Actor-Network-Theory and Communication Networks: Toward Convergence

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1. Introduction

A major methodological trap lurks beneath attempts to conceptualize the processes that come into play when existing social concepts are reinvented or new ones are introduced in the context of rapid technological and social change: the search for what Frederic Jameson called "the ultimately determining instance" (1995, p.37). This instance is most often looked for in the dichotomy of society and technology. Approaches which lean toward society being this instance begin with the assumption that technology and its resulting consequences are planned and inaugurated by social actors, most often large institutional entities. The main focus is either on the political economy of the object of study (Mosco, Wasco, 1988; Mosco, 1996) or on the social construction of the artifact of interest (MacKenzie, Wajcman, 1986; Bijker, 1994). Particularly the latter, the Social Construction of Technology (SCOT), "points to technology as being through and through social." (Pinch, 1996) The most extreme position on this side of the spectrum is "social determinism".

On the other hand, approaches leaning towards technology as this instance assume that technology develops according to its own internal necessity and out of dynamics beyond human control. It is focussed on the impact of technology which is seen as the distinguishing element between the past and the future (most prominently, Toffler, 1980; Glider, 1989; for a general discussion see Smith, Marx, 1994). At the extreme end of that side of the spectrum is "technological determinism". Characteristic for both models is a clear distinction between society on one side and technology on the other. The main disagreement lies in the question, which is leading which? Is technology constructed of society or society made up of technology?

An interesting approach to thinking about the social and technological development all at once has been developed as "Actor-Network Theory". This approach is one stream within the Social Construction of Technology, a recent movement in the history and sociology of science and technology. It is most prominently associated with the French sociologists of science Bruno Latour and Michel Callon. The theory's aim is to describe a society of humans and non-humans as equal actors tied together into networks built and maintained in order to achieve a particular goal, for example the development of a product. To achieve this aim, the theory uses a somewhat specialized vocabulary. The key term actor, for example, is not used as in conventional sociology where actors are usually defined as "discrete individual, corporate, or collective social units." (Wasserman, Faust, 1994, p.17)

It is therefore necessary to introduce the particular meaning of the central concepts in the Actor-Network Theory. This is done in section 2 of this paper. The third section concentrates on networks in action, their emergence, dynamics and stabilization. The fourth section looks at some neighbouring concepts. They are introduced in the light of their usefulness to adapt the Actor-Network Theory, which has been developed for the analysis of science, to the analysis of computer-based communication networks, their applications and dynamics. Most interesting in this regard are recent concepts of complexity and evolution, as well as some aspects of systems theory.

The fifth and final section reviews the concepts developed so far. It assesses the role of biological concepts in developing an approach for understanding the socio-technological dynamics in computer-based communication networks.

2. Central Concepts

For Bruno Latour (1993) the Actor-Network Theory attempts to overcome what he sees as the major shortfall of Modernism and Postmodernism: the slicing of a continuous, "hybrid" reality into analytical domains. The epistemology of Modernism divided nature and society into two incommensurable poles. Nature was only observed, never man-made; whereas society was only made by humans. The two poles were indirectly connected by language which allowed us to make stable references to either one of them. Postmodernism separated the middle ground, language, from both poles by declaring it autonomous. This autonomous domain has been described as free-floating signs (Baudrillard) or as self-referential texts and language games (Derrida). It is Latour's goal to show that the separation introduced by Modernism and extended by Postmodernism is artificial. Because (technological) reality is "simultaneously real, like nature, narrated, like discourse, and collective, like society" (p.6) he does not follow the clean divisions envisioned by Modernism and recently claimed that Modernity never happened, that We Have Never Been Modern (1993).

In order integrate the three separated domains of nature, society and language(to "retie the Gordian knot"(the key terms in the Actor-Network Theory take on somewhat unusual meanings. This serves to highlight how humans and non-human can both be actors which are integrated into networks, sometimes sealed in black boxes. These network can be read through the inscription in the intermediaries, which circulate within those networks. The intended product of these networks varies: it can be nature in form of scientific facts (Latour, Woolgar, 1986; Latour, 1987) it can be technology (Bijker, 1994; Law, Callon, 1992; Latour, 1991), and it can also be society (Woolgar, 1991). The means and actual products of these enterprises are never purely one or the other, they are always "hybrids" comprising all three domains simultaneously. This is somewhat confusing to begin with.

These concepts(actor, black box, network, inscription, intermediary (need, therefore, some clarification before they can be employed to their full potential. Unfortunately, the terminologies used in different studies are inconsistent. Different terms are used to describe the same concept while, on the other hand, the same expression appears to have different meanings. The following 'definitions', therefore, are put together from different sources to capture those aspects of their meaning which I find most pertinent.

Actor

Actors are "entities that do things" (Latour, 1992a, p. 241, emphasis in the original). Even in this most minimal definition, the main difference from the more conventional sociological definition of actors as "social entities" is stressed: what actors are, whether social or technological entities, is less important, whereas the aspect of action, doing things, is emphasized. "The distinction between humans and non-humans, embodied or disembodied skills, impersonation or 'machination', are less interesting than the complete chain along which competences and actions are distributed." (Latour, 1992a, p.243) Actor is further defined as "whatever acts or shifts action, action itself being define by a list of performances through trials; from these performances are deduced a set of competences with which the actant is endowed. .... An actor is an actant endowed with a character." (Akrich, Latour, 1992, p.259) While actant is the thing itself in its unspecified "nature", actor comprises the thing and competences which are attached to it. The competences are negotiated in processes of trial (and error). For example, a coin as piece of metal is an actant. Within the context of money-based economy, a valid coin has an attributed competence, it serves as a standard measure of value and mechanism for exchange, it becomes an actor. It is important to stress that actors have an independent reality outside the settings that turn them into actors that do particular things. In this sense they are simultaneously real like nature and collective like society.

