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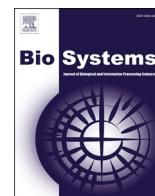
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# The evolutionary dynamics of expectations: Interactions among codes in inter-human communications

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## ABSTRACT

Double contingency—each of us (*Ego*) expects others (*Alter*) to entertain expectations as we entertain them ourselves—can be considered as the micro-operation of an above-individual (i.e., social) logic of expectations. Meaning is provided to events from the perspective of hindsight, but with reference to horizons of meaning. Whereas “natural selection” is based on genotypes that are observable (like DNA), cultural selection mechanisms *are not hard-wired, but evolve*.

The “genotypes” of cultural evolution are codes in the communication which can operate as selections upon one another. Local instantiations shape trajectories; regimes operate as selection pressure with reference to the next-order horizons of meaning. These orders of expectations can operate incursively and hyper-incursively against the arrow of time and thus generate redundancies: (i) horizons of meaning can be expected to overlap and (ii) distinctions generate new options enlarging the maximum capacities. Information theory and the theory of anticipatory systems can be used for the elaboration of operations against the arrow of time. New options can be a synergetic effect of interactions among codes in the communication and serve as sources of wealth in a knowledge-based economy.

## 1. Introduction: monism and dualism

In his influential book entitled *Descartes' Error*, Damasio (1994) argued that Descartes' statement *Cogito ergo sum* (“I think therefore I am”) has been a major source of *error* in Western philosophy. Damasio formulated as follows: “Taken literally, the statement illustrates precisely the opposite of what I believe to be true about the origins of mind and about the relation between mind and body” (p. 245).

Although there is no necessary relation between “big data” and “monism”—the program of reducing cultural and mental processes to computational and biological principles—both these programs reject a Cartesian dualism between *res extensa* and *res cogitans*. In a paper entitled “The End of Theory,” Anderson (2008), for example, formulated the program of “big data” as follows:

This is a world where massive amounts of data and applied mathematics replace every other tool that might be brought to bear. Out with every theory of human behavior, from linguistics to sociology. Forget taxonomy, ontology, and psychology. Who knows why people do what they do? The point is they do it, and we can track and

measure it with unprecedented fidelity. With enough data, the numbers speak for themselves.

In a similar spirit—but with another methodology—Ramstead et al. (2017), for example, presented “a hierarchical multiscale free energy formulation [...] that offers the sciences of life, mind, behavior and society with a principled, computationally tractable guide to discovery” (p. 13). In this ontology, the system levels self-organize into a hierarchy. *Homo sapiens sapiens* is then placed at the top of this hierarchy as “the world’s most complex living system.” Humans are said to generate “(epi) genetically-specified expectations that have been shaped by selection to guide action-perception cycles toward adaptive or unsurprising states” (p. 12; cf. Leydesdorff, 2018).

These various authors have in common that their program is to *reduce* cultural phenomena to biological and computational principles (Porankiewicz-Żukowska, 2017). We shall argue in this contribution, that the exchanges of and interactions among expectations are *not* epi-genetic, but shape a cultural layer with a dynamic operating as a feedback on the (human) carriers of this evolution. Unlike biological evolution which follows the entropy flow, codes in the communication

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can generate redundancies; for example, by refining distinctions. In this model, however, humans are not at the top of “the” hierarchy, but can function as infra-reflexive linchpins among hierarchies and heterarchies of variably codified communications. Not *Homo sapiens sapiens* but the complexity of the communication among humans is further evolving in terms of new recombinations among codes.

## 2. *Homo sapiens sapiens* and the cybernetics of ego

In addition to his many discoveries about mental illnesses, Freud carved out the epistemological boundaries of the psychological domain with biology on the one side and sociology on the other. Using Freud's (1933) well-known metaphor of *Ego* sitting as a rider on a horse, *Ego* is not to be considered as an energy system but as a “cybernetic” (Parsons, 1958, p. 108). In relation to sociology, Freud commented at a workshop in Vienna in 1926 “that he felt like the skipper of a barge who had always hugged the coast, who had now learned that others, more adventurous, had set out for the open sea.” He wished them well, but he could no longer participate in their endeavor (Waelder, 1958, at pp. 243f.). The sociologist Parsons (1968), however, argued that Freud himself—approximately at the same time as (Durkheim, 1894; Durkheim, 1912)—had discovered the social as the proper subject of sociology.

Parsons (1968) summarized Freud's contribution from this perspective, as follows:

Relatively early, Freud gained the insight that the expression of instinctual need was regulated by the society's moral standards—often, but in no simple sense always, in conflict with instinctual needs—and that these standards were *introjected* into the personality itself, becoming components of its structure. The final form of this conception crystallized about the famous idea of the superego. Later, [...] the famous “reality principle” came to focus on “object relations,” which for Freud meant relations to other persons, especially the parents, considered as agents of socialization. But these human objects were not only “adapted to” in the sense true for physical objects; they were also introjected—or, as we now usually say, internalized—to form part of the personality structure, particularly of the ego, in Freud's sense. (p. 432)

Why had Freud himself become reluctant to investigate the social at the above-individual level? Parsons (1951) formulated the beginning of an answer to this question, as follows:

The inescapable conclusion is that not only moral standards, but all the components of the common culture are internalized as part of the personality structure. Moral standards, indeed, cannot in this respect be dissociated from the *content* of the orientation patterns which they regulate; as I have pointed out, the content of both cathectic-attitudes and cognitive-status definitions have cultural, hence normative significance. This *content is cultural* and learned. (p. 23; italics added, L.)

In other words, Parsons considered *content* as a next-order co-ordination mechanism in interpersonal communications. On the basis of this appreciation, Parsons was able to relate Freud's concept of internalization to American pragmatism. “Society,” as Cooley (1902) argued, exists inside the individual in the form of language and thoughts. Parsons, (1951, p. 94) formulated the concept of double contingency as the micro-operation of this order, as follows:

Depending on *which of several alternatives open to me I take*, I will set *alter* a problem to which he will react in terms of the alternative system of his own which is oriented to my action.

