Chapter 14

A COMMUNICATION FRAMEWORK TOWARDS FLEXIBLE ASSOCIATIONS OF BUSINESSES IN EVOLVING ENVIRONMENTS*

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Abstract The Internet and electronic commerce have become indispensable for many of us. To adequately use the increasing amount of data available, attempts are made to extend data processing from a lexical view towards a multi-level view, including meaning and/or context (e.g., DAML, Web Services). The goal of this paper is to introduce a formal framework, which models communications from such a multi-level perspective. Therein, we discuss fundamental ideas of communication, such as agents involved and their respective structure. We integrate the concept of an agent's adaptive behaviour in order to assure a high degree of understanding. The framework is illustrated using a practical example to depict its usefulness and how it may be further developed.

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1. Introduction

Information technology has become the corner stone in today's society. Businesses, organizations, governments and individuals rely on IT systems for their prosperous functioning, behavior, and development. These IT systems are composed of many different units that interact and work in concert to satisfy some goal. Furthermore, they do not stand alone but interact with their environment, be it other IT systems or humans. In the context of e-business or e-commerce, examples of such systems include ERP systems or transactional Web sites. Clearly, as far as the interaction between systems is concerned, the (public) Internet plays a predominant role. However, it must be noted that in many cases, such as in the banking sector, private networks are often used in place. Communication of information, knowledge or in general any cognitive structure between different systems and with a system's environment, which may include humans, is therefore a central element. In general, such systems are called *Communication and Information Systems* (CIS).

Organizations or systems of this kind are set up, designed, and implemented by humans, and are therefore subject to human rationality. Such a necessarily bounded rationality results in a limited view, which leads to *satisficing,* as it is called by Herbert A. Simon [Simon, 1996], which renders a system and its environment static, making a system to appear as acting and existing in empty space [Plaice and Kropf, 2000]. Indeed, current IT systems are limited to fixed, pre-defined ontologies which do not allow for a system's evolution or adaptation as a result of interaction in a space that may be described in a holistic way such as Aristotle's *aether.* A system is transformed into a new evolved system by the knowledge transfered by communication from one system to the other, from a system to its environment or *vice versa.* In the event of a desired change in a systems behavior and functionnality, the standard procedure today is to replace the existing system with a new release or a completely new system. A first attempt to allow for greater system flexibility and evolution at a technical level stems from agent technology [Luck et al., 2003] and to some extent from Web Services where different (new) onthologies may be dynamically integrated. From an economic point of view, adaptation is necessary for economic survival and sustained competitiveness [Heylighen and Campbell, 1995] and fitness [Kauffman, 1995].

Interaction through communcation is the driving force for change and evolution. We therefore propose in this paper a communication framework as the basis for adaptive or coevolutive behavior of communication and information systems. CIS are defined and characterized at many different abstraction levels, from technical specifications of data transmission or data structures and methods up to the communication of facts, knowledge or the sharing and adaptation of entire cognitive sturctures. This leads to a recursively defined structure of

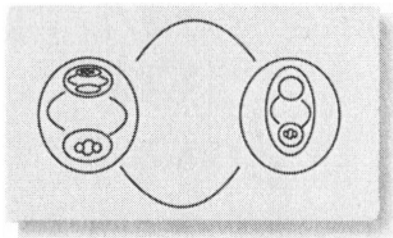

Figure 1. **Recursiveness of communication**

a system, which we call an *agent,* and all possible communications. The next section discusses evolutionary aspects of communication followed by the formal definition of the proposed communication framework. Using the proposed framework, section 1.3 analyzes how agents may evolve through interaction. Before concluding the paper, we present in Section 1.4 a first attempt of identifying relevant levels of abstractions of the framework.

1.1 (Co)evolutionary aspects of communication

Communication is any kind of interaction between systems that happens at any conceivable abstraction level. If we consider human communication, we could decide not to include communication above the human mind–based cognitive level as we are *a priori* not able to conceive such kind of interaction, albeit it might exist. Nevertheless, in order for us to set up a complete model including all abstraction levels, we follow a generic approach of recursiveness within the communication event to assure the coverage of all necessary elements to install and maintain high levels of mutual comprehension. This means that every system as well as every communication level serves as a sublevel embedded into a higher structure and as a superlevel concerning a related lower structure (Fig. 1). In short, recursiveness may be applied to the grouping of the involved systems and the grouping of possible communication levels as stated above.

