The Knowledge-Based Economy: The Potentially Globalizing and Self-Organizing Dynamics of Interactions among Differently Codified Systems of Communication

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Abstract

Alongside economic exchange relations and political control, the organization of codified knowledge in scientific discourses has become increasingly a third coordination mechanism at the level of the social system. When three coordination mechanisms interact, one can expect the resulting dynamics to be complex and self-organizing. Each coordination mechanism is specific in terms of its code of communication. For example, "energy" has a meaning in physics very different from its meaning in the economy or for policy-makers. In addition to providing the communications with functionally different meanings, the codes can be symbolically generalized, and then meaning can be globalized. Symbolically generalized codes of communication can be expected to span competing horizons of meaning that 'self-organize' given historical conditions. From this perspective, the historical organization of meaning—for example, in discourses—can be considered as instantiations or retention mechanisms. In other words, meaning can further be codified in communication flows. Knowledge, for example, can be considered as a meaning which makes a difference. In the case of discursive knowledge, this difference is defined with reference to a code in the communication. When discursive knowledge is socially organized (e.g., as R&D) its dynamics can increasingly compete with other social coordination mechanisms in the construction and reproduction of a knowledge-based order.

1. Introduction

Marx envisaged a knowledge-based economy as early as 1857 (in *Grundriße*) when he formulated the following:

> Nature builds no machines, no locomotives, railways, electric telegraphs, self-acting mules etc. These are products of human industry; natural material transformed into organs of the human will over nature, or of human participation in nature. They are *organs of the human brain, created by the human hand;* the power of knowledge, objectified. The development of fixed capital indicates to what degree general social knowledge has become a *direct force of production,* and to what degree, hence, the conditions of the process of social life itself have come under the control of the general intellect and been transformed in accordance with it. (Marx, 1973, at p. 706).[1]

[1] German edition, 1974, at p. 594.

Grundriße can be considered as a preparatory study for *Capital* which was published ten years later. Note that Marx only *hypothesized* that science and technology provide 'a direct force of production.' Might 'the general intellect' in his time already have become a production force more important than labor? Marx recognized this as an empirical question and even specified an operationalization ('the development of fixed capital indicates to what degree […]').

In *Capital*, on the basis of his calculations in the years thereafter, he rejected the hypothesis of a knowledge-based economy in favor of a dialectics between capital and labor as the main contradiction between production relations and production forces (Rosenberg, 1974). Thus, he inferred on the basis of empirical studies the thesis of historical materialism when he formulated the following:

> The steam-engine itself, such as it was at its invention, during the manufacturing period at the close of the 17th century, and such as it continued to be down to 1780,[2] did not give rise to any industrial revolution. It was, on the contrary, the invention of machines that made a revolution in the form of steam-engines necessary. (Marx, 1971, at p. 394f.).[3]

After Marx had finished *Capital* in 1867, the production system began rapidly to change. Marxist historians (e.g., Braverman, 1974; Noble, 1977) have characterized the period 1870-1910 as 'the scientific-technical revolution.' Unlike the scientific revolution of the 17th century, this scientific-technical revolution coupled the production of knowledge to industrial production processes. For example, industrial research laboratories emerged, and—in some sectors more than in others—technological innovation became a major source of competitive advantages. Thus, scientific and technical knowledge was more systematically absorbed into the production process.

Braverman (1974, at pp. 167f.) identified this scientific-technical revolution at the level of social *structure* because, as he put it: 'the key innovation is not to be found in chemistry, electronics, automatic machinery, aeronautics, atomic physics, or any of the products of these science-technologies, but rather in the transformation of science itself into capital.' He placed this development historically for Germany after unification in 1870. For the United States, Noble (1977, at p. 6) mentions the period 1880-1920, that is, including World War I. Conversely, the absorption of science by capital has gradually transformed the latter: the productive forces are no longer necessarily linked to the managerial decisions and instrumental actions of persons engaged in the labor process (Habermas, 1968a). Taylor's *Principles of Scientific Management*, for example, dates from 1911.

1.1 Knowledge-based innovations in economic models

In economic models, innovation was for a long period considered as an exogenous (Rosenberg, 1976a, 1982) or residual factor for which one cannot account in terms of

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[2] It was, indeed, very much improved by Watt's first so-called single acting engine; but, in this form, it continued to be a mere machine for raising water, and the liquor from salt mines.
[3] translated into English at http://www.marxists.org/archive/marx/works/1867-c1/ch15.htm#S1)

capital and labor as input factors (Abramowitz, 1956; Solow, 1957). However, Schumpeter ([1939], 1964, at pp. 66 ff.) is well-known for his argument that the dynamics of innovation upset the market mechanism (Nelson and Winter, 1982). While market forces seek equilibrium between supply and demand at any given moment in time, novelty production generates a dynamic along the time axis causing disequilibria.

Using the model of a production function—in which output is a function of the input factors, capital and labor—technological innovation can then be modeled as a shift towards the origin (Sahal, 1981a). Changes along the production function are based on the relative prices of labor and capital (Figure 1). Technological innovations enable enterprises to reduce factor costs in both capital and labor (Salter, 1960).

Within this model, technological change is considered as perpendicular to the economic mechanism. The orthogonality between the mechanisms suggests independence of technological change from economic substitution. However, these two analytically distinguished dynamics can be expected also to interact in the case of innovation. Labor or capital-saving innovations can be advantageous given certain political conditions (Rosenberg, 1976b) or because of additional economies of scale and scope (Sahal, 1985). Improving a system innovatively presumes that one is able to handle the system purposefully. When this reflection is further refined by socially organizing knowledge, the innovative dynamic can be reinforced (Leydesdorff & Van den Besselaar, 1998).

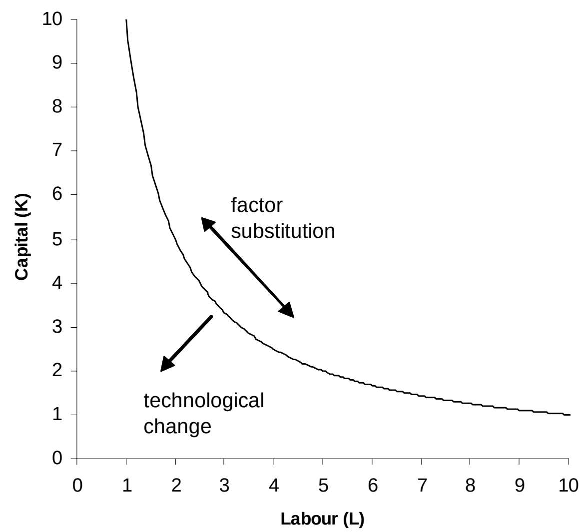

Figure 1: Using the production function (Q = c.K.L), factor substitution and technological change can be distinguished as perpendicular subdynamics.

This reinforcement can be expected to occur at some *places* more than at others. In addition to economic exchanges and technological innovations a third dimension pertinent to our subject can thus be specified: the geographical—and potentially national—distribution of whatever is invented, produced, traded, or retained. Nation-states, for example, can be expected to differ in terms of the relationship between their political economies and their knowledge bases (Lundvall, 1992; Nelson, 1993). Different fields of science are organized nationally and/or internationally to varying degrees (Wagner & Leydesdorff, 2005; Walsh & Bayma, 1996); the retention mechanisms can be expected to vary accordingly.

Geographical positions, economic exchange relations, and novelty production cannot be reduced to one another. However, they can be expected to interact to varying extents. Variations can be expected among nations and regions, industrial sectors and technologies, and sizes of enterprises in different markets. From the perspective of regional economics, Storper (1997, at p. 26) considered the web of relations among these three dimensions as a 'holy trinity' of technology, organization, and geography when he formulated the following:

> Technology involves not just the tension between scale and variety, but that between the codifiability or noncodifiability of knowledge;[4] its substantive domain is learning and *becoming*, not just diffusion and deployment. Organizations are knit together, their boundaries defined and changed, and their relations to each other accomplished not simply as input-output relations or linkages, but as untraded interdependencies subject to a high degree of reflexivity. Territorial economies are not only created, in a globalizing world economy, by proximity in input-output relations, but more so by proximity in the untraded or relational dimensions of organizations and technologies. Their principal assets—because scarce and slow to create and imitate—are no longer material, but relational. (*Ibid*., at p. 28.)

One can envisage a three-dimensional model of the geographic, technological, and economic dimensions and their interactions in a knowledge-based economy as follows:

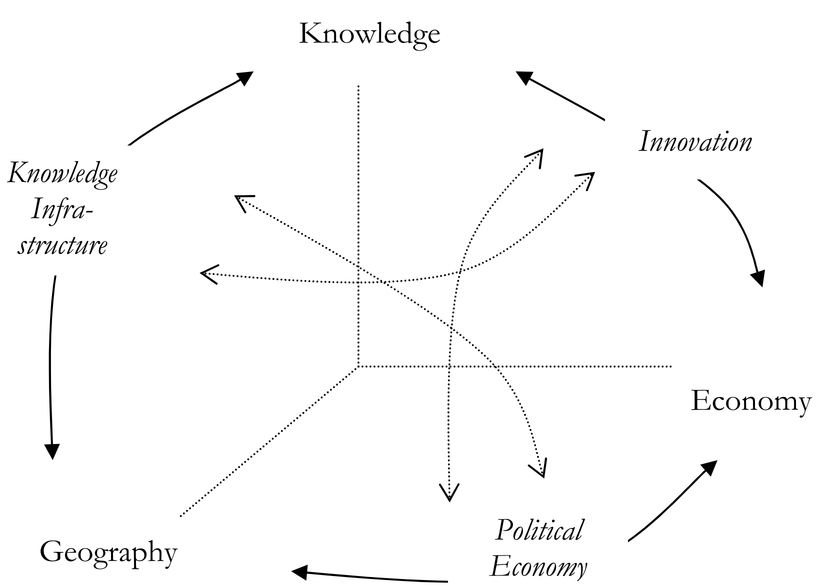

Figure 2: Three dimensions of the social system with their three interaction terms.