Latour (1987, p.84) extends one definition of actor to "whoever and whatever is represented [is an] actant." Acting and being represented? Is that not almost contradictory? Remember, Latour (1993) aims at retying the separated categories of language, nature and society. In Science in Action (1987), the level of observation is scientific texts and what appears in those texts, what is "represented" there. While analyzing reality as being constructed in texts sounds suspiciously like French Postmodernism, the concept of actors marks the difference from these theories. Actor indicates that the elements represented in texts act, that they do particular things. Outside the text, the elements are actants, entities that have an independent reality. Inside the text, they become actors, entities that do things, hopefully those things the texts were written for. They act precisely because they are represented in the text. A text can be understood as a network aligning heterogeneous elements(people, other texts, equipment, procedures, institutions, and more(to achieve a particular goal, which can be proving a scientific discovery, manufacturing a product, or introducing a new procedure. Each of these aligned elements has a reality outside the text. This reality outside the text allows enforcement of the meaning and of the strength of the text. For example, if microbes wouldn't exist independently of a scientific text, then representing them in such a text would be meaningless. However, it took a Louis Pasteur to align them in his texts with all kinds of other elements and turn them into the acknowledged source of infections, thus making them (social) actors (Latour, 1986).

The more heterogeneous elements a text or object is implicitly or explicitly able to align, the more it becomes. A coin, for example, is able to mobilize the reputation of a whole national economy to simplify mundane transactions, such as buying a pack of cigarettes. If the coin cannot mobilize those elements because it is forged, or if the mobilized elements are weak, because the government is in discredit, the coin loses some or all its power, which resides its unquestioned value. A coin is an actor because it can mobilize a network of heterogeneous allies to do things, to store and exchange value. In a valid coin this network of allies is tightly sealed and it is almost impossible to question the connections of those networks for an individual using the coins (and thus becoming a part of the network of the coins)1. A coin is in this sense a "black box".

Black Box

"A black box contains that which no longer needs to be considered, those things whose contents have become a matter of indifference." (Callon, Latour, 1981 p.285) A black box, therefore, is any setting2 that, no matter how complex it is or how contested its history has been, is now so stable and certain that it can be treated as a fact where only the input and output counts.

The term itself is derived from cybernetics, where it signifies a piece of machinery or a set of commands that might be very complex but can be substituted by a box because it is regular and stable (Wiener, 1948).

The law, for example, is a collection of black boxes. In its formation stage a law is a contested set of competing sentences around which occasionally large alliances are built to influence their specific shape. During the legislative process they are fluid and open. Once the legislation has been passed, contested sentences turn into a black box, sealing all the elements, however arbitrary they might be, in a fixed and stable relationship that cannot be questioned easily. Similar processes happen with any product once it passes from the development stage to the production stage.

The stability of a black box is influenced by the costs of reopening it. This is not only determined by the social groups and procedures sealed into the black box, but also by the materials which are included. The media into which such a setting is sealed are a crucial element for understanding its overall dynamics. Turned into a black box, hardware tends to be very closed. It took, for example, a earthquake to open (literally and metaphorically) the black box of the Interstate 880 in Oakland, CA and uncover the corruption and construction errors which it had enclosed (Bijker, Law, 1992). Software, on the other hand, is constantly reopened and sealed again because of its fluidity and low production costs. This is the process of constantly questioning some elements of the box (finding bugs) and trying to seal it again in a new up-grade.

The more a box appears to be closed, the more are the networks it includes assumed to be reliable and stable themselves. "The more automatic and the blacker the box is, the more it has to be accompanied by people." (Latour, 1987 p.137) To isolate a black box and conceptualize it with a trajectory of its own right means to presuppose as a given all the conditions that keep that box closed.

In one sentence: a black box contains a sealed network of people and things.

Network

Besides actor, network is the second central concept-hence the name Actor-Network Theory. The term network is defined as a "group of unspecified relationships among entities of which the nature itself is undetermined." (Callon, 1993, p.263) The inclusive character of this definition becomes more evident when contrasted with one of the conventional sociological definitions of network where "a social network3 consists of a finite set or sets of actors and the relation or relations defined on them" (Wasserman, Faust, 1994, p.20). An actor-network is not restricted to 'social actors', not even to actors in the theory's broader sense.

A network ties together two systems of alliances:
People: everyone who is involved in the invention, construction, distribution, and usage of an artifact: describing this

system leads to a "sociogram". Sociological analysis, such as social network analysis, focusses on this set of alliances (Wasserman, Faust, 1994; Wellmann, 1983).
Things: all the pieces that were already on stage or had to be brought into place in order to connect the people. Describing this system leads to a "technogram".

However, while it is useful for clarification purposes to separate the two levels analytically, it is not appropriate to study these systems separately because they are highly interconnected. A change on one level will simultaneously change the other. Each modification in one system of alliances is visible in the other. Each alteration in the technogram is made to overcome a limitation in the sociogram and vice versa (Latour, 1987, p. 138-139).

Interrelations between the sociogram and the technogram become evident, for example, when a product is not accepted by its envisioned users. One way to react to this mismatch might be to change the product, to bring a different technological network into place in order to give rise to acceptance by the users, change the sociogram. However, market failure does not lead necessarily to a change in the product. It is possible that the sociogram, the network of people who are associated with a product, is changed by adding more people to a company's marketing department. In order to understand the dynamics in one level of a network, one has to examine the dynamics in the other part.

Actor and network are mutually constitutive. An actor can not act without an network and a network consists of actors. This relationship is highlighted in yet another definition of actor as "any element which bends space around itself, makes other elements dependent upon itself and translates their will into a language of its own." (Callon, Latour, 1981, p.286) Actor and network constantly redefine each other, one is dependent on the other. Michel Callon (1987, p.93) details the interrelation between the two:
"the actor network is reducible neither to an actor alone nor to a network. Like a network it is composed of a series of heterogeneous elements, animate and inanimate, that have been linked to one another for certain period of time. ... An actor network is simultaneously an actor whose activity is networking heterogeneous elements and a network that is able to redefine and transform what it is made of."

The size or importance of an actor is dependent on the size of the networks he/she/it can command and the size of the networks depends on the number of actors it can align. Since networks consist of a (large) number of actors which have different possibilities to influence other members of the same network, the specific power of an actor depends on the position within his/her/its network. There is no structural difference between large and small actors, between a major institution or a single individual or even a thing as mundane as a door opener (Latour, 1992). This does not say that they are all equal. This simply means that the main differences between micro and macro actors is the size of the network they can bring into place for a particular goal, that is the number of actors they can arrange according to their objectives. These objectives can be a strategic choice of options, adaptive necessities or built-in properties of a certain piece of equipment. Properties of a setting, the fact that it makes certain things possible and others impossible, are called prescriptions.

