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COMMUNICATION IN THE DIGITAL CITY AND ARTIFACT LIVES

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Abstract: This paper proposes a theoretical basis for the design and analysis of distributed information systems. A quantitative criterion is defined to estimate the efficiency of computer-mediated communication, and to monitor artifact lives as well. The theoretical concepts are discussed in a context of an example related to car use and servicing.

Key words: Distributed information systems, User interface design, Semiotics

1. INTRODUCTION

Recent advances in networked technologies and in performance of computing devices created the present situation, where the most critical problems in information system design concern with user interface. A user interface of an information system may be understood as a collection of symbols and interaction procedures that are to enable communication of the system users. The now generally recognized requirement of interface adaptability to both a particular user and dynamically changing system contents quickly made the task of interface design too complex to rely on hand-crafted decision procedures. Presently, however, no single theory exists that could provide comprehensive guidelines for the design and analysis of distributed information systems, such as digital cities, corporate memories, or the entire World-Wide Web [5].

In this study, we attempt to establish a theoretical basis – a new communication theory – by introducing fundamental axioms that would allow for the development of a science of information system design with its own explanatory and experimental apparatus. (Some applications of the proposed theory have been presented elsewhere [3-4].)

2. COMMUNICATION IN A DIGITAL CITY

A digital city usually comes as a distributed information system comprising a range of information resources associated with a certain geographical place or a specific human activity [5]. The principal function of a digital city is to support navigation of its users in the physical or abstract space by providing relevant information in a timely manner. To do this, the digital city enables various social interactions between users (e.g. through posting and retrieving documents), i.e. it enables communication of its users.

To illustrate major difficulties in designing and using digital city interfaces, let us consider a typical situation where a user of a digital city interacts with the system to find and, perhaps, go to "a good car-maintenance service station." First, the user must formulate her or his goal in terms, which can effectively and correctly be understood by the system. There may or may not be an appropriate pre-defined hyperlink (e.g. "car repair"), while submitting a query (e.g. "car maintenance") to a search engine will, as a rule, produce hyperlinks of arbitrary relevance to the user's goal (e.g. FAQ on the topic or any other document indexed with the query keywords). The user should yet unequivocally express her or his subjective notion of the "good" (e.g. some repair shop would be "good" in terms of service quality, but be too far from the user's location). To be effective, the interface has to develop and utilize a model of the user's goal and behavior.

Next, the user may access a component of the digital city (e.g. a site representing a "physical" car service-station). The semantics of the original query may then change, owing to the component design (e.g. some instructions on car maintenance or a "how-to-reach" map) and/or experience and practice currently prevailing in the society of the system's users (e.g. a particular shop may be considered "good" just because it is conveniently located and/or it is, at the moment, most strongly associated with the query keywords, owing to feedback from previous users).

After all, while browsing, the user may refine or even change her or his goal (e.g. to "to find a gas station"), based on the information learned from the different recourses (e.g. that the desired services are offered by gas stations). Therefore, to successfully communicate, the user has dynamically to adjust her or his behaviour and reconcile her or his subjective semantics with semantics implemented in the different parts of the system. It is understood that the efficiency of this adaptation process depends on both, the individual and the social dynamics of communication.

As a digital city is composed of a number of independently developed heterogeneous recourses – system components, its user interface usually consists of multiple parts that may employ different languages of different "digital genres" (e.g. text vs. graphics) and implement different and even conflicting semantics corresponding to different communities (e.g. "Western" *vs*. "Eastern") of the system users. To make the digital city interface capable of social adaptation, it is necessary to develop an integrated perspective on the communication process. Any of the current holistic approaches to modeling communication is, however, limited in the sense that it is based on an *ex ante* analysis, which assumes the (pre)existence of a society of the system users. In the case of digital cities, such a society does not pre-exist but emerges after a version of the digital city has been set up and made accessible. This emerged society is not stable, as not stable is the structure of the system: the users as well as the resources incorporated in the digital city have internal dynamics and are autonomous but mutually dependent when communicate. Being allied (functionally and/or communicatively), they create a complex system with a dynamics generally indefinable in terms of the classical communication theories. Thus, new approaches need to be found to provide guidelines for the design and development of distributed information systems, such as digital cities.

3. FROM QUANTITATIVE SEMIOTICS TO A NEW COMMUNICATION THEORY

3.1 Conceptual Framework

We will assume that all the systems (e.g. psychic) involved into communication are (higher order) autopoietic systems acting in the consensual domain (for details, see [5] and [4]). Each of these systems "belongs" to at least one self-organizing social system seen as a realization of the consensual domain. We will also assume that a psychic system engaged in communication is composed of interpretants (i.e. meanings) and is observationally equivalent to the totality of experientially effective behavior called objects. The social system is composed of signs and is equivalent to the totality of behavior maintaining the social system as a whole. (It should be noted that our treatment of the semiotic triad *object-sign-interpretant*, although does not generally contradict to the concept of infinite semiosis, moves forward from the canonical Peircean definition.)