The three dimensions provide us with different micro-operations of the social system because agents (*i*) are differently positioned, (*ii*) can maintain exchange relations, and (*iii*) are able to learn interactively about their local positions in their networks of relations (Lundvall, 1988; Andersen, 1994; Bathelt, 2003).

[4] I return to the issue of codifiability and noncodifiability of knowledge more extensively below.

Furthermore, figure 2 elaborates upon this conceptualization by specifying the interaction terms between each two of the three dimensions. For example, innovations can be considered as the results of interactions between the economic mechanism and the dynamics of knowledge production. Geographically positioned agents like national governments are the organizers of political economies; knowledge infrastructures can be attributed to organizational units (e.g., corporations) and thus considered as retention mechanisms of knowledge flows.

In general, two interacting subdynamics can be expected to co-evolve in a process of 'mutual shaping' (McLuhan, 1964) along a trajectory when the third dynamic is kept relatively constant. However, when three subdynamics are left free to operate upon one another, the resulting dynamics are complex and potentially chaotic (May, 1973, 1976; May & Leonard, 1975; Sonis, 1992, 2000). In a pluriform society, the various interactions among these subdynamics are no longer synchronized *ex ante*, and thus the interactions may begin to interact among themselves (Etzkowitz & Leydesdorff, 2000).

For example, during the formation of political economies in national systems during the nineteenth century (List, 1841; Freeman & Soete, 1997), knowledge production was first considered as exogenous to the economy. Under the condition of constitutional stability in the advanced nation-states after 1870,[5] political economies offered institutional niches in which *national* systems of innovation could gradually be developed as a coevolution among the axes of economic exchange and organized knowledge production and control (Noble, 1977; Rosenberg, 1976a and b, 1982).

Following up on Freeman's (1987, 1988) studies about the Japanese innovation system (cf. Irvine & Martin, 1984), Lundvall (1988) proposed that the nation be considered as a first candidate for the analysis of innovation systems in the, then, newly emerging specialty of evolutionary economics ('neo-Schumpeterians'). However, he formulated this claim carefully in terms of a heuristic:

> The interdependency between production and innovation goes both ways. […] This interdependency between production and innovation makes it legitimate to take the national system of production as a starting point when defining a system of innovation. (Lundvall, 1988, at p. 362)

The idea of integrating innovation into production at the *national* level has the advantage of providing the analyst with institutionally demarcated units for which extensive statistics are already available. The specification of this relatively stable system of reference enables an analyst to study, for example, the so-called 'differential productivity growth puzzle' which is generated by the different speeds of technological development among the various sectors of an economy (Nelson and Winter, 1975). This problem cannot be defined properly without the specification of an economy as a system that

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[5] In 1870, Germany and Italy were unified; France had gone through a revolution leading to the establishment of a modern (third) republic. The Meji Restoration of 1869 had made Japan a player in the industrial competition, and the U.S.A. had emerged from the Civil War in 1865. Thus, the global system had been reshaped into a system of nations.

equilibrates among different sectors (Nelson, 1982, 1993, 1994). The solutions to the differential productivity puzzle can accordingly be expected to differ among nation-states and their respective political economies.

While from a Schumpeterian perspective the market is continuously upset by innovation, the nation can perhaps be considered as another, albeit institutionally organized equilibrium (Williamson, 1975, 1985; Lundvall, 1988; Aoki, 2001). However, the emergence of transnational levels of governance like the European Union, together with an increased awareness of regional differences within and across nations, has changed the functions of national governments (Braczyk *et al*., 1998; Cooke & Leydesdorff, 2006). This historical progression varies among nations, and integration at the national level still plays a major role in systems of innovation (Skolnikoff, 1993). Nevertheless, 'government' has analytically evolved from a fixed point of reference into the variable 'governance,' that spans a variety of sub- and supranational levels (Kooiman, 1993). Larédo (2003) argued that this polycentric environment of stimulation has become a condition for innovation policies in a knowledge-based economy (Commission of the European Communities, 2000).

The research program of *national* systems of innovation lost credibility among evolutionary economists and policy makers after the demise of the Soviet-Union (in 1991) and with the increasing use of information and communication technologies across the globe during the 1990s. Notably, the European Commission no longer wished to support this research program because the possibly synergetic effects among the nations of the EU were not central to the analysis. In response to these critiques, Foray & Lundvall (1996) introduced the concept of a 'knowledge-based economy' at a workshop of the Organization of Economic Cooperation and Development (OECD) in 1994 (OECD, 1996a; cf. Godin, 2006). In that same workshop, Abramowitz and David (1996) suggested that *codified* knowledge should be made central to the analysis. These authors formulated as follows (at p. 35):

> Perhaps this single most salient characteristic of recent economic growth has been the secularly rising reliance upon *codified* knowledge as a basis for the organization and conduct of economic activities, including among the latter the purposive extension of the economically relevant knowledge base. While tacit knowledge continues to play critical roles, affecting individual and organizational competencies and the localization of scientific and technological advances, codification has been both the motive force and the favoured form taken by the expansion of the knowledge base.

Analytically, this focus on *codified* knowledge demarcated the new research program at the same time from the older concept of a 'knowledge economy' with its focus on knowledge workers and hence embodied knowledge (Penrose, 1959; Machlup, 1962; Cooke, 2002). Embodied and tacit knowledge is embedded in contexts (Polanyi, 1961; Collins, 1974; Bowker, 2005), while codified knowledge can be decontextualized, and therefore, among other things, traded (Dasgupta & David, 1984).

Carter (1996) noted immediately that the measurement of a 'knowledge-based economy' would not be a *sine cure*. While 'national systems of innovation' can be measured in terms of sectors and institutions, for example, by using national statistics and/or network analysis among the agents active in a national economy, this new concept of a 'knowledge-based economy' was analytical and suggested a more difficult and theoretically guided research agenda (Foray, 2004). How is a knowledge-based economy different from a market or industry-based economy? How might something as volatile as knowledge provide the base for something relatively robust as an economy?

The OECD devoted considerable resources for developing indicators of the knowledge-based economy (David & Foray, 1995; OECD, 1996b, 1996c). This led to the yearly publication of the so-called *Science, Technology, and Innovation Scoreboards*,[6] and the periodic summary of progress at the ministerial level in *Science and Technology Statistical Compendia*.[7] Godin (2006, at p. 24) evaluated that the 'knowledge-based economy' functioned, in this context, mainly as a label for reorganizing existing indicators—most of the time, assuming national systems of member states explicitly or implicitly as units of analysis—and warned that 'important methodological difficulties await anyone interested in measuring intangibles like knowledge.'

1.2 Non-economic perspectives on codified knowledge

The codification of knowledge and information has extensively been studied in the information sciences and in science and technology studies, albeit it from different angles (e.g., Biagioli & Galison, 2003; Dasgupta & David, 1994; Cowan, David, and Foray, 1997, 2002; Foray, 2004; Moed *et al*., 2004). In science and technology studies, the intellectual and social organization of knowledge in science, technology, and innovation is focal (Spiegel-Rösing & Price, 1977; Whitley, 1984; Jasanoff *et al*., 1994; Hackett *et al*., 2007). However, the relations between knowledge and information-processing were not unpacked in this sociological program as can be done from the perspective of the information sciences and cybernetics (e.g., MacKay, 1969; Bateson, 1972; Dretske, 1981).

The sociological and the information-science perspectives add to the economic perspective in the sense that the black box of the knowledge production process is opened (Rosenberg, 1976, 1982; Whitley, 1972). Whereas economists are mainly interested in the *effects* of codification on the economy more than in the process of codification itself, Daniel Bell had formulated the programmatic focus of this research program already in 1973 as follows (at p. 20):

> Now, knowledge has of course been necessary in the functioning of any society. What is distinctive about the post-industrial society is the change in the character of knowledge itself. What has become decisive for the organization of decisions and the direction of change is the centrality of *theoretical* knowledge—the primacy of theory over empiricism and the codification of knowledge into abstract systems of symbols that, as in any axiomatic system, can be used to illustrate many different and varied areas of experience.

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[6] The *Science, Technology, and Innovation Scoreboard 2005* is available at http://www.oecd.org/document/43/0,2340,en_2649_33703_35455595_1_1_1_1,00.html.
[7] The *Science and Technology Statistical Compendium 2004* is available at http://www.oecd.org/document/8/0,2340,en_2649_33703_23654472_1_1_1_1,00.html

On the one hand, the sociological analysis focused on the codification process as historical. One can expect feedback mechanisms and 'mutual shaping' (McLuhan, 1964) in coevolutions between the production of knowledge and its diffusion in the economy (Callon, 1998). However, codification is never complete while one needs tacit knowledge for the understanding of codified knowledge. The degree of codification of information into knowledge became another relevant subject of study in management studies (Nonaka & Takeuchi, 1995; Biggiero, 2001). On the other hand, the question of how information is codified into knowledge is analytical and thus requires an information-theoretical approach.