Prescription

Several related concepts have been developed to 'read' a setting, to understand the constrains and forces which come to bear through a technological artifact, a procedure or a scientific discovery. The activity of the analysist is called description which is the "analysis of what the various actors in a setting are doing to one another". The opposite movement, inscription, is the activity of the engineer, inventor or manufacturer who make others do certain things (Akrich, Latour, 1992, p.259). In the process of inscription, the properties of a setting are assembled bearing the mark of the actors aligned in the network which produces that setting. For the process of description one type of inscriptions are particularly helpful, texts. Texts which explain the object, be it in form of a manual, on the device itself or in a separate brochure, of promotional material, of critical reviews or others. The actor-network can be read in its texts not because it is made up of text (in the Postmodern sense). It can be read because texts are often the preferred way in which the actors align themselves into the network4.

The activity of inscriptions materializes in the prescriptions of an given object. Prescription5 is "what a device allows or forbids from the actors(humans and non-humans(that it anticipates; it is the morality of a setting both negative (what it prescribes) and positive (what it permits)." (ibid., p.261)

To complicate matters even more, the different activities are not necessarily precisely separable. What may seem to be an impassionate description of an object in the prototype phase may be at the same time the ardent attempt to realize the inscription of different properties into that very same object. This is a classic conflict of any (social science) research that is concerned with the making of the present. The status of an artifact can be highly contested and emerge just as the result of complex strategies. For instance, to strengthen the inscriptive force of a text, the author might insist on its descriptive, hence scientific and objective, character. Those who want to weaken its authoritative, and hence possibly inscriptive, power will try to cast doubt on its descriptive quality. They may, for example, initiate a counter study to demonstrate a different type of description or the bias of the author.

For the aims of this paper, it is not necessary to go into further details to define the different aspects of the scripting activities. It is more important to note that they are activities, the results of actors doing things, be it assembling a setting, be it using the setting or the analyst deconstructing the setting, i.e. opening the black box. All these activities shape the form and content of the product. Therefore, as Michel Callon notes, "the social can be read in the inscriptions that mark the intermediaries." (1991, p.140)

Intermediary

Intermediary is the last of the central concepts that needs to be defined. Intermediaries provide the still missing link which connects actors into a network and defines the network itself. Actors form networks by circulating intermediaries among themselves, thus defining the respective position of the actors within the networks and in doing so constituting the actors and the networks themselves. An intermediary is anything that "passes between actors in the course of relatively stable transactions." (Bijker, Law, 1992 p.25) It can be a text, a product, a service, or money.

Intermediaries are the language of the network. Through intermediaries actors communicate with one another and that is the way actors translate their intentions into other actors. Considering the definition of actors as any element "which makes other elements dependent upon itself and translates their will into a language of its own" (Callon, Latour, 1981, p.286), the possibility to command intermediaries lies at the heart of action itself, which is translating an actor's will into other actors.

With the concept of translation we have arrived at the point things begin to get dynamic. We now have to use the tools prepared so far to describe some central aspects of the dynamics within actor-networks.

3. The Dynamics of Actor-Networks

In the dynamics of networks three phases can be distinguished. While there is not necessarily any need that they be separated, it is useful to construct them as analytical idealtypes (Max Weber) of the stages a network may undergo during its lifetime.

Emergence

Networks are put into place by actors. However, since there is no actor without a network, new networks emerge out of already existing ones6. Sometimes this happens through subtle changes, sometime as the results of revolutionary developments which might push into the background the element of continuity that is part of every dynamic. Defining a beginning is a necessary but 'artificial' analytical operation based on the interests of the analyst within his/her particular empirical situation. If the interest is in a product, then the beginning might be found in some form of perceived need or possibility. This could be based on, for example, a new invention, which would then be one of the old networks out of which a new network emerges. Other things could serve as a mark for the beginning as well. John Law and Michel Callon (1992) trace the beginning of a failed project for a British military aircraft back to a policy decision for rationalization of the aircraft industry. This decision, however, in itself contested, functioned only as an intermediary, (re)connecting existing networks of industry, labour and government to begin aligning themselves for the development and production a new aircraft.

At the beginning, therefore, stands an intermediary which is brought into circulation by a network in order to align more/different actors for the network's own interest. In other words, the attempt of an existing actor to grow and include new domains can be a good starting point to observe the emergence of a network.

Networks allow actors to translate their objectives, be it conscious human choice or prescription of an object, into other actors and adding the other actors' power to their own. "By translation we understand all the negotiations, intrigues, calculations, acts of persuasion and violence thanks to which an actor or force takes, or causes to be conferred to itself, authority to speak or act on behalf of another actor or force." (Callon, Latour, 1981, p.279) Networks emerge and are shaped by aligning more and more actors. In this way an actor can grow. The importance of an actor depends therefore on the number of actors within his/her/its networks which he/she/it can employ to a particular purpose. Actors are isomorphic, which means their size and shape is not a priori but the result of a long development. There is no fundamental difference between a large structure and a small actor, the only difference is in the number of actors that can be employed. It is a mistake to take differences in size of a network for differences in level, because networks always connect at the same time what conventional sociology differentiates into micro and macro levels. This interconnection renders such a distinction less significant, because "that which is large is that which has successfully translated others and has therefore grown. Since size is nothing more than the end-product of translation, the need for two analytical vocabularies is thus avoided." (Callon, Law, Rip, 1986, p.228) Networks are made up of what they network-actors which are always localized-yet these networks can extend around the globe. Networks can be so large and stable that they appear to be independent from the actors. This, however, is a misconception. While they can (and do) seriously constrain the range of action for certain actors, they always need actors. Any given actor might be replaceable, but only by another actor. There is, therefore, no gap between the individual and the structure which is made up of individuals which are made up of structure which is made up of individuals and so on, endlessly. For Bruno Latour "the two extremes, local and global, are much less interesting than the intermediary arrangements that we are calling networks." (1993, p.122)

To observe the emergence, formation and growth of a network, one has to look at the intermediaries that are put into circulation, who sends them, where they suddenly appear, what they do there, as well as how they are translated and put into further circulation.

