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Open Semantic Service Networks: Modeling and Analysis

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Abstract. A new interesting research area is the representation and analysis of the networked economy using Open Semantic Service Networks (OSSN). OSSN are represented using the service description language USDL to model nodes and using the service relationship model OSSR to model edges. Nonetheless, in their current form USDL and OSSR do not provide constructs to capture the dynamic behavior of service networks. To bridge this gap, we used the General System Theory (GST) as a framework guiding the extension of USDL and OSSR to model dynamic OSSN. We evaluated the extensions made by applying USDL and OSSR to two distinct types of dynamic OSSN analysis: 1) evolutionary by using a Preferential Attachment (PA) and 2) analytical by using concepts from System Dynamics (SD). Results indicate that OSSN can constitute the first stepping stones toward the analysis of global service-based economies.

Key words: open services, service systems, service networks, system dynamics, services

1 Introduction

Networks have been playing an increasingly important role in many fields. The Internet, the World Wide Web, social networks, and Linked Open Data (LOD)[1] 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.

To address the growing importance of service systems, we have introduced the concept of Open Semantic Service Network (OSSN)[2]. OSSNs are global service networks which relate services with the assumption that firms make the information of their service systems openly available using suitable models. Service systems, relationships, and networks are said to be open when their models are transparently available and accessible by external entities and follow an open-world assumption. The objective of open services is very similar to the one explored by the linked open data initiative: exposing, sharing, and connecting pieces of data and information on the Semantic Web using URIs and RDF.

One limitation of OSSNs is that they were conceived without accounting for the dynamic behavior of service networks. In other words, they can only capture static snapshots of service-based economies. In this paper, our objective is to bridge this gap by bringing dynamic modeling capabilities to OSSNs. Our approach explores the General System Theory (GST)[3], a theory successfully applied in many fields of research (e.g. by John Von Neumann in computing and Ed Yourdon in structured analysis and structured design), to identify important requirements to model dynamic service networks. From these requirements, we studied the suitability of using USDL[1] (Unified Service Description Language) [4, 5, 6] and OSSR[2] (Open Semantic Service Relationship) [7] to represent dynamic service networks. USDL is a language which provides machine-processable descriptions for service systems. With the introduction of USDL there is a paradigm shift which sees that business services can be represented and controlled using guiding specifications. OSSR systematizes key elements to establish rich relationships between service systems such as the role of services (e.g. consumer, competitor, and complementor), the strength of relationships, and the level at which service systems are related (e.g. activities and actors).

Based on our study of GST, both USDL and OSSR models were extended with primitives to capture the dynamic behavior of open semantic service networks. Three extensions were identified: 1) attractiveness, 2) cause-effect relationships, and 3) time bounding. We validated our approach with two scenarios. One was based on an evolutionary analysis using a Preferential Attachment (PA)[8], while the second used System Dynamics (SD)[9] to forecast the behavior of an OSSN. The relations between the various theories and models explored in our work are illustrated in Figure 1. Our findings suggest that current developments – such as USDL, OSSR, and OSSN – have reached a maturity stage which enables the implementation of algorithms and simulation models to gain insights on the evolution of global service networks.

This paper is organized as follows. In the next section, we describe a motivation scenario for the application and relevance of open semantic service networks. Section 3 presents the related work. Section 4 describes the set of requirements which was identified after analysing the GST that is relevant to support dynamic service networks. Section 5 highlights the limitations of USDL and OSSR to model dynamic networks. Section 6 presents the extensions made to USDL and OSSR. Section 7 evaluates our approach by analysing dynamic networks using evolutionary and analytical methods. Section 8 provides the conclusion.

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[1] When not otherwise stated, we will use the term USDL to refer to the service description language version named Linked-USDL (`http://linked-usdl.org/`).

