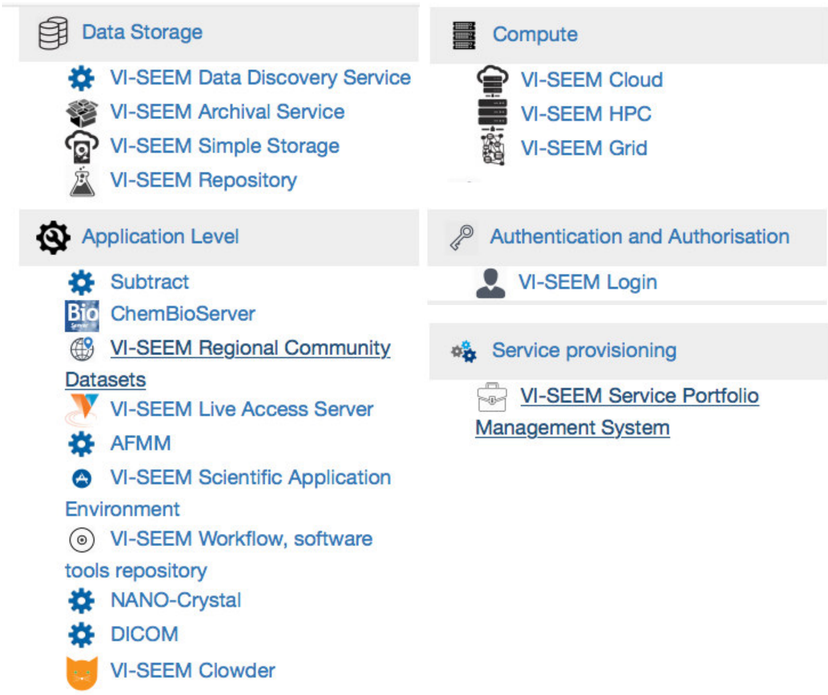

Fig. 4.2. *Services offered in the VI-SEEM VRE service catalogue*

researchers from three different communities: life sciences, climate, and digital cultural heritage and support their interdisciplinary activities seeking to lower the barrier to access and use complex e-Infrastructures.

This paper explored the different requirements and aspects of building a successful and sustainable federated virtual research environment. We indicated the different challenges and solution aspects of our VRE solution proposal, focusing on the service orientation paradigm and its importance for the end users. Another important aspect that was considered especially in terms of future growth and sustainability is the possibility to extend the offered services in a higher level environment by using open interoperable APIs.

The paper focused on the implementation of services offered within the VRE with the service management aspects being the most crucial link in the process of the creation of the VRE. The workings of the service portfolio and catalogue that are offered and operated by the project have been discussed. The complete service management approach is based upon the FitSM framework, where we presented the core processes and components that were put in place. The detailed description of the design of the service catalogue and portfolio can be used as a blueprint for building a service management system based on a federated approach that incorporates all service management aspects and clearly defines the roles and responsibilities of the federation members.

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