Development

A network can develop in two different directions, towards convergence or towards divergence of its actors. Adding new actors to a network at first increases their divergence. The processes of translation by which the will of one actor is transferred to another actor become initially more difficult because each new actor is already included in other networks that might have aligned him/her/it for different goals. What to do in and how to account for new situations, how to assess the meaning of an intermediary is unclear at the beginning. The divergence of a situation or an element of the network is its "interpretative flexibility" (Bijker, 1994).

There is a process of mutual shaping between a new actor and an existing network. In the end7 neither the network nor the actor now included remains the same. The changes can be so subtle that they are negligible or they might be massive for either one or for both of them.

Translation is a process that is performed by one actor (A) on another actor (B). The translation always has a direction, A translates B. However, A is not completely free in how it translates B because B is never independent or undefined but always already part of other networks which define the possibilities of what B can be translated into. In this process, A might have to alter itself in order to translate B more successfully or the translation might result in different effects on B than A expected. Translation is at the beginning always an attempt which might or might not be successful. The most simple translation process theoretically possible, the one including only two actors, consists of three parts. A, an intermediary (I), and B. I is what is passed between A and B; it is what connects the two. I, therefore, bears the inscriptions of both actors and is therefore an ideal object to describe a network.

For networks to operate successfully, the circulation of intermediaries needs to be coordinated. This means the included actors do not, or may only to a limited extent, contest their own translation. Actors thrive toward an internal agreement which allows for an optimal circulation of intermediaries, because their strength depends on the coordination within the networks. In networks where the actors have successfully converged, i.e. are strongly coordinated, the network as a whole stands behind any one of the actors who make it up.

The way agreement can be reached, the scope of the translations possible, shapes the form of the network. In other words, "the network is constructed according to the translation's own logic." (Callon, 1992, p.84) The stronger the coordination of the circulation is, the more the different elements are aligned, the more stable and predictable it becomes. The more stable a network is, the better it defines its components. The possibilities decrease for other networks to untie the connections in order to redefine an actor for his/her/its own purposes. The setting turns into a black box.

Actors do not necessarily need to be successful in their attempt to optimize the circulation of intermediaries. The translation process can be denied. People might not want to become users and not buy a product, or they might stop being willful citizens and overthrow their government. A machine can fall apart because of a construction error; a new invention may render old solutions obsolete and channel money and other resources into new directions. The circulation of intermediaries within a network, then, becomes more and more difficult and the alignment of actors becomes weaker and weaker, the actors begin to diverge and the setting to disintegrate. The black box loses its integrity, the edges become fuzzy.

Convergence and divergence point at the directions into which a network can move, either towards a stabilizing itself or towards disintegration in which it becomes easier and easier to reverse its connections. Convergence in a network does not mean that every element acts or becomes the same. It "simply means that any one actor's activity fits easily with those of the other actors, despite their heterogeneity." (Callon, 1992 p.87; my emphasis)

We have now arrived at the classic problem for any deconstructionist theory. We have accounted for the openness of any development (within certain "existentialist" restrictions) and for the multiple determination and interpretative flexibility of every element within a network, as well as the network itself. However, our society of humans and non-humans works quite well and in a surprisingly stable fashion. We flip a switch and the light turns on. Our planes take off and land precisely enough to plan a trip around the world in a couple of minutes. Strategic plans can be set years ahead. How do we account for such an incredible success of networks?

Stabilization

Nothings succeeds like success, as the saying goes. In other words, networks that are not able to stabilize themselves to a certain degree disappear from the scene, while those which were able to achieve a certain convergence proliferate and become the necessary starting point for any new network.

An actor-network thrives for stabilization because none of the entities which make it up would exist without that network in that form. The promotion of a network is a way to ensure the actor's existence and development. It is, therefore, in the interest of all actors within a particular network to stabilize the network which guarantees their own survival to a higher or lower extent. The stability of a network depends on the "impossibility it creates of returning to a situation in which its [current form] was only one [of many] possible option among others" (Callon, 1992, p.89). In other words, stabilization, or closure "means that the interpretive flexibility diminishes. Consensus among the different relevant social groups [or more broadly, actors] about the dominant meaning of an artifact merges and the 'pluralism of artifacts' decreases." (Bijker, 1994, p.86)

Once forged into an artifact, embedded social relations remain stable as long as the artifact is used8. Bruno Latour details in his programmatic essay, Technology Is Society Made Durable, how the social relations embedded in artifacts are a stabilizing factor of society:
"Society and technology are not two ontologically distinct entities but more like phases of the same essential action. By replacing those two arbitrary divisions with syntagm and paradigm, we may draw a few more methodological conclusions. The description of socio-technical networks is often opposed to their explanation, which is supposed to come afterwards. ... If we display a socio-technical network - defining trajectories by actants' association and substitution, defining actants by all the trajectories in which they enter, by following translations and, finally, by varying the observer's point of view - we have no need to look for any additional causes. The explanation emerges once the description is saturated. ... There is no need to go searching for mysterious or global causes outside networks. If something is missing, it is because something is missing. Period." (1991, pp. 129-130, emphasis in the original)

Heterogeneity is another, central aspect of a stable network. The more the diverse elements are interrelated, the more complex and stable a network becomes. In a heterogeneous network each element is kept in place through a set of heterogeneous ties to other actors and in order to untie such a multiple determined actors, multiple connections have to be untied.

The size and the heterogeneity of a network are related. The larger it becomes the more heterogeneous it becomes because it develops additional elements just to keep all other elements in place. In the language of systems theory this development is called "differentiation" (Parsons, 1968). The network starts to develop its own trajectory, supported by its elements which themselves depend on the network as environment. A network therefore starts to "become heavy with norms of all sorts" (Callon, 1992, p.91) in the course of stabilization. This means, of course, nothing else than that more actors are integrated or created.

