A Neurobiological Perspective on Socio-Technical Systems

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Abstract. The Socio-Technical Systems approach assumes that an organizational work system can be seen as two independent but tightly correlated systems – a technical one and a social one. Together, these systems determine the performance of the work system. However, in spite of decades of research efforts, it is far from clear how to define these systems. Without a firm basis, analytical and constructive initiatives are bound to become either fragmented or ad-hoc. To this end, the purpose of this paper is to suggest a *neurobiological* perspective on Socio-Technical Systems. The reason for this seemingly odd point of departure is quite simple: any conceptualization of Socio-Technical Systems must ultimately take stock of the *sine qua non* of our existence as biological creatures. A fundamental prerequisite for survival is coordination – without coordination, acting in the world is inhibited. Based on many years of coordinating complex system development tasks in industry, I have proposed the construct of *activity modalities – objectivation, contextualization, spatialization, temporalization, stabilization, and transition* – as intrinsic neural predispositions enabling coordination. This position is elaborated into a particular kind of work system, called the *activity domain*. In the activity domain, individual lines of actions are fit together using means such as IT artifacts and common identifiers to achieve a common goal. Actions are manifested internally as changed brain structures in individuals, and externally as various artifacts reflecting the modalities. In conclusion, I claim that this approach indicates a paradigm shift, which may provide a solid ground for further inquiries into the analysis and construction of Socio-Technical Systems.

Keywords: Socio-Technical Systems ·work systems · coordination · neurobiology ·activity modalities ·functional organs· equipment · joint action ·common identifiers · activity domain

1 Introduction

The core of the Socio-Technical Systems (STS) approach is to regard organizational work as composed of two independent but tightly correlated systems – a technical one and a social one:

> The technical system is concerned with the processes, tasks, and technology needed to transform inputs to outputs. The social system is concerned with the attributes of people {e.g., attitudes, skills, values), the relationships among people, reward systems, and authority structures. It is assumed that the outputs of the work system are the result of joint interactions between these two systems. Thus, any design or redesign of a work system must deal with both systems in an integrated form [3, pp. 17-18].

However, in spite of decades of research efforts, it is far from clear how to define these two systems. For example, Baxter & Sommerville state that

> There is considerable variation in what people mean by the term socio-technical system … Nowadays, many different fields have adopted the term, often using their own interpretation—sometimes focusing on the social system, sometimes on the technical, but rarely on both together [1, p. 8].

STS approaches have long been prominent lines of research in the Information systems (ISs) discipline [14]. ISs lie at the intersection of people, organizations, and technology [18], and have from the discipline's outset been regarded as socio-technical systems. For example, Goldkuhl and Lyytinen suggest that ISs should be analyzed as "social systems, only technically implemented" [8, p. 14]. A more recent research stream is centered on the concept of "sociomateriality", which is a reaction against the conspicuous absence of technology in organizational research [15]. Sociomateriality posits "the inherent inseparability between the technical and the social" [ibid, p. 454]. Humans and technologies have no inherent properties, "but acquire form, attributes, and capabilities through their interpenetration" [ibid, p. 455-456].

As with the STS approach, the IS discipline has problems to define its core. For example, Lee claims that: "Virtually all the extant IS literature fails to explicitly specify meaning for the very label that identifies it. This is a vital omission, because without defining what we are talking about, we can hardly know it" [10, p. 338]. Moreover, "To its detriment, past research in information systems … has taken for granted many of its own key concepts, including 'information,' 'theory,' 'system,' 'organization,' and 'relevance.'" [ibid, p. 336].

There is something very disturbing about this state of play. In spite of continued research efforts, there seems to be little progress in articulating a firm basis from which analytical and constructive initiatives can proceed. Without such a basis, any initiative faces the danger of becoming either fragmented or ad-hoc. To this end, the purpose of this paper is to suggest an alternative conceptualization of Socio-Technical Systems from an *individual* perspective. In focusing on the 'social' and 'technical', the individual has been relegated into the background. However, in the final analysis it is necessary to bring the individual back to the fore since the concept of 'socio-technical' becomes void of meaning without the individual.

