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VIRTUAL ORGANIZATIONS – CONCEPTUAL MODELLING

DUMITRU RĂDOIU

ABSTRACT. Although there is a vast literature on virtual organizations (VO), there's little agreement on this subject from the definition to the reference model. Explanation seems to be the lack of a consistent, easy to operate with and largely accepted definition and the absence of a framework to build useful conceptual models, based on formal theories. The present paper, presents an axiomatic, easy to operate with VO definition, the outline of VO concept modelling and a theorem supporting the idea that a consistent VO conceptual model must be backed up by a non-trivial formal theory (T). Empirically derived models – based on interpreting and generalising available "experimental" data - might lead to valid VO models but in the end, formalism (i.e. just formal description) cannot substitute formal theory.

Keywords: Virtual organization, conceptual model, formalism, formal theory

1. VO conceptual models

A VO conceptual model is a theoretical construct, an idealized logical framework, representing VO through a set of logical and mathematical objects (e.g. axioms, formulas, functions, processes). A conceptual model is explicitly chosen to be independent of implementation details. The value of a solid conceptual model is in the easiness of reasoning about VOs making it an important component of any scientific research. Reasoning on VOs with models is determined by a set of logical principles and regards a large spectre of aspects, starting from logically describing operation functions to theoretically evaluating hypotheses, and devising experimental procedures to test them (including computer simulations).

Developing a conceptual model within any domain, assumes the existence of domain ontology. By ontology we understand a consistent set of concepts within the domain and the relationships between those concepts. In the beginning of the paper we will address some general aspects regarding VO ontology.

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1998 *CR Categories and Descriptors.* K.6.3 [**Management of Computing and Information Systems**]: Software Management – *Software process*.

The description of a conceptual model assumes a description/modelling language. The paper identifies several required qualities of the modelling languages, necessary to develop VO conceptual models: syntactic quality (correctness, validity, completeness with respect to the VO domain) and semantic quality (validity and completeness). Validity regards correctness of mappings with regard to VO. Completeness regards relevancy of mappings in solving the problem. The above conclusions are based on an axiomatic definition of VO.

2. An axiomatic definition of VO

The Virtual Organization (VO) concept was introduced by Mowshowitz (1986) and started to be popularized by Davidow and Malone (1992). In the following years a very large number of papers approached this topic presenting VO as a way to address critical issues like accessing expertise in a global market, sharing skills and information within a network of independent entities which present themselves as a unified actor in a joint project, reducing costs, increasing flexibility, boosting innovation, accommodating increased demands from employees for a better quality of life.

A major effort to clarify the concept was conducted by Kasper-Fuehrer (2004) who reviewed a vast literature dealing with VO, written by German and English authors. Introducing an ideal definition Kasper-Fuehrer (2004) derives ten corollaries (natural consequences) which give the definition more accuracy and flexibility, in the same time dramatically diminishing its operability (i.e. easiness to operate with the definition in a formal manner).

We believe that an axiomatic definition of VO is simpler and eliminates the necessity of corollaries. Here are the axioms.

Axiom 1. *All co-operation forms (collective actions, following collective goals, based on dependencies among members) are enabled (in some instances created) by one or more forms of symbolic communication.*

The evidence of this axiom is based on the process of converting an unsecure transaction into a secure collaboration (well known aspect from the game theory). Symbolic communication is required to build the "trust mechanism", to convert the "unsecure game" into an "insurance game":

Axiom 2. *New forms of cooperation - enabled by new communication technologies – are successful only if they succeed to create new forms of wealth or add new value (e.g. info, sharing knowledge).*

Axiom 3. *The new forms of collective organizations may act to influence / further-develop the communication technology to secure their success.*

The reason for introducing Axioms 2 and 3 is evident: the success of the collective approach/action. If we accept these Axioms:

- We cast a clear light on the beginnings of collective actions (from individual action towards collective action involving complex dependencies)
- We underline the effect of the information and communication technologies (ICT) in the emergence of new forms of collective action
- Anticipate the emergence of new forms of organization as an effect of new communication technologies

In order to introduce the definition of VO, we start from one of the most largely accepted definition of an organization:

Definition 1. *An **Organization (O)** is a collective action among a group of members which pursues specific collective goals, controls its performance, and has a boundary separating it from its environment.*

Definition 2. *A **Virtual Organization (VO)** is an organization with the following characteristics:*

- *spatial: operates within geographically distributed work environments*
- *temporal: has a limited life span, until it performs its tasks or actions*
- *configurational: uses information and communication technology ICT to enable, maintain and sustain member relationships*

As the term organization is used in multiple ways, it is necessary to specify that in this paper we consider only **process-related type of organizations** (organization as task or action) as opposed to **functional organizations** (organizations as permanent structures) or **institutional organizations** (as an actual purposeful structure within a social context)

Examples:

(1) Co-operation with the goal of creating new forms of wealth is VOs using off-shore services in software development (dedicated individuals and/or teams belonging to different permanent organizations participate in a project)

(2) Co-operation with the goal of creating a new form of value is Open Source movement. It represents a new form of production (peer to peer production). E.g. Linux is world class software developed in a virtual organization.