A network which stabilizes itself does
"not only resist competing translations but also restrict[s] the number of possible future translations. This means in order to establish other links and set-up new translations you would first have to undo those which already exist, and change the equivalence in operation, which would in turn mean mobilizing and enrolling new alliances. ... Thus non-linearity and path dependence can be seen to be integral to the dynamics of [a network]." (ibid., p.92)

In my cursory overview, I have now reached some of the cutting edge of the Actor-Network-Theory as far as it has been developed today, much remains open at this point. Concepts like differentiation and path dependence, however, form links to neighbouring concepts that are themselves concerned with the development of heterogeneous and interdependent elements and how, based on local actors, global order can emerge. The following section examines a few of those concepts in order to further develop the scope of the network metaphor as an analytical tool.

4. Neighbouring Theories

Even though the Actor-Network theorists make very few references to sources outside the fields of sociology and history of science and technology, there are evident overlaps with other (theoretical) endeavours which explore the network metaphor, or more broadly, open adaptive systems9. In sociology, to begin with the closest relative of the Actor-Network Theory, the Parsonian Systems Theory is revived and revised as 'Neofunctionalism' (Colomy, 1992) and Berkley sociologist Manuel Castells, albeit from a different vantage point, uses the network as the central metaphor in his The Rise of the Network Society (1996). In economics, new concepts of path-dependence and increasing returns (Arthur, 1996; 1994) have found acceptance and, as a common endeavour of different disciplines, led by the natural sciences and biology, the field of complexity has been opened and developed (as an overview, see Mitchell, 1992; Coveney, Highfield, 1995).

The following section will examine some aspects of those neighbouring concepts to further sharpen the ideas of the Actor-Network Theory and to position them in broader trends in current thinking concerned with questions about networks, complexity and self-organization.

Systems Theory and the Concept of the Border

One set of questions that remains somewhat vague in the Actor-Network Theory is how to limit the analysis; where does one network end and the next one begin? Michel Callon refers simply back to empirical studies in concluding "a network's boundary can be related to its degree of convergence. We will say that element Y is outside of a network if locating the links between it and the actors (A, B, C ...) significantly decreases the network's degree of convergence." (1992, p.88). Not of much more help are Wiebe Bijker and John Law stating that "in effect it rests on a bet that for certain purposes some phenomena are more important than others. It simplifies down to what it takes to be essential." (1992, p.7) For Bruno Latour, the description of a network is simply finished when it is "saturated" and an explanation emerges. In other words, the question of how to limit the analysis can only be addressed on an empirical level. However, other theoretical traditions have long been concerned with similar questions and their conclusions can help to clarify this question.

The concepts of system, boundary, and environment, are central to systems theory as developed after the Second World War. Systems theory in social sciences has long been dominated by the works of Talcott Parson (1951, 1966, 1968, 1971), the doyen of US sociology in the 1950s and 1960s. His legacy even influenced some of the founding studies of the SCOT approach. Thomas P. Hughes' study of the building of the electrical network between1880 and 1930, for example, is an attempt to integrate systems theory into the study of the social development of technology. Unfortunately for us, Hughes mainly referred to the engineering stream in Parsons work as it has been influenced by Wiener's Cybernetics (1948). Aptly for his subject, the electric network, he defines a system as being
"constituted of related parts of components. These components are connected by a network or a structure .... The interconnected components of technical systems are often centrally controlled, and usually the limits of the system are established by the extent of this control." (1983, p. 5)

While the notion of central control is hardly applicable to networks of highly interrelated and mutually constituting elements, more helpful is the idea that a network can only be defined from the inside, that the network is defined by its own components. What belongs to a system (or a network) can only be decided based on the definition of the system itself. This definition of the system is-similarly to the definition of the beginning of an actor-network-an a priori decision made by the observer who chooses to account for a defined section of a continuous reality; for example, The Life and The Death of an Aircraft (Law, Callon, 1992).

A general definition of systems has been provided by Parsons who refers "both to a complex of interdependencies between parts, components, and processes that involves discernible regularities in relationship, and to a similar type of interdependency between such a complex and its surrounding environment." (1968, p. 458) What marks the difference between the internal and the external interdependencies of a system is its boundary. The boundary is at the same time separating the system from its environment and connecting it to it by serving as a filter to translate stimuli into input that can be dealt with by the system's internal structure. "The boundary, therefore, separates and unites and, as such, illustrates the dynamic characteristic of every distinction." (van Dongen, 1992, p.50) Establishing and maintaining such a boundary is always an active process. This process of establishing a boundary, of defining who is included in and who is excluded from a network, can be used as one of the indicators of how to limit the extension of a network.

The boundary separates and joins two sets of relationships: those of the system (internal) and those to the environment (external). An influential theory of those processes-the difference between the internal structure, the boundary and the environment-has been developed by the Chilean cell-biologists Humberto Maturana and Francisco Varela (1980) as the theory of "autopoiesis" (self-formation). They defined autopoietic systems as "self-contained unities whose only reference is to themselves." To qualify as an autopoietic system they developed six criteria:

- The system needs a border to make it identifiable.
- It needs components so that the system is analyzable.
- The interaction of the components can be described in general physical laws, in other words, the system is a natural system.
- The boundary is self-maintained by preferential neigbourhood relations. The system, therefore, can stabilize its own boundary.
- The systems is contained within and producing the boundary.
- The system is self-productive. The system uses only its own components or transformed imported components (Mingers, 1995; Zeleny, 1996).

The concept of a self-formation has been originally developed to describe biological cells but has permeated into a variety of disciplines (Mingers, 1995). Maturana and Varela themselves have expanded the concept into a theory of cognition (1987) and in Germany, for example, Niklas Luhman turned it into one of the cornerstones of his influential revision of Parsons' systems theory (1986, 1989).

The transfer of concepts and models from one field to another is a difficult and risky undertaking and the discussions of the limitations and dangers of doing so from biology to social science fill countless volumes of secondary literature (as an excellent contribution, see Khalil, Boulding, 1996)-at least since Herbert Spencer expanded Darwin's evolutionary theories onto society in the 1880s. For the current purposes, the aims are closely restricted. The focus is on which of the criteria developed above might help expand the Actor-Network Theory in defining the limits of an actor-network and how they might do so.