In other words, double contingency means that each of us (*Ego*) expects others (*Alter*) to entertain expectations as we entertain them ourselves. The expectations are contingent because they can be changed.

The second contingency among expectations operates on top of the first contingency of empirical processes in the physical and biological domains, but with a different dynamic: both consciousness and communication develop in substantive and reflexive layers, but with different mechanisms. For example, meanings can be shared, but cannot be communicated as Shannon-type information. However, the relations between the two contingencies can be asymmetrical. The first contingency is reflexively internalized into the second; the next-order contingency leaves traces (e.g., cultural artifacts) in the previous one. Furthermore, the communicative structures are vertically layered and can be differentiated horizontally in terms of codes operating in parallel. Simon (1973) conjectured that there may be an alphabet of such codes (power, truth, love, etc.).

## 3. The specification of alter

The *Alter of Ego* belongs to the *cogitata*: the things about which one remains in doubt. In today's language, one could say that one has cognitive access to the *cogitata* via a model. Models are not only reflexively processed in *Ego*'s mind, but can be entertained in a discourse among reflexive agents. Models can be communicated. Entertaining a model provides the communication with anticipatory capacity based on discursive knowledge (Rosen, 1985). Options in the supra-individual domain of *cogitata* can be volatile and proliferate more rapidly than in the hardware of *res extensa*.

Husserl (1929) envisaged the *cogitata* as *intersubjective intentionality*. Intentionality is a logic, but not necessarily a system (Searle, 1983). Independently of each other, Maturana (2000) and Latour (1996) proposed “inter-objectivity” as a potential result of intersubjective codification. Codifications shape contents. For example, the various chemical elements can be distinguished using the periodic table. As one fills the table further on the basis of observations, new chemical elements are added to our reality on the basis of theorizing and testing assumptions.

Not incidentally, Husserl called his *Meditations* “Cartesian”; the second contingency has a dynamic of its own. This philosophy of science is dualistic: concepts are shaped in a communication process by codifications. For example, manuscripts contain knowledge claims developed in the context of discovery for further selection in the context of justification before discursive knowledge can be validated and absorbed in the archive. The interacting communication loops shape redundancies among meanings on top of a linear (Shannon-type) information flow (cf. Maturana, 2000).

## 4. Descartes' error

In our opinion, Damasio's rejection of Descartes' dualism in favor of monism is based on a poor reading of Descartes as a straw man (cf. Gluck, 2007). This misreading, however, is more wide-spread: the sociologist Schutz (1975, at p. 82), for example, criticized Husserl's ([1929] 1960) *Cartesian Meditations* in a similar vein, as follows:

[...] As a result of these considerations we must conclude that Husserl's attempt to account for the constitution of transcendental intersubjectivity in terms of operations of the consciousness of the transcendental ego has not succeeded. [...] As long as man is born of woman, intersubjectivity and the we-relationship will be the foundation for all other categories of human existence. The possibility of reflection on the self, discovery of the ego, capacity for performing any epoch, and the possibility of all communication and of establishing a communicative surrounding world as well, are founded on the primal experience of the we-relationship.

Schutz (1975, p. 72) opposed Husserl's position that “all communication [...] is not constituted except by communication.” From Schutz's perspective, the “we-relationship” remains a biological and psychological fundament at the micro level. In other words, one can consider

Schutz's (micro)foundation as existential—grounded in relations—whereas Husserl grounds intentionality in interpersonal expectations; that is, the double contingency as a different micro-operation.

In our opinion, both Schutz and Damasio read Descartes from a present-day perspective: his words are provided with empirical meanings that are different from their philosophical meaning in his time. Descartes did not wish to make an empirical inference about thinking and being, or the genesis of consciousness in mother-child (“we”) relationships. *Cogito ergo sum* is meant to be the formulation of a “first principle” in Descartes’ philosophy. Although Damasio (1994) mentioned this alternative interpretation as possible (at p. 249), he did not elaborate on it.

Descartes (1637) specified *Cogito ergo sum* in *Discourse on Method* (Part 4), and formulated as a conclusion<sup>1</sup>

[...] the mind by which I am what I am, is wholly distinct from the body, and is even more easily known than the latter, and is such that even if the latter were not, it would still continue to be all that it is.”

The “mind by which I am what I am” is not an empirical subject of study, but a philosophical grounding which “is even more easily known” than the body, because the body can be an empirical object of study. *Cogito*, however, is not empirical; it belongs as a first principle to what the Greek philosophers characterized as “the mathematical.” *Cogito ergo sum* is a statement with a status similar to “two plus two is four” (cf. Hoegl, 2003). The inference can be made on the basis of *a priori* reasoning. Heidegger ([1962], 1970, p. 70), for example, explained the text as follows<sup>2</sup>

The formula [...] “*Cogito ergo sum*” suggests the misunderstanding that it is here a question of inference. That is not the case and cannot be so, because this conclusion would have to have as its major premise: *Id quod cogitat, est*—“that which thinks, exists.” [...] Descartes himself emphasizes that no inference is present. The *sum* is not a consequence of the thinking, but *vice versa*; it is the ground of thinking, the *fundamentum*. In the essence of positing lies the proposition: I posit. [...] The I is the *subjectum* of the very first principle. Before Descartes everything present-at-hand for itself was a “subject”; but now the “I” becomes the special subject, that with regard to which all the remaining things first determine themselves as such. ([at p. 82], p. 69f.)

Hintikka (1962) suggests that *Cogito ergo sum* is not an inference but were to be considered as performative.

In Descartes’ philosophy, God’s Goodness (*Veracitas*) warrants our capacity to bridge the gap between *res cogitans* and *res extensa*, and thus to develop empirical knowledge. In the *Critique of Pure Reason*, however, Kant (1787: B620–B630) refuted Descartes’ ontological inferences. Kant concluded that one can remain agnostic about the existence of God or a transcendental reality. However, one cannot remain indifferent in one’s relations to others. The relation of *Ego* to other human beings is discussed by Kant (1788) in the *Critique of Practical Reason* which follows upon the *Critique of Pure Reason*.

