Foundations of Open Semantic Service Networks

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ABSTRACT

This article provides the foundations for the new field of research coined Service Networks research. Understanding what factors explain the structure and dynamics of global service networks may lead to a more efficient and balanced society and economy. The concept of service network is formally represented as a business structure made up of services systems which are nodes connected by one or more specific types of relationships. They can be used to represent the global economy, i.e. a complex network composed of national economies, which are themselves networks of markets, and markets are also networks of providers, brokers, intermediaries, and consumers. The authors' key challenge consists in developing a novel perspective on socio-economic dynamics by connecting service models representing service systems (e.g. consulting, governmental, and educational services). Theories to be developed will enable to understand, describe, explain, analyze, predict, and control the evolution of global service networks..

Keywords: *Linked Data,Relationship Descriptions, Semantic Web, Service, Service Descriptions,Service Networks*

1. INTRODUCTION

Many systems around us can be described by network models. The examples available are numerous and range from social networks, to the Internet, and to power grids. Understanding how services evolve as networks and the risks and gains of different topologies is also becoming increasingly critical for society (Spohrer & Maglio, 2010). The impact on society can be compared to contributions made in the areas of social networks and the Web. Considering every single individual on this planet as a po-

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tential owner of resources that are relevant for the provision of at least one real-world service, we would count seven billion *service systems*, and therefore information systems need to be in place to enable each individual to have an active role in service-centric societies.

The ability to construct service networks is the most basic requirement to understand the dynamics of global service-based economies, and their innovation. However, currently available techniques fall short of providing workable solutions as they are unable to deal with the automated description of open and rich relationships between services. In this article, we focus on the particularly challenging task of providing the foundations for constructing *open semantic service networks (OSSN)* by accessing, retrieving, and combining information from *service systems* and *relationship models* globally distributed. Service systems, relationships and service networks are said to be *open* when their models are transparently available and accessible by external entities and follow an open world assumption. Networks are said to be *semantic* since service systems and relationship models are expected to have a shared understanding regarding vocabularies, rules and semantic Web theories and technologies.

Current developments are targeting the computer-understandable description of services using comprehensive languages such as the Unified Service Description Language (*-USDL) (Cardoso, Barros, May, & Kylau, 2010). In the near future, these languages will allow formalizing the description of service systems in such a way that they can be used effectively for dynamic service outsourcing, efficient SaaS trading, and automatic service contract negotiation (when no ambiguity arises, we will simply use the term service to refer to a service system).

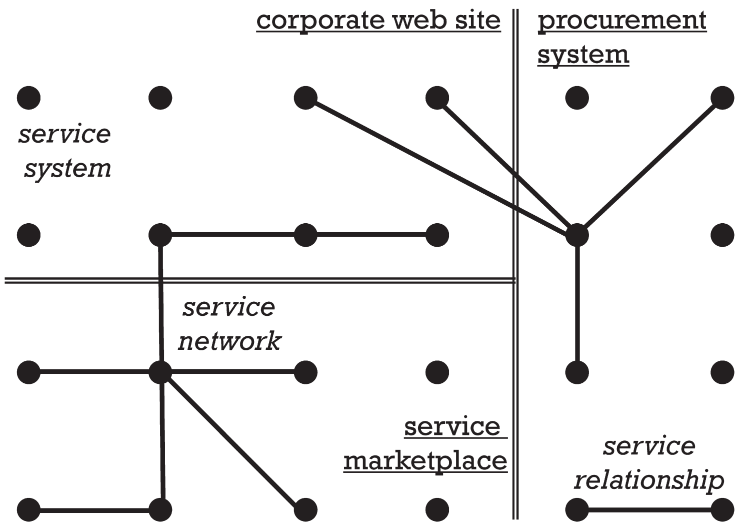
We take the challenge of developing a novel perspective on the global economy by connecting service models representing open business service systems (e.g. consulting, e-governmental, SaaS and educational services) typically provisioned by commercial companies and governmental agencies. The difficulties which we face in doing so differ significantly from those tackled by prior work in global distributed information integration and large scale systems. Compared to previous work in Service-Oriented Architecture (SOA), we target the study of business services which goes beyond the analysis of Web services (e.g. WSDL, SOAP, and REST) in complexity. Furthermore, SOA generally relies on top-down and BPM (Business Process Management) strategies to develop process models. We take a totally different approach: we follow a self-governing and bottom-up approach which generates network models by using relationships instead of using temporal and control-flow connectors.