And here are a few observations:

- The VOs set is a subset of the Os set
- Spatial distribution condition is critical for is the reason for the manifestation of virtuality within a VO
- By definition, all VOs are temporary and only exist until they perform towards their collective goals, be it the creation of (new form of) wealth or (a new) value

- The definition can accommodate new forms of VOs as new forms of symbolic communication emerge (e.g. avatar face-to-face communication in virtual worlds like Second Life)

3. Some ontology aspects of VOs

As we mentioned before, conceptual modelling assumes the existence of a consistent set of concepts within the VO domain and the relationships between those concepts. By VO ontology we understand the common vocabulary describing the concepts, the actors and relationships.

We start with a few observations on architecture. For a significant number of VOs the Internet is the network supporting ICT services for:

- Creating, gathering, integrating and distributing information throughout the organization components
- Sharing (human) resources via platforms through which individuals collaborate.

Noting that technology is just the platform over which information is distributed and resources shared, we can consider three large areas which should addressed in VO ontology and concept modelling:

- VO Enabling Technology (the platform, e.g. applications, components), enabling information to be created, distributed, consumed (e.g. interoperability, standardization, security, speed)
- VO Processes Design, or how VO uses the platform (how we create, organize, distribute and consume information, how it supports the VO operations (procedures), and tactics (business processes)
- VO Superstructure (business level), or how we create new wealth and/or new value (strategy, trust mechanisms, organization)

In Figure 1 a simplified **business architectures** is represented.

The role of each architecture level is to support the level above and in a first approximation ("week interaction approximation") one can develop a theory and an "independent" model for each level considering its own role is to support the level above. (The approximation consists in neglecting the changes/optimisations of any supporting level, induced by the level above). VO involves coupling at different levels and coupling assumes the existence of models.

Based on VO goals, strategy and organization, next step would be to select the most adequate **topology** of the type of VO we want to model. The main topologies are **process oriented, peer-to-peer** or **main contractor topology**. Topology clarifies not only at what levels the parties need to manifest interoperability but also their major roles in the VO.

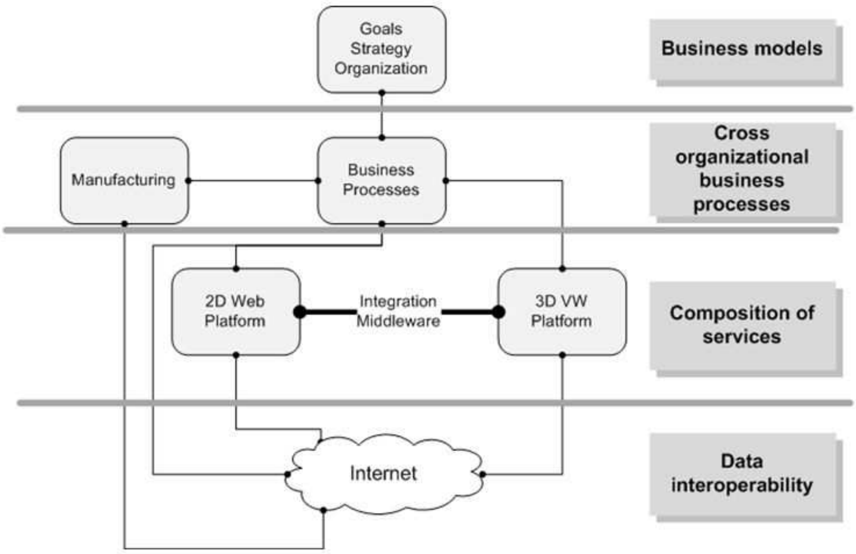

Figure 1. Basic VO architecture types: financial services, telecommunications, and manufacturing (adapted from Radoiu, 2008)

Based on topology, next step is to identify **VO life cycle functions**, and model them for each phase: **creation, operation, evolution, and dissolution**; emphasise on operation.