## 5. The secularization of *alter*

By secularizing contingency and transcendence as expectations of human beings about one another, this domain becomes a *second contingency* in which meanings are provided to things and events. As against *Ego*’s relation to God, one’s relations with fellow human beings are empirical. However, one cannot expect an order of expectations to be

<sup>1</sup> [https://www.literatureproject.com/discourse-reason/discourse-reason\\_4.htm](https://www.literatureproject.com/discourse-reason/discourse-reason_4.htm). I have used this translation with minor changes.

<sup>2</sup> On the moral issue of using Heidegger’s writings, see, for example, Bernstein (1992, pp. 79–141).

observable “out there” for inspection and measurement. This order fails to be; it is fragile and fragmented. One needs analytical specifications before one can proceed to the operationalization and measurement.

Using Simon’s (1973) model of complex systems and Luhmann’s (1995 [1984]) theory of social systems, one can specify hypotheses about this above-individual order. The horizontal differentiation among differently coded communications span horizons of meaning in various directions. The recursive communications shape hierarchies along these axes, but the communications disturb one another since the systems are *nearly* decomposable and can fall apart into heterarchies operating in parallel (that is, heterarchically). Ivanova and Leydesdorff (2015) proposed considering this communication structure as a “fractal manifold” of hierarchies and heterarchies.

Scientific discourse, for example, can be interrupted by political discussions, and *vice versa*. The axes of the manifold can be considered as hypothesized eigenvectors of a communication matrix when the latter is repeatedly multiplied by itself. The patterns are shaped by mechanisms of preferential attachments (Barabási and Albert, 1999) and cumulative advantages (Price, 1976), which drive criticality and thus generate avalanches and crises, leading to a need for restructuring (Bak et al., 1987). The horizontal differentiations and the vertical layers are *asymmetrical*, and so is the difference between the past and the future in the historical present.

First, there is the (entropic) information flow which can be represented as an observable graph. The graph shows the footprints of the system’s morphogenesis and retention in historical time. In addition to specific relations in a network, vectors of relations and *non*-relations (ones and zeros) can be correlated and thus span a vector space. Meaning is provided in this latter space from positions which open perspectives (Leydesdorff and Ahrweiler, 2014). Along the time dimension, meaning is provided from the perspective of hindsight to the events, but with reference to other possible meanings. The codes in the communication (operationalized as the dynamics of eigenvectors in a vector space) span potentially overlapping “horizons of meaning.” Limiting “reality” *a priori* to a single (universal) perspective may throw the baby of alternative perspectives away with the bath-water in the name of a rigorous commitment to “monistic” positivism.

## 6. The priority of other possibilities

The (second) contingency of mutual expectations can be considered as *the proper domain of the social sciences and humanities*. In parallel to investigating events in the natural and life-sciences, one can always ask “what do things mean?” Attempts to make this domain the subject of the natural and life sciences in the name of ideals such as “the unity of science,” “monism,” or a “grand synthesis” tend to reduce the social sciences to a relatively irrelevant commentary to the “real” world of science and “hard” scientific facts.

The issue is not whether facts are socially constructed or given in nature. Both “facts” and “constructs” are mediated, as we have to articulate content first in discourse. Discursive knowledge cannot be generated without linguistic mediation or, in other words, a content that is under study. The facts are the constructs of discourses. On the basis of the philosophical *a priori* of “monism” and “big data,” however, the social sciences cannot be developed beyond the study of behavior from a meta-biological perspective. From this perspective, one models language after “linguaging,” that is, a form of behavior (Maturana, 1978). The languaging agents—human beings—are then considered as interacting “observers”. However, one cannot infer from the specification of an *observer* to the content of an *observation* (Habermas, 1987; Leydesdorff, 2006).

Under appropriate (e.g., institutional) conditions, the feedback arrow from *res cogitans* on the development of *extensa* can generate redundancies and therefore ranges of options which can serve as sources of wealth in a knowledge-based economy. Each new dimension or technology *multiplies* the number of options. As long as transportation over

the Alps, for example, was constrained by passes such as the Brenner and the Gotthard, the number of these passes determined the maximum capacity. Railways tunneled through the mountains and airplanes which can cross the Alps independently of conditions on the ground multiply the number of options by adding communication channels. Unlike biological systems, the maximum capacity of a cultural system (the  $H_{max}$  in information theory) is not a given. New options can be invented as alternative possibilities. The empty boxes add to the redundancy.

Ulanowicz (1986, pp. 143 ff.; 1997) used this possible generation of redundancy for developing “ascendency theory”: under specifiable conditions, biological populations can proliferate beyond control. Ulanowicz (2014) compared his studies of redundancy generation with “apophatic theology.” In apophatic theology, one can identify God only in terms of what He is *not*. Ulanowicz argued that the *apophasis* ( $A$ )—i.e., redundancy—cannot teach us anything about historical events. A biological system with more options than are realized ( $A > D$ ) would be vulnerable to perturbations such that a catastrophe would be unavoidable (Ulanowicz, 2014, p. 26; see also Ulanowicz, 1986, p. 92).

In our opinion, one is able to specify expectations about the above-individual dynamics using information theory and the theory of anticipatory systems. On top of the historical events but from another perspective, the initially empty boxes generated by (knowledge-based) distinctions add redundancy to the maximum capacity of the systems under study. The empty boxes can be filled with values on the basis of observations. In his book *Incomplete Nature*, Deacon (2012, at p. 3) proposed focusing on the challenges of the zeros:

What is absent matters, and yet our current understanding of the physical universe suggests that it should not. A causal role for absence seems to be absent from the natural sciences.

[...] This something-not-there permeates and organizes what is physically present in these phenomena. Its absent mode of existence, so to speak, is at most only a potentiality, a placeholder. [...] Zero is the paradigm example of such a placeholder. (p. 10)

The zeros do not add to the information but to the redundancy, by enlarging the maximum entropy. A systemic generation of options can be considered as the footprint of a knowledge base in operation; for example, in an innovation system. Against the idea that the zeros and the missing cases are not informative, we suggest that the social sciences not only construct the empty boxes and fill out the zeros by specifying and testing expectations; they can also provide us with insight into the potentially negative values of the intangibles that organize our understandings into discourses.