This article is structured as follows. In Section 2, we provide a motivation scenario for the importance of constructing global service networks. Section 3 provides a literature review in this emerging field of science. Then, Section 4 suggests seven principles for community-based design of OSSN. Next, Section 5 presents an approach that can both maximize the usage of available service information and enable the location of related services in online marketplaces. Our solution involves four research activities: 1) identification of a suitable schema, language, or ontology to model services, 2) creation of an open and rich model to represent relationships between service models, 3) populate service and relationship models, and 4) development of an infrastructure to query and access distributed service models, and dynamically construct global service networks. Section 6 illustrates the value of OSSN in the context of several research projects. Finally, Section 7 provides the conclusion.

2. MOTIVATION

A *service network* can be defined as a business structure, i.e., a graph in which nodes represent service systems that are connected by one or more specific types of relationships. Figure 1 shows the main elements of service networks and their environment. Relationships are illustrated with edges and represent the transfer

Figure 1. Services, service relationships, and service networks



of goods, revenue, knowledge, social ties, market positions, and intangible benefits (Håkansson & Ford, 2002).

Let us consider the networked economy by looking into a specific class of service networks: financial service networks. Today's financial networks are highly interrelated and interdependent. Any disorders that occur in one service of the network may create consequences in other services of the network. For example, in 2008, the economic problems initiated a chain reaction that started in the U.S. and caused problems in European markets and almost took Iceland to bankruptcy. Leading financial services closed (e.g. Lehman Brothers investment bank), others merged, and yet new services were created. The configuration and topology of financial service networks changed as a reaction mechanism. The disaster was a surprise for most people, but local information to each financial institution and financial service was available and could have been utilized to anticipate the catastrophe. Unfortunately, the information was not accessible to regulators.

Now consider that governments had the technology and legal power to force institutions to describe all their financial services using machine-understandable standard description models (e.g. *-USDL). Using this approach, all the services and their descriptions would be remotely accessible to regulation bodies. Consider also that financial institutions had to indicate to which services provided by other institutions their own services established relationships with. In other words, if bank A provides loaning or consulting services to bank B, this information is also described using machine-understandable standard description models and is remotely accessible to regulators. In such a scenario, regulation bodies could at any time access and retrieve service and relationship models to (re)construct financial service networks. Afterwards, the querying and analysis of the network would enable to identify financial network's vulnerable services to protect the functionality of the network. Conflicts of interests, suspicious relationships, unlawful practices, and patterns indicating monopolies or oligopolies could be identified and trigger legal investigations to later execute reparative actions if necessary.

The work presented in this article describes the current research steps we have already made to bring this scenario to life.

3. OVERVIEW AND LITERATURE REVIEW

The study of services has been approached from different perspectives, although some strands are more mature than others. This section provides a short overview of the main contributions relevant to the study of service networks. Razo-Zapata et al. (2012 a) provide a more comprehensive survey and suggest how the two major trends, i.e., value as opposed to process-orientation, driving these approaches can converge.

3.1. Technical Perspective

From a technical perspective there is a lot of work done regarding the description of *software-based services*, the description of service-based architectures, and service composition into higher-level business processes (Erl, 2005). The interfaces of the popular web services have long been described using WSDL (in the case of REST, WADL is used – nonetheless, it did not find a strong acceptance) in a machine-readable manner that allows systems to find out how to perform invocations and what results to expect. Later efforts focused on adding semantics to those descriptions, giving rise to initiatives such as SAWSDL, OWL-S, and WSMO (Pedrinaci, Domingue, & Sheth, 2010). It became possible to account for domain knowledge and not just technical syntax. GoodRelations (Hepp, 2011) provided a different perspective by introducing a vocabulary to describe products and services in a structured way so that, for example, web searches and comparisons could be more easily and systematically done by customers. Standards for the organization and behavior of registries (in essence, catalogs of available services) also emerged, notably UDDI, which, again, was later complemented by semantic extensions or variants that enabled the search of services by business goals and not just strictly by the service name. Several other standards, collectively known as the WS-* family, address issues such as policy, security, reliability, among others. The paradigm shift from silo applications to pools of services, that could be recombined as needed, called for efforts to describe such service-oriented architectures (SOA). SoaML (OMG, 2012) is one such initiative, for model-driven software engineering of services. It addresses, for instance, service requirements, dependencies, functional capabilities, policies for use and provision, partitioning, or constrains.

All these efforts show the considerable progress that has been done so far in service-orientation from a technical point of view. But to enable our proposed research on open semantic service networks, additional capabilities are needed. For instance, service descriptions must include new business-related characteristics, which aggregate, structure, and configure people, resources, and information to create new value for consumers (see Akkermans et al., 2004; Baida, Gordijn, & Omelayenko, 2004).