The concepts-autopoiesis and actor-network-have some overlap in the notion of self-formation and the idea of mutual constitution between actor and network. A network is composed of actors which define the network, or, the network forms and maintains itself out of its own components. It is in this sense autopoietic. The criteria of self-production can be applied to define the limits of a network. It then includes all elements which are necessary to achieve and maintain objectives of the network. Environments are, then, all elements that influence the network but are themselves not actively involved in maintaining the network. In other words, the environment can only influence a network insofar as it is translated into the network by one or more components of the network. The communication, therefore, between the network and the environment is always indirect and determined by the characteristics of the network itself.

The place where this translation takes place is the border. The border in a social system is evidently not physical, as in a cell, but logical or functional (Zeleny, 1996). For example, the members of a family are determined be the relationship to one another, a company is an entity even if it is dispersed around the globe or entirely virtual, and, a doctor does not leave the system of the hospital system as long as he/she is connected with a beeper.

The notion of the border developed so far can be used to clarify that any element which is directly needed to achieve a certain goal is inside the network. Any element that is able to influence an actor but is not inside the network belongs to the environment. The separation and connection between the two which occurs at the border is maintained by the network itself.

Evolution and the Dynamics of Systems

While I have now roughly laid out a possible way to account for the limits of a network which allow us to view it as unity, it is still questionable why they develop at all. Why does an actor act and why are networks dynamic?

The Actor-Network Theory has paid little attention to those questions. The acting actor and the dynamic network are presupposed as a given; they develop simply "deliberately or otherwise" (Law, Callon, 1992, p.21). However, while actors in networks thrive towards convergence and stability, one of the central aims of the theory is to account for dynamic, change and innovation (Law, Callon, 1992). Even the blackest boxes spring open under the right conditions. In exceptional cases it might take more than a thousand years and the form of a "paradigm shift" (e.g. from Ptolomy to Copernicus) or a popular revolution (as in Central Europe 1989), in more mundane cases it might be an earthquake, a political decision, or almost anything else. Actor-networks are always potentially dynamic; they are subject to evolution on all scales and in all paces.

The concept of autopoietic systems which served as an inspiration to conceptualize the limits of a network provides also an interesting idea for understanding the dynamics of such systems: this is known as "structural coupling". The changes which a system can undergo are determined by the Organization10 of the system, which is maintained within and through the border. In this sense, the system is organizationally closed because it can only change according to its inner Organization. These changes may preserve a system's Structure or they may alter it radically, e.g. a seed growing into a tree. A Structure exists within a environment that perturbs it and can trigger changes. The environment does not determine the changes, rather the environment selects changes made possible by the system's Organization. An acorn can or cannot grow into an oak which can be taller or shorter; however, it can never grow into a pine. Because the environment can trigger changes, the system is interactively open (Mingers, 1995)11.

In an environment characterized by recurring states (as opposed to total randomness or invariability) and natural selection those structures which are suitable for that environment are most likely to survive. As a result, any such (self-referential) unit is structurally coupled with the environment . Since the environment consists of other units that function according to similar principles, autopoietic systems are structurally coupled. The units provide the environment for and stand in constant relationship to one another. Through this interdependence, change can ripple through a large number of systems: several systems, arguably all living (and non-living) systems on earth co-evolve (Lovelock, 1979).

Co-evolution expresses in biology the idea that at every observable level (e.g. cells, organs, individuals, or species) evolutionary adaptation in system A changes the conditions for all other systems to which system A is (part of) the environment. Therefore even previously stable systems come under adaptive pressure if their environment changes. Adaptation, or more general adaptive capacity, is a central concept in systems theory. For Talcott Parsons, standing within the concept of functionalism, it served as the indicator of development and progress of a system. The higher the adaptive capacity of a social system the higher it is developed (1966).

The equivalent of structural coupling in the actor-network is the conception that all actors are participating in several (sometimes conflicting) networks (Callon, 1986, p.24). In this sense, even networks which are extremely closed and stable-black boxes-are connected to an ever changing environment. A change in one of the networks in which an actor is involved might alter him/her/it in such a radical way that he/she/it is, as an effect, ripped out of another, previously sealed network. The Copernican Revolution, for example, not only changed astronomy but also had considerable influence on the catholic church which up to that point had maintained its network of meaning (theology) with the earth as the actor at the center of the universe, a stable platform upon which the celestial ladder was firmly planted.

Networks, while maintaining themselves, are therefore interrelated with one another across their boundaries. While networks constitute themselves in the circulation of intermediaries among actors which are themselves defined by the same circulation of intermediaries, no actor is exclusively defined by one such network. The case can be made even stronger: the reason why a particular actor is included in a given or emerging network is precisely because he/she/it brings along all the actors of the other networks to which he/she/it belongs. In Latour's analysis this is one of the reasons why scientists refer to the classic authors of their field. By including those cherished pillars of the discipline into their text authors try not only to include a specific piece of information but also its reputation, i.e. all the other actors which also positively refer to this source (Latour, 1987).

Networks develop because they are in inseparable dynamic interaction with other networks and self-reproduction requires adaptation to an ever changing environment.

Complexity and the Evolution of Order

So far I have sketched some ideas for how to account for the coherence and heterogeneity of an actor-network, why they are integrally dynamic and how the action in one network can influence the conditions of another. However, this has complicated the picture. We now face actors and networks which are not only mutually constitutive but, furthermore, each actor is constituted by multiple networks which are all in constant dynamics. Once again, the question looms why such interrelation yields quite stable patterns instead of just pure randomness. Why do networks have a tendency to attempt convergence not only internally but also externally by being coordinated with other networks? I omitted that problem in the previous section by adding the modifier 'recurrent states' to the environment wherein evolution takes place. How does one account for the emergence of recurrent states which allow networks to evolve into orderly and stable patterns out of multiple defined, unsteady actors?

These are very much the questions of the recently much publicized science of complexity. Why is there such apparent order on all levels when one might expect randomness in the absence of an overarching plan or deterministic laws? How do simple local rules and strategies give rise to global patterns? As in the previous sections this is not the place to introduce a major scientific idea adequately or provide a critical account of its history (for a general introduction to the science of complexity, see Mitchell, 1992; Coveney, Highfield, 1995). I want to focus here on one aspect of the complexity theories as applied to biology by Stuart A. Kauffman (1993, 1995, 1996): the self-organized, critical state of a system.