## 7. The generation of redundancy

Whereas the information flow generates uncertainty, the cultural feedback terms can be expected to reduce uncertainty by adding redundancy. The inversion by the feedback is not just a minus sign, since discrete “time” is irreversible. “Selection” mechanisms have to be specified when selection is no longer “natural.” Selections can also compete or be spuriously correlated (cf. Nelson and Winter, 1977). In his discussions with Habermas, Luhmann (1990 [1971]) formulated this need for another concept of “selection” with reference to cultural evolution, as follows:

[...] [W]hat is special about the meaningful or meaning-based processing of experience is that it makes possible *both* the reduction and the preservation of complexity; i.e., it provides a form of selection that prevents the world from shrinking down to just one particular content of consciousness with each act of determining experience. ([1971, p. 34]; 1990, p. 27)

The codes developed in the communication provide selection criteria and thus co-ordinate the systems in which they emerge. Codes have to be constructed in historical processes of “morphogenesis” (Archer, 1982)

before they can take control over the logic in the communications from which they emerged. The emerging order builds on support structures that also have to be reproduced. The construction of codes in the communication may take centuries (e.g., Foucault (1984) about the shaping of noso-politics in the eighteenth century, or both Luhmann (1986) and Giddens (1992) about the development of the code of intimacy (cf. Elias [1969] 2000).

Communications build on communications and thus shape patterns. These recursively repeated patterns of communications code the communication increasingly in specific directions as they emerge. After their emergence, the codes shape the room for further communications in feedback loops. For example, money enables us to accelerate economic transactions: one can pay the price of a commodity instead of having to bargain on the market. Credit further speeds up monetary transactions; credit cards enable us to shop, for example, worldwide.

The codes of communication operate within *and* on top of the communications from which they emerge. The codes are part of the communication, but as a second dimension. Their evolutionary logic of control is different from that of the historical developments in the communications. While the communications develop along trajectories, the emerging codes operate as regimes—that is, next-order selection pressure pending as hyper-selection on the survival chances of variants (Bruckner et al., 1994). Trajectories are geometrically localizable; regimes are next-order and therefore relatively global selection mechanisms. One then needs a calculus.

As in the case of money, the mechanisms of scientific communication have become internally structured in terms of trajectories and regimes by using an interplay of codes: the “context of justification” operates as a selection mechanism on outcomes of the “context of discovery” providing variations (Popper, 1959). The context of justification can be considered as a “self-organized” control mechanism of the communication (Merton, 1942, 1948); the context of discovery provides the larger environment from which knowledge can be generated.

Knowledge claims are formulated, for example, in manuscripts. These manuscripts can be reviewed in the context of justification and then selectively codified before possibly becoming globally recognized as part of the archive of science. This dynamic of discursive knowledge has become part of the self-understanding of the sciences (e.g., Hempel and Oppenheim, 1948). Popper (1959), for example, argued against positivism, as follows:

The empirical basis of objective science has thus nothing ‘absolute’ about it. Science does not rest upon solid bedrock. The bold structure of its theories rises, as it were, above a swamp. It is like a building erected on piles. The piles are driven down from above into the swamp, but not down to any natural or ‘given’ base; and if we stop driving the piles deeper, it is not because we have reached firm ground. We simply stop when we are satisfied that the piles are firm enough to carry the structure, at least for the time being. (p. 111)

Although an evolutionary mechanism was envisaged, the evolutionary model is not further specified; when Popper formulated in the above quotation that “we simply stop when we are satisfied,” one can raise the question “who are the ‘we’?” Was not “objective knowledge” in World 3 defined by Popper, 1972, at pp. 131 ff.) as knowledge without a subject? Are the “we” an aggregate of the “I’s” or an interaction term among us and/or them? By focusing on “meanings,” the units of analysis shifts from the constructing agency to the knowledge-based dynamics of “reconstructions and revolutions” in the constructs (Hesse, 1980). It is *no longer the agents or the texts that are updated, but the expectations*. The updates can be reflected by agents and in texts.

## 8. Historical developments and evolutionary dynamics

Communications are *not grounded, but anchored* by codes of communications. The codes can be the unintended results of repeating

patterns in the communication; the logic of the codes is intersubjective, while individual intentions remain subjective. The patterns develop in terms of selections over time operating upon selections at each moment. Some selections can be selected for stabilization along a trajectory; some stabilizations can be selected for globalization at the level of a next-order regime. Whereas trajectories co-ordinate historical practices, regimes structure expectations or, in other words, the domain of possible practices; trajectories can also be considered as instantiations of regimes.

As next-order controls emerge, the meanings of the communications can be restructured. The communication is structured in terms of the reflexive capacity of communications to rewrite the history and content of communications at lower levels. Citing Neurath' 1932, p. 206 well-known dictum, "the ship has to be rebuilt while a storm is raging on the open sea." Changes in the variation add up to unintended changes in the structures of the variations.

In summary: flows of communication are molded by selective structures, on the one hand, and variation, on the other (Fig. 1). These two contexts provide analytically different perspectives on the same events; the data is organized using different logics. From an historical perspective, one focuses on variation and agency, and the potential (morpho)genesis of systemic relations in the data. From an evolutionary perspective, the focus is on the same data indicating selection environments which can be specified (as hypotheses) on the basis of a reflexive turn.

Analogously, human minds not only partake in the network dynamics as the constructive agents who generate variation, but can at the same time be involved reflexively in the processes of providing meanings to the data. The perceptive role is different from the constructive one. The evolutionary driver is the generation of new options for experiencing and action in synergies among the codes (Weinstein and Platt, 1969). An increasing number of options provides an evolutionary advantage in terms of, for example, the viability of systems (Petersen et al., 2016; Stafford Beer, 1989). New options can be generated as redundancy in translations among three (or more) differently coded communications.

## 9. Options for further research

Two research programs focusing on redundancy generation (when the arrow of time is inverted in the model), in our opinion, are most relevant for the operationalization and measurement of the above articulations: (i) the computation of anticipatory systems (Dubois, 1998), and (ii) the generation of potentially negative mutual information at interfaces among three or more codes. In the computation of anticipatory systems, the time axis is inverted by assuming that future states can incur on current states; mutual information in three dimensions can have a minus sign, indicating a similar inversion of the arrow of time.