As any VO is based on **interoperability**, it follows that this also must be modelled and most likely at all levels: business level (e.g. organizational roles), business processes (e.g. sharing knowledge assets), enabling technology (e.g. communication components).

It appears obvious that **ontology descriptions** at all levels must be developed and used in order to secure consistent VO concept modelling.

It also appears evident that a "complete conceptual model" will actually consist of a collection of models developed at each architecture level, for a specific topology and for all VO lifecycle functions.

4. Towards VO conceptual modelling

Models – for each of the levels in discussion - are developed using a modelling environment. Modelling environments (platforms, languages, tools and paradigms) are specific to each level (as we have different semantic needs at each level, it is likely that we use different modelling languages at each architecture level). At this moment, the author is not aware of any concept model of

VOs. The explanation seems to be the substitution of the formal theory with formalism and it is here where we would like to make some comments. Comments refer to the modelling process which makes all the difference between formalism and formal modelling. The difference between the two concepts (formalism vs formal theory in VO modelling) has been firstly discussed by Putnik, (2004).

The main elements of every **modelling environment** are: the **modelling language (L)** (containing the elements with which a model can be described) and the **modelling algorithms** for each step of the modelling process which validate the outcome of the **modelling process**.

Advantages of using a **modelling process** (and we underline the word process) are:

- One can predict the outcome (e.g. a valid and successful conceptual model)
- The outcome of the modelling process (the conceptual model) depends on the capability of the modelling process
- An algorithmic process enables consistent quantitative approaches (use of metrics)
- An algorithmic modelling process lowers the risks with regard to the value of the VO model

For virtual organizations, obviously, the modelling environment must permit the modelling of all characteristics of a VO (e.g. spatial, temporal and configurational) plus the modelling of the coupling mechanisms among parties in a VO (having in mind the topology) and most important, the VO life cycle functions.

In order to reveal the requirements of VO conceptual modelling we will use the analogy between mathematical abstract models and VO concept models.

A **mathematical model** is an **abstract model** that uses **mathematical language** (**formal language**) to describe an existing system (or a system to be constructed) which presents knowledge of that system in usable form (Sakharov, 2008).

A **formal language** is defined by an alphabet and formation rules. Syntactically complex languages are defined by means of **grammars** or regular expressions (Sakharov, 2008). The alphabet is a set of symbols used to build the language. The formation rules specify which strings of symbols count as well-formed.The **well-formed strings** of symbols are also called **words, expressions, formulas, or terms**. The **formation rules** are usually recursive. Some rules postulate that such and such expressions belong to the language in question. Some other rules establish how to build well-formed expressions from other expressions belonging to the language.

Any meaningful mathematical model is based on a theory, the **theory** being the set of sentences which is closed under logical implication. One of its useful aspects is that, given any subset of sentences $\{s_1, s_2, ..., \}$ in the theory, if sentence r is a logical consequence of $\{s_1, s_2, ..., \}$, then r must also be in the theory (Weisstein, E. W.).

Back to VO conceptual modelling, let us define a **VO conceptual model** as an **abstract model** that uses **modelling language** to describe the system. The modelling language is described by its **alphabet, syntax (grammar)**, *and* **semantics**. The similarity with mathematical modelling is straightforward. Any useful VO conceptual model must be described by a **theory**. A set of sentences closed under a logical implication. But, there's at least one more aspect.

In connection with the modelling language we have a **syntax constructs domain** (D), defined as the set of all formulas which are part of the language. We note $\mathbf{L}^S$ the **modelling language** built with the syntax S over a given alphabet. Worth mentioning here that there are two major approaches to describe a syntax: **graph grammars** and **meta-models** (i.e. a meta-model is the model of the syntax) (Karagiannis, 2002). As such, a language is useless as long as we do not associate meanings to all its syntax constructs (terms, formulas, sentences). The meaning is given by a chosen set of "meaning values" (i.e. significance values) which are formally named the **semantics domain** (V). It follows than that the **semantics** of a **language** $\mathbf{L}^S$ describes the significance of a modelling language by mapping (say a map a) the set of all syntax constructs (D) to a set of significance values (V). Obviously, in our case, the significance values must be related to the VO theory. The map a will allocate a VO-related meaning to every syntactically correct construction in a given language. Because of the degree of freedom in choosing the set (V), different syntax constructs, expressed in different modelling languages, could have the same meaning/interpretation. It follows that there's not only one language susceptible to describe VOs.

The map a and the domain (V) form a **structure** and is noted *VOstructure* $= (V, a)$);

If under a given **interpretation** a **formula** becomes true, then that **interpretation** is a **model** of that **formula**. A **sentence** is called **satisfiable** if there is at least one **interpretation** under which that sentence is true.