Organizations and work systems exist for a reason. People act together in order to achieve something. Acting in turn requires coordination; be that swinging an axe to cut down a tree, or participating in a coordinated assault on an enemy. If, for some reason, an individual is unable to coordinate her actions alone or together with others, she cannot ultimately survive: "I do not see any way to avoid the problem of coordination and still understand the physical basis of life" [16, p. 167]. Thus, it is highly

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plausible that the phylogenetic evolution of humankind has brought about some kind of neurobiological predispositions for coordinating actions in the situations we encounter during our lifetime. Consequently,

> …the mental is inextricably interwoven with body, world and action: the mind consists of structures that operate on the world via their role in determining action [11, p. 527]

In the following, I will elaborate on this position, using certain elements from extant research: the conceptualization coordination as a complex functional system [12], the activity modalities as intrinsic, neural factors contributing to this functional system [20], the notions of functional organs [13] and equipment [9] for relating neural structures and artifacts, and the terms joint action and common identifiers [2] for reconciling the individual and social aspects of coordination.

These elements are brought together in a particular kind of work system, called the *activity domain* [20], in which the 'social', 'technical', and 'individual' are integrated into a coherent whole. This enables a paradigm shift in the conceptualization of Socio-Technical Systems. Rather than seeing work systems as the result of as two interacting systems, the 'social' and 'technical' become aspects of a more basic construct, the activity domain, which is ultimately grounded the *sine qua non* for our existence as biological creatures.

2 A Neurobiological Perspective

Imagine that you can travel some 30,000 years back in time, and that you are a member of an 'organization' specialized in exploiting mammoths for the benefit of your tribe. The activity of one 'business unit' in this organization is illustrated in Fig. 1 – hunting the mammoth. What neurobiological faculties enable you to participate in this activity?

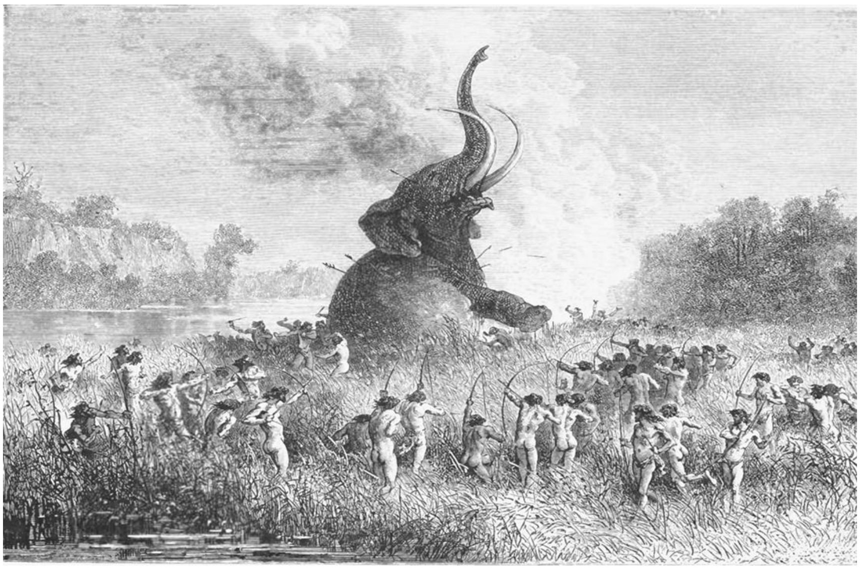

Fig. 1. Illustration of a mammoth hunt. Source: Original wood engraving by E Bayard; in [6].

2.1 The activity modalities

First, you need to *contextualize* the situation. You have to grasp that which is relevant for the hunt, and disregard the rest. For example, hunters, bows, arrows, actions, shouts, gestures, and other hunters are certainly relevant, while the beetles and other insects in the trees in the background can safely be ignored.

Second, you must focus on *the object* for the activity, the mammoth. Object orientation is fundamental for carrying out any kind of action: “Human beings live in a world or environment of objects, and their activities are formed around objects” [2, p. 68].

Third, you need to orient yourself *spatially* in the context. You must recognize how relevant things, such as how the mammoth, river, trees, and hunters are positioned in relation to your own position.