### 9.1. "Double contingency" in anticipatory systems

"Double contingency" can—in our opinion, elegantly—be specified in terms of the theory of anticipatory systems (Dubois, 1998, 2003) as follows:

$$x_t = ax_{t+1}(1 - x_{t+1}); 0 \leq x > 1; \quad (1)$$

In words: *Ego* ( $x$ ) operates in the present (as  $x_t$ ) on the basis of an expectation of its own next state ( $x_{t+1}$ ) and the anticipated next state of *Alter* ( $1 - x_{t+1}$ ). Note that the expectation of *Alter* ( $1 - x_{t+1}$ ) is here defined in terms of *Ego*'s expectations about *non-Ego*. The expectations constructed in one's mind about oneself and *Alter* precede possible communication between *Ego*'s and *Alter*'s expectations about each other.

Interactions imply an historical instantiation. The term ( $1 - x_{t+1}$ ) in Eq. (1) models a selection of *Ego*'s expectations of *Alter* as *non-Ego*. However, one can expect each *Alter* ( $y$ ) to entertain as another *Ego* an analogous selection term ( $1 - y_{t+1}$ ). The two selection terms can operate

upon one another and thus lead to the quadratic Equation (2):

$$x_t = b(1 - x_{t+1})(1 - y_{t+1}) \quad (2)$$

or more abstractly:

$$x_t = b(1 - x_{t+1})(1 - x_{t+1}) \quad (3)$$

These equations do not contain a reference to a previous state of the system itself ( $x_{t-1}$ ). In both cases, only future states are operating as independent variables. Unlike double contingency (Eq. (1)), Eq. (2) models the effects of interactions between expectations (cf. Leydesdorff and Dubois, 2004). Eq. (3) abstracts from content in order to focus on the mathematical properties of this hyper-incursive equation. Whereas future states can incur on the present, *hyper-incursion* is used for the reconstruction of expectations on the basis of expectations. Only social systems have this option; for example, the rule of law may necessitate the changing of a law.

Eq. (2) can be further extended to more complex configurations by adding a third or further selection environment. One can add this third (or each next) term as hyper-incursive or incursive routines, and thus obtain the following two equations:

$$x_t = c(1 - x_{t+1})(1 - x_{t+1})(1 - x_{t+1}) \quad (4)$$

$$x_t = d(1 - x_{t+1})(1 - x_{t+1})(1 - x_t) \quad (5)$$

Eq. (4) is a cubic equation which models a "triple contingency" of expectations. The third contingency potentially closes the triad so that the communication can loop. In a paper entitled "Triple Contingency: The theoretical problem of the public in communication societies," Strydom (1999) argued that "the increasing differentiation and organization of communication processes eventuated in the recognition of the epistemic authority of the public, which in turn compels us to conceptualize a new level of contingency." According to Strydom, the differentiation of "public" versus "private" as codes in the communication generated modernity (cf. Leydesdorff, 2009). Note that from this perspective, the public is not considered as a sphere (Habermas, 1974) or an audience (Latour, 1988), but as a code in the communication.

Eq. (5) differs from Eq. (4) in terms of the time subscript in the right-most factor. Eq. (5) can be used to model a specific organization of meanings as an *instantiation* in the present. The reference to the present in this third factor makes this model incursive and thus historical, whereas the self-organizing system modeled in Eq. (4) operates hyper-incursively and without reference to a current state, in terms of expectations about possible future states. An instantiation, however, requires (provisional) integration and organization at specific moments of time. In Eq. (5), the interaction among expectations is specifically instantiated as a configuration at time  $t = t$ . In summary, Eqs. (4) and (5) model algorithmically a trade-off between the evolutionary and historical perspectives among expectations in Triple-Helix models (Leydesdorff et al., 2017).<sup>3</sup>

### 9.2. Solving the equations

Incursive and hyper-incursive equations have solutions that can be very different from the corresponding recursive equations. As is well known about the logistic equation (e.g., May 1976), the bifurcation diagram of a system  $x$  plotted against the so-called bifurcation parameter  $a$  is increasingly chaotic when  $a \rightarrow 4$ , and cannot exist for  $a \geq 4$ . A system can, for example, be an innovation system in which knowledge is generated and options exploited with different efficiencies. In Fig. 2, the

<sup>3</sup> Other incursive and hyper-incursive equations follow as possible members of this family of equations based on the logistic equation, but will not be further discussed here. We limit ourselves to the discussion of the so-called bifurcation diagram in the next section here below.

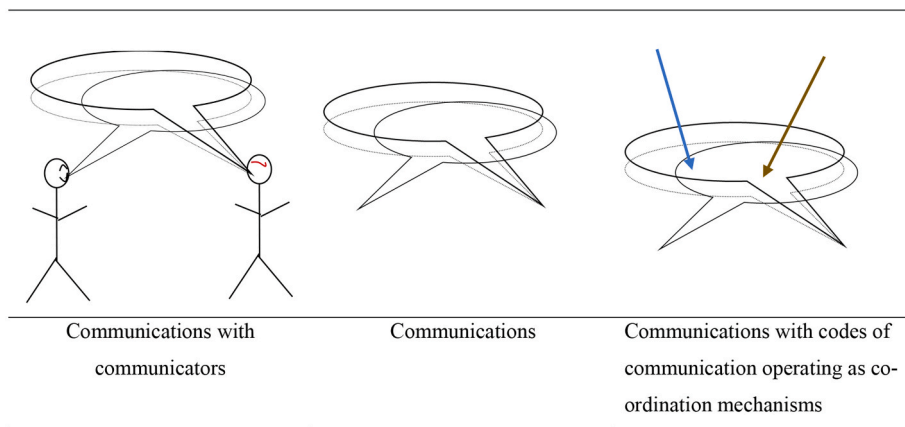


Fig. 1. Communications can be considered as attributes of communicators, but they can also be considered as second-order units of analysis to which codes of communication can be attributed.

well-known bifurcation diagram of the logistic equation is depicted as the left half of the figure. In the case of an *incursive* Eq. (6), however, this limit value (for  $a \rightarrow 4$ ) is not specifically relevant, while it is, for the hyper-incursive Eq. (1) which we used above for modeling double contingency.