Communication is the relation between two systems. From a system's perspective, it is perceived as the relations of that system to its environment, i.e., the rest of the universe. The environment, hence other systems, is by definition beyond the direct influence of the system; it nevertheless influences the functioning of that system. More precisely, the environment "… is considered as the system of surrounding things, conditions or influences, affecting somehow the existence or development of someone, something…," [Krippendorf, 1986] hence another system, all part of communication as we see it.

We further infer that, in a bidirectional manner, a system is not only influenced by its environment but it also influences other systems as a part of their environment. A familiar example may be that of competing companies, such as the "rat race" between *Intel* and *AMD* where the latter has to adapt (e.g., by producing more powerful processors) to the first, i.e., its environment and *vice versa.* To stay "competitive," a system must optimize fitness, where fitness is a complex function of the system and its environment, an index of the likelihood that the system would persist and evolve [Heylighen and Campbell, 1995]. Those configurations with the highest fitness will be selected to contribute at best to a system's survivability, which by the way doesn't mean replacement. This fitness function concerning system's mutual influence emphasizes evolution to a changing environment and is called coevolution [Kauffman, 1995].

Aligning the above considerations to our context, we state that quasi-continuous CIS ought to obey to the same principles. We base this assumption on the fact that CIS, as they support business processes, have a *coordination* or *controlling* function. They serve to distribute data and information aiming the control of processes, operations, employees, teams, etc. In order to adequately fulfill this function, a control system must mimic or map the organizational structure for which it is installed [Conant and Ashby, 1970].

2. A communication framework

In what follows, we propose a formal framework describing interactions between systems, which takes into consideration the recursive nature of both systems and communications, as well as the coevolution principles stated above. The building blocks of the model are the following:

- *agents* are systems that may interact with each other. An agent may be hierarchically structured. Note that we use the term "agent" here in a broad sense, not limited to the agent paradigm. For us, an agent is any system (computer module, computer program, human, organizations, etc.) that is *actively involved* in the exchange of data;

- a *communication signal* is a single transmission of data from one agent to another agent. This corresponds to a single message transmitted, without any feedback;

- a *communication event* is some non-empty arbitrary sequence of communication signals. This corresponds to an interaction between agents and will therefore imply many communication signals;

- a *cognitive structure* is a structured representation of data. It is used to describe an agent's knowledge as well as the data transmitted in a communication signal.

2.1 The cognitive structure

We first must consider how data, stored by agents and transmitted by communication signals, should be structured. We distinguish here between data, which are mere facts and values, from information which is data that leads to a reaction. As stated earlier (sect. 1.1), data is represented at different abstraction levels. Therefore, any representation of data must consider these different levels. Consequently, we have that:

- Λ is some multidimensional space of abstraction levels on which a partial order is defined;
- $\lambda \in \Lambda$ is some abstraction level to represent data;
- $\check{\lambda}$ is the lowest abstraction level recognized by an agent or transmitted by a communication signal;
- $\hat{\lambda}$ is the highest abstraction level recognized by an agent or transmitted by a communication signal;
- ψ^λ, called a *partial cognitive structure,* is some representation of the structure of data at abstraction level λ, such that $\psi^\lambda = f(\psi^{\check{\lambda}}, \ldots, \psi^{\lambda-1})$. It therefore represents the emergent data obtained by combining data at lower abstraction levels. Furthermore, $\forall \lambda \notin [\check{\lambda}, \hat{\lambda}], \psi^\lambda = \emptyset$; and
- Ψ is a *total cognitive structure.* Given an agent or a communication signal, we have that $\Psi = (\psi^{\check{\lambda}}, \ldots, \psi^{\hat{\lambda}})$.