Fourth, you must acquire a sense for how actions should be carried out in a certain order, which is a *temporalization* capability. For example, shooting an arrow involves the steps of grasping the arrow, placing it on the bow, stretching the bow, aiming at the target, and releasing the arrow.

Fifth, you cannot shoot your arrows in any way you like. Shooting in a wrong direction may result in other hunters being hit rather than the mammoth. You must learn how to perform appropriate mammoth hunting; something that will be accrued after participating in many successful, and, presumably, some less successful mammoth hunts. Eventually, this habituation lends a sense of *stability* to your actions, which need not be questioned as long as it works.

Sixth, an activity is typically related to other activities. For example, the prey will most likely be cut into pieces and prepared to eat in another ‘business unit’ – the

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cooking activity. This has its own motive, to satisfy hunger, and object, which happens to be the same as for the hunting activity, the mammoth. However, here other aspects of the mammoth are contextualized as relevant, such as which parts of the mammoth are edible. In order to conceive of other activities, you must be capable of refocusing your attention and *transit* from one activity to another.

The six dimensions outlined above – *contextualization*, *objectivation*, *spatialization*, *temporalization*, *stabilization*, and *transition* between activities – are denoted *activity modalities*. These modalities, which were instigated from my work with coordinating complex development projects in the telecom industry, are predicated to underlie the inception of every human activity [20]. It follows that the brain is capable of perceiving, processing, and integrating multimodal sensory impressions into an action capability in the form of the activity modalities and their interdependencies. This capability is the same regardless of whether actions are carried out in solitude or together with other individuals, as in the mammoth hunt example.

Since the human neurobiological constitution has not changed significantly since the emergence of early hominids some 3.5 million years ago, the same activity modalities are at play today when we try to use of extant technology and manage modern organizations. We still need to contextualize situations, focus on the target, orient ourselves spatially, plan for actions, learn to distinguish purposeful actions from aimless ones, and refocus our attention between situations. It is this very foundation that ultimately determines how we use technology and organize social work.

2.2 Coordination as a mental functional system

The brain structures underlying higher mental functions such as coordination have been conceptualized as *functional systems*:

> Each functional system consists of a group of circumscribed brain areas, and each brain area has its specific elementary function. It is the integrated activity of an entire functional brain system that underlies the activity of a higher mental function [7, p. 561].

Each brain area provides a specific *factor* in the realization of the functional system:

> But it is especially significant that *each of these zones contributes its own factor to the making of a functional system* [12, p. 12, italics in original].

This means that coordination may be seen as a functional system in which the activity modalities are contributing factors. I have proposed [21] that such a functional system may be modeled as *dependencies between factors* as illustrated in Fig. 2 (the activity modalities are emphasized):