First, one can derive on the basis of the incursive Eq. (6), as follows:

$$x_t = ax_t(1 - x_{t+1}) \tag{6}$$

$$x_{t+1} = ax_t - ax_t x_{t+1} \tag{7}$$

$$x_{t+1}(1 + ax_t) = ax_t \tag{8}$$

$$x_{t+1} = ax_t / (1 + ax_t) \tag{9}$$

By replacing  $x_{t+1}$  with  $x_t$  in Eq. (9), two steady states can be found for  $x = 0$  and  $x = (1 - a)/a$ , respectively:

$$x = ax/(1 + ax) \tag{10}$$

$$1 = a/(1 + ax) \tag{11}$$

$$1 + ax = a \tag{12}$$

$$x = (a - 1)/a \tag{13}$$

It follows from Eq. (13) that  $x$  can be considered as a constant function applicable to all values of  $a$ . This evolution towards a constant value of such a system ( $x$ ) through incursive anticipation can be

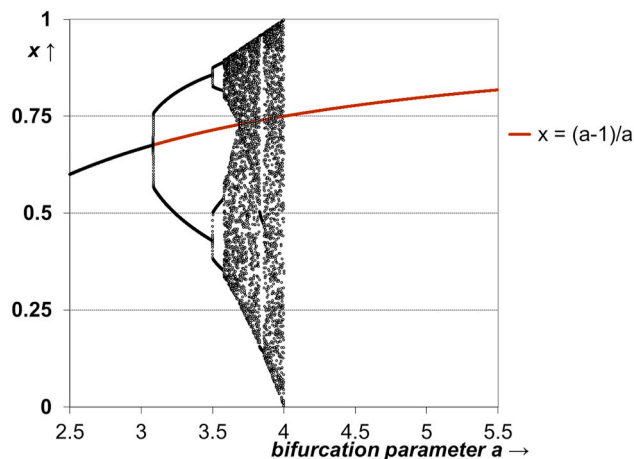


Fig. 2. The development of the incursive system with the bifurcation parameter  $a$ .

considered as the development of a single-valued self-reference of an expected “identity.” In the second contingency, identity is based not on the history of previous states, but on entertaining the expectation of continuity of the “self.” The observable identity in the network “me” can be distinguished from the “I” at the regime level (Mead, 1934, at pp. 26f.). Like individuals, organizations can be expected to develop identity in the second contingency.

The line penciled into Fig. 2 shows the development of Eq. (6) as an incursive system. Incursivity provides meaning(s) to events; for example, by integrating them into both the biological domain ( $a < 4$ ; e.g., bodily perceptions) and the domain of meaning-sharing and processing ( $a \geq 4$ ). The instantiation of the two arguments in a single receiver integrates information and meaning processing (e.g., in action), and thus can function as a linchpin between anticipatory minds ( $a < 4$ ) and anticipatory communications in the cultural (i.e., non-natural) domain of meaning-processing ( $a \geq 4$ ). .

The hyper-incursive equation (Eq. (1)) proposed above for modeling double contingency is quadratic in  $x_{t+1}$  and therefore has two possible roots (Dubois, 1998, 2003):

$$x_t = ax_{t+1}(1 - x_{t+1}) \tag{1}$$

$$x_t = ax_{t+1} - ax_{t+1}^2 \tag{14}$$

$$ax_{t+1}^2 - ax_{t+1} + x_t = 0 \tag{15}$$

$$x_{t+1}^2 - x_{t+1} + x_t/a = 0 \tag{16}$$

$$x_{t+1} = \frac{1}{2} \pm \frac{1}{2} \sqrt{[1 - (4/a) x_t]} \tag{17}$$

This system has no real roots for  $a < 4$ , but it has two solutions for values of  $a > 4$ . (For  $a = 4$ , the two roots are equal:  $x_1 = x_2 = 1/2$ ; see Fig. 3.)

For  $a > 4$ , two expectations are generated at each time-step: one on the basis of the plus and one on the basis of the minus sign in Eq. (17). After  $N$  time-steps,  $2^N$  future states are possible if this system were to operate without historical retention by making decisions. Thus, the system of expectations needs a mechanism for making choices between two options, because otherwise the system would rapidly become overburdened with options. In other words, in due time the communication cannot be further developed without agent(s) able to make choices between options.

### 9.3. Historical organization versus evolutionary self-organization of meanings

In addition to the algorithmic approach, one of us elaborated more

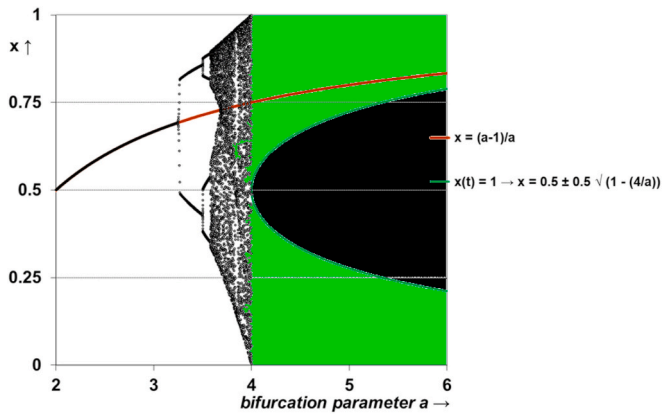


Fig. 3. The system of expectations as a result of hyper-incursion. Source: Leydesdorff and Franse.

recently an information-theoretical perspective on the problem of operationalization and measurement of the dynamics between historical organization (Eq. (5)) and the evolutionary self-organization of meaning (Eq. (4)). Fig. 4a shows two differently coded subsets and Fig. 4b three:

Using Shannon (1948), the two subsets in Fig. 4a can be aggregated as follows:

$$H_{12} = H_1 + H_2 - T_{12} \tag{18}$$

$$T_{12} = H_1 + H_2 - H_{12} \tag{19}$$

$H_1$  and  $H_2$  can be used as labels for the information contents of the two sets with an overlap in  $T_{12}$ , the “mutual information” or “transmission” between  $H_1$  and  $H_2$ . If  $T_{12}$  were not subtracted from  $(H_1 + H_2)$ , the overlap would be counted twice; however, this second time would be redundant. In this case, redundancy  $R_{12}$  is equal to  $-T_{12}$  or, in other words,  $R_{12}$  is negative while the mutual information ( $T_{12}$ ) itself is necessarily positive.