We will consider communication as a partial sequence of interdependent semiosis processes $C=\{S_1,S_2,\ldots,S_K\}$, where $S_t=\{Object_t,Sign_t,Interpretant_t\}$ is a single semiosis process specified through its manifestation (that is an interpreted sign), and t is a discrete time-mark. The dynamics of the communication process is described as follows:

$$\begin{cases} \mathbf{Objects}_{t+1} = \text{Externalizing}(\mathbf{Objects}_t, \mathit{PsychicState}_t) \\ \mathit{PsychicState}_{t+1} = \text{Interpreting}(\mathit{PsychicState}_t, \mathbf{Signs}_{t+1}) \end{cases} \quad (1a)$$

$$\begin{cases} \mathbf{Signs}_{t+1} = \text{Authorizing}(\mathbf{Signs}_t, \mathit{SocialState}_t) \\ \mathit{SocialState}_{t+1} = \text{Evolving}(\mathit{SocialState}_t, \mathbf{Objects}_{t+1}) \end{cases} \quad (1b)$$

where "**Objects**" is a state vector representing behavior, i.e. psychic states as (self)observed, which are communicatively effective, and "**Signs**" is a state vector representing behavior socially valid. "Externalizing" and "Interpreting" are operators that represent the uttering and the understanding processes, respectively; likewise, "Authorizing" and "Evolving" represent the corresponding implied processes of social dynamics (see Fig. 1).

3.2 Quantitative Semiotics: Essential Definitions

To refine and make the conceptual model (1*a*-*b*) formal, the apparatus of algebraic semiotics can be used [1]. We will consider a sign system Ξ a logical theory that consists of ordered sets of symbols (for details, see [1]). We will call a semiotic morphism $f:\Xi \rightarrow \Xi'$ a translation from a sign system Ξ to a sign system Ξ'. We will also call a composition of semiotic morphisms $\mu_{t+1} : f_t[\Xi_t] \xrightarrow[P_{t+1}]{} \Xi_{t+1}$ as a basic semiotic component, where f_t is a single semiotic morphism on Ξ_t, and μ_{t+1} is a *probabilistic semiotic morphism* that specifies a set of L_{t+1} possible translations from Ξ_t to Ξ_{t+1} with probabilities $P_{t+1} = \{p_1, p_2, ..., p_{L_{t+1}}\}$, one for each translation.

__**Axiom I.**__ A psychic system can be represented by a sign system Ξ. The state of the psychic system is completely described by a set of signs in Ξ. ♦

__**Definition 1.**__ Two states of the psychic system, α and β, are called orthogonal, written $\alpha \perp \beta$, if α implies the negation of β, or vice versa. ♦

__**Definition 2.**__ For a subset of states $A \subset \Xi$, its orthogonal complement is $A^{\perp} = \{\alpha \in A | \forall \alpha' \in A^{\perp} : \alpha \perp \alpha'\}$. ♦

__**Definition 3.**__ $A \subset \Xi$ is orthogonally closed if $A = A^{\perp\perp}$. ♦

__**Definition 4.**__ We will call *Object* an orthogonally closed set of psychic states with a single *Interpretant* understood as a distinction. ♦

An interpretant is a psychic state but also the result of interpretation. E.g., the experiencing of a "good repair shop" implies certain psychic states, and

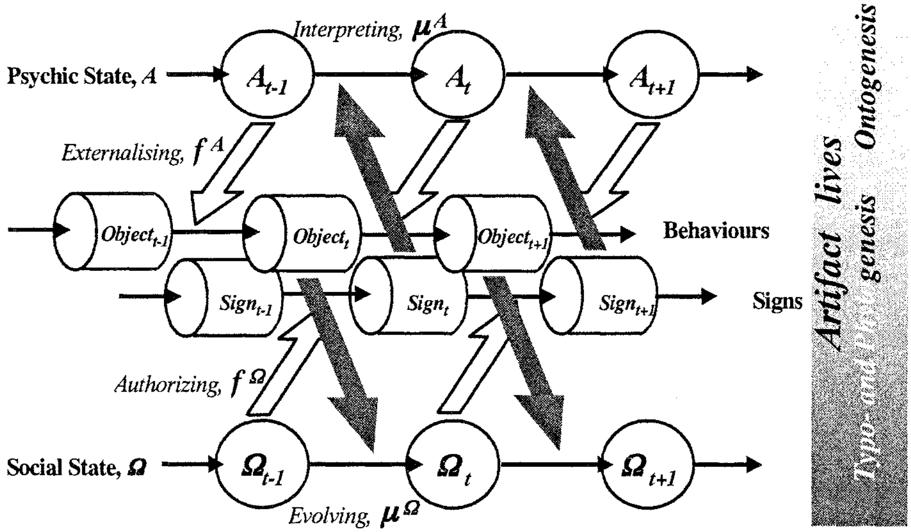

Figure 1. Semiosis of communication and artifact lives (also see [2])

interpretation of the signs "good repair shop" will result in a psychic state determined by the (past) experiences of the interpreter.