3.2. Business models

A number of researchers worked on formalizing business models. For example, Weiner and Weisbecker (2011) describe a set of models addressing value networks, market interfaces, products and services, and financial aspects. Osterwalder, Pigneur, and Clark (2010) presented the business model canvas, a simple conceptual model and graphical tool for sketching business models. Nonetheless, most business modeling approaches fail to adhere to *service-dominant logic* and focus too much inward the company instead of the network they belong to. Some efforts have been done to overcome this and account for cross-company collaboration in complex value networks. Entering further into the business field, we can find contributions aimed at conceptual modeling of business networks, which are often described in natural language (see Weill & Vitale, 2001; Chesbrough & Rosenbloom, 2002; Applegate, 2001; Tapscott, Lowy, & Ticoll, 2000; Parolini, 1999; Mörschel & Höck, 2001). However, these efforts do not constitute a solution for large-scale OSSN analysis, since they are not open, machine-readable, or semantically described. The STOF Framework (Bouwman, Faber, Haaker, Kijl, & Reuver, 2008) addresses business and technical issues in an integrated manner, namely Service (added value of a service offering and its market segment), Technology (technical implementation), Organization (structure of the multi-actor value network required to create and distribute the service offering), and Finance (revenue model). Nevertheless, this is still aimed at fairly circumscribed business model design.

All these approaches are, however, generally aimed at communication with business model stakeholders and manual analysis of networks with relatively stable boundaries. For OSSNs we seek the global and automatic re(construction) of possibly unknown service networks to enable the large scale processing of service information. A good starting point can be provided by the ontology-based methods for automated composition and verification of service value networks as supported by e3service (Razo-Zapata, De Leenheer, Gordijn & Akkermans (2012 b).

3.3. Hybrid Services

More recently, services are increasingly seen as hybrid entities that, albeit being invoked using a digital interface, can be fulfilled by a mix of human and automatic activities. Amazon's Mechanical Turk is a case in point. A web interface is offered to either provision or procure work in the form of HITs - Human Intelligence Tasks. Tagging images, finding specific information on the web, or translating a piece of text are examples of activities that, behind the digital facade, are carried out by humans. The involvement of people in processes had been previously addressed by BPEL extensions, such as BPEL4People, but new initiatives are emerging. The Social Compute Unit (Dustdar & Truong, 2012), aims at integrating people, in the form of human-based computing, and software services into one composite system. The Human Behavioral Modeling Language (HBML) is rooted on the belief that *a common framework for the systematic analysis of behaviors of people, networks and engineered systems is both possible and much needed* (Sandell, Savell, Twardowski, & Cybenko, 2009).

These advances are relevant for research on OSSNs, since this hybridity is typical in the global service economy.

4. SEVEN PRINCIPLES FOR COMMUNITY-BASED DESIGN OF OSSN

Open semantic service networks are structures created with the objective to sustain and power the digital representation, modeling and reasoning about business service networks. This overarching objective requires underlying assumptions and normative rules. Therefore, an OSSN and its construction are based on the following seven design principles:

1. **Service vs. Web Service:** A business, or real world, service is a system which aggregates, structures and configures people, resources, and information to create new value for consumers. On the other hand, a Web service is a computational entity and software artifact which is able to be invoked remotely to achieve a user goal. OSSNs encompass the former.
2. **Social Process:** The (re)construction of OSSNs is the result of a peer-to-peer social process. Firms, groups and individuals (i.e. the community) are equal participants which freely cooperate to provide information on services and their relationships to ultimately create a unique global, large-scale service network.
3. **Self-Governance:** OSSNs are the common good which the community tries to create by using forms of decision-making and autonomy that are widely distributed throughout the network. A service network is governed by the participants themselves, not by an external central authority or a hierarchical management structure.

4. **Openness and Free-Access:** The OSSNs created, being the elements of value created by the community, are freely accessible on a universal basis. Nonetheless, the individual authorship and contribution of services and relationships is recognized and is traced back to its originator.
5. **Autonomy and Distribution:** The participants (i.e. firms, groups, and individuals) of the community have the autonomy to advertise their know-how, capabilities and skills in the form of services to the world and to establish relationships with any other service. Services are distributed over space, time, and they come together to form new services as networks.
6. **Semantic Networks:** OSSNs are said to be semantic since they explicitly describe their services and relationships typically using a conceptual domain model, shared vocabularies, and ideally using Semantic Web standards and techniques.
7. **Decoupling:** Decoupling denotes that OSSNs are made of service descriptions and service relationships, but relationships are defined in isolation with respect to service descriptions. In other words, each relationship is specified independently without regard to any specific service description language, and vice-versa.