2. The sociological perspective

Cognitive codifications in the development of science and technology interact and co-construct the historical organization of scholars and discourses into research programs, specialties, and disciplines. The intellectual organization of the sciences cannot be appreciated sufficiently unless this cognitive process is considered as an analytically independent source of variance (Gilbert & Mulkay, 1984; Slezak, 1989; Leydesdorff, 1995). However, in the post-modern sociology of scientific knowledge (Barnes, 1974; Bloor, 1976; Collins, 1983) and the sociology of translation (Callon *et al.*, 1983, 1986; Latour, 1987), the heterogeneous sources of variance (authors, texts, cognitions) have been homogenized *a priori* in concepts like *practices* and *actor-networks*.

In comparison with older traditions in the sociology of science (Merton, 1942, 1973), the focus on practices led to descriptions of the world of science that were empirically richer than those provided by more traditional approaches in sociology and philosophy. For example, it was no longer possible to describe a specialty only in terms of the organizational variables of a scientific community (Crane 1969, 1972; Whitley 1984). Similarly, a specialty could no longer be operationalized in purely epistemological terms as a set of theoretical questions linked to relations among observations, arguments, and inferences (Hesse 1980); nor could it be adequately described as a body of literature or a communication structure (Price, 1961, 1963). As with all major concepts in science studies, it was henceforth necessary to develop the definition of 'specialty' from the perspectives of social organization, cognitive structure, and scientific literature.

The potential tensions among these different evaluations were not appreciated in the new sociology of scientific knowledge, but 'heterogeneously engineered' into practices. Practices were assumed to operate as 'mangles' (Pickering, 1995) and an analyst would be left no options other than that of 'following the actors' as an ethnographer (Latour, 1987). Scholars working in the tradition of Actor-Network Theory (ANT) radicalized this position by including non-human elements in the description (Callon *et al*., 1986; Callon and Latour, 1981).

For example, in a study of the introduction of scientific principles of breeding into fishery, Callon (1986) argued that the actor-network consisted of the oceanologists who try to transform fishing into 'aquaculture,' the science of oceanology which imposes a problem-formulation, the fishermen who defend their interests, and the scallops who breed and enter the networks of the fishermen as 'actants.' When all these elements interact, the system can be 'translated' because an 'obligatory passage point' is generated.

Note that in this 'sociology of translation,' the cognitive or natural constraints on the situation are not analyzed *as if* they acted upon the situation—that is, as a heuristic device; every unit should instead be analyzed in substantively similar terms, that is, as semiotic 'actants' in a network. The actor-network is constructed as a next-order unit of performance (containing 'relational strength'), into which the heterogeneous dimensions are homogenized. In other words, the substantive heterogeneity in the *explanandum* is not addressed in terms of analytically different dimensions, but rather in terms of an assumed coincidence and congruity between *explanandum* and *explanans* within the subject matter.

The sociology of scientific knowledge and actor-network theory thus deprived themselves of the possibility of an explanation. The actor-networks cannot be explained other than by describing them as empirical practices. Since one assumes *a priori* that the relations in the actor-network are mutual and symmetrical, nothing can ultimately be explained, and the sole purpose of the analysis is to tell a story (Latour, 1987; Collins and Yearley, 1992). Consequently, the actor-network is not only an *empirical* category; it is also a denial of the *methodological* problem of analyzing 'heterogeneity' among social, cognitive, and textual dynamics (Mulkay *et al*., 1983; Slezak, 1989). From this constructivist perspective, the concept of a knowledge-based system or economy could only be (dis)appreciated as a reification (Mirowski & Sent, 2007; cf. Wyatt, 2007).

2.1. The codification of discursive knowledge

In his study *Die Wissenschaft der Gesellschaft*, Niklas Luhmann (1990a) argued in favor of shifting attention away from the social process of construction by agency towards the outcomes of historical constructions. For example, when a scientific paper is first presented at a conference, its content has only the status of a knowledge claim. However, when the paper is subsequently reviewed by peers and published in the literature, this knowledge claim is validated, and thus the epistemological status of the content is changed by the operation of the relevant social system (Myers, 1985). Peer review is, amongst other things, expected to check the paper under study for its quality, and while doing so it inscribes an expectation of quality into the paper.

What has been added to the article during this process? Building on Parsons's (1963a, 1963b) concept of symbolically generalized media of communication with specific codes and Husserl's (1929) notion of horizons of meaning, Luhmann suggested that the coding of the communication implies a domain-specific selection. This expectation of a selection allows the participants in the communication to handle more complexity by focusing on the cognitive content of a knowledge claim. In other words, the paper goes through a process of selection whereby it is invested with symbolic value.

The cognitive code of the communication was characterized by Luhmann (1990a) as a selection on whether the content of the paper is also 'true.' In my opinion, whether and how knowledge claims are validated (or rejected) also assumes an historical process. The constructivists have been convincing when arguing that truth can no longer be considered as a given but itself is a social construct (e.g., Kuhn, 1962; Barnes, 1969, 1974; Bloor, 1976; Gilbert & Mulkay, 1984). However, Luhmann's general point about a more abstract code operating at a next-order level is well taken. Standards operate as selection mechanisms at a different level from that of the knowledge claims. The latter provide only the variation. Variation is observable, selection is latent; variation can be stochastic, but selection is structural and deterministic.

In other words, the next-order selection mechanism is constructed bottom-up, but once in place control tends to become increasingly top-down. The historical construction of the codes of scientific communication as the basis for a scientific culture has taken centuries. For example, the scientific journal was an invention of the 17th century (Price, 1961), while the modern citation was invented only at the end of the 19th century (Leydesdorff & Wouters, 1999). Cognitive criteria operate globally as horizons of possible meanings which are reproduced locally by specification under historical circumstances, that is, by accepting or rejecting the knowledge claims in each paper under review (Fujigaki, 1998).

2.2. Codification at the supra-individual level

The notion of 'horizons of meaning' was taken by Luhmann from Husserl's transcendental phenomenology (Paul, 2001; Knudsen, 2006). In the *Cartesian Meditations* of 1929, Husserl specified intersubjectivity and communication as a domain different from the psychological one. (Husserl used Leibniz's word 'monade' instead of 'domain' in order to express the intended focus on the dynamics.) By placing the psyche as a subject of psychology between brackets—in what Husserl called an epoché (*ἐποχη*)—one is able to uncover (meditatively and not yet discursively)[8] a *double contingency* in one's relation with fellow human beings.

In this 'double contingency' of interactions, *Ego* knows the *Alter* to be a reflexive *Cogito* who equally entertains expectations (Parsons, 1968, at p. 436; Parsons & Shils, 1951, at p. 16; Vanderstraeten, 2002). Thus, a social reality is constructed in which a symbolic order is invoked (Lévi-Strauss, 1987). In this social order of expectations, *Ego* not only encounters the other as another human *being*—the physical existence of the other provides a first contingency in the *res extensa*—but expects *Alter* to entertain expectations similar in nature but potentially different from those one is able to perceive in one's own *Ego* (Elmer, 1995). This second contingency remains in the domain of expectations or, in other words, in the *res cogitans.* Husserl suggested distinguishing between the individual minds as *cogitantes* versus the dynamics of the second contingency as *cogitatum*, that is, the intersubjective constructs which provide the external referents to our reflections. They remain uncertain; their epistemological status remains that of hypotheses.

The exchange of expectations in interactions generates (potentially codified) meaning at a supra-individual level as potentially different from meanings entertained by each individual. In general, meaning can further be codified. Knowledge, for example, can be

[8] According to Husserl, the *noesis* precedes the discursive construction.

considered as a meaning that makes a difference. In the case of discursive knowledge, this difference is defined with reference to a code in the communication. However, the codes of communication remain uncertain and contingent. For example, the codes in the scientific discourse may have to be redefined thoroughly in the case of a crisis in the communication (Kuhn, 1962). Thus, the networks of communication develop eigen-dynamics which are partly (that is, reflexively) accessible and partly latent for the agents who carry the communications (Lazarsfeld & Henry, 1968; Von Foerster, 1982).

Luhmann took from Parsons (1963a and 1963b) the idea that codes of the communication can be generalized symbolically and differentiated among them functionally. For example, transactions in the market place are guided by a code that is very different from the code(s) governing scientific communications. However, Parsons did not combine these two elements—functional differentiation and codification—of his own theory of social systems.[9] Furthermore, Luhmann (e.g., 1986) added to social-systems theory the theory of *autopoiesis* or self-organization, which he took from Maturana and Varela (1980, 1984).

Using the concept of *autopoiesis*, differentiation can be considered as an endogenous result of the codification of communication. Codification allows the networks of communications to be spanned up in different dimensions. The dimensions first differentiate and then tend to become orthogonal (Simon, 1969). The functionally differentiated system can process more complexity than the hierarchically organized one. Luhmann (1984, 1986) submitted that the communication among human beings self-organizes in terms of the different meanings. When meanings can again be communicated, differences among them can also be codified.

Maturana (1978, at p. 49) specified how a semantic domain can be generated within an autopoietic system, but communication within this domain remained based on the exchange of information among the communicating agents. In this cybernetic model 'observers' (in Maturana's case, brain cells) can provide meaning to incoming information, but they are not yet able to communicate meaning. I submit that human language can be considered as the *evolutionary* achievement that has enabled us to use the two channels of information exchange and meaning processing simultaneously. The two layers recursively perturb each other (Andersen, 2002). By developing semantics, one can further codify the interactions between these layers (Luhmann, 2008).[10]

The historical progression of codification in semantic exchanges remains conditioned by the communicative competences of the carrying agents (Habermas, 1981) because the

[9] In Parsons's theory, actions are differentiated with reference to functions for the social system and not as communications with reference to codes. For this reason, the media and not the codes are symbolically generalized and functionally differentiated in Parsons's theory. Luhmann followed Parsons in this latter respect, and did also not elaborate on the relationship between codification and further development of the (symbolically generalized) media of communication (Künzler, 1987).