When applying an **interpretation** to a **sentence** the assignment of variables is irrelevant (as the **sentence** has no variables occurring free). Thus one can say that a **sentence** is **satisfiable** if exists at least one **structure** making the **sentence** true, that is, if exists at least one **structure** that is a **model** of the **sentence**. As seen before, some of the **formulas** that constitute a **language** are **sentences**. From all those **sentences** some will eventually be **satisfiable**. The subset of all **sentences,** whose elements are **satisfiable sentences**, **and closed under consequence**, is a **Theory**. Because **sentences** are **satisfied** by *VOstructure,* the referred subset of **sentences** can be designated by **Theory of *VOs***.

Theorem 1. *The condition of a given modelling language (L^S) to correctly describe a VO conceptual model is to permit the description of at least one nontrivial theory (T) on that VO.*

And here is an informal proof of this theorem. If the sentences describing the model do not verify the axioms and are not consistent with the definitions, than the model is not describing a VO. Let us assume that the axioms are verified. Another group of sentences must completely describe the architecture, topology, operation functions, and interoperability functions. We find ourselves in the situation where the sentences are satisfied by a VO*structure.* As the modelling sentences have to be true under the same restrictions, these sentences can be referred as the theory of VO. Obviously, not any modelling language (L^S) fulfils the above criteria. Next to general modelling language qualities (syntactic correctness and validity), a few other are essential: syntactic completeness and semantic validity and completeness with respect to the VO domain (i.e. to be able to describe the theory behind VO). Semantic validity regards correctness of mappings with regard to VO. Completeness regards relevancy of mappings in solving the conceptual modelling problem.

ONTOLOGY				
Complete			Concept Models	
Partial				
Vague				
	Informal	**Formalism**	**Theory**	**DESCRIPTION**

TABLE 1. Models classification with regard to description and ontology

Another observation is that semantic completeness requires a complete ontology of the domain.

In the end, it is fair to ask what the benefits of VO concept modelling are. After all, working VO models were discovered and could be perfected through observations (e.g. analyzing and generalizing empirical data, case studies).

The immediate risk is that a theoretical approach alone is likely to produce results without practical importance. The utility of a theoretical approach is several folds. Firstly, a formal theory approach always proves to have utility for "engineering" tasks such as design and implementation of VOs, because it provides the "desired efficiency and effectiveness" (Putnik 2005). Secondly, it could be used to explain the success or failure of different VOs, their emergence or absence in the market. Thirdly, it could help existing VOs to lower the risk in their future development and help them better understand the mechanisms of their informally and iteratively developed working model. And it could also help future VOs in developing their working model. Obviously, the conditions for VO emergence exist for some time now, but only those which were able to develop (so far, empirically) a consistent working model, survived.

5. Comments around a simple example and conclusions

Let us take a very simple example: a VO consisting of two parties, dedicated to custom software development. The theory which must be supported by modelling language (e.g. the logic of an operation function at the business process level) will be described at the highest level by the meta-model which concepts and operations must be reflected by the appropriate modelling language. The spatial distribution of VO allow us to focus only at the business process level and ICT services level assuming that ICT infrastructure is the Internet. At the business level, the goal is developing custom made software applications, the strategy is to address the market needs using geographically dispersed resources, the organization consists of high level design process undertaken by one party, low level design, development, and testing with the other. Let us assume that the trust mechanism is contractual. The topology is obviously of the type "main contractor". Starting from the theory describing the methodology of custom software development process, and introducing the constraints (the process is being carried out by a distributed organization), the modelling language for the business process level must be able to consistently describe business processes interoperability: input, output, coordination events and events notification). The modelling language must be able to model interoperability at the ITC services level (e.g. files synchronisation). The VO conceptual model will consist of several models:

- Operational model (formally describing the realization of the operations functions)
- Evolution model (formally describing VO growth)
- Integration models at all three levels: business level, business processes, enabling technology (formally describing how parties will practically integrate)