[2] `http://rdfs.genssiz.org/ossr.rdf`

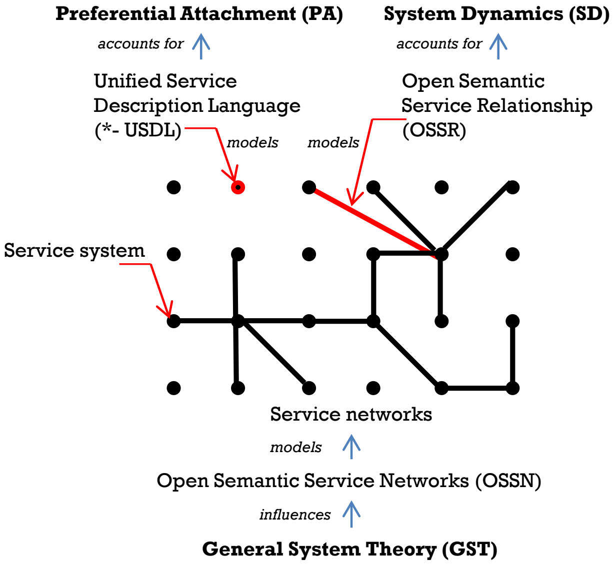

Fig. 1. Relations between theories (GST, PA, and SD) and service/relationship modeling languages (USDL and OSSR)

2 Motivation Scenario

A *service network* can be defined as a graph structure made up of service systems which are nodes, connected by one or more specific types of relationships. A *service system* is a self-contained representation of a repeatable business activity which typically aggregates people, processes, resources, consumables, regulations, and equipment that together create value to both consumers and providers. A service system can rely on other service systems to operate and are connected and interact via value propositions and shared information (language, laws, measures, etc.). Interactions that occur can be between people, information systems, businesses, or even nations.

The dynamic nature of service networks indicates that their topology might be shaped according to some intrinsic property, e.g. service cost, availability, or extrinsic property, e.g. perceived customer preference. This dynamic behavior has been verified in many fields. For example, the world-wide web forms a large directed graph with an apparent random character. Nonetheless, the topology of this graph has evolved to a scale-free network [10] by preferential attachment [8], i.e. when establishing hyperlinks, documents prefer the 'popularity' of certain documents (of 'popular sites') which overtime become hubs.

In service networks, we can hypothesize that a similar mechanism to the one describing the evolution of the web can also explain their evolution. Service networks are appropriate models of networked societies whereby consumers adopt a service system on the basis of its value proposition (e.g a preferential attachment) since it was argued that networks are an implicit element of a service-dominant logic [11]. Thus, the competition between one type of network node, the providers, for the attention of another type of node, the consumers, mediated by a preferential attachment drives an emergent dynamic process that eventually leads the service network to some stable fixed point, to a cyclic, time-varying topology, or to a chaotic, unknown structure or stochastic pattern. Finding the mechanisms, laws, and properties of dynamic service networks can enable to better understand and explain why some service networks survive, prosper, decline or die.

3 Related Work

e^{3}service and e^{3}value [12, 13] provide ontologies to represent e-business models, services, and the value exchanged within companies. The e^{3}value model places emphasis on wants, benefits, needs, and demand. Nonetheless, to model networks, a more detailed description of services is needed and should include aspects such as pricing, quality levels, and legal constraints. On the other hand, e^{3}service targets to represent very simple relations between services from an internal perspective, e.g. core-enhancing, core-supporting, and substitute. From an external perspective, the value chains proposed do not capture explicitly service networks across agents and do not try to analyse quantitatively the effect of relationships. Therefore, service network analysis is not possible. The e^{3}service and e^{3}value approaches fail to adhere to service-dominant logic and focus too much inward the company instead of the large-scale network they belong to.

In [14], the authors look at service networks from a Business Process Management (BPM) and Service Oriented Architecture (SOA) perspectives, and present the Service Network Notation (SNN). SNN provides UML artifacts to model value chain relationships of economic value. These relationships take the form of what we can call 'weak' relationships since they only capture offerings and rewards which occur between service systems. The focus is on composition, processes, and on establishing how new services can be created using BPM to describe the interactions of existing SOA-based services. On the other hand, OSSNs are not compositions of services, but rather a description of how services relate to each other in service markets.