[10] In series of studies bundled in four volumes entitled *Gesellschaftstrukutur und Semantik: Studien zur Wissenssoziologie der modernen Gesellschaft* (*The Structure of Society and Semantics: Studies in the Sociology of Knowledge in Modern Societies*), Luhmann (1980, 1981, 1989, 1995a) further developed this thesis.

exchange of meaning is complex and failure-prone. Symbolic generalization of the codes of communication (e.g., relying on a bank account instead of saving one's money in a box) assumes a process of rationalization and increasing discipline (e.g., Elias, 1939; Foucault, 1966, 1972, 1984; Luhmann, 1982). More abstract schemata need to be constructed both socially and at the level of the personality (Weinstein & Platt, 1972).

2.3. The communication of meaning as an operation

While traditionally in the social sciences, actors and their actions have been considered as units of analysis, one can similarly focus on communications as units of *operation* in relations among agents. Units of operation cannot be observed without further reflection, that is, the specification of a theoretical perspective. Since communicative operations can also feed back on and change the underlying units of analysis (that is, the communicators), this specification of the operations can be expected to enrich our understanding of how networks develop. From the perspective of communications as operations, the observables can be considered as temporarily stabilized traces of previous communications. The observables, however, can be analyzed as results of communicative operations if these operations are first properly specified.

Luhmann (1984, at p. 226 [1995b, at p. 164]) already emphasized that *'communication cannot be observed directly, only inferred'* (italics in the original).[11] Some authors have followed him in calling this reflexive inference a 'second-order' observation (Baecker, 1999; Luhmann *et al*., 1990). As theoretical guidance is required to make such an inference, a 'second-order observation' can also be considered as the specification of an expectation. However, expectations are, in important respects, different from observations. For example, expectations operate in terms of uncertainties, while observations can serve the observer by reducing uncertainty.

In summary, *expectations* operate as the specific substance of communication in the second contingency at the level of social systems (Stichweh, 2000, at p. 241; cf. Luhmann, 1984, at pp. 364 ff.; 1995b, at pp. 267 ff.; Strydom, 1999). Meaning is communicated in terms of expectations, anticipations, and intentions. This fragile system of communications emerges on top of the historical processing of information in the first contingency.

3. Information, uncertainty, and meaning

Can the layer of meaning exchanges be modeled on the basis of our understanding of the layer of the information exchange, but *mutatis mutandis*? Unlike information, meaning cannot be transferred. The communication of meaning, therefore, would be more complex than the communication of information. In the meantime, however, Shannon's (1948) mathematical theory of communication was elaborated into a theory about dissipative or entropical systems (Smolensky, 1986), the nonlinear dynamics of coding (Abramson, 1963), and entropy statistics (Theil, 1972). Can a non-linear dynamics of

[11] Luhmann (1984, at p. 226): 'Die wichtigste Konsequenz dieser Analyse ist: *daß Kommunikation nicht direkt beobachtet, sondern nur erschlossen werden kann.*'

meaning perhaps be specified? In my opinion, we may have no hold other than this mathematical access when addressing 'intangibles' such as the communication of meaning. How can meanings (or knowledge) be attributed to a system other than individual consciousness?

Let us first raise the question of whether one is able to define meaning analogously to information in formal terms? Shannon detached himself from the implications of his counter-intuitive definition of information as uncertainty by stating upfront that the 'semantic aspects of communication are irrelevant to the engineering problem' (Shannon, 1948, at p. 379; Shannon & Weaver, 1949, at p. 3). The mathematical theory of communication has often been discredited in the social sciences with the argument that Shannon (1948) defined information as uncertainty (e.g., Bailey, 1994). This definition is counter-intuitive, since one is inclined to associate 'information' with a message that 'in-forms' a receiving system (Varela *et al*., 1991).

From the perspective of a receiving system, information can be defined only as meaningful information or, in Bateson's (1972, at p. 453) famous words, as 'a difference that makes a difference.' Luhmann (1984, at p. 103; 1995b, at p. 67) followed this systems-theoretical definition of information. An observer, for example, can be considered as a system for which a difference may make a difference (Spencer-Brown, 1969, at p. 76; Von Foerster, 1982; Baeker, 1999).

The use of two concepts of 'information' in the literature has led to considerable confusion (Hayles, 1990; Kauffman *et al*., 2008). Let me therefore first specify the difference between information as uncertainty and information that can be meaningful to a system receiving this information. This will lead me to a formal definition of meaning and to the specification of the difference between information and meaningful information: meaning selectively codifies Shannon-type information into meaningful information and some meaningful information can be further selected as more meaningful than others.

Shannon-type information has no intrinsic meaning (Miller, 2002). The Shannon-type information is *expected* information contained in a distribution and not information *observed* by a system. At this formal level of abstraction, the system of reference is deliberately *not yet* specified (Theil, 1972). The unit of measurement of the uncertainty thus generated (that is, bits of information) remains dimensionless.[12] The measurement instruments and the (entropy) statistics of information theory can be applied to any system that operates in terms of distributions.

When a system receives Shannon-type information, it may be disturbed and therefore initially become more uncertain (about its environment, for example). By processing the uncertainty internally, the receiving system can sometimes—that is, if it contains sufficient identity to perform this operation—discard part of the incoming information as noise. The remainder is then selectively designated as meaningful information. After this

[12] Thermodynamic entropy is different from probabilistic entropy because the former is measured in terms of Joule/Kelvin, while the specification in terms of bits of information is dimensionless.

de-selection, the meaningful information potentially reduces the uncertainty within the system. Following Schrödinger (1944), Brillouin (1962) formalized this reduction in the uncertainty as 'negentropy.' Negentropy adds to the redundancy of a system.[13]

Despite the confusion regarding the two concepts of information found in the literature, the cybernetic theory of autopoietic systems (e.g., Maturana & Varela, 1984) and the information-theoretical approach (e.g., McGill, 1954; Abramson, 1963; Theil, 1972) have been consistent in excluding each other's definitions of 'information' for analytical reasons (Boshouwers, 1997). Biological systems can be considered as found 'naturally,' and therefore the biologist is inclined to begin with the specification of an observation by a system rather than the mathematical uncertainty of an expectation. As Maturana & Varela (1980, at p. 90) formulated it:

> Notions such as coding and transmission of information do not enter in the realization of a concrete autopoietic system because they do not refer to actual processes in it.

While these authors insisted on the historical (e.g., biological) realization of *observed* information within a system, Shannon's co-author Weaver (1949, at pp. 116f.) noted the problem of defining 'meaning' from the perspective of a mathematical theory of communication:

> The concept of information developed in this theory at first seems disappointing and bizarre—disappointing because it has nothing to do with the meaning, and bizarre because it deals not with a single message but rather with the statistical character of a whole ensemble of messages, bizarre also because in these statistical terms the two words *information* and *uncertainty* find themselves to be partners.
>
> I think, however, that these should be only temporary reactions; and that one should say, at the end, that this analysis has so penetratingly cleared the air that one is now, perhaps for the first time, ready for a real theory of meaning.

Let us follow Weaver's intuition and ask whether it is possible to define meaning as abstract as information, that is, without reference to a specific (e.g., biological or sociological) realization. I submit that *meaning can be defined as the operation which is generated when a system of reference is specified*. This definition precedes the operationalization in terms of a specific system of reference, and is in this sense mathematical. In general, the analytical specification of a system of reference endows the uncertainty with specific meaning.

The formal specification of a system of reference does not yet imply the substantive specification of meaning. To this end, one needs to make a substantive step by specifying 'what' the system would be expected to communicate when it operates. However primitive, such a substantive theory may be, it is needed for the specification of 'what' is selected and potentially evolving (Andersen, 1994). The generation of meaning assumes a system operating over time (Varela, 1975, at p. 20). However, the meaning of

[13] By definition, the uncertainty plus the redundancy in a system of communication are equal to the system's maximum information content.

(Shannon-type, i.e., meaningless) information can substantively be defined only with reference to a system that is able to organize disturbances in terms of signals and noise, or, in the terminology of cybernetics, an observing system.

Meaning is given to uncertainty from the perspective of hindsight, that is, after the operation. If a system is not able to update, it cannot provide specific meaning to the observed information. The substance of a system can also be considered as its medium for communication. When operating, this substance is distributed after the event differently from before and, therefore, Shannon-type information, or equivalently probabilistic entropy, is generated.[14] This Shannon-type information can be *measured* when the substance that is redistributed during the communication is theoretically specified. The measurement results (in bits) can then be provided with an interpretation in terms of the system(s) of communication under study (McKay, 1956; Steinmueller, 2002).

For example, when molecules are communicated, life can autopoietically be generated (Maturana & Varela, 1984). The communication of atoms can lead to a chemical evolution of molecules (Mason, 1991). The assumption of the conservation of energy and momenta when redistributed has been a major assumption of Newtonian physics. All the sciences can thus be considered as special theories of communication; the specification of a system of reference is based on a hypothesis about *what* is being communicated in the substantive dimension. Additionally, the mathematical theory of communication and its further elaboration into entropy statistics and the non-linear dynamics of entropical systems provide us with formal models which may be useful across special theories of communication. As these mathematical models are content-free, they can serve us as heuristics in disciplines other than the ones from which they were generated.

The discursive elaboration and operationalization in a research design enables us to remain reflexive upon whether the theorizing involved is formal or substantive. The relations between the substantive and formal dynamics can thus be controlled. The sociological research design requires this methodological sophistication because of the variety of levels and perspectives (Monge & Contractor, 2003). Both participants and analysts can participate in the relevant communications and provide them with meaning reflexively (Geertz, 1973). The two levels generate a double hermeneutics (Giddens, 1976) or as noted above, a double contingency: social systems do not only process information, but also meaning.