Axiom II. Right after an interpretation of an *Object* standing for some psychic states γ, which resulted in α, the psychic system is represented by α, i.e. the original states γ are translated to the *Interpretant* α by the interpretation. ♦

Similarly with a quantum system, the psychic system is in multiple states at once, and it cannot uniquely be interpreted: at every single moment, there can be made more than just one interpretation of the psychic system state. E.g. a repair shop can be "good" but "remote" for a particular customer.

Proposition I (Context Principle). For every two distinct psychic states $\alpha \neq \beta \subset \Xi$, there exists a context state $\alpha \cup \beta = \gamma \subset \Xi$ such that $\forall \delta \subset \Xi$, if $\delta \perp \alpha$ and $\delta \perp \beta$, then $\delta \perp \gamma$. ♦

Axiom III. Each interpreted psychic state can be represented in a unique way by a probabilistic semiotic morphism μ with $P = \{p_1, p_2, ..., p_L\}$ on Ξ. The probabilities of the morphism correspond to the possible interpretation results. ♦ (Probabilities P are determined with Axiom V, which is omitted in this paper, using the notion of semantic distance [4].)

An interpretant exists always only to the extent as the corresponding psychic states (i.e. the domain of μ) are accessible for interpretation. E.g., the words "a good repair shop" can hardly be associated with a unique psychic state unless an additional language context is provided.

Axiom IV. For a psychic system engaged into communication, the dynamics of the communication process is given by a pair of sequences of basic semiotic components defined recurrently as follows (see also Fig. 1):

$$\mathrm{A} = \{\mathrm{M}^{\mathrm{A}}, \mathrm{P}^{\mathrm{A}}, \mathrm{F}^{\mathrm{A}}, \Xi_{objects}\}, \tag{2a}$$

$$\Omega = \{\mathrm{M}^{\Omega}, \mathrm{P}^{\Omega}, \mathrm{F}^{\Omega}, \Xi_{signs}\}, \tag{2b}$$

where A is the model of the psychic system that includes M^{A} a set of semiotic morphisms μ_{t+1}, P^{A} a set of probabilities for each μ_{t+1} in M^{A}, F^{A} a set of semiotic morphisms f_t, $t=1,\ldots,K$, and $\Xi_{objects} = \bigcup_{m=1}^{M} Object_m$, M is the number of the interpretants by the psychic system prior to the communication. Ω is the model of the social system with analogously defined M^{Ω}, P^{Ω}, and F^{Ω}, and $\Xi_{signs} = \bigcup_{n=1}^{N} \Xi_{objects_n}$, where N is the number of psychic systems constituting the social system. ♦

3.3 Semiosis of Communication and Artifact Lives

(Closure) Theorem I. A communication is orthogonally closed *pragmatically* through the laws of nature in the sense that given an interpretant $Interpretant_t$, it is only the physical laws that determine its object $Object_t$ so that $Object_t = Object_t^{\perp\perp}$; *semantically* through the psychic system in the sense that $\Xi_{objects} = \Xi_{objects}^{\perp\perp}$; and *syntactically* through the social system in the sense that $\Xi_{signs} = \Xi_{signs}^{\perp\perp}$. ♦

It follows from the theorem (for the proof, see [4]) that psychic states corresponding to every physically possible *Object* should uniquely be determined as indicative of the given communication situation, but also that *Object* corresponding to a psychic state does not have to be unique. Besides, the theorem dictates that every single communication is orthogonally closed only to a degree. Indeed, given a communication situation, its pragmatic closure can be established if one considers all the possible *Objects*, which are to express the physical frames of the situation and to establish the interpretant (e.g. a perception or emotion). The latter is not a practical case (unless one considers learning by trial and error), and *Objects* are results of some relations (that are not necessarily conventions) developed from individual experience rather than exhaustive representations of the psychic state. It is obvious (due to Axiom IV) that semantic and syntactic closures are hardly reachable, too. Hence, *every single communication is uncertain.*