Allee [15] uses a graph-based notation to model value flows inside a network of agents such as the exchange of goods, services, revenue, knowledge, and intangible values. The approach only takes into account value flows and does not consider other types of relationships that can be established between agents. Furthermore, the automatic machine-processing of services and flows was not a concern, hence limiting the applicability of the approach to the analysis of distributed large-scale networks.

While less related to our work, a number of researchers worked on formalizing models to capture business networks which also account for the representation of relationships. For example, Weiner and Weisbecker [16] describe a set of models addressing value networks, market interfaces, products and services, and financial aspects. Other research on value chains, value nets, and value networks (see [17]) all attempt to represent business transactions using networks. Nonetheless, the emphasis is on textual or conceptual representations and the automatic machine-processing of networked models is not explored.

4 Theoretical Foundations

Due to its wide applicability to various domains, we used the General System Theory as a guiding framework to represent service systems and networks. We first analysed the properties proposed by the GST, i.e. wholeness, interdependence, hierarchy, self-regulation and control, interchange with the environment, balance/homeostasis, change and adaptability, and equifinality. Our analysis identified three important requirements: internal service relationships (`R1`), external relationships with other service systems (`R2`), and system dynamics and change (`R3`).

Internal Relationships (`R1`). A service modeling language needs to establish cause-effect relations between the internal elements of the machinery of a service system that range from participants, to information, to resources, to legal aspects, and to pricing. These elements are interdependent. For example, a change in the quality level of one activity of a service's business process can produce changes in the cost of another related activity.

External Relationships (R2). A comprehensive modeling requires facility in establishing cause-effect relations between internal- and external service systems. For example, if two services have established a relationship at the operational level and one service depends on the other, then the quality level delivered by one of the services depends on the quality level of the other.

Understanding Change (`R3`). To ignore the centrality of change overtime is to limit the modeling of service networks as snapshots that are alienated from reality. Time needs to be an integral modeling element. Another aspect is the attractiveness of a service (see Chapter 10 of [18]). It is relevant since it has been shown in other areas (e.g. the Web, business, and social networks) that a network may grow by adding relationships - not randomly, but by attraction or preference [8] to certain nodes.

5 Modeling Service Networks and its Limitations

In our second activity, we made a literature review to investigate if existing work could be used to model service systems and service networks.

5.1 Service Modeling with USDL

Our research reviewed existing work from software-based service description languages (e.g. OWL-S, WSMO, SoaML, SML, SaaS-DL), business-oriented service descriptions (e.g. ITIL and CMMI for Services), and conceptual and ontology-based service descriptions (e.g. e^3service [12], General Service Model [19], and Alter [20]). Our analysis yielded that, compared to previous developments, USDL provides a comprehensive model and a base to represent service networks for the following reasons (see Section 3 for a deeper comparison):

- It models the business, operational, and technical perspectives of service systems enabling to reason about the influence of pricing models, legal constraints, quality levels, business processes, and agents on service networks' dynamism.
- A version of the model based on Semantic Web principles, called Linked-USDL, was developed to provide the means for publishing and interlinking distributed services for an automatic and computer-based processing.