3.1. The historical generation of meaning

Providing meaning to information is a selective operation or, in other words, the expectations in the layer of meaning processing operate on the expected information content of the distributions in underlying layers of information processing. How can this next-order level be generated within an information-processing system?

[14] It can be shown that the Second Law is valid also for probabilistic entropy (Theil, 1972, at pp. 59f.): the probabilistic entropy generated by an operation along the arrow of time is always positive (Georgescu-Roegen, 1971).

By relating in the network, in terms of aggregations and disaggregations, and over time, the 'actants'—that is, whatever may be relating—develop a network with an architecture in the medium. When written as a matrix, this network can be analyzed in terms of the so-called eigen-structure of the matrix; and when repeated over time, these structures may be expected to contain eigen-time, that is, options for further developments which are more or less likely to occur.[15]

The possibility to vary among the delineations of multi-variate datasets and the lengths of time-series provides us with yet another degree of freedom. This reconstruction in terms of both eigen-structure and eigen-time allows us to distinguish datasets which increasingly behave as distributed identities, that is, which tend to maintain their (complex) structure along a trajectory over time (Figure 3a). A fourth degree of freedom would provide room for changing the identity of the system under study with hindsight (Figure 3b).

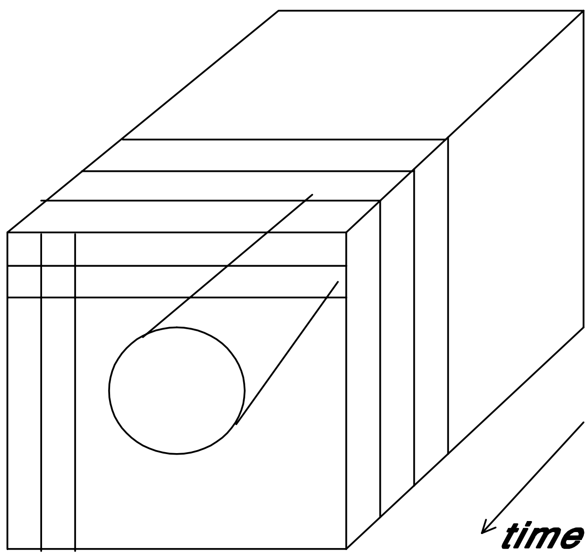

Figure 3a: An observable trajectory of a (potentially complex) system in three dimensions.

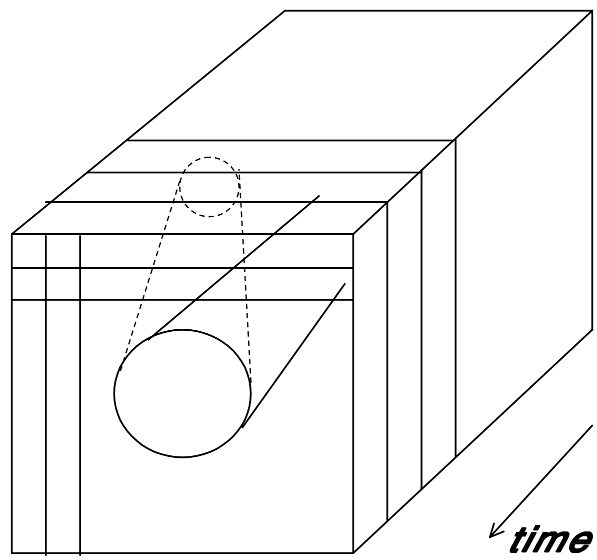

Figure 3b: Selection among representations of the past using a fourth degree of freedom.

Note that structure, stability, recognizable trajectories, and reflections from the perspective of hindsight remain model-based hypotheses. Structure is not given, but is inferred on the basis of a reconstruction. In other words: the analyst can reconstruct the state of a system in terms of its eigen-structure. This eigen-structure can be pronounced, and the maintenance of a specific pattern can be attributed to the self-referentiality of the system under study.

Time series of data can be assessed on whether a system can be expected to have developed an eigen-time (e.g., a life-cycle). Using the degree of freedom between eigen-

[15] In quantum mechanics, an eigen-frequency is defined as a frequency at which a system will vibrate.

structure and eigen-time, one can hypothesize that a system has the option to organize itself increasingly in terms of its operation. A self-organizing construct would be able to use this additional (that is, fourth) degree of freedom to maintain the character of its communication reflexively, despite alternatives and disturbances.[16]

The expectation values for the four-dimensional hyper-cube of probabilistic entropy on the basis of the *hypothesis* of self-organization can be tested against the data which can be observed: if a complex data structure operates as a system, it is expected to exhibit (co-)variations differently from when its elements change independently (e.g., Riba-Vilanova & Leydesdorff, 2001; Leydesdorff & Fritsch, 2006). A self-organizing system can be expected to recover from temporary losses of structure. It dwells in its own basin of attraction or, in other words, it contains a second-order structure (a regime) which is pending on its historical manifestations (along trajectories) as selection pressure (Dosi, 1982).

For example, the clear factor structures which have so often been reported from studies of aggregated journal-journal citation data (e.g., Carpenter and Narin, 1973; Doreian and Farraro 1985; Leydesdorff 1986; Tijssen *et al.* 1987; Tijssen 1992; Leydesdorff, 2006a) are not the incidental results of one clustering algorithm or another on this 'data' as given in a 'natural' history; they are rather the results of selective operations among the various specialty structures involved. There is nothing in these journals which makes them cluster, except that they refer to specialties and disciplines as *next-order* communication regimes. These cycles of communication are not observable in terms of the communicating agents (that is, the citing texts in the journals), but they can be distinguished analytically as virtual hyper-cycles of communication for explaining the observed structure and continuity in the data.

By interpreting lower-level communications with reference to a next-order system, hypotheses with respect to the latter system can be updated by observing the composing units. For example, theorizing about interdisciplinary developments in the sciences can provide meaning to changes in the observable patterns of aggregated citations among journals (Leydesdorff *et al*., 1994; Leydesdorff & Schank, forthcoming). However, the self-organizing systems and subsystems remain analytical possibilities which are contained in the distributions within and among such units of observation, and are reflexively reconstructed.

In other words, the next-order systems should not be reified at the meta-level in terms of the gods and demigods who supposedly govern history at lower levels. Communication systems remain empirical uncertainties contained in multi-dimensional probability distributions. However, the eigen-vectors of eigen-structure and the eigen-frequencies of eigen-time cannot be attributed to the constitutive elements; eigen-structure and eigen-time are latent and virtual properties, respectively, of the probability distributions which

[16] "Furthermore, it is worth notifying that the social and time dimensions themselves become reflexive when functional differentiation becomes the prevailing form of differentiation. This means that these dimensions reflect themselves in themselves or, in other words, allow for a re-entry of each dimension into itself." (Luhmann, 2008, at p. 21; my translation).

represent the networks and their possible developments over time. Insofar as they are stable over time, these latent dimensions can be considered as the system's codifications: structures are reproduced because they are considered functional for the further development of communication systems.

3.2. The globalization of meaning

A distribution of expectations can be provided with meaning recursively: some meanings can be codified as more meaningful than others. Recognizing one meaning as one among a number of possible meanings opens a horizon of possible meanings (Luhmann, 1984, pp. 114ff.). However, this next-order relationship of meaning to other possible meanings can be distinguished from the historical generation of specific meaning(s) along trajectories that was discussed in the previous section.

In the four-dimensional array of information (Figure 3b), it is no longer given which dimensions provide the variation and which function as selection mechanisms, and at which moment in time. The four dimensions operate upon each other and the selection mechanisms can thus alternate in their functionality at different moments. Meaning-processing systems can be expected to select some of the previous (instantaneous) selections for stabilization along an orthogonal axis.

Since selections reduce uncertainty, stabilization can be expected to reduce uncertainty at another order of magnitude when compared with first-order selections. Two selection mechanisms operating upon each other can stabilize along a trajectory in a process of mutual shaping. At a next round of selection, stabilizations can further be selected for globalization. This next-order systems layer—which remains a subdynamic of the system which it globalizes—can be considered as global with reference to the stabilization and other ongoing selection processes within the globalizing system.

Globalization can thus be considered as a second-order selection process (Hayami & Ruttan, 1970; Nelson & Winter, 1982). Stabilizations can analogously be considered as second-order variation. Unlike first-order variation, stabilization is no longer stochastic but pre-structured (Dosi, 1982). Like first-order selection upon the variation, second-order selection (globalization) operates at each moment in time. A globalizing system is able to select among the results of the first-order stabilizations.

The distribution of possible meanings provides a dimension to the system evolving in the present different from the historical stabilizations of meanings along trajectories hitherto. The next-order system builds upon the lower-level ones by selecting among them and by potentially rewriting the previously attributed meanings in terms of their relative weights within the distribution of possible meanings. This emergent distribution contains an uncertainty which interacts with uncertainty along the other axes. Therefore, all these operations remain uncertain: the globalization of the system cannot be completed, but remains under construction on top of fragile and temporary stabilizations of meaning hitherto.

In summary, g*lobalization is not a state but one operation among concurrent operations within a globalizing system.* Stabilization and globalization can be considered as different subdynamics operating on each other and on underlying selections. Thus, the self-organization of the constructing system comes under the selection pressure of its global dimension as specific constructions are historically realized and stabilized along trajectories.

As a system is shaped historically along the time dimension in a forward mode, the selective attribution of global meaning with hindsight finds a foothold for its own organization. The construction of this dimension is reflexively achieved by comparing the historical realizations with other envisioned options for organizing the complexity. This operation is knowledge-based because the alternatives were not yet realized.