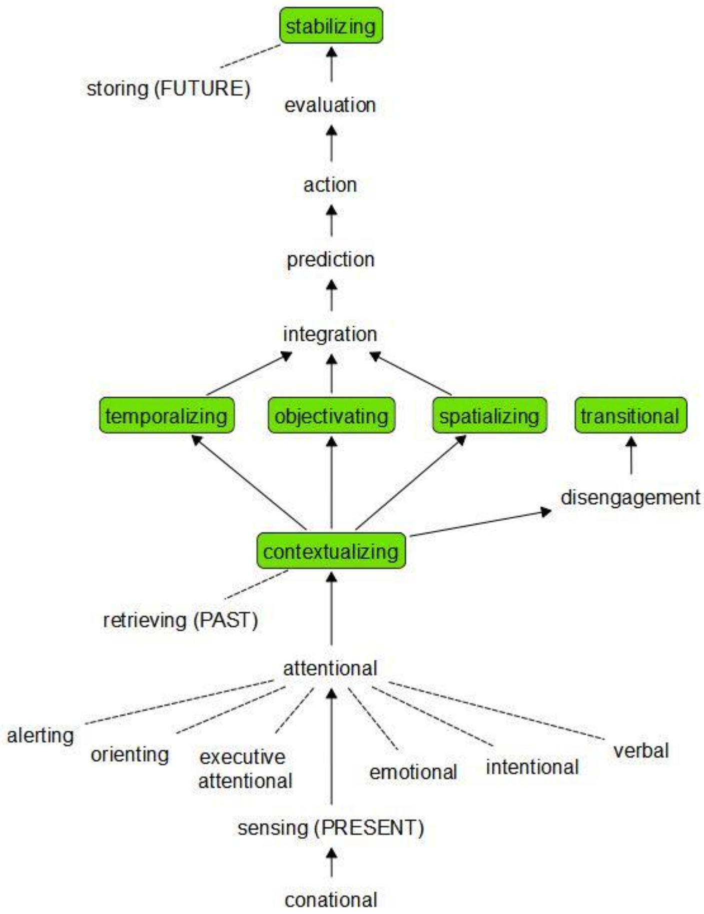

Fig. 2. Factors contributing to a functional system for coordination

The illustration should be read from the bottom up. The working zones realizing a certain factor "may be located in completely different and often far distant areas of the brain" [13, p. 31]. A lesion in a particular zone in the brain may destroy any of the factors. For example, the entorhinal cortex has a crucial role in spatial representation and navigation [22]. If this area is affected, the spatialization modality is demolished, and consequently the ability to act since spatial orientation is inhibited.

The significance of a model like the one in Fig. 2 is its character of a *boundary object* [4] between the social and neural realms. Towards the neural realm, the factors provide a way to ground the activity modalities in extant neuroscience results, and towards the social realm, manifestations of these modalities can be studied and analyzed for improving the coordination of activities.

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2.3 Functional organs and equipments

Before you can participate in the hunt, you need to master various means such as bows, arrows, hunt-specific language, gestures, etc. This can be seen as an encounter between phylogenetically evolved morphological features of the brain and body, and the ontogenetic development of the individual in a particular cultural and historical situation. How to understand this encounter was in focus for such eminent scholars as Lev Vygotsky, Aleksei Leontiev, and Alexander Luria. A common tenet in their thinking is that the socio-historical environment plays a decisive role in the formation of higher mental functions. The brain is formed "under the influence of people's concrete activity in the process of their communication with each other" [12, p. 6]. External, historically formed artefacts such as tools, symbols, or objects, among others "tie new knots in the activity of man's brain, and it is the presence of these functional knots, or, as some people call them 'new functional organs' (…) that is one of the most important features distinguishing the functional organization of the human brain from an animal's brain" [ibid.].

From the moment you start engaging with an artefact, functional connections between individual parts of the brain are gradually established, which means that "areas of the brain, which previously were independent, become the components of a single functional system" [13, p. 31]. This can be seen as an *equipment* constructing process, where the artefact passes from a state of being *present-at-hand* to *ready-at-hand* [9, 17]. Equipment is encountered in terms of its use in practices rather than in terms of its properties: "our concern subordinates itself to the 'in-order-to' which is constitutive for the equipment we are employing at the time" [9, p. 98]. In this process, the artefact itself may or may not be modified, but for the actor, the tool recedes, as it were, from "thingness" into equipment, when the in-order-to aspect – what the tool can be used for – takes precedence. A nice example of this process originates from the cellist Mstislav Rostropovich:

> "There no longer exist relations between us. Some time ago I lost my sense of the border between us…. I experience no difficulty in playing sounds…. The cello is my tool no more" [23, p. 295].

2.4 Joint action

When several individuals coordinate their actions in order to achieve a common goal, they are engaged in "joint action" according to Blumer [2]. This term refers to the "larger collective form of action that is constituted by the fitting together of the lines of behavior of the separate participants" [ibid, p. 70]. Since each actor occupies a different position in space and "acts from that position in a separate and distinctive act" [ibid, p. 70], joint action cannot be interpreted as participants forming identical functional organs and equipments. Rather, individual equipments need to be fitted together by external artefacts, which provide guidance in directing individual acts so as "to fit into the acts of the others" [ibid, p. 71]. Such artefacts are called "common identifiers" by Blumer. Joint action is a fundamental aspect of a society: "To be understood, a society must be seen ... in terms of the joint action into which the separate lines of action fit and merge” [ibid, p. 71].