The formula for the entropy of the combined set in three dimensions  $H_{123}$  follows the corrected numbers of elements using summations and subtractions analogously to overlaps among two sets, as follows:

$$H_{123} = H_1 + H_2 + H_3 - T_{12} - T_{13} - T_{23} + T_{123} \tag{20}$$

In Eq. (20), the trilateral overlap  $T_{123}$  would be included three times in  $(H_1 + H_2 + H_3)$  and then subtracted three times as the subsets in the bilateral overlaps ( $-T_{12} - T_{13} - T_{23}$ ). It follows that  $T_{123}$  has to be added once more after the subtractions of the bilateral overlaps. Since  $T_{123}$  is added, while  $T_{12}$  had to be subtracted (in Eq. (19)), the sign of the last term representing the mutual redundancy in three dimensions is opposite to that representing an even number of dimensions:  $R_{12} = -T_{12}$  and  $R_{123} = +T_{123}$ .

By replacing  $T_{12}$  in Eq. (20) with  $(H_1 + H_2 - H_{12})$  on the basis of Eq. (19) above, one can formulate as follows:

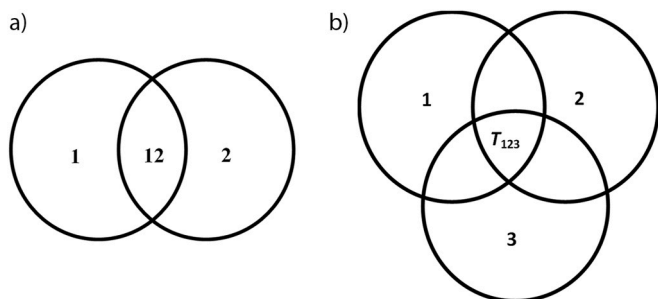


Fig. 4. 4a and 4b: Overlapping uncertainties among two and three variables.

$$H_{123} = H_1 + H_2 + H_3 - (H_1 + H_2 - H_{12}) - (H_1 + H_3 - H_{13}) - (H_2 + H_3 - H_{23}) + T_{123} \tag{21}$$

Or after reorganization of the order of the terms:

$$T_{123} = +H_{123} - H_1 - H_2 - H_3 + (H_1 + H_2 - H_{12}) + (H_1 + H_3 - H_{13}) + (H_2 + H_3 - H_{23}) \tag{22}$$

$$H_{123} = H_1 + H_2 + H_3 - H_{12} - H_{13} - H_{23} + H_{123} \tag{22}$$

$$T_{123} = [H_1 + H_2 + H_3] + H_{123} - [H_{12} + H_{13} + H_{23}] \tag{23}$$

Although this result follows directly from the Shannon equations (e.g., Yeung, 2008, 59f.), the potentially negative value of this indicator also generates a puzzle. Shannon-type information can by definition only be positive—because of Shannon (1948) choice for the  $H$  in the second law of thermodynamics ( $S = k_B * H$ ;  $H = -\sum_1^i p_i * \log_2 p_i$ ).

Because of the potentially negative sign, this indicator cannot be considered a Shannon entropy; it measures feedback from a (hypothesized) future state against the arrow of time (Krippendorff, 2009b).

As a further complication, the indicator changes sign with the dimensionality of the system(s) under study (Krippendorff, 2009a). While synergy is indicated by negative values in the case of three dimensions, it is positive in the case of four, etc. From the perspective of further developing the Triple-Helix model, however, one would like to have an indicator that can be extended to a quadruple, quintuple, or  $n$ -tuple helix in a single framework (Carayannis and Campbell, 2010).

In October 2013, Inga Ivanova solved the first problem of the negative sign in an email conversation: mutual information in three (or more) dimensions can only be negative as redundancy and not as information. In other words, one can extend the Shannon-framework with a theory and perhaps a calculus of redundancy (Leydesdorff, 2018). Whereas redundancy and uncertainty are by definition each other’s complement to the maximum information content of a distribution, adding to the redundancy reduces the relative information or prevailing uncertainty. In my opinion, the generation of redundancy from reflexive interactions among codes provides the selection mechanism that Luhmann, 1990, p. 27) envisaged already at the time of his discussion with Habermas. In the first contingency, the variations interact; in the second, selection mechanisms can also interact.

The second problem of the sign alternating with the dimensionality was solved by Alexander Petersen (see Leydesdorff et al., 2017, pp. 17f.). It follows inductively from the sub-additivity of the entropy that for any given dimension  $n$ , one can formulate combinations of mutual information corresponding to  $\sum_1^n H(x_i) - H(x_1, \dots, x_n)$  that are by definition positive (or zero in the null case of complete independence). For example (up to four dimensions) as follows:

$$0 \leq \sum_{i=1}^{n=2} H(x_i) - H(x_1, x_2) = T_{12}$$

$$0 \leq \sum_{i=1}^{n=3} H(x_i) - H(x_1, x_2, x_3) = \sum_{ij} T_{ij} - T_{123} \tag{24}$$

$$0 \leq \sum_{i=1}^{n=4} H(x_i) - H(x_1, x_2, x_3, x_4) = \sum_{ij} T_{ij} - \sum_{ijk} T_{ijk} + T_{1234}$$

where the sums on the right-hand side are over the  $\binom{n}{k}$  permutations of the indices.

Returning to the relation between  $R_{12}$  and  $T_{12}$ , it follows (using first two dimensions instructively) that:

$$R_{12} = -T_{12}$$

$$= H(x_1, x_2) - \sum_1^2 H(x_i) \leq 0$$



and thus,  $T_{12} \geq 0$ .