3.3. Weak and strong anticipation

A reflection operating in the present (x_t) and from the perspective of hindsight—that is, against the arrow of time—can be distinguished from the recursive update of meaning operating with reference to an historically previous state of the system (x_{t-1})—that is, along the arrow of time. Dubois (1998a) proposed calling a recursion with reference to the present state of a system an ‘incursion.’ Incursion occurs within systems under historical conditions, that is, as an empirical relation to historically constructed (and recursively reconstructed) trajectories. An incursive system is able to select among its current representations of the past in terms of the system’s ‘survival value’ in a next-order selection environment. Thus, the incursive generation of meaning provides the system with one or more representations of itself.

Rosen (1985) defined anticipatory systems as systems which entertain a model of themselves. A model provides meaning to the modeled system. As a static metaphor, a system which contains a model of itself seems paradoxical because the model would model both the system and its model, and this would lead to an infinite regress. Dynamically, however, one can compute anticipatory systems using incursive algorithms (Dubois, 1998a; Leydesdorff & Dubois, 2004). Using these algorithms, one can formalize relations in time other than the one along the arrow of time. In other words, the degree of freedom in the time variate is exploited by these models.

For example, one can write incursive and hyper-incursive variants of the well-known logistic equation as follows:

recursively: $$x_t = ax_{t-1}(1 - x_{t-1}) \quad (1)$$

incursively: $$x_t = ax_{t-1}(1 - x_t) \quad (2)$$

or hyper-incursively: $$x_t = ax_{t+1}(1 - x_{t+1}) \quad (3)$$

While the *recursive* equation develops along the arrow of time, i.e., historically, the feedback term $(1 - x_t)$ in the *incursive* case provides selection pressure in the present. This model can, for example, be used to generate a modeling system (‘observer’) within a system (Leydesdorff, 2005).

The hyper-incursive equation (Eq. 3) can be appreciated as a model of double contingency: *Ego* in the present (x_t) operates on the basis of expectations of its own future state (x_{t+1}) and the expected state of *non-Ego* or *Alter* ($1 - x_{t+1}$) (Leydesdorff, 2008, 2009). Hyper-incursion at the level of a social system of interactions among incursions (by individual minds) and historical recursions can be expected to intertwine as globalization and stabilizations because of the distributed modes of communication. At some places and in some subsystems globalization may prevail, while at other places local stabilizations can be more important. The social system is not restricted by the condition of synchronization among its subdynamics—like an individual who may be expected to synchronize in the present in order to maintain an identity. The social system can differentiate between the modeling or meaning-processing system and the modeled and information-processing system.

As a result of its ability to select among a variety of possible representations of itself, an incursive system can already learn to anticipate possible further developments and thereby become increasingly self-organizing and knowledge-based. In the computation of anticipatory systems, this is defined as weak anticipation. A strongly anticipatory system, however, can construct knowledge-based representations that compete with those previously generated. Unlike *artificial* systems, social systems of communication remain historical and thus referential to first-order events and (incursive) actions. The various selection mechanisms in the system, including the virtual operation in the global dimension, can be expected to continue to interact.[17] Due to this periodic interaction with its contingent history, the meaning-processing system can be expected to *fail* to self-organize globally.

The metaphor of 'self-'organization provided us with a hypothesis which both the participants and the analysts can invoke for understanding the dynamics of a system. At this point—among others—I deviate from Luhmann's theory: in my opinion, Luhmann sometimes conflates the analytical distinctions with the observable realizations (Leydesdorff, 2006b, and forthcoming). Historically, self-organization on the basis of functional differentiation among the symbolically generalized codes of communication remains only a (potentially dominant) tendency among other subdynamics (Habermas, 1968a, 1987). Because of this additional sub-dynamics, one can expect that the capacity of the social system to tolerate tensions and differentiations can be orders of magnitude larger than that of individuals who face the need to perform and act in a prevailingly integrated mode along a life-cycle. The additional degree of freedom in the social system is disbursed in terms of a distribution of observable instances. The observables, however, remain to be explained.

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[17] Evaluation of a (quadratic) hyper-incursive equation (Eq. 3) leads to more than a single option. Because these options can be reflected by the reflexive agents carrying this system, decisions are to be taken, and historical organizations shaped (Dubois, 1998b, at p. 208f.; Leydesdorff, 2009).

4. Codification

Whereas variation can be observed, selection is a negative operation. One is not able to observe selections directly, but one can observe the distributional effects of selections and then make an inference. The selection mechanisms are to be specified as hypotheses. This specification of selection mechanisms is needed when selection can no longer be considered as given naturalistically (as was the case with Darwin's 'natural selection').

Stabilizations can again be observed. The negative sign of the selection can be expected to lead alternately to 'observable' and 'expected' events with each consequent turn. The globalizing regime remains pending as selection pressure on the systems and subsystems upon which it rests. By attributing an analytical identity to this next-order regime one can reduce one's complexity and choose an analytical perspective. However, the self-organization of the social system—or the economy as one of its subsystems—can be expected to remain uncertain, and other (and potentially incommensurable) appreciations are possible.[18] Thus, the identification of a global system is analytical: the self-organization of a social system can be specified only as an expectation.

A crucial question is whether entertaining this hypothesis contributes to our understanding of the complex dynamics in the observable phenomena such as the globalizing economy (Krugman, 1996). In other words, the self-organization of the social system beyond its stabilization is an intrinsically knowledge-based assumption. What is observable provides us with fragments of the global system, which can only be appreciated as instantiations on the basis of entertaining a hypothesis about a range of options.

In this context, Luhmann (1975, 1984, and 1997) proposed distinguishing among three representations of the social system: *society* as the global system of communication, the historical *organization* of communication, and local (e.g., face to face) *interactions*. By using social network analysis, lower-level *interactions* can be analyzed as being *organized* by latent dimensions (Burt, 1982; Lazarsfeld and Henry, 1968). This organization of the interactions can (provisionally) be stabilized. However, the further selection of the interactions by a next-order level of *self-organization* assumes that another subdynamic is additionally operating in the fluxes of communication.

A globalizing system of communications would be expected to self-organize the interactions and organizations subsumed under it using an hypothesized degree of freedom for the reflexive selection. A globalizing system, however, can also be expected to fail to achieve this level of control. The mechanisms remain analytical abstractions. In other words, the knowledge base of a communication system is part of the *res cogitans* and not the *res extensa*. (I come back to this distinction in a later section.) By specifying and entertaining this hypothesis, one is able to distinguish analytically between a system developing its complexity historically, that is, along a trajectory, and a self-organizing system that has one more degree of freedom for adjusting reflexively to its environments.

[18] An identity can perhaps be defined as a codified and, therefore, symbolically stabilized system that is able to entertain its relation to its own next-order system reflexively without loosing stability.

When this additional degree of freedom can be used within the system as a dimension of uncertain communication, a meaning-processing system can be generated on top of the information-processing on which it reflects. Rosen-type anticipation could already be defined at the biological level: the system contains one model or another which enables it to show different phenotypes under different circumstances. Rosen (1985) used a tree as an example. The tree is able to use the intensity of sunlight as a model for the change of seasons, and accordingly can adjust its foliage. The semantic domain containing the models is hard-wired. At the psychological level, an intentional system is able to select among possible meanings because one is able to entertain different models. The reflexive communication of these models generates the non-linear dynamics of meaning processing because the different meanings are reflexively reorganized, for example, as in a discourse.

A reflexive system can provide meaning to the incoming information, but the communication of meaning may destabilize the system to the extent that it can globalize. However, in that case the communication has to find a footing in the stabilizing dynamics of communication itself, that is, as codification of the communication. If this additional selection mechanism can reflexively be used within the social system for organizing the reflections—like in scientific discourses—communication of meaning can also be globalized.

The study of scientific discourses provided us with a substantive model (Mulkay *et al*., 1983; Leydesdorff, 1995): an hypothesis which is first an individual proposal can be stabilized at the level of the discourse by embedding it into a theoretical framework. For example, when Lavoisier proposed oxygen it first was considered to be 'dephlogisticated air,' capable of combining with more phlogiston and thus supporting combustion for longer than ordinary air. Gradually, oxygen became part of our common knowledge base about how air is composed. The concept became symbolically generalized and globally accepted as true because it explains our expectations. We—as reflexive and weakly anticipatory systems—have learned to understand the functionality of this scientific codification at the supra-individual level, and our understanding of what constitutes 'air' has changed accordingly.

4.1. Language

Human language extends Maturana's (1978) biological concept of a linguistic domain because order is not constructed in a biological environment and then stabilized as 'natural,' but rather remains flexible and under (re)construction among reflexive agents who are able to use language for the communication of meaning and intentions. Linguistic denotations can be generalized and used symbolically. Thus, one can learn from reading or listening in addition to learning from experiences.

The constructed order can be changed at a next moment in time or by adding a new dimension to the system. For example, elements once 'far apart' can be brought into relation to each other using symbolic mediation. Through translation between different meanings, discursive knowledge is generated because one has to distinguish among possible meanings in different contexts.

In scientific discourse, for example, ‘energy’ has a meaning very different from its meaning in political discourse. While economists and politicians are able to worry about ‘shortages of energy,’ ‘energy’ is defined as a conserved quantity in physics. Thus, the word ‘energy’ can be provided with different meanings in different contexts. Yet, if one is knowledgeable about the differences among the codes of communication, translations become possible. Codification adds another layer to the exchanges.