2.2 Agents and the agent hierarchy

We now depict in greater details the agents' hierarchical structure and thereafter its relation to the cognitive structure. We distinguish between *atomic agents,* which are the smallest possible agents that may be involved in communications, and *complex agents,* which represent hierarchical groupings of agents. Hence, complex agents represent recursive structures. Agents may therefore be characterized as follows:

- $l \in \mathbf{N}$ is some hierarchical level of agent composition;
- A^0 is the set of atomic agents; and
- $A^l = \{a | a \in \mathcal{P}(A^{l-1}) \wedge \mathbf{Card}(a) \geq 1\}$ is the set of complex agents at level $l > 0$.

This definition implies that an agent $a \in A^l$ is either atomic $(l = 0)$ or some arbitrary grouping of agents, such that any member of that group is an agent of level $l - 1$ $(\forall a' \in a, a \in A^l \wedge l > 0 \wedge a' \in A^{l-1})$. When the number of member agents is 1 ($\mathbf{Card}(a) = 1$), we say that agent a is a virtual group. This is useful, for instance, to represent merging of organizations with different hierarchical levels.

Given two agents $a \in A^l$ and $a' \in A^{l'}$, we say that agent a is a member of a', noted a **in** a', if and only if

$$a \textbf{ in } a' \equiv (a \subseteq a') \vee (\exists a'' \in a' | a \textbf{ in } a'').$$

Cognitive structure of agents. Every agent has its own cognitive structure, which emerges from those of its composing agents. Consequently, we have:

- ψ_a^λ is the cognitive structure of agent a at level λ;
- $\check{\lambda}_a$ is the lowest abstraction level at which agent a is able to manipulate data. It is therefore the lowest level λ_a at which a cognitive structure ψ_a^λ is available for agent a. For $a \in A^l$ we have that

$$\check{\lambda}_a \le \min_{a' \in a} \check{\lambda}_{a'} \le \min_{a' \in a} \left[\min_{a'' \in a'} \check{\lambda}_{a''} \right] \le \ldots;$$

- $\hat{\lambda}_a$ is the highest abstraction level at which agent a is able to manipulate data. It is therefore the highest level λ_a at which a cognitive structure ψ_a^λ is available for agent a. For $a \in A^l$ we have that

$$\hat{\lambda}_a \ge \max_{a' \in a} \hat{\lambda}_{a'} \ge \max_{a' \in a} \left[\max_{a'' \in a'} \hat{\lambda}_{a''} \right] \ge \ldots; \text{ and}$$

- Ψ_a is the *total cognitive structure* of agent a. We have that $\Psi_a = (\psi_a^{\check{\lambda}_a}, \ldots, \psi_a^{\hat{\lambda}_a})$.

2.3 Communication signals

In our framework, a communication signal is formally defined as tuple $\omega = \langle a, \Psi_\omega, a' \rangle$, where:

- a is the emitting agent with global cognitive structure Ψ_a and a' is the receiving agent with global cognitive structure $\Psi_{a'}$;
- ψ_ω^λ is the cognitive structure of the data transmitted by ω at level λ;
- $\check{\lambda}_\omega$ is the lowest abstraction level of data transmitted by ω;
- $\hat{\lambda}_\omega$ is the highest abstraction level of data transmitted by ω;
- Ψ_ω is the *total cognitive structure* of communication signal ω. We have that $\Psi_\omega = (\psi_\omega^{\check{\lambda}_\omega}, \ldots, \psi_\omega^{\hat{\lambda}_\omega})$; and

- $\omega^{\circlearrowleft} = \langle a, \Psi_\omega, a \rangle$ is an implicitly induced *loopback signal,* which corresponds to the emitting agent being concious of (i.e., "listening" on) ω.

There is no restriction on the relationship between a and d. For instance, we may have that $a = a'$, in which case, an agent is communicating with itself. We may also have that a **in** a' or that a' **in** a, in which cases an agent is communicating with a super group or with a subgroup, respectively.

We define $\delta(\psi_a^\lambda, \psi_\omega^\lambda) \in [0,1]$ as the *cognitive difference* between agent a and communication signal ω at abstraction level λ, such that:

- $\delta(\psi_a^\lambda, \psi_\omega^\lambda) = 0$ if and only if $\psi_a^\lambda \supseteq \psi_\omega^\lambda$,
- $\delta(\psi_a^\lambda, \psi_\omega^\lambda) = 1$ if and only if $\psi_a^\lambda \cap \psi_\omega^\lambda = \emptyset \wedge \psi_\omega^\lambda \neq \emptyset$,
- $\delta(\psi_a^\lambda, \psi_\omega^\lambda) \in]0,1[$ otherwise.