Nonetheless, requirement `R1` identified in Section 4 is not supported. In other words, internal *cause-effect relationships* are not currently modeled with USDL. We propose to model them using KPI (Key Performance Indicator) as often recommended by ITIL and COBIT best practices, and suggested by Spohrer et. al. in [21]. Our idea is expressed in the following example. Two services – s_a and s_b – may establish a cause-effect relationship at the process level between the KPI `error_rate` of a process of service s_a with the KPI `redo_cost` of a process of service s_b. When a positive variation of the KPI of s_a occurs, it can be inferred that it will provoke an effect on the KPI of service s_b. In other words, an increase of the number of errors in s_b originates an increase of cost in s_b. This is an important aspect since a service network is more than the sum of its parts only if the internal and external 'wiring' of services are established. To support requirement `R3`, and since *time-bounds* are a central variable in system theory and provides a referent for the very idea of dynamics, we propose an extension to USDL by using the formal time ontology proposed by Pan and Hobbs [22]. With respect also to requirement `R3`, since the concept of attractiveness [18] of a service may dictate the emergent topology of a network, we model this construct by allowing service systems to state their *attractiveness* to serve as the selecting rule (this is explained in Section 6).

5.2 Relationship Modeling with OSSR

As with the Web and the Semantic Web, the power of service systems is enhanced through the network effect produced as service systems create relationships to other service systems with the value determined by Metcalfe's law [23]: *the value of a network is proportional to the square of the number of connected service systems (n), i.e.* n^2. Our research also reviewed various proposals including value chains/nets/networks [17], and the service network notation [14] to evaluate their suitability to model service networks. Most work focuses on the business aspects of industries and do not take a close look at relationships. They are simply viewed as connecting elements which represent offerings and transactions. Furthermore, the modeling approaches are informal and, often, used as a communication tool.

What is needed is to be able to represent and identify richer relationships between services. This requirement goes well beyond what is offered by current approaches. While other types of relationships are also important, e.g. between services and actors, we follow the service-dominant logic [11] principal and consider that any other type of relationship is always mediated by services. This simplifies the construction and analysis of a network since all the nodes are homogeneous, i.e. they are services. Therefore, relations can occur between the actors that operate inside two service systems connected by a relationship.

We adopted the OSSR model, a multi-layer relationship specification composed of five layers: 1) role, 2) level, 3) involvement, 4) comparison, and 5) association. The model enables to interconnect services and indicate the properties of the connection. For example, it enables to indicate that two services maintain a relationship and one service is the consumer while the other is the provider. It also enables to indicate if a relationship represents a high or low involvement from its actors, or if a service is functionally dependent on another service.

While rich and comprehensive, a limitation of OSSR is that it does not model *cause-effect relationships* between services (requirement `R2`). To resolve this limitation, and to be consistent with the way we have addressed requirement `R1`, we rely on KPIs. For example, if a provider is competing by providing an efficient service, then internal KPIs related with activities' duration should be linked to KPIs of the same type present in other services of the same network. In other words, internal KPIs must be related to the KPIs of other service systems when forming service networks. Requirement `R3` will also be addressed by including the modeling of time in relationships indicating that they are often *time-bounded*.

6 Modeling Dynamic Behavior

Based on the limitations identified in Section 5, we present three extensions to USDL and OSSR to model dynamic OSSN: 1) attractiveness, 2) cause-effect relationships, and 3) time bounding.

The attractiveness or preferential attachment is expressed by adding to USDL the concept `usdl-core:ValueProposition`. It allows service systems to state their value proposition by using a single KPI or a mathematical expression involving several KPIs. If should be noticed that more complex structures have been proposed (see [24]) to model a value proposition. Nonetheless, in our work, we are particularly concerned in showing that value propositions are a corner stone to simulate service systems dynamics rather than showing the completeness of value proposition. Therefore, we opt to explore the utility of measurable value propositions.

While USDL does not foresee the definition of KPIs, its model is organized into several clusters (e.g. service level and pricing) which provide a wealth of variables which can be used as KPIs. For example, service level and quality of service variables such as availability, reliability, and response time. The value proposition can refer to existing USDL concepts such as `usdl-price:Variable`, `usdl-sla:Variable`, `usdl-core:Parameter`, or to construct complex expressions using `usdl-sla:ServiceLevelExpression`. The calculation of the expression yields the value proposition. While the addition of a single concept to USDL seems simple, its implications are enormous. Preferential attachments [8] have been shown to be the main distinguishing feature which leads random networks to evolve into scale-free networks in particular domains such as the Web or social networks [10]. Thus, we can hypothesize that it can potentially be also a key factor which influences and determines the topological evolution of service networks.