As our work advances we expect to adjust, generalize or specialize this initial list of seven design principles. To this end, we could adopt related work in other fields. E.g., De Leenheer, Christiaens, and Meersman (2010) devised six principles for community-driven ontology design that form the basis for Business Semantics Management. They can be partly mapped as follows to our principles for community-based service network design, that could ultimately frame a "Business Service Semantics Management" approach (coined by De Leenheer, Cardoso, & Pedrinaci, 2013). Principle 3 maps to *ICT democracy*, which states that "an ontology should be defined by its owning community, and not by a single developer". Principle 2 maps to *emergence*, i.e. "semantic interoperability requirements emerge autonomously from community evolution processes", and *co-evolution*, i.e., "ontology evolution processes are driven by the changing semantic interoperability requirements". These principles concern semantic interoperability requirements between data systems, but could be meaningfully repurposed for OSSNs with unanticipated service needs. Principle 4 maps to *perspective rendering*: "ontology evolution processes must reflect the various stakeholders' perspectives"; and *unification*, i.e., "in building the common ontology, relevant parts of the various stakeholder perspectives serve as input for the unified perspective". Finally, *validation* states that "the explicit rendering of stakeholders perspectives allows us to capture the ontology evolution process completely, and validate the ontology against these perspectives respectively".

5. APPROACH TO OPEN SEMANTIC SERVICE NETWORKS

As described previously, our long term goal is to develop rich, open service networks and this undertaking involves four main activities:

- **Service Modeling:** The creation of an ontology by identifying and modeling business service concepts. Semantic Web ontologies can be used to enrich service descriptions and to make the underlying information available to both humans and remote software applications.
- **Expressing Rich Service Relationships:** The creation of a model for specifying connections between services. The encoding of relationships needs to be rich, include business information, and be computer-understandable, allowing an automatic extraction and construction of service networks.
- **Populating Service and Relationship Models:** In order to enable a widespread use, there is the need to bootstrap service networks with up-to-date services and relationship instances. Crawling, Web

mining, and crowdsourcing are viable options to create initial service descriptions, traces about the created service networks, and service relationships inferencing.

- **Service Network Construction:** The construction of service networks, globally distributed, requires service models to be accessed, retrieved, stored and integrated. Therefore, new research on parallel approaches and scalable and distributed storage systems is indispensable.

In the following sections, we will describe in detail each activity.

5.1. Service Modeling

Due to the presence of mainly unstructured information about business services publicly available at corporates' Web sites, in business reports or academic studies (e.g., Kapuscinski, Zhang, Carbonneau, Moore, & Reeves, 2004), it is extremely difficult to identify anything substantial and significant about service models and relationships. The information available is unstructured (see for example (Frei, 2008)), does not comply to any common semantics, and is often not easily accessible. Therefore, our work targets to address these limitations and provide building blocks using service and relationship modeling for remote access and retrieval.

5.1.1. Describing Services with USDL

In the field of service modeling, we have been working on descriptions for business services. Our previous work has produced USDL (Cardoso et al., 2010), the Unified Service Description Language. In the past, only the quality of physical goods and products was primarily driven by adherence to manufacturing specifications. With the introduction of USDL there is a paradigm shift which sees that the quality of services can also be represented and controlled using guiding specifications. In general, service modeling suffers from an impedance mismatch between at least two modeling perspectives which USDL integrates into one specification:

1. The business perspective adopts a service-dominant logic to understand *why* and *how* enterprises should form networks on the service Web. Resource-service dynamics describes *what* resources have to acted upon by *whom* and *how*.
2. The ICT perspective adopts service-oriented modeling as a paradigm to automate business network interactions. Web service modeling aims at the interoperability of communication protocols (e.g., SOAP, REST) and data formats between heterogeneous *service parks*.

USDL bridges a business, an operational and a technical perspective. The language models service concepts and properties such as service level, pricing, legal aspects, participants, marketing material, distribution channels, bundling, operations, interfaces, resources, etc. It provides a comprehensive view on services.

5.1.2. Describing Services with Linked USDL

The initial version of USDL was ready in 2009. It was later renamed to α-USDL (pronounced alpha-USDL). Based on the experiences gained from α-USDL, a W3C Incubator group was created and USDL was adapted and extended based on industry feedback. This second version was finalized at the end of 2011. In order to make the specification gain a wider global acceptance, a version called Linked USDL[1] emerged using semantic Web principles and its development is still in progress. The term Linked USDL should not be confused with the idea that the language attempts creating relationships between services. The goal of Linked USDL is to develop an ontology to represent services by establishing explicit ontological links to other existing ontologies emerging from Linked Data initiatives. This is the reason for using the term *linked*. Linked USDL was designed based on Linked Data principles.

Linked Data is a relatively recent effort derived from research on the semantic Web, whose main objective is to generate a Web exposing and interlinking data previously enclosed within silos (Bizer, Heath, & Berners-Lee, 2009). From a technical perspective, Linked Data prescribes a set of principles that shall be followed when publishing data on the Web so that it is machine-readable, its meaning is explicitly defined, and it can be interlinked with other datasets.