The differentiation of the codes of communication has the evolutionary function of potentially furthering the development of the communication (sub)systems. Translation of meaning from one code to another provides a mechanism for the regeneration and updating of meaningful expectations. The translation mechanism can thus be made functional to the ‘reproduction’ of the knowledge base of the social system. Novelty is generated when new representations emerge from the potentially innovative recombinations among codes.

The recursivity in this process of reflexive refinement improves the coordination locally and generates new knowledge endogenously, that is, as a control mechanism of the communication. Meanings which are functional can be distinguished from those which are not (or no longer) functional. Solutions to puzzles can first be communicated as potential innovations and then selectively codified in a next round. When repeated over time, the different selections generate couplings both horizontally and vertically within the knowledge base of the system (Simon, 1973). This knowledge infrastructure can be expected to contain sets of rationalized expectations, that is, bodies of knowledge.

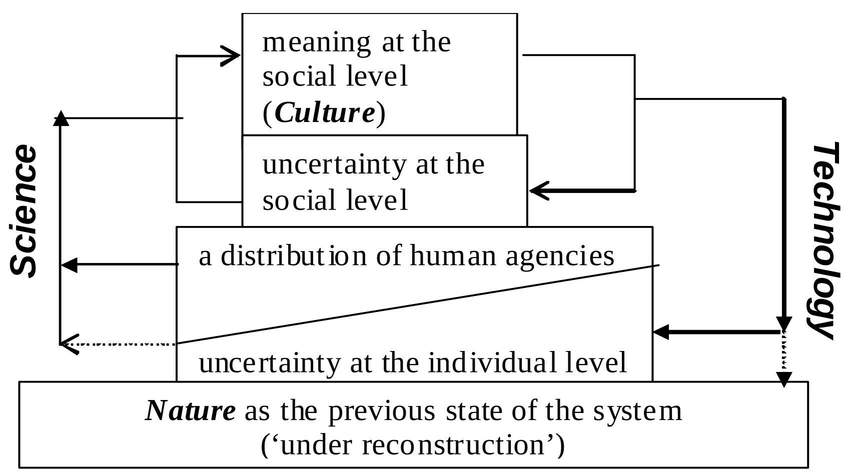
When specific couplings are provisionally stabilized in a knowledge infrastructure, a next round of reflection or deconstruction from another perspective may enable us to reconstruct the coordination system under study and perhaps renew it by searching for solutions of problems at interfaces that are different from the ones generated ‘naturally’ or at previous moments in time. In the Netherlands, for example, polder vegetation can be considered ‘natural’ even though the polder as a technical system of water management remains artificial. The social system is increasingly able to replace its historically given base with an evolving knowledge base whose operations are different from the historically previous organizations of meaning. Reflexive reconstructions of codifications in relevant exchange processes (e.g., at markets, in scientific discourses, etc.) enables us to deconstruct interfaces between communication systems in terms of their composing (sub)dynamics. The interfaces can then sometimes be reconstructed as technological artifacts.

4.2. The science-society-technology cycle

Whereas the social system is generated from and remains structurally coupled to the carriers of communication at the nodes of the network, the interactions (links) among these carriers are operational and therefore transformative. Furthermore, in the case of a network among human beings, the carriers are doubly contingent: they can operate both incursively and recursively. The networks can be expected to exhibit a complex dynamics because recursive and incursive operations are continuously recombined. Agents at the nodes may be able to make a system relatively more stable both unintendedly and/or reflexively, for example, under equilibrium conditions. This social system of communications, however, can also be meta-stabilized or globalized.

The historical structuring of the realized networks breaks the symmetry between past and future, and generates non-linear dynamics. Thus, the self-organization of communications remains contingent upon its historical manifestations.[19] The evolutionary metaphor and the historical metaphor are two sides of the same coin in the operation of the social system, but with foci from different perspectives. This co-evolution of incursive and recursive subroutines drives the development of the knowledge base from an emerging dimension of the social system into a techno-economic evolution that can become increasingly knowledge-based. The previously reconstructed system can be considered as the naturally given one in a next round. However, what is considered 'natural' can be deconstructed ('unpacked') and reflexively reconstructed.

The realization of the model requires the operation of the strongly anticipatory system, that is, a further selection among possible models. While intentionality is generated at the level of individual reflexivity (by an embodied *Ego*) in an interaction with other intentionalities (*Alter*), double contingency in these interactions generates an intersubjective dynamics. While human beings are able to reconstruct their history and their environment, they are not able to individually reconstruct this environment, that is, without invoking and instantiating the transformative capacities of the social system. The combination of incursive reflexivity at the level of individual minds and hyper-incursive operating at the level of a social system can generate a strongly anticipatory system: horizons of alternatives can thus be envisaged *and* chosen from.



[19] The historical configuration may sometimes be so stable that it successfully feeds back on the factors disturbing equilibrium; for example, in a high culture or otherwise hyper-stabilized organization.

Figure 4: The Science-Society-Technology Cycle of Knowledge-Based Reconstructions

The strongly anticipatory system operates as a pump in the science-society-technology cycle depicted in Figure 4. At the interface of the reflexive mind and the biological body, individuals are able to codify perceptions into language, and language itself can further be codified into scientific communication. While one can express expectations in language, scientific communications further functionalize the expectations with reference to specific codes. The different expectations can be interfaced innovatively.

Due to the capacity of these codes to enable us to deconstruct interfaces among systems of expectations discursively, the sciences can increasingly be interfaced with technologies which enable us to construct solutions different from previous ones. The technologies in turn change the 'natural' environments. Other agents may be affected by these technologies, and they are equally able to reflect on what happens in their environment and subsequently to propose and perhaps enforce other solutions. Biological evolution is thus enrolled in a cultural evolution as a next-order level of control, and the system of inter-human coordination mechanisms can increasingly become knowledge-based.

5. **Summary**

Before turning to a more philosophical reflection, let me summarize my argument hitherto. I argued in the first part of this review that the organization of knowledge as an (analytically) independent coordination mechanism in the social system emerged within industrial capitalism during the second half of the 19^{th} century. The scientific enterprise itself was the fruit of the scientific revolution of the 17^{th} century, but it had been organized loosely, for example, at the courts or in scholarly circles (Bazerman, 1988; Stichweh, 1984, 1990). Industrial capitalism emerged within mercantile capitalism during the 18^{th} century with the increased role of the nation state in the shaping of a political economy (Montesquieu, 1748). With the American and French revolutions, these developments were codified into modern constitutions which could be made functional to the further advancements of political economies in pluriform societies.

A knowledge-based economy can be generated when the organization of knowledge is added as a third coordination mechanism *at the level of the social system*. Knowledge is thus 'alienated' from its origins as a human activity and organized at the supra-individual level (Habermas, 1968a and b; Richta *et al*., 1968). When scientific knowledge is increasingly organized intellectually in discourses at the global level, and stabilized locally in scientific practices (e.g., R&D institutions), this new coordination mechanism becomes sufficiently complex to compete with economic and political mechanisms of coordination (Mulkay *et al*., 1983; Whitley, 1984). The interactions among three coordination mechanisms (economic exchange, political organization, and codification of discursive knowledge) entrained the social system into a self-organizing mode which contains de-stabilization, meta-stabilization, and globalization among its options.

The scholarly response to this new type of alienation was initially deconstructive: in the post-modern sociology of scientific knowledge, science was placed in 'contexts' and, according to these scholars, scientific developments had to be analyzed as action, that is, not as providing social structure (Berger & Luckmann, 1966; Latour, 1987). The shift of emphasis from social *construction* to the *constructed* system proposed by Luhmann (1990a) provided room to reintegrate concepts like functional differentiation and symbolic generalization—available from Parsons's and Merton's older sociologies of science—from a communication-theoretical perspective.

In the third section, Luhmann's communication-theoretical perspective was operationalized using information theory. This required another translation because in Luhmann's sociology *uncertainty* remained external to the communication of meaning in the cultural layer. Information was defined by Luhmann (e.g., 1984, at p. 103; 1995b, at p. 67)—with a reference to Bateson (1972, at p. 453)—as 'a difference that makes a difference' and therefore as a *selection*. In Luhmann's conceptualization, the subsystems are 'operationally closed' by the respective codes of communication, and this closure seems to generate a boundary at the structural level (like a biological membrane).

Habermas (1987) argued that Luhmann (1984) had thus replaced meta-physics with a meta-biology. However, this characterization is too simple. In a programmatic article entitled 'The Cognitive Program of Constructivism and a Reality that Remains Unknown,' Luhmann (1990b, at pp. 73f.) emphasized his intervention as a *de-ontologization* and formulated the following:

> Cognitive systems, therefore, have only a momentlike existence, as a result of the burden of simultaneity which keeps them on the ground. This existence must reproduce itself autopoietically in order to attain stability, even if it is only a dynamic one. They experience the world, therefore, with future and past—that is, as *duration* —only in the form of *non presentness.'*

This sociological perspective is, in my opinion, compatible with the critical tradition in the philosophy of science (Popper, 1959, 1972; Bhaskar, 1975, 1998; Mingers, 1995): discursive knowledge evolves on the basis of distinctions and remains based on hypotheses, arguments, and intersubjective and evolving discourse. The resulting systems of rationalized expectations can be updated by (series of) empirical observations.

Within the sciences, codification manifests itself in discursive reasoning. Through discursive reasoning, criteria are developed for accepting or declining contributions. These criteria remain flexible and have continuously to be reconstructed in evaluative practices which select between new knowledge claims. The different disciplines and specialties develop specific jargons for this purpose. Interfacing can sometimes lead to new recombinations, but in most cases the interdisciplinary language will be selected away as insufficiently precise. Interdisciplinarity can be made functional to the reproduction of communication when a recombination leads to new artifacts (e.g., instrumentalities; Price, 1984) that can be used to code new domains of communication (Shinn & Lamy, 2006; Leydesdorff & Schank, forthcoming).