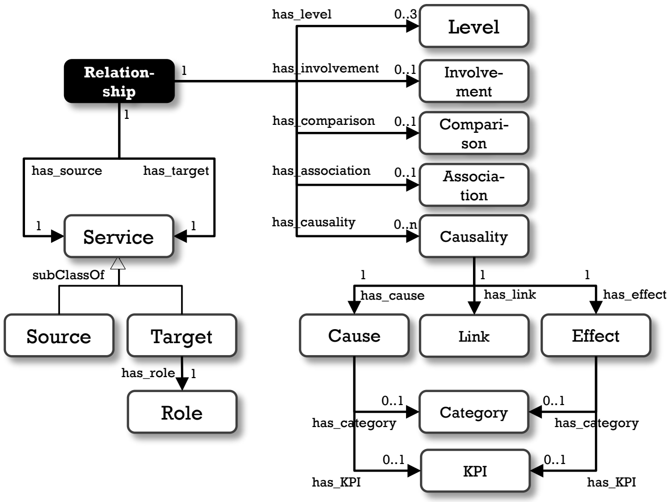

Fig. 2. The structure of the OSSR model

To model cause-effect relationships, we use the concept of causality from the area of System Dynamics (SD) [9] to express and quantify the impact that one service has in other services. Internal and external relationships of an OSSN are specified using the concept `ossr:Relationship` of the OSSR model (Figure 2). This concept involves the definition of two endpoints: the source service and the target service (for readability reasons, the prefix `ossr:` will be omitted from now on). When modeling an internal relationship, both source and target refer to the same service. A `Relationship` can capture several relations by using the concept `Causality` more than once. The concept can be thought as a 'wire' connecting two internal or external service system KPIs described with USDL. The concept

`Causality` describes how a `Cause` event occurring in a service has an `Effect` in the same or in another service. The concept `Link` connects two KPIs and sets the sign of the link: `Positive` or `Negative`. A positive link indicates that a change in a service KPI (increase or decrease) results in the same type of change in another service KPI (increase or decrease). A negative link indicates that a change in a service KPI results in the opposite change in another service KPI. KPIs are described within the concepts `Cause` and `Effect`. For example, if a service provider uses Invoice Reliability as a KPI to control the quality of a service, it can be connected to the Response Time Delivery KPI of a service customer. An increase of the first KPI originates an increase in the second KPI since errors in the invoice require time to be resolved.

Since KPIs are often domain dependent and their semantics may not always be clear to analysts, individual measures of performance in a cause-effects relation are classified by the concept `Category` in one of five elements (c.f. [25]): quality, time, cost, flexibility, and other. The category 'other' was added to make the classification complete.

Time, one of the aspects identified by requirement `R3`, was modeled by using the time ontology `http://www.w3.org/2006/time` by adding the class `time:Interval`. This class contains the properties `time:hasBeginning` and `time:hasEnd` to define the beginning and the end of an interval in which a service specification is valid. While it is a simple concept, the time ontology provides a powerful mechanism to reason about the dynamics of service networks.

7 Evaluation of Dynamic OSSN

In this section, we evaluate the applicability of the extensions proposed to USDL and OSSR to model dynamic OSSN by using evolutionary and analytical approaches. The evaluation addresses the following two competency questions: 1) for a current service market share, what is the service market share forecast and 2) what is the effect that an increase of KPI_a, in service s_a, has on KPI_b of service s_b?