Providing a global scheme for describing, exposing and trading services on a large scale as aimed by USDL, necessarily requires data interoperability at a large scale like the one promoted and supported by Linked Data. Thus, Linked USDL has taken on the ambitious goal of USDL by embracing Linked Data as the core means for capturing data about people, organizations, resources and services.

5.1.3. USDL and Service Networks

While Linked USDL has been initially constructed to describe business services, our analysis revealed in a preliminary study that it can be used to model services and service networks by adding rich, multi-level relationships. Linked USDL is suitable to support the concept of open service systems and makes service information accessible to remote and heterogeneous software applications which can retrieve and align service models into service networks for various exploratory uses.

At present, work done in the domain of service modeling, such as *-USDL service description languages, has tackled services as single atomic entities and groups of services (i.e. service bundles). Without additional research, these languages will lead to the construction of service marketplace silos where a wealth of information on economic activities will be available but with no information on service relationships. Without information on relationships between services available, it will not be possible to harness sufficient knowledge to construct service networks. The study and formalization of relationships is examined in the next section.

5.2. Expressing Rich Service Relationships

Our approach will connect service models hosted in marketplaces, corporate Web sites, and procurement systems using a computer-understandable format. The existence of tangible relationships between companies has been observed in a range of studies over the past 25 years, but the phenomena of service systems was discovered only recently (Håkansson & Ford, 2002). Nonetheless, its profound importance for society has already attracted a remarkable attention from academia and industry.

In order to develop a model for rich service relationships, research from the areas of business management and supply chain networks is required. For example, Weill and Vitale (2001) have introduced a set of simple schematics intended to provide tools for the analysis and design of business initiatives based on participants (firms of interest, customers, suppliers, and allies), relationships, and flows (e.g. of money, information, products, or services), which may provide a baseline for the work which needs to be done on service networks. The e3value and e3service approaches adopt a few dependency relationships that impede or enforce service configurations such as excluding, core/enhancing and optional bundling (Akkermans et al., 2004).

Nonetheless, relationships should be more expressive than simply establishing the added value of services when bundled together. Organizational, strategic, process and activity, social, KPI dependencies, and cause-effect relationships also need to be considered. Spohrer and Maglio (2010) defined the Initiate-Service-Propose-Agree-Realize (ISPAR) typology of interactions that may occur between service systems. Some of them are directly value-creating (such as proposing, agreeing and realizing the service), also called value interactions; while others are not qualified to create value (such as disputes). Analysis of interactions may give insights in the evolution of service systems. Since these research streams are relevant, it is indispensable to explore their use and applicability for service networks.

Open and rich relationships are very different from the temporal and control-flow relations found in business process models (e.g. BPEL, BPMN, Petri nets, EPC). Once constructed, they are open and can be freely and individually accessed and retrieved over the Web. They are rich since they relate two services using a multi-layer model which enables to indicate, for example, the role of services in a network (e.g. provider, consumer, competitor, or complementor), the strength of a relationship (e.g. high or low), if a service depends on another service for its survival, the comparison of two services based on the number and types of operations provided, and the types of resources transfered between services (e.g. data, knowledge, physical resources, or financial).

In Cardoso (2013) and Cardoso, Pedrinaci, and De Leenheer (2013), we addressed the modeling of service relationships. Our approach yielded a rich, multi-level relationship model – named Open Semantic Service Relationship (OSSR) model – from an extensive literature review process. The model is shown in Figure 2. Service relationships are very different from the temporal and control-flow relations found in business process models. They need to relate service systems accounting for various perspectives such as roles, associations, dependencies, and comparisons. After designing the OSSR conceptual model, it was evaluated and implemented. The encoding was based on Linked Data principles to retain simplicity for computation, reuse existing vocabularies to maximize compatibility, and provide a simple – yet effective – means for publishing and interlinking distributed service descriptions for automated computer analysis.

Finally, we note that there are two viewpoints on service networks, as depicted in Figure 3, where either:

1. **Service Descriptions are First-Class Citizens:** "service network is a set of services [descriptions] and their interrelationships" (as pointed out in Section 2). A service relationship is functional, i.e. it constraints possible networks by setting permitted and obligated interactions (hence events) between pairs of services in terms of business rules (cause-effect relations