By extension,

$$\Delta(\Psi_a, \Psi_\omega) = \sum_{\lambda=\min(\check{\lambda}_a, \check{\lambda}_\omega)}^{\max(\hat{\lambda}_a, \hat{\lambda}_\omega)} \delta(\psi_a^\lambda, \psi_\omega^\lambda)$$

Similarly, we define $\delta(\psi_a^\lambda, \psi_{a'}^\lambda) \in [0,1]$ as the *cognitive difference* from agent a to agent a' at abstraction level λ, such that:

- $\delta(\psi_a^\lambda, \psi_{a'}^\lambda) = 0$ if and only if $\psi_a^\lambda \supseteq \psi_{a'}^\lambda$, hence $\delta()$ is clearly non-commutative,
- $\delta(\psi_a^\lambda, \psi_{a'}^\lambda) = 1$ if and only if $\psi_a^\lambda \cap \psi_{a'}^\lambda = \emptyset \wedge \psi_{a'}^\lambda \neq \emptyset$,
- $\delta(\psi_a^\lambda, \psi_{a'}^\lambda) \in]0,1[$ otherwise.

By extension,

$$\Delta(\Psi_a, \Psi_{a'}) = \sum_{\lambda=\min(\check{\lambda}_a, \check{\lambda}_{a'})}^{\max(\hat{\lambda}_a, \hat{\lambda}_{a'})} \delta(\psi_a^\lambda, \psi_{a'}^\lambda)$$

A communication signal ω can, in principle, be exercised between agents a and a' at any two levels l and l' within the agent hierarchy (i.e, $a \in A^l$ and $a' \in A^{l'}$). Nevertheless, the probability that a and d understand each other decreases as the distance between l and l increases, since this may also increase the cognitive difference from a to d (i.e., $\Delta(\Psi_a, \Psi_{a'})$ increases) or from a' to a (i.e., $\Delta(\Psi_{a'}, \Psi_a)$ increases). For instance, consider two humans within the same society and the same educational background, compared to two humans within the same society, compared to two humans, compared to two creatures from different species, etc. [Jin et al., 2001].

A true meaningful communication signal must imply some change (however infinitesimal it may be) in the cognitive structure of either the emitter or the receiver, or both. Changes in the emitter's cognitive structure are not a direct result of a communication signal itself, but rather of the loopback signal that follows from that communication signal ($\omega^{\circlearrowleft}$).

2.4 Communication events

In reality, it seems awkward to consider single communication signals; interactions between agents usually imply a sequence of communication signals being transmitted between them, minimally to provide feedback on an original communication signal. Consequently, we introduce the notion of communication events, which represents an ordered sequence of communication signals. Formally, a communication event Ω is an ordered list of communication signals $\langle\langle\omega_1, \ldots, \omega_i, \ldots, \omega_j, \ldots \omega_n\rangle\rangle$, where ω_i occurred before ω_j when $i < j$.

3. Explaining how an agent evolves

We already pointed out that an agent's evolution is a consequence of its interactions with other agents. A basic motivation for evolution is what we consider to be an intrinsic feature of agents, namely minimizing the energy they use to emit/receive a communication signal $w = \langle a, \Psi_w, a' \rangle$. Energy is used at two distinct points: by agent a in constructing the message to emit (Ψ_w) and by agent a' in interpreting the message received. In the following, we explain how agents evolve using the above definitions (Sect. 1.2).