7.1 Evolutionary Analysis of OSSN

In many scenarios, a service network contains two different types of service nodes: service consumers and services provided. Note that in our work customers are also seen as service systems. The network is bipartite and is represented by SN, such as $SN(t) = \{S(t), C(t), R(t), f(t)\}$, where $S(t)$ is the set of services provided, $C(t)$ is the set of service consumers, $S(t)$ and $C(t)$ are modeled with USDL, $R(t)$ is the set of relationships modeled with OSSR connecting consumers and services provided, and $f(t)$ is the mapping function $f : C \rightarrow S$. Network SN is directed, such that a relationship from consumer node c_i to service node s_j; $r : c_i \rightarrow s_j$, means that c_i has adopted service s_j. Time is represented by parameter t. Customers alter the topology of a service network by diffusion when they adopt or abandon a service by adding or deleting an OSSR relationship to it.

To construct a service network SN, USDL and OSSR models are remotely accessed and retrieved (an overview description of the infrastructure to access and retrieve USDL and OSSR instances is described in [2]). OSSR models are mapped to relationship $R(t)$ and functions $f(t)$. By retrieving the `ossr:Role` concept of a relationship $r : c_i \rightarrow s_j$, the concepts `ossr:Source` and `ossr:Target` point to the USDL models to be mapped into services provided $S(t)$ and consumers $C(t)$.

The USDL model of each service system contains a value proposition communicated to customers (i.e, the attractiveness elements or preferential attachment). Service value is judged from the perspective of consumers as they compare services among the alternatives. For simplicity reasons, we assume that the value proposition is similar for all service systems and it is the `price` of the services calculated from a `usdl-price:PricePlan`[3].

Since our objective is to forecast the evolution of a service network over time, we use the following function to calculate the Market Share of each service provided $MS(s_i) = degree(s_i)/m$; where $degree(s_i)$ is the number of relationships established by service s_i with service consumers and m is the total number of relationships established between providers and consumers. Overtime, customers change preferences by changing from one service system to another service system. To monitor these changes in an OSSN, OSSR need to be regularly accessed and retrieved (since OSSR have a validity time stamp, optimization mechanisms can be implemented to reduce traffic and increase algorithms' efficiency.)

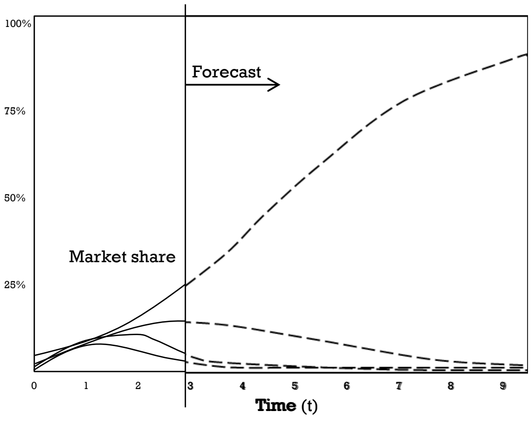

Fig. 3. Service market share evolution overtime

Let us assume that the (re)constructed SN topology shows that overtime the market share is the one represented in Figure 3 at $t = 3$. The question to

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[3] For simplicity reasons, we consider that each service has only one pricing plan.

be answered is: what will happen to the market in the future if the conditions are not changed (i.e. the value propositions of s_i remain the same and $m \ngtr c_i$). According to Bass model [26], the leading service system will reach a fixedpoint market share according to the following formula (a and b are constants):

$$MS(s_i, t) = \frac{1 - e^{-bt}}{1 + ae^{-bt}}; 0 \leq t \leq 9 \tag{1}$$

Figure 3 illustrates that from the four services provided, three also rise in market share during the early stages, reach a peak, and then decline as the service leader accelerates because of the increasing returns effect of preferential attachment. In this case, all but one service provided leaves the market, leaving one monopoly competitor. Such network forecast evolution is of utmost importance for regulatory bodies such as the European Commission which routinely passes directives for various markets to avoid monopolistic markets.