The concept of the self-organized, critical state of a system joins two major ideas together. First, order in such systems emerges only out of the interrelations of the elements of the systems. As a result the patterns on the macro level can be more complex than the patterns at the micro level. Second, this order is critical in the sense that it is unstable between two stable states; the state of "frozen" stability where nothing moves and the state of random change which exhibits not stable pattern. In both stable states, evolution is not possible. This idea is best demonstrated in the Kauffman's model of a "correlated fitness landscape".

Biological fitness of a system, its ability to reproduce itself, can be modeled as a landscape where the peaks indicate high reproductive ability and the valleys low reproductive ability. The position of a unit on this landscape indicates its adaptation to the reproductive constraints imposed by the environment. A unit within such a landscape can move from whatever site it is located at a given point in time to any of the neighbouring sites, one step at a time. Moving upwards means that the next generation inherits better reproductive ability, moving downwards means that the next generation inherits a less well adapted set of abilities. Each generation takes one step12 until it reaches either the top of the peak or becomes extinct. This movement is thought to be blind, a trial and error procedure, a "random walk". However, over the course of generations natural selection "pushes" the units upwards.

So far, it is a very unrealistic model. Without any further specification, we have to think of this landscape as random, very much like the surface of the moon: stable and whimsically rugged. Local peaks and local valleys soaring and plummeting everywhere. In such a landscape evolution cannot develop very far because it would get stuck very soon on a local peak where all neighbouring states are lower, but the local peak itself might not be very high. The opposite of such a rugged landscape is a smooth one with one or a very few high peaks, resembling the landscape of Mount Fujiama. However, with random assignment of fitness, such a landscape is highly unlikely. Moreover, fitness landscapes in biological systems are dynamic or correlated because living units are structurally coupled, providing the environment for each other. This means that every adaptive change in one unit changes the fitness landscape for others because it changes the environment to which they have to adapt to. The peaks and valleys are shifting constantly. In random, rugged landscapes, the variables that influence survival change constantly; evolution is impossible, i.e. the fitness of all units is low and threatened by unpredictable developments.

This is evidently not the case in real life. Because selection favours the fitter, it favours not simply the one which is best adapted to the environment at a given instant, but the one which can also sustain an environment in which its own development is optimized. The co-evolving units influence the conditions of their own evolution. The landscape develops along dynamic patterns and in a more or less smooth topology. Evolution evolves! Talking about the development of cells, Kauffman concludes that
"we plausibly believe that selection can alter organisms and their components so as to modify the structure of the fitness landscapes over which those organisms evolve. By taking genomic networks form the chaotic to the ordered regime, selection tunes the network behavior to be sure. By tuning epistatic coupling of genes13 it tunes landscape structure from rugged to smooth." (1995, p.187)

The units order themselves and at the same time order their evolutionary environment into patterns, they self-organize on the micro and the macro level. The state of this self-organized system is critical because it is between the two poles of absolute stability and total randomness which allow no evolution. In order to evolve, a system must stabilize itself in this unstable critical state.

On a very general level, this means that a system can only develop at a certain pace and in a certain direction which must be related to the environment. Wrongly paced or misdirected development of one system will diminish its chance for survival because the larger system is tuned into a certain pattern. However, this does not mean stability. The pattern can be rapid change14. In this case, maintaining a invariant pattern would mean to slide down the slope in the fitness landscape.

The similarity to actor networks is that the rate of change a network can introduce or must adopt is related to the overall dynamics of the environment. Introducing too radical change would mean that the environment becomes very disturbed, which in turn might rip the network apart. Not adopting change at the right moment might mean that the actors become involved in an increasing number of conflicts between the different networks to which they belong as they go "out of tune". In this sense, because actors and networks are multiply determined, they are involved in constant processes of tuning themselves to one another.

5. Conclusion

With my sketchy venture into autopoiesis, evolution and biological complexity I do not advocate any kind of direct continuity to or natural laws in socio-technological development. This would be utterly inappropriate for, at least, two reasons. First, even on the level which these ideas have been so far developed, they are nothing more than intriguing, promising, and contested hypotheses. Kauffman, for example, regards his own theories as "proto-science" (1996). Second and more important is, dynamics on one level can not determine dynamics on levels above15. Even within one field it is impossible to deduct the development on one level from the development of the underlying one. Zeleny (1980) stresses this point by referring to ideas of the molecular biologist P.A. Weiss16, who remarked that "moving down" from the cell to its components one finds:
"(a) rather well defined and stable complexes of functional and structural properties which are embedded in and naturally related through, (b) matrices of much less well-defined, more fleeting configurations, allowing their constituent parts a much higher range of freedom than could be reconciled with the macromechanical concept of a cell."

The patterns on each level are self-organized according to the dynamics arising in that particular level and are not determined but related to the dynamics of the levels below. If that holds true for two neighbouring levels of complexity-the cell and its components-it is even more significant for levels which are far away from each other-the cell and the human society. Referring to this idea, Dupuy understands The Autonomy of Social Reality (1996) in a "double, paradoxical sense" (p.71): Every (natural) system is hierarchical; it is made up of different interlocking levels of integration. However, it is necessary to formulate the autonomy of each level based on the principle of circular causality. In an organism, for example, the laws of physics leave a large degree of freedom to the individual elements. This basic indeterminacy is reduced by the constraints exercised by the whole, constraints which are themselves the result of the composition of elementary activity. The whole and the parts are mutually determined, and this co-determination explains the complexity of living systems. In other words, each level is constrained but not determined by the level below and the level above. Each higher level arises out of the activities of elements at the level below but has to be analyzed in its own right and with its appropriate conceptual tools.

For the analysis of socio-technological development, such a tool is the Actor-Network Theory. It examines how competences are distributed within heterogeneous networks composed of human and non-human actors. Actors and networks are mutually constitutive in the sense that a network shapes and defines the actors who align themselves into a network. Intermediaries are passed among the actors to assure a certain degree of convergence among them.