2.5 The activity domain

If we put together the notions of complex functional systems, activity modalities, functional organs, equipments, and joint action, the contours of a neurobiological conceptualization of activity begin to materialize. As individuals, we are endowed with certain neural faculties for coordinating actions, which we call activity modalities. We employ the very same faculties in every situation we encounter; it could not possibly be otherwise. When acting, we may use various artifacts such as tools or other means. These we learn to use in an equipment forming process, which “tie new knots” in our brains – functional organs.

At the same time as we are all unique individuals, we are also inherently social beings. From the moment we are born, we enter into a specific cultural and historical situation. In pursuit of fulfilling common social needs, we coordinate our own actions with others in joint action, which requires recognizable and meaningful external artifacts – the common identifiers.

In order to conveniently theorize about work systems thus conceptualized, Taxén has proposed the term *activity domain* [20]. Thus, the activity domain comprises both tangible elements – manifestations of the activity modalities – and intangible ones – the functional organs “manifested” in the brains of each participating individual.

3 Practical Illustration

In order to illustrate the approach in a contemporary context, I will use an example from Ericsson, a major provider of telecommunication systems worldwide. In the late 1990s, Ericsson was developing the 3rd generation of mobile systems [19]. The challenges posed by this endeavor were unprecedented in terms of technology, size, development methods, and IT-support:

> The total technical changes being implemented in this project are enormous. Using traditional methods then the scope of change implemented in single steps will be too large and cannot be managed (Total project manager 3G, Dec 1999)

As its peak, around 140 projects and subprojects worked on different parts of the system. One particular part was the so called Main Switching Center (MSC) node, which involved about 1000 persons, distributed on 22 subprojects and 18 design units world-wide. These units were coordinated from two places called the S-site (in Stockholm, Sweden), and the A-site (in Aachen, Germany). In order to convey a sense for the size of this project, a so called integration plan for the MSC node is shown in Fig. 3.

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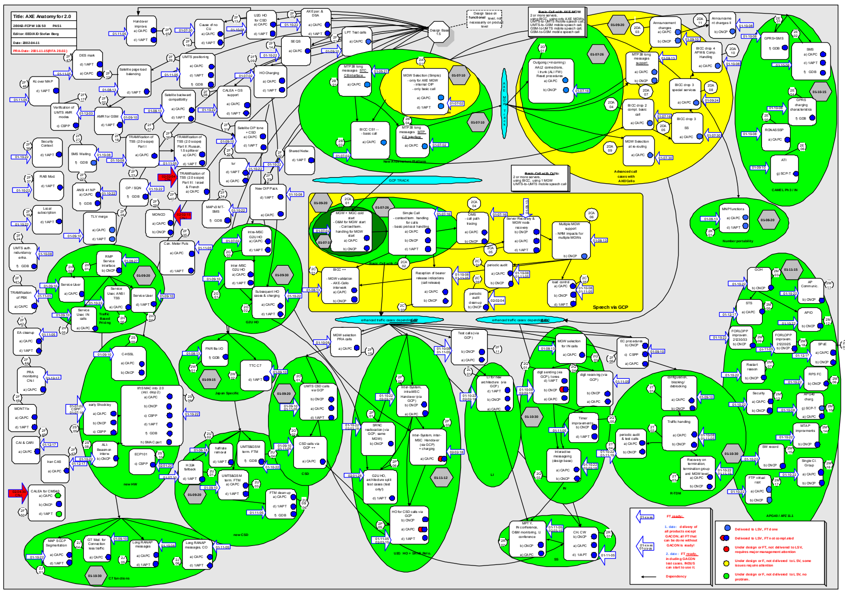


Fig. 3. Integration plan for the MSC node

Each of the white squares signifies a sub-project; a work package that delivers a tested functionality to integration and verification of the whole system. The lines indicate dependencies; from basic functionalities at the top and progressing step by step to the full functionality at the bottom of the figure. Ellipses mark major functional groups such as locating the mobile, handover between mobile cells, mobile owner data, etc. The small dots in each work package show, in a traffic-light manner, the status of the package such as 'under design for function test', 'requires major revision', 'delivered to system test', and the like.