7.2 Analytical Analysis of OSSN

In our second evaluation, we explored the suitability of dynamic OSSNs to model system dynamics. Instead of looking at causes and their effects in isolation, we analyse service networks as systems made up of interacting parts (see Section 6). Once an OSSN is created from distributed service models, cause-effect diagrams can be derived for the network. For example, Figure 4 shows service systems S_i, S_j, S_k, and directed edges illustrating internal and external relationships.

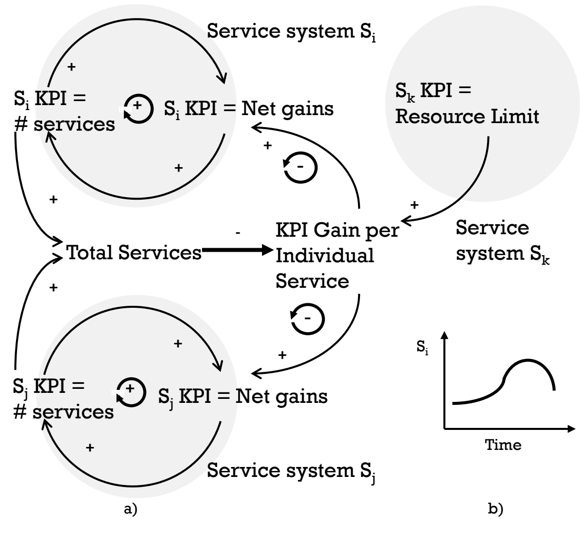

Fig. 4. Service networks and system dynamics

Looking closer, causal relationships connect KPIs from different services' and within services. The pattern represented by this OSSN is commonly known as the 'Tragedy of the Commons' archetype. It hypothesizes that if the two services S_i and S_j overuse the common/shared service S_k, it will become overloaded or depleted and all the providers will experience diminishing benefits. Service S_i and S_j provide services to costumers. To increase net gains, both providers increase the availability of service instances. As the number of instances increases, the margin decreases and there is the need to increase even more the number of instances available. As the number of instances increases, the stress on the availability of service S_k is so strong that the service collapses or cannot respond anymore as needed. At that point, service S_i and S_j can no longer fully operate and the net gain is dramatically reduced for all the parties involved as shown in Figure 4.b).

To better understand the dynamics and the structure of the service network, the notions of stock and flow diagram, and causal loop diagram should be accounted for. They provide the basis for the quantification and the simulation of the behavior of the service network overtime. We refer the reader to [9] for a detailed description of dynamic systems and their representation.

While a deeper evaluation needs to be conducted, this first results show that the modeling of cause-effect relationships using the extensions proposed provides the required mechanism to execute an analytical analysis of dynamic OSSN.

8 Conclusions and Future Work

While network science has made contributions in the areas of social networks and the WWW, the concept of service networks is recent and presents new challenges. They are large scale, open, dynamic, highly distributed, and have the ambitious goal to model worldwide service-based economies. In this paper, we relied on the General System Theory to identify requirements to develop dynamic open semantic service networks (OSSN), an important extension to static OSSN. Requirements related to internal and external relationships between services, and change suggested that current models to represent networks should be extended. Therefore, we adapted the Unified Service Description Language (USDL) and the Open Semantic Service Relationship (OSSR) model to enable the representation of dynamic service networks. To demonstrate that the extensions to USDL and OSSR indeed enabled to model dynamic behavior, we evaluated their applicability to carry out an evolutionary and analytical analysis of dynamic OSSN. The results are promising since they constitute the first set of stepping stones for the development of algorithms to simulate and understand service-based economies.

For future work, we plan to complement the analysis of the GST with the analysis of the Viable System Model (VSM), proposed by Stafford Beer, to provide an additional theoretical conceptualization for OSSN. We also plan to conduct a more comprehensive validation by creating a working example to illustrate the applicability of the OSSN model and apply it in form of a case study with primary data. Action research will provide the foundations for validation and establishing a warranted belief that the OSSN model can contribute to the understanding, analyse, and design of service systems.

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