Figure 2. The open semantic service relationship model

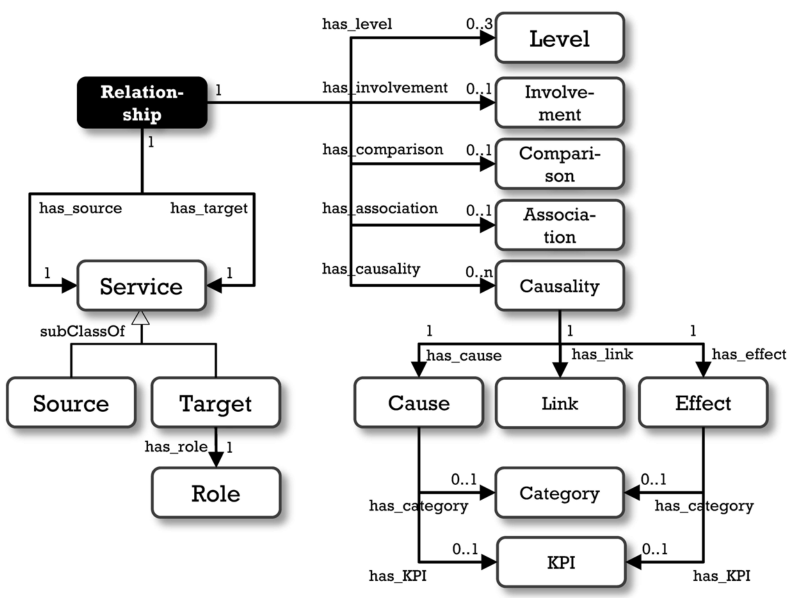
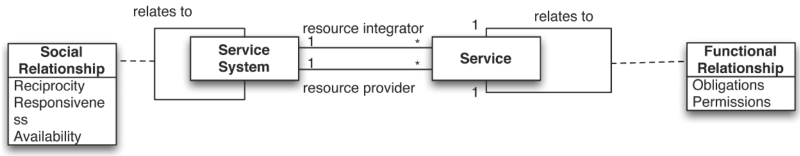


Figure 3. Service relationships



between existing services: e.g., Telephone service is core enhancing for ADSL-based internet service; if a car repair service is 5 days overdue then a requiting payment by the car owner is not required. It forms the basis to define temporal and control-flow connectors in the process view (Kapuruge, Han, & Colman, 2012). Work to integrate the business view into the process is found in Graml, Bracht, & Spies (2007). Most other work - such as Enterprise Service Bus and Service Component Architecture - does not capture relationships in this sense as entities on their own.

2. **Service Systems are First-Class Citizens:** "a service network is a team of peers [read: service systems] that establishes the necessary relationships to provide a service" (Lovelock & Wirtz, 2007). A relationship between service systems is social, i.e. it is defined by mutual social trust (e.g., responsiveness, reciprocity, availability based on collaboration history) and their (operand and operant) resources. The relationships constrain possible social interactions that (directly or indirectly) cumulate to the creation, commitment to, execution, and detention of (new) service offerings. This is a view agreed on by the Service Science community.

Either viewpoint is necessary to provide a complete description of social relationships between service systems and functional relationships between the services they offer. For reasoning purposes, service networks nodes and relationships have to be further ontologically analyzed to allow for conceptual hierarchies (part-of, is-a) between them. Yet for service innovation the latter is the most important because it is not restricted to existing services. If a new need emerges, it is up to the service systems to exploit their social relationships to fill actual gaps in the current functional relationships. Further we have to define service encounters as meaningful grouping of interactions where providers engage with the end-user hence leads to the service. Quality of service delivery can be measured by assessing each of the interactions between service systems using the previously mentioned ISPAR model.

5.3. Populating Service and Relationship Models

When we think about applying the open service network concept at a global scale, a thorny question immediately arises: "how will service and service relationship models be created? ". This aspect is important since to enable a widespread usability of service networks there is the need to bootstrap up-to-date services and relationship instances. Previous approaches typically collected business data manually from survey firms, teardown reports or on-site analysis (e.g. Dell supply chain analysis (Kapuscinski et al., 2004) and Apple's iPod networks (Linden, Kraemer, & Dedrick, 2009). Although, these techniques have punctually been successful, they cannot scale to study global service networks given the size and dynamicity of the environment.

5.3.1. Populating Service Models

A first and direct (semi)automated approach to populating service models will rely on the aggregated combined input by different users. On the one hand, service providers are likely to see the interest in providing machine interpretable descriptions of the services they offer in an attempt to improve the accuracy of dedicated search engines in locating their offers. This process, which is already well underway for product description using GoodRelations, will rely on the (semi)automated annotation of existing providers databases by their own IT departments. Additionally, dedicated service search engines focused on locating and supporting advanced search of services on a Web-scale will accelerate this process providing indirect incentives for the publication of machine processable descriptions of services.

Automated methods, e.g. by using Web crawlers combined with data mining and scraping techniques (Baeza-Yates & Ribeiro-Neto, 2011), can crawl unstructured service descriptions from corporate Web sites and marketplaces (e.g. ServiceMagic.com, Sears' ServiceLive.com, ServiceAlley.com, and Redbeacon.com), in order to automatically create models on-the-fly. These techniques have been successfully applied to other domains and we have ourselves carried out experiments on harvesting service descriptions from an online catalog containing e-learning services (Razo-Zapata, Gordijn, De Leenheer, & Akkermans, 2011).