It was soon realized that keeping track of all these work packages being delivered from all over the world to integration required extensive IS support. With the introduction of modern, object-relational databases in the mid-1990s, quite new information management capabilities became available. In one sub-project, coordinated from the S-site, a decision was taken in 1997 to try this new technology out. A particular IT platform called Matrix was acquired for this purpose. Matrix was multi-tier, web-technology based, generic purpose information management system on which organizational specific IT applications could be developed. A particularly important feature of Matrix was the so called Modeling studio, which enabled applications to be easily modified.

One particular challenge in the 3G project was traceability from requirement to system parts implementing these requirements. A small team consisting of the project manager, a requirement manager, a consultant from the vendor of Matrix, and this author, was set up to work with this task. By ceaselessly iterating between construction of a requirement information model and its implementation in Matrix, a useful way of managing requirements was gradually worked out. An example of the information model is shown in Fig. 4.

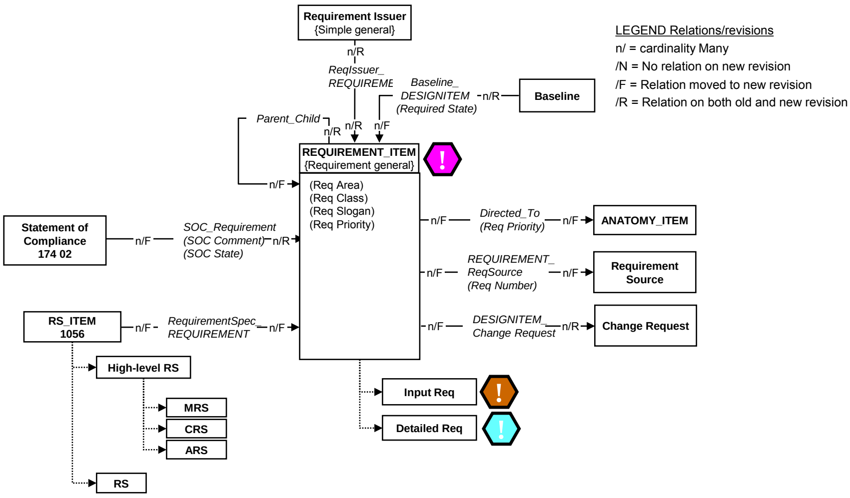
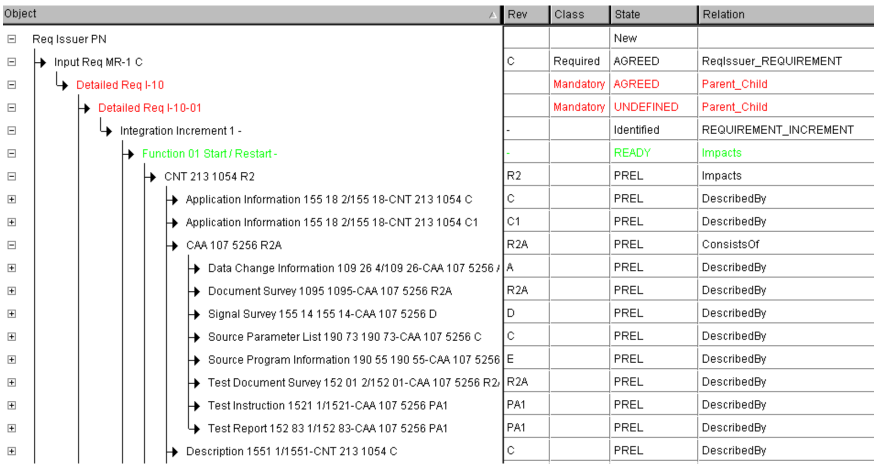


Fig. 4. An information model for requirement management

As can be seen from Fig. 4, the construction comprised quite many details that had to be settled. A snapshot from Matrix is illustrated in Fig. 5 where individual requirements can be traced all the way from the organization issuing the requirement ("PN") down to system modules contributing to the realization of the requirement ("CNT", "CAA") and the software code ("Source Program Information"):