Within domains of society other than science, codifications may be less reflexively transparent when symbolically generalized. However, symbolic generalization also enables us in these other domains to rely on the codification without having to question the medium when one operates with it. For example, one can pay nowadays with credit cards although as an analyst one would be able first to deconstruct the shaping of money as a cultural construct, then the standardization of value in coins and thereafter also in banknotes, and finally the credit system as layers of cultural construction which have taken centuries to be constructed. Nevertheless, money can be used naturalistically as a reliable basis for transactions (in most cases). When the (symbolically generalized) codes of communication can function as organizers of the communication—in addition to face-to-face communications and historical formats of organization—the new (modern) system can be expected to outcompete a stratified one (e.g., a high culture) by being able to process much more complexity.

6. A further reflection on the communication-based perspective

The articulation of the idea that human beings not only provide meaning to events, but are able to communicate meaning in addition to the communication of information emerged gradually during the 20th century with the development of sociology as a discipline. According to Weber (e.g., 1904, 1917) values can be considered as the crucial domain of human encounter and social development. As is well-known, Weber advocated adopting ‘value freeness’ as a methodological principle in the sociological analysis, while paying proper attention to the value-ladenness of the subject matter in the sociological analysis (Watkins, 1952). Values govern, from Weber’s perspective, human history as givens. Did secularization bring the Greek Gods back on stage as supra-individual agents (Weber, 1919)?

Durkheim (1912) noted in this same period that values can also be considered as ‘collective consciousness.’ Parsons (1968) emphasized that this concept of *another dynamic at the supra-individual level* can with hindsight be considered as constitutive for the new science of sociology. He traced it—that is, the idea that social interaction bestows events with qualitatively different meaning—back to American pragmatism (Mead, 1934), on the one hand, and on the other to Freud’s (1911) and Durkheim’s (1912) independent discoveries of the ‘reality principle’ and ‘collective consciousness,’ respectively.[20]

This new sociological program of research clashed with positivism—which also finds its origins in sociology (e.g., Auguste Comte), in opposition, however, to idealistic philosophies of the 19th century—because the focus was no longer on empirical data, but rather on what the data means, and how the subjects under study can sometimes reach consensus or otherwise dwell in conflicts about such meaning. The ensuing ‘Positivismusstreit’ in German sociology had its origins in the 1930s, but was exported to the United States by German emigrants in the prewar period (Adorno *et al*., 1969).

[20] According to Parsons’s (1952) reading of Freud, the social environment is internalized at the level of the super-ego.

In his 1971-debates with Habermas (who as a neo-marxist sided with the anti-positivists in the 'Positivismusstreit'), Luhmann (1971) proposed that the communication of meaning be considered as the very subject of sociology: coordination among human beings is not brought about by information transfer, but rather by the communication of meaning (Habermas & Luhmann, 1971). Unlike information, meaning cannot be transferred over a cable, but it can be communicated in interactions among reflexive agents. (Thus, the second contingency is involved.) According to Luhmann (1984), sociologists should focus on the dynamics of meaning in communication (e.g., Luhmann, 1988). Habermas (1981, 1987), however, wished to focus on 'communicative action' as an attribute of human beings.

In these exchanges, both Habermas and Luhmann made references to Husserl's reflections on 'intersubjectivity' as a common base, but they provided Husserl's philosophy with another interpretation (Husserl, 1929, 1936, 1962; Derrida, 1964). Habermas (1981, at pp. 178f.) followed Schutz (1952, at p. 105) in arguing that Husserl had failed to ground his concept of 'intersubjectivity' in interhuman communication (cf. Luhmann, 1995c, at p. 170). This grounding would require the concept of a 'life-world' in which communication is embedded. In my opinion, Luhmann remained closer to Husserl's so-called transcendental phenomenology by considering social relations as instantiations (Giddens, 1979, 1984) which are embedded in 'virtual,' yet structured communication fluxes.

The *locus classicus* for the alleged failure of Husserl is Alfred Schutz's (1952) study entitled 'Das Problem der transzendentalen Intersubjektivität bei Husserl' ('The problem of intersubjectivity with Husserl'; Schutz, 1975). Schutz formulated in this essay:

> All communication, whether by so-called expressive movements, deictic gestures, or the use of visual or acoustic signs, already presupposes an external event in that common surrounding world which, according to Husserl, is not constituted except by communication. (Schutz, 1975, at p. 72).

Schutz, therefore, wished to ground the communication in a common frame of reference. He called this the 'life-world' and criticized Husserl for explaining this ground as a result of and not as a condition for communication. However, Husserl considered the external referent of communication as a 'horizon of meanings.' Husserl's 'intersubjectivity' remained intentional, whereas Schutz argued in favor of an existential grounding of intersubjectivity in a 'we,' for example, when he went on to say: 'As long as man is born from woman, intersubjectivity and the we-relationship will be the foundation for all other categories of human existence.' (*ibid*., at p. 82).[21]

In other words, despite his admiration for Husserl (e.g., Schutz, 1953), Schutz disagreed with Husserl about the possibility of *deriving* social relations from communication. Social relations, in Schutz's opinion, are prior to communications, while Husserl argued that social relations are embedded in communications or—as he put it—'transcendental

[21] 'Solange Menschen von Müttern geboren warden, fundiert Intersubjektivität und Wirbeziehung alle anderen Kategorien des Menschseins.' (Schutz, 1952, at p. 105).

intersubjectivity.' It has been argued above that the question of what 'prior' means in these contexts depends on recursive or incursive perspectives. In the incursive case the system of reference evolves reflexively in the present by reconstructing the past. The reconstructed past is then analytically later than the reconstructing system which operates from the perspective of hindsight. The arrow of time is inverted locally (Coveney & Highfield, 1990).

In the *Cartesian Mediations* of 1929, Husserl followed Descartes by questioning not only what it means to be 'human,' but also the referent of human intentionality. While the first question refers back to Descartes' (1637) '*cogito ergo sum*,' the latter addresses the subject of doubt, that is, the *cogitatum*: the external referent of one's doubting. For Descartes this *cogitatum* could be distinguished only negatively from the *cogito* as that which transcends the contingency of one's *cogito*. From this perspective, the other in the act of doubting is defined as God. God transcends the contingency of the *cogito*, and therefore one can expect this Other to be eternal.

Husserl proposed to consider the *cogitatum* no longer as a personal God, but as the intentional substance *among* human beings which provides the *cogito* with an horizon of meanings. We—as *cogitantes*—are uncertain about what things mean, and the communication of this uncertainty generates an intersubjectivity which transcends our individual subjectivities. Although meanings are structured at the supra-individual level, these structures are no longer identified with a personal God. On the contrary, meaning can be constructed, enriched, and reproduced among human beings by using language.[22]

By using language one is able to relate meanings to one another, but within language the world is resurrected as an architecture in which the words can be provided with additional meaning at the supra-individual level. However, this meaning is not provided by the words or their concatenations in sentences or networks of co-occurrences (Leydesdorff, 1997). Language merely organizes the concepts by providing specific meaning to the words at specific moments in time. However, the instantiations refer to what could have been differently constructed and understood. In other words, the *cogitata* are not specific; they remain uncertain.

Husserl emphasized that this substance of the social system ('intersubjective intentionality') is different from subjective intentionality because one knows it *ex ante* as beyond the domain of the individual. The study of this new domain—as noted, Husserl used the Leibniz's word 'monade'—might provide us with 'a concrete ontology and a theory of science' (*ibid*., at p. 159). However, Husserl conceded that he had no instruments beyond the transcendental apperception of this domain and therefore he had to refrain from empirical investigations:

> We must forgo a more precise investigation of the layer of meaning which provides the human world and culture, as such, with a specific meaning and therewith

[22] Husserl acknowledged this function of language in the generation of meaning when he formulated for example: 'The beginning is the pure and one might say still mute experience which first has to be brought into the articulation of its meaning' (*ibid*., p. 40).

> provides this world with specifically 'mental' predicates. (Husserl, 1929, at p. 138; my translation).

In my opinion, two important developments in applied mathematics have made it possible to address the questions which Husserl felt as beyond his reach: first, Shannon's mathematical theory of communication provided us with categories for analyzing communications in terms of uncertainties (Abramson, 1963; Theil, 1972; Leydesdorff, 1995), and, second, Rosen's (1985) mathematical theory of anticipatory system and Dubois's (1998a) elaboration of this theory into the computation of anticipatory systems provided us with categories for studying the evolution of systems which are based on expectations and their potential functions for further developing codified communications.

In addition to these methodological advancements, Luhmann (1984, 1990a, and 1997) elaborated a sociological theory of the dynamics of codified communications on the basis of Maturana & Varela's (1980, 1984) theory of *autopoiesis*. Furthermore, Luhmann (1990a, at p. 340) formulated that differentiation in the codification generates a feedback that changes the social system, and added that 'developing this perspective is only possible if an accordingly complex systems-theoretical arrangement is specified.' In my opinion, this requires an information-theoretical reflection and methodological elaboration of the sociology of communication (Brooks & Wiley, 1986; Leydesdorff, 1996, 2000).

The knowledge-based economy can be modeled, measured, and simulated by building bridges among these methodological and theoretical advances (Leydesdorff, 2006c). This research program is a piecemeal enterprise. Because of their emphasis on operationalization and measurement the information sciences are excellently positioned to make a contribution by further specifying the complex (since nonlinear) relations among the processing of uncertainty, meaningful information, expectations, intentions, meaning, and knowledge in communication systems.

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