In other words, the mutual information is larger than or equal to zero. The relations for  $R_{123}$  and  $R_{1234}$  follow analogously from Eq. (12), and in the general case of more than two dimension ( $n > 2$ ):

$$R_n = (-1)^{1+n} T_{1234\dots n}$$

$$R_n = \left[ H(x_1, \dots, x_n) - \sum_1^n H(x_i) \right]$$

$$+ \left[ \binom{n}{2} T_{ij} - \binom{n}{3} T_{ijk} + \binom{n}{4} T_{ijkl} - \dots + (-1)^{1+n} \binom{n}{ijkl\dots(n-1)} T_{ijkl\dots(n-1)} \right]$$

(25)

The left-bracketed term of Eq. (25)— $[H(x_1, \dots, x_n) - \sum_1^n H(x_i)]$ — is necessarily negative (because of the subadditivity of the entropy; see above), while the configuration of the mutual information relations contributes a second term on the right which can be positive and which indicates change in terms of relations, as against changes in the relations among substructures. This right-hand term represents the entropy generated by the realization of the network relations in historical time.

In summary, Eq. (25) models the generation of redundancy (with a negative sign) on the one side versus the historical process of uncertainty generation in the relations (with a positive sign) on the other. A system with more than two codes (e.g., three alphabets) can operate as such an empirical balance. When the resulting  $R_n$  is negative, self-organization is indicated as prevailing over organization in the configuration(s) under study, whereas a positive  $R_n$  indicates conversely a predominance of historical organization over evolutionary self-organization. The additional options are generated in the *interactions among the codes of communication* at a second-order level different from first-order interactions among the observable communicators generating variations.

## 10. Discussion and concluding remarks

Before the invention of theories of evolution in the nineteenth century, “data” were “given” and studied in “natural philosophy.” From the perspective of evolution theory, data is considered as phenotypical, whereas selection is considered as “natural” in Darwin’s evolution theory. The juxtaposition of market and non-market selection environments in evolutionary economics requires theoretical specification of the selection criteria (Nelson and Winter 1975). In the context of Artificial Life, Langton (1989, at pp. 22f.) stated that “we need to generalize the notions of *genotype* and *phenotype*, so that we may apply them in non-biological situations.”

In his study entitled *Evolutionary Economics: Post-Schumpeterian Contributions*, Andersen (1994) used the implicit answers to the question of “what is evolving?” to assess various models of evolutionary economics and evolutionary game theory. In game-theoretical models, for example, strategies of interaction are evolving (e.g., Axelrod, 1997), whereas in Nelson and Winter (1982) economic models the organizational routines of firms are indicated as evolving. However, Casson (1997) argued that a focus on firm behavior leads to a theory of the firm, but not to the specification of economic evolution. In this context, Boulding told the following anecdote:

My Oxford philosophy tutor, who had the curious habit of crawling under the table while giving his tutorials, commented in a high British voice coming from underneath the table on a paper I had given on evolution, “It is all very well to talk about evolution, Mr. Boulding, but what evolves, what evolves, what evolves?”

Andersen (1994, pp. 188f.) added:

Forty years after this conspicuous form of pedagogics, Boulding had a ‘glimmering’ of an answer: ‘What evolves is something very much like knowledge.’ (*ibid.*) While this answer is undoubtedly correct, it is also radically incomplete in relation to the development of an analysis of economic evolution. Especially, we would like to find an evolving substance which has a much less amorphous character than the commonsense kinds of ‘knowledge.’ To be able to give rise to an evolutionary process, the ‘thing’ we are studying should have an aspect of preservability, mutability, and selectability.

We argued that *the complexity of the communication* is evolving, and not the bounded rationality in the *behavior* of firms or individuals. Agents and their behavior are historical phenomena; they make choices and may thus generate variants. The bounded rationality of their decisions depends on their capacity to learn reflexively and recognize opportunities. However, evolution is taking place in terms of what is genotypical and not in terms of phenotypical variations. At the supra-individual level of society, the selection mechanisms have become knowledge-intensive and therefore increasingly transparent and available for reconstruction. Perhaps, analogical concepts can be formulated for biological evolution, but not being biologists we have to leave this to others.

On the basis of the distinction between historically observable developments and the evolutionary dynamics in the background, one can, for example, distinguish between two Triple-Helix models of university-industry-government relations (Etzkowitz and Leydesdorff, 2000) as in Eqs. (3) and (4), respectively: an entrepreneurial and a neo-evolutionary one. The entrepreneurial model shares with Nelson & Winter’s (1977; 1982) models a focus on institutional arrangements and entrepreneurship. The neo-evolutionary Triple-Helix model of wealth generation in industry, novelty production in academia, and governance focuses on synergies among functions in interactions among communications differentiated both horizontally and vertically. Assumptions about the relationship between innovation and entrepreneurship can then be further considered from an evolutionary perspective.

As against biological code (DNA), the codes in the communication remain language-based. The codes enable us to communicate about what is not-observable. These non-observable carriers of the explanations have a pronounced status in scholarly discourse. Using (human) language one can discuss counterfactuals and absent cases: absences (zeros) can be reported where values larger than zero were expected; zeros may prevail where values were expected. As Popper, 1972, pp. 259f.) put it:

I cannot, of course, hope to convince you of the truth of my thesis that observation comes after expectation or hypothesis. But I do hope that I have been able to show you that there may exist an alternative to the venerable doctrine that knowledge, and especially scientific knowledge, always starts from observation.

In summary, from different backgrounds Popper and Husserl both argued against a logical positivism which insisted on observations and considered non-verifiable statements as “metaphysical.” Pieces of the puzzle of a model of cultural evolution were specified by these philosophers. However, empirical operationalization and measurement were beyond the scope. In our opinion, the subjective (“consciousness”) and the inter-objective (“communication”) were not sufficiently distinguished as shaping different contingencies (Luhmann, 1995 [1984]). This dividing line between the philosophy of science and empirical science and technology studies (STS) can be re-organized from the perspective of communication theory (Leydesdorff, 2021 forthcoming). A calculus of redundancy can perhaps be further developed as a complement to the calculus of information theory.

## Conflicts of interest

There is no conflict of interests.

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