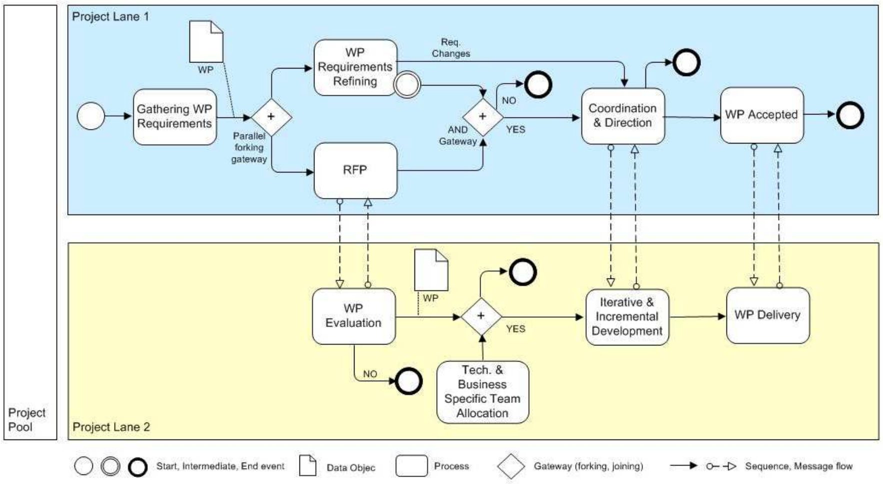

FIGURE 2. One operation function (software development), modelled with BPMN, for business processes level

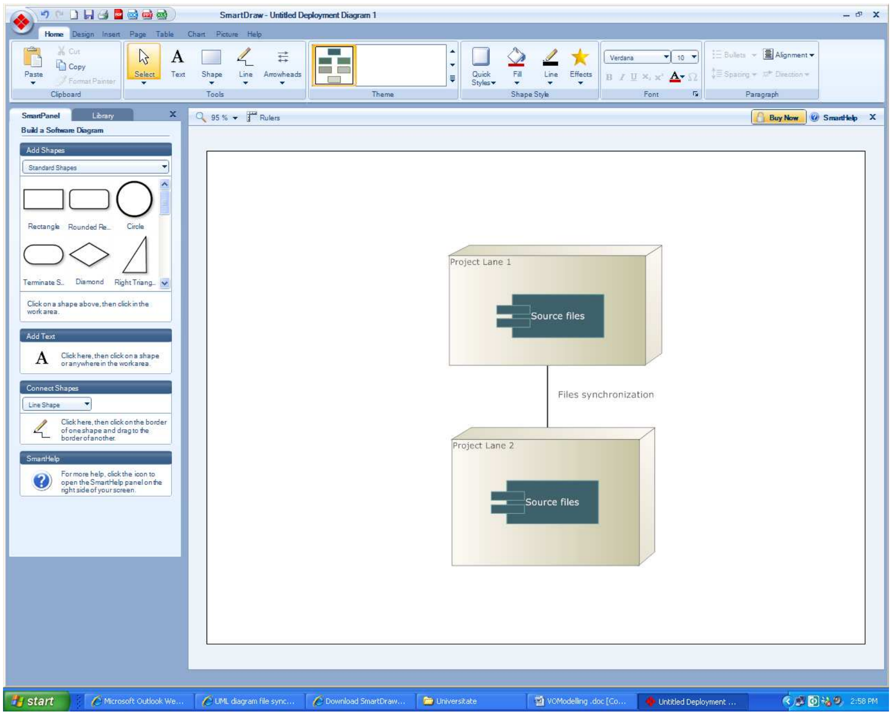

FIGURE 3. One integration function (file synchronization), modelled with UML, for two parties VO ITC services level

Two of these models are depicted in Fig. 2 and 3.

Let Σ be the set of sub-processes necessary to cover the custom software development workflow in the VO, in line with the specifications of such a workflow. Let be Σ_1 the sub-processes taking place within Lane 1 and $\Sigma_2$the sub-processes taking place within Lane 2.

$\Sigma = \Sigma_1 U\ \Sigma_2$ (set of sub-processes necessary to cover the custom software development workflow is the reunion of Σ_1 and Σ_2. AS All of these sub-processes are mandatory, the interfaces between the two project lanes must formally describe the channels for input data, output data, event notification, and monitoring and control events.

Today "VO research area is recognized as a scientific discipline" and it is probable that "in 2015 most enterprises will be part of some sustainable collaborative networks that will act as breeding environments for the formation of dynamic virtual organizations in response to fast changing market conditions", Camarinha (2002, 2003). The drivers for this trend (Gartner, 2007) are: maturing technology and standards (e.g. EDI, XML, GDS, CPFR, SOA, Web services, virtualization, semantic Web (Berners-Lee, 2003)), improved integration (integration as a service) and potential business impact.

Conceptual modelling proves its utility in the design and implementation of VOs also helping existing VOs to lower the risk in their present operation and future development.

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Petru Maior University, 1 Nicolae Iorga St., Târgu Mureş, Romania
E-mail address: Dumitru.Radoiu@Sysgenic.com