Object	Rev	Class	State	Relation
Req Issuer PN			New	
Input Req MR-1 C	C	Required	AGREED	ReqIssuer_REQUIREMENT
Detailed Req I-10		Mandatory	AGREED	Parent_Child
Detailed Req I-10-01		Mandatory	UNDEFINED	Parent_Child
Integration Increment 1 -	-		Identified	REQUIREMENT_INCREMENT
Function 01 Start / Restart -	-		READY	Impacts
CNT 213 1054 R2	R2		PREL	Impacts
Application Information 155 18 2/155 18-CNT 213 1054 C	C		PREL	DescribedBy
Application Information 155 18 2/155 18-CNT 213 1054 C1	C1		PREL	DescribedBy
CAA 107 5256 R2A	R2A		PREL	ConsistsOf
Data Change Information 109 26 4/109 26-CAA 107 5256 /	A		PREL	DescribedBy
Document Survey 1095 1095-CAA 107 5256 R2A	R2A		PREL	DescribedBy
Signal Survey 155 14 155 14-CAA 107 5256 D	D		PREL	DescribedBy
Source Parameter List 190 73 190 73-CAA 107 5256 C	C		PREL	DescribedBy
Source Program Information 190 55 190 55-CAA 107 5256	E		PREL	DescribedBy
Test Document Survey 152 01 2/152 01-CAA 107 5256 R2/	R2A		PREL	DescribedBy
Test Instruction 1521 1/1521-CAA 107 5256 PA1	PA1		PREL	DescribedBy
Test Report 152 83 1/152 83-CAA 107 5256 PA1	PA1		PREL	DescribedBy
Description 1551 1/1551-CNT 213 1054 C	C		PREL	DescribedBy

Fig. 5. Project data loaded in Matrix

3.1 Interpretation

The process of working out a way to manage requirements can be seen as the construction of an activity domain focused on the object "requirement". In this process, each individual team member gradually "tied new knots" in their brains related to the objectivation activity modality. So, for example, if one member had been hit by a stroke affecting the perirhinal cortex, she would have been unable to continue her work since this part of the cortex is involved in object recognition [5].

In the same manner, functional organs related to spatialization developed in interaction with the information model and its implementation in Matrix. The model in Fig. 4 has a distinct spatial character (things related to each other and characterized by relevant attributes, relations, cardinalities, and so on.). Moreover, traces of the other modalities can be noted in Fig. 5. Stabilization is signified by the endemic way of naming elements (for example "CAA 231 1054 R2" for signifying a particular revision of a software module). Temporalization can be noticed as different states of elements ("AGREED", "PREL", etc.).

When establishing the requirement management context, the model and its implementation in Matrix function as common identifiers, fitting individual lines of action together. The convergence of this process was indeed long and arduous. The form and content of the model were constantly discussed and implemented in Matrix over and over again; resulting in two kinds of manifestations. The first one is the external, tangible artifacts in Fig. 4 (the information model) and the IT application visualized as in Fig. 5. The second one is the internal, intangible functional organs evolved in each participant's brain. Both these kinds are intrinsically related; one could not evolve without the other. However, this does not mean that they become "inherently inseparable" as in the previously mentioned sociomaterial view on socio-technical systems. There is no problem in distinguishing a team member from the information model or the IT application.

4 Concluding Remarks

In this contribution, I have suggested an alternative conceptualization of Socio-Technical Systems. Taking neurobiology as a point of departure opens up quite new lines of research into these systems. However, such a bold enterprise needs to be corroborated by future research on many points. For example, the notion of activity modalities requires a thorough investigation of possible neural correlates realizing these factors. Moreover, coordination is but one aspect, albeit perhaps the most important one. If we believe that the individual has a definite role to play in conceptualizing Socio-Technical Systems, the issues of coordination and action cannot be avoided.

In conclusion, the concept of the activity domain integrates the 'social', 'technical', and 'individual' into a coherent whole. This enables a paradigm shift in the conceptualization of Socio-Technical Systems. Rather than seeing work systems as the result of as two interacting systems, the 'social' and 'technical' become aspects of a more basic level, the neurobiological one, which is undeniably the *sine qua non* for our existence.

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