Lemma I. Given a communication situation with a pragmatic uncertainty *Const*, a natural limitation on the minimal requisite interaction for a psychic system engaged into the communication is determined by the degree of the communication closure $E_{O,M}$. The latter is inversely proportional to the communication uncertainty and can be estimated using the following formula ($E_{O,M}\in[0,1]$, $E_{O,M}=1$ is for the absolute certainty):

$$E_{O,M} = k_s\sum_{i=1}^{M}\left(\sum_{j=1}^{M}\frac{N_{Int}(Object_i \cap Object_j)}{N_{Int}(Object_i \cup Object_j)} - 1\right) + k_c\sum_{i=1}^{O}\left(\sum_{j=1}^{O}\frac{N_{Int}(Sign_i \cap Sign_j)}{N_{Int}(Sign_i \cup Sign_j)} - 1\right) - Const =$$
$$= k_s\sum_{i=1}^{M}\left(\sum_{j=1}^{M}\frac{N_{Int}(Object_i \cap Object_j)}{N_{Int}(Object_i) + N_{Int}(Object_j) - N_{Int}(Object_i \cap Object_j)} - 1\right) +$$
$$+ k_c\sum_{i=1}^{O}\left(\sum_{j=1}^{O}\frac{N_{Int}(Sign_i \cap Sign_j)}{N_{Int}(Sign_i) + N_{Int}(Sign_j) - N_{Int}(Sign_i \cap Sign_j)} - 1\right) - Const, \quad (3)$$

where M is the number of *Objects* produced by the psychic system in the given communication, O is the number of *Signs* received by the psychic system, $N_{Int}(Object_i)$ is the number of interpretants by the psychic system for the same object $Object_i$, $N_{Int}(Object_i \cap Object_j)$ is the number of interpretants for both $Object_i$ and $Object_j$, $N_{Int}(Sign_i)$ is the number of interpretants of the same sign $Sign_i$ in the social system, $N_{Int}(Sign_i \cap Sign_j)$ is the number of common interpretants of $Sign_i$ and $Sign_j$, k_c and k_s are normalizing coefficients. Note that generally, $M \neq O$. ♦ (The proof can be found in [4].)

Const depends on pragmatics of the communication situation that may change throughout the lives of the artifacts (if any) in focus. In the case of a car repair shop, *Const* depends on the characteristics of the shop as a physical object, e.g. its organization. Having assumed that the uncertainty caused by the social dynamics converges to a constant for each particular topic in the given social system, one can (though indirectly) evaluate and assess the lives of artifacts-subjects of communication by monitoring the dynamics of $E_{O,M}$ (see Fig. 2). On the other hand, whenever *Const* is independent of time, $E_{O,M}$ can be used as a measure of the interface/information system quality or communication efficiency [3].

4. CONCLUDING REMARKS

In this paper, we have presented the new communication theory that offers a systematic basis for the description of communication phenomena. The proposed framework provides guidelines for the design and development of information systems capable of socio-cognitive adaptation, while the formalization permits us to qualitatively assess the efficiency of communication in each particular case. Furthermore, the theory explicitly defines and allows for exploring, both theoretically and empirically, the relationship between artifact lives and the efficiency of communication. All these are novel contributions of this study.

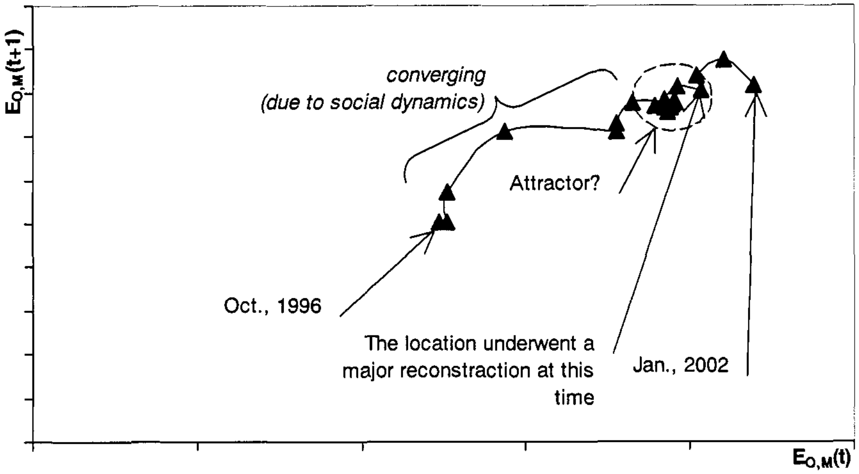

Figure 2. Monitoring artifact lives: Return map for $E_{O,M}$ (t) calculated for a (part of a) "Digital City" associated with a certain geographical location for the period from Oct., 1996, to Feb., 2002, with 1 month subinterval (65 months); the data obtained from the Web Archive http://www.archive.org

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