Let us first consider a communication event $\Omega = \langle\langle\omega_1, \ldots, \omega_n\rangle\rangle$ that involves only two agents, a and a', such that a is not a member of a' $(\neg(a \textbf{ in } a'))$ and *vice versa* $(\neg(a' \textbf{ in } a))$. For such a communication event, we have that

$$\forall \omega_i, i \in [1, n], \omega_i = \langle a, \Psi_{\omega_i}, a' \rangle \vee \omega_i = \langle a', \Psi_{\omega_i}, a \rangle.$$

Agents a and a' aim at maximizing what we call their *internal* and *external coherence.* We define internal coherence as the adequation between an agent's cognitive structure and the cognitive structure of messages it emits. An agent a maximizes internal coherence by minimizing the cognitive difference between a and all messages it emits. Formally, we have

$$\min \sum_{\substack{\omega_i \in \Omega \wedge \\ \omega_i = \langle a, \Psi_{\omega_i}, a' \rangle}} \Delta(\Psi_a, \Psi_{\omega_i}).$$

Similarly, external coherence is the adequation between an agent's cognitive structure and the cognitive structure of messages it receives. Hence, maximal external coherence for agent a is acheived by minimizing the cognitive difference between a and all messages it receives. In formal terms, we have

$$\min \sum_{\substack{\omega_i \in \Omega \wedge \\ \omega_i = \langle a', \Psi_{\omega_i}, a \rangle}} \Delta(\Psi_a, \Psi_{\omega_i}).$$

In this particular context, both agents a and a' can optimize their cognitive structure in order to minimize the energy deployed. The only factor that may empede that reduction of energy deployment is the nature of these agents, or more concretely their capacity to modify their cognitive structures.

To illustrate this case, consider the following B2C situation, where an enterprise (agent a) is interacting with a single consumer (agent a'). In this context, agent a is most likely composed of many agents, acting as a whole rather than as individuals, which in turn, may be organized in teams. Hence, $a \in A^l, l > 0$. Similarly, we can easily assume that a' is an atomic agent (i.e., it is not decomposable), and therefore that $a' \in A^0$. In order to complete a sale, many communication signals ω_i may be exchanged between a and a', composing a communication event Ω. The communication event therefore corresponds to the negotiation occuring between a and a' in order to understand what the needs of a' are and what a may supply to fulfill those needs.

There is coevolution, since at the end of the communication event Ω, a' knows more about products available at the enterprise a, while a learned about the needs of its single customer. Depending on how the communication event was concluded, it may in turn bring a to change its sales methods and even its product line. In the framework, this means that the enterprise conginitive structure (Ψ_a) will be modified to take these changes into consideration.

In this limited context, both agents could evolve to the point that only minimal interactions are required since:

- enterprise a knows perfectly what its customer a' buys. In fact, a may adjust its product list to meet all requirements of a' to the point that only products required by a' are sold by a,

- customer a' only needs to indicate the quantity to deliver, since a has only a' as client and it already knows the name, the billing address, the shipping address, and the product characteristics for that unique client.

When an arbitrary number of agents are involved, the situation may also be explained as a maximization of internal and external coherence. Consider a communication event $\Omega = \langle\langle \omega_1, \ldots, \omega_n \rangle\rangle$ involving an agent a_0 interacting with agents $a_1, \ldots, a_m$, such that $\neg(a_j \textbf{ in } a_k)$ with $j, k \in [0, m] \wedge j \neq k$. In this case, we have that

$$\forall \omega_i, i \in [1, n], \omega_i = \langle a_j, \Psi_{\omega_i}, a_k \rangle \textbf{ with } j, k \in [0, m] \wedge j \neq k.$$

Here, agent a_0 maximizes internal coherence by minimizing the cognitive difference with all the messages it emits,

$$\min \sum_{j=1}^{m} \sum_{\substack{\omega_i \in \Omega \wedge \\ \omega_i = \langle a_0, \Psi_{\omega_i}, a_j \rangle}} \Delta(\Psi_{a_0}, \Psi_{\omega_i}),$$

while it achieves maximal external coherence by minimizing the cognitive difference with all the messages it receives,

$$\min \sum_{j=1}^{m} \sum_{\substack{\omega_i \in \Omega \wedge \\ \omega_i = \langle a_j, \Psi_{\omega_i}, a_0 \rangle}} \Delta(\Psi_{a_0}, \Psi_{\omega_i}).$$

The optimization of internal and external coherence is more difficult to achieve in this context since agent a_0 must not only consider its capacity to change but also the impact of change on its energy deployment when interacting with all the agents in its environment (i.e., agents $a_1, \ldots, a_m$). This in turn leads to satisficing.