This convergence allows the heterogeneous network to act in a coherent way, that is to translate one actor's objectives through a number of different actors to achieve a goal. The prominence and the potential of an actor is defined by he/her/its position within the network and by the size and degree of convergence of the network. The higher the degree of convergence within a network-the better, easier and more reliable the translation process works-the more powerful it becomes. Convergence is always (potentially) contested. In cases of very high convergence the network itself becomes so stable that it can be treated as a black box,. Its complexity can be factored out of the equation because the input-output relation is stable regardless of the heterogeneity of the network it incorporates. Black boxes can take on different forms, they can be artifacts, facts, norms, traditions, or structures. They allow the reduction of the complexity of socio-technological reality, in everyday life as well as in social theory. We do not need to know the intimate details of mechanics to drive a car. All we need to know is how to connect input (steering) with output (the motion of the car), and, whom to call when the car breaks down. We do not need to know the personality of the clerk at the cash register in order to trust him or her to hand over the money to pay for our shopping. We do not have to take into account everything down to every component. Whole sets of black boxes can be integrated purely on the level of their in- and out-put because they remain stable.

To transfer the tools of the Actor-Network Theory from the study of science and physical technology, for example, a high speed transit system (Latour, 1996) to the study of process in and around computer-based communication networks, we have to expand the concepts into specific directions to better capture the particular dynamics of this setting. These dynamics arise out of the structural properties of the communication networks, which as powerful actors have to be integrated into the actor-networks which are set up and maintained for a specific goal within those communication networks. Their complexity and interrelatedness, their evolutionary character and the stunning absence of any overarching plan, all indicate that there are different dynamics at play than in other sectors of technology. Latour demonstrates how different elements shape the development and the plans for a transit system, however, the systems failed finally because it was not possible to adopt one general plan. Bijker (1994, 1992) analyses how an artifact changed significantly in its distribution phase, but still, at all times, it had a centrally planned design. During the development of the product the actors and the plan changed, but not the plan's centrality. The science of complexity, as nascent as it is, can help us to develop tools to think about settings that have no overall plan but nevertheless show regularities.

The extraordinary pace of the development adds further dimensions to the process. Not only the fixed artifacts or procedures are important, but their evolutionary character moves into the foreground as one of their integral, regular patterns. McLuhan pointed this out decades ago when he claimed that change is the only constant in the electronic environment. Theories of evolution are well experienced in accelerating time, especially now that they can be tested in computers where 10,000 generations can develop in a single day. They can sharpen the intuition to see in compressed time the structure of change which becomes central in the immediate feedback loops of the electronic environment.

Amidst all those changes, the elements show a great ability in maintaining their identity, in differentiating themselves from their environment by constantly interacting with it. The concept of the border in the theory of autopoietic systems is one example of how to think about organizational closure and continuity at once with interactive openness and structural plasticity.

Whatever the credibility of these biological theories in their field may be, for the study of socio-technological processes they are nothing more (and nothing less) than inspiring. Their explanatory reputation cannot be transferred from one field to another. It has to be gained in each field anew. However, they serve well as inspiration to further develop the tools we have to conceptualize our techno-cultural environment and foster cross-disciplinary thinking. I hope this paper sketched a promising beginning in that direction.

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Endnotes

1 The currency markets, to expand on the coin example, are a mechanism to question, adjust and reinforce the value of the allies mobilized by a coin which belongs to a traded currency.

2"Assemblies of humans and nonhuman actants where the competences and performances are distributed. The object of analysis is called setting or setup." (Akrich, Latour, 1992, p.259)

3 It is telling to note that neither in Wasserman and Faust (1994) nor in the latest edition of the Oxford Dictionary of Sociology (1994) the term network appears without the modifier social.

4 Texts are one of the languages of the network, another is money. See the section on intermediaries below.

5 Proscription, affordance, and allowance are synonyms to prescription.

6 The Actor-Network Theory takes the existence of networks as a precondition for the emergence of new networks. Having the perspective that the world precedes the actor who had to act on the basis of the given, the theory has somewhat existentialist undertones.

7 The end of a network description is evidently, like the beginning, an 'artificial' analytical decision.

8 Even a black box allows a certain range of networks. The usage of an artifact, for example, can differ widely from the creator's original intention.

9 It would be interesting to examine whether such concepts have the capacity to form a new paradigm in the Kuhnian sense, as claimed by authors like Kevin Kelly (1994). However, it is evident that concepts of adaptive systems and networks have been introduced or reexamined in a large variety of disciplines.

10 Unfortunately, the terminology is confusing here. Varela and Maturana use the terms organization and structure in somewhat particular ways. Organization is used for the patterns of interaction among elements of a given system. This defines the system as belonging to a particular class, e.g. a cell or a family. Structure is used for the actual realization of the elements and those patterns in time. This differentiates the actual realizations (with their temporal turnover) within a class from one another. In the social sciences the use of the terms is generally reversed (Mingers, 1995, p.14). I will capitalize the terms if I use them in Maturana/Varela's sense.

11 An open question is the beginning, how the initial differentiation between system and environment came into existence.

12 This is a very simplified account of the model which includes, among others, also the idea of a jump, a massive change in a system's Organization.

13 Epistatic coupling means "that genes at other places on the chromosomes affect the fitness contribution of a gene at a given place." (Kauffman, 1995, p.170) In other words, genetic code has a syntax.

14 An experimental model of change in self-organized critical systems has been set up by theoretical physicists: grains of sand are dropped on a desk. Over time, the sand will pile up to the point where it starts to become unstable and avalanches occur. While the size and the distribution of these slides form certain patterns, it is impossible to determine the connection between a particular grain falling on the sand pile and the size or the place of the slide it causes (Gell-Mann, 1994). The intuition to take away from that example is that self-organized systems can change unpredictably and rapidly without being chaotic.

15 The "level" means degree of complexity. The level above a cell, for example, is the organ which is composed of those cells. The level above individuals is the group or society which is composed of those individuals. Defining levels is a decision made by the observer.

16 Weiss, Paul A. (1968). The Living System: Determinism Stratified. pp. 3-35 in Koestler, Arthur; Smythies, R. (eds.) Beyond Determinism. New York: MacMillan. Weiss is credited with having coined the phrase "molecular biology" in 1951.

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