We also believe that the application and adoption of the aforementioned techniques will be accelerated in a rather autonomous and transparent manner by the network effect leading to the snowballing process described by Carter, Ellram, and Tate (2007). Notably, as the number of rich service descriptions being available online will grow, the need for providers to generate rich descriptions in order to be found by potential customers will increase exponentially in a similar way to what occurred with the creation of companies Web sites in the early days of the Internet. This growth in terms of publicly available rich service models would be a solid basis on top of which open semantic service networks may be able to flourish.

5.3.2. Populating Relationship Models

We anticipate that the population of rich service relationships leading to the of emergence open and complex service networks will also be achieved by combining a range of automated and manual techniques. In the simplest form, firms may wish to identify suppliers, involved partners and other stakeholders to ensure their customers are aware of the provenance and quality of the services provided. This may in certain circumstances even be required by governmental regulations for particularly sensitive cases like, for instance, investment services. This simplest form of network population will be complemented by automated data mining and machine learning algorithms applied over the existing descriptions of services and providers as well as over the logs tracking user's behavior. Applying these techniques at different levels of abstraction exploiting the plethora of information on the Web would allow the automated characterization of services, companies, and users which shall in turn serve as a basis for automatically populating service networks on the basis of rich relationships as those introduced earlier on.

One such case that we anticipate is the use of content analysis techniques for profiling services and companies (e.g., using open content from sources like OpenCorporates.com). On the basis of this characterization it shall be possible to identify similar services (e.g., using document similarity techniques as in Baeza-Yates & Ribeiro-Neto (2011)), identify similar companies, and exploit both kinds of information to figure out and capture the existence of similar or competing services for future exploitation. This kind of information would certainly be most valuable for potential customers as it would allow them to locate similar services, in a similar way that online shops use content-based recommendation (Resnick & Varian, 1997). It would additionally allow companies to identify potential competitors which in turn would presumably encourage further innovation and an evolution in service offerings in search for gaining a competitive advantage. More advanced analysis could also involve the mining of recurrent service bundles across different providers to identify things like, e.g., that a typical bundle offering is "Internet + Telephone + TV". Analyzing these bundles would allow to scale the analysis of service similarity beyond atomic services and it would also enable the identification of similar services not previously identified or services belonging to the same category. For instance, one may be able to figure out that a new service is actually a newer kind of Internet connection service or simply a newer telecommunication service in general, by realizing that it is bundled frequently with the Telephone and TV services.

5.4. Service Network Construction

Once service and relationship models are populated and published as Linked Data (see previous section), the access and retrieval of distributed models from the Web require parallel approaches to fetch service and relationship models and distributed solutions to store and (re)construct service networks. We will achieve scalability by merging two state-of-the-art developments resulting in a novel crawling and storage system. We will couple LDSpider (Isele, Umbrich, Bizer, & Harth, 2010), which provides load-balancing capabilities, with the Sesame RDF repository (studies have shown that Sesame and Virtuoso are some of the fastest semantic-based repositories).

On the one hand, LDSpider – an extensible Linked Data crawling framework – can enable to traverse and to concurrently consume distributed service models. LDSpider will need to be extended to implement specific crawling strategies. For example, new crawling algorithms that consider only specific types of rich service relationships and domain specific business knowledge to retrieve models can be designed and implemented to increase efficiency.

On the other hand, there is the need to extend current RDF repositories, such as Sesame, using similar approaches to the one followed in Schwarte, Haase, Hose, Schenkel, and Schmidt (2011), i.e. by applying a federation layer as an extension to Sesame. Several other approaches for storage, such as Jena SDB, are used in conjunction with a traditional DB like MySQL to provide a triple store. These approaches are inefficient since they provide costly mechanisms specific to databases which are not necessary for RDF stores (e.g. multiuser, table-orientation, primary and secondary keys, etc.). Furthermore, service discovery requires transforming customer needs into concrete service offerings and should not rely on traditional low level querying mechanisms to express desired services.

Having this infrastructure and machinery in place, service networks can be discovered and become accessible as massive distributed information systems which enable the development of efficient algorithms to analyze, mine, reason and optimize service networks. In Cardoso, Pedrinaci, and De Leenheer (2013), we demonstrated that Linked USDL and OSSR can be used in conjunction to model dynamic behavior. The evolutionary and analytic analysis of dynamic OSSN are promising since they constitute the first stepping stones for the development of algorithms to simulate and understand service-based economies.