In order to illustrate this situation, we extend the example presented above. Here, we assume that the selling enterprise is agent a_0. This enterprise will interact with many customers (agents $a_1, \ldots, a_m$). Here, the evolution of the enterprise is constrained by the requirements of all its customers, which may be contradictory, since different customers may need different products or features. In this case, the enterprise cognitive structure (Ψ_{a_0}) is adapted to consider these different requirements and possible contradictions. However, this adaptation may not occur as fast as the market requires it.

To keep these customers, the enterprise must adjust its products to fulfill as much of these requirements as possible, while minimizing production effort (and hence costs). Furthermore, in addition to the quantity and product ordered, each customer a_i must identify himself to enterprise a_0 whenever he orders a product, since many customers interact with enterprise a_0.

4. A preliminary identification of abstraction levels

In defining Λ (Sect. 1.2.1), we stated that it was "some multidimensional space of abstraction levels." Originally, we were considering a one-dimensional space, such that we could determine the ordering of all possible abstraction levels. It did not take long before we realized that abstraction levels cannot be structured in such a linear space.

What we offer here is a preliminary identification of two of many potential dimensions, and of their respective abstraction levels. The first dimension relates to *modeling* of data. At the lowest abstraction level, we find facts (or simply data). The next level along that dimension is concerned with models (or metadata). Then follows metamodels (or meta-metadata), etc.

A second dimension relates to the *representation* of data. We base this dimension on [Habermas, 1984][Kropf et al., 1998][Shannon and Weaver, 1964] [Ulrich, 2001]. At the lowest level, we have symbols, which are the building blocks of representations. Then, we have the lexical level, which describes rules for assembling symbols into words. This level is followed by syntactic, then semantics. At this point, we limit the levels along this dimension to pragmatics (i.e., contextual information).

Clearly, any abstraction level within the modeling dimension may be refined by levels of the representation dimension, and *vice versa.* This simple observation is what lead us to a multidimensional Λ. For instance, a model (metadata) is represented using symbols (boxes, arrows, letters, etc.) which are connected together to form a diagram following construction (lexical and syntactic) rules. The diagram may be interpreted by analysts (semantics). And so on.

5. Conclusion and Future Work

In this paper, we presented a formal communication framework, which may be used to describe and explain these interactions and relationships, and others as well. We mainly focussed on the identification of fundamental concepts pertaining to interactions among agents, and how these agents evolve as a consequence of these interactions.

We feel however that the real impact of the framework does not lie in its expressiveness, but rather in the way it helps us reason about communications and evolution. Furthermore, we envision information systems, developed by using the framework, that may "understand" their environment and adapt to it. For instance, by better understanding the cognitive structure of communication events, we could dynamically determine what minimal data is required in electronic transactions between two agents, and hence modify dynamically the forms that customers must fill out when ordering products on a B2C Web site.

Such future development may not be forseen without considering the hurdles that lie ahead. Many questions come to mind. How should the abstraction levels space Λ be decomposed to adequatly account for specific business contexts? How do we create software artefacts that have intrinsic understanding of the cognitive structure received (Ψ_ω), referred to as the "symbol grounding problem" [Harnad, 1990]? How do we create software artefacts (i.e., agents) that have adaptable cognitive structures (Ψ_a)? How do we create software artefacts (i.e., agents) that can decide when and how to adapt?

In the short term, as the number of Web Services and the number of XML dialects grow, it will become increasingly important to understand how interactions between enterprises occur. Clearly, Web Services do not solve anything unless we have some way to describe what the service is providing, and not only the how. A service name is not sufficient. The same name may have different meanings in different contexts. Furthermore, there must be mechanisms to simplify the deployment and the use of all these remote services.

The framework presented herein will be used to provide a better understanding of interactions between enterprises, not only at the lexical and syntactic levels (format of data exchanged), but also from semantical and pragmatic perspectives (meaning of data exchanged). As such, it will bring about solutions to the problems enterprises face when deploying Web Services. In the long term, the framework will also provide a basis for the development of truly adaptable CIS, which will "understand" their environment [Pfeiffer and Scheier, 1999], and will coevolve with that environment.

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