6. CURRENT INITIATIVES AND APPLICATION FIELDS FOR OSSN

While the main motivation scenario from Section 2 was drawn from financial networks, here we show the potential use of OSSNs in other domains. A number of running projects are using Linked USDL for various applications which have their own characteristics and requirements for service descriptions. Namely, we will look into two projects: FI-WARE (http://www.fi-ware.eu/) and FINEST (http://www.finest-ppp.eu/). These initiatives already use Linked USDL and constitute application fields for OSSNs.

Many other projects, such as MSEE, OUTSMART, Value4Cloud, Deutsche Digitale Bibliothek, Broker@Cloud, and TRESOR, are currently building on top of Linked USDL for service description and greatly helped us to validate our approach in different domains.

6.1. The FI-WARE Project

The FI-WARE project, part of the EU Future Internet PPP program, aims to deliver a service infrastructure which offers reusable and shared functionality for service oriented businesses in the cloud. The *Application and Services Ecosystem and Provisioning Framework* focuses on business aspects of service ecosystems such as describing and exposing services, aggregation and composition, service marketplaces, business models, execution and revenue sharing. Open semantic service networks are a valuable concept which provides a new dimension to analyze, control and innovate business models out of existing services and their relationships.

For marketplaces, OSSNs provide a rich knowledge base to derive information for service discovery and matching offering and demand. Because a service is connected to other services and other business elements (providers, suppliers, partners, competitors, etc.) via a OSSR, the marketplace can utilize this information to achieve a more effective matchmaking. Since FI-WARE marketplace provides a wide range of functionalities, it can advance beyond matching and improve, for example, recommendations, ratings, market intelligence, and price calculation support. OSSNs can also constitute the underlying distributed model for SAP's Business Web to combine services from cloud providers, telecommunication carriers, and application and content providers, and serve as a network mirroring mobile business on the Internet.

6.2. The FINEST Project

The FINEST project is aiming to support the transport and logistics (T&L) ecosystem, in which many service providers collaborate in order to transport goods over a consecutive chain of different legs. The main challenges in the transport and logistics domain are:

- Reduce logistics costs,
- Increase customer responsiveness,
- Achieve profitable growth,
- Increase working capital efficiency,
- Improve quality, and
- Reduce order to delivery cycle.

In order to achieve these goals, it is necessary to improve business processes within service network ecosystem. One of the cornerstones of a future logistics platform is to increase the degree of automation in planning, monitoring, resource management, and collaboration. For instance, in the planning phase it is necessary to support searching and matching transport service offerings. Consequently, one of the major challenges is to make transparent offerings and capacities in a globally uniform way. The FINEST consortium has chosen Linked USDL as a basis for the description and publishing of transport and logistics service offerings in their platform.

The power of the Linked Data approach followed by Linked USDL enabled FINEST to extend and combine the core USDL service vocabularies with dedicated T&L vocabularies covering specific transport and logistics aspects and link them via the basic concepts of Linked USDL for describing non-functional service properties, pricing and service level models. The benefit is that the generic enablers for service repository, marketplace services, composition and mashup could be used for the FINEST T&L platform and easily adapted to the this domain.

In order for the FINEST T&L platform to support the concept of OSSN, it is required to model service relationships between the service systems provided by stakeholders. This translates into using the OSSR model to create relationships between planning companies, tendering agencies, consignees, transport companies in different countries, freight forwarders, carriers, warehouses, harbors, port authorities, shippers, customs, and more. These relationships can identify the role of the service systems involved in a relationship, the level (e.g. activity, resources, or people) at which a relation is established, the strength of a relationship, and the comparison of service systems involved in a relationship (Cardoso, 2013).

7. CONCLUSION

Networks have been playing an increasingly important role in many fields. The Internet, the

World Wide Web, social networks, and Linked Data are examples of some of the myriad types of networks that are a part of everyday life of many people. Service networks are another class of networks of emerging interest since worldwide economies are becoming increasingly connected and service-oriented. This article presented methodological, conceptual, and technological foundations to create a worldwide Open Semantic Service Network. This global scale network present an entirely different class of challenges not faced by the large body of prior work on services. The primary challenge stems from the fact that currently business services' information is often hidden in unstructured marketplaces and corporate Web sites, and no information about service relationships between services is available. Therefore, to construct service networks, four premises need to be fulfilled. First, the information on service systems needs to be open and remotely accessible. Second, service models need to be related using rich, open semantic service relationships to handle the heterogeneity of the Web and business industries. Third, the construction of service networks by using rich relationships needs massively parallel platforms for querying, integrating, and aligning service models. Finally, algorithms, simulation, and analytic methods need to be in place to understand, describe, explain, analyze, predict, and control the evolution of global service networks over time.

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ENDNOTES

1 www.linked-usdl.org