Chapter 11
Summary and Conclusions

Three themes have been central to my research program: (1) the dynamics of science, technology, and innovation; (2) the scientometric operationalization and measurement of these dynamics; and (3) the Triple Helix (TH) of university-industry-government relations. University-industry-government relations provide an institutional infrastructure carrying the potential of self-organization in the knowledge base of an economy. I elaborated these themes into the problem of relating (i) Luhmann's sociological theory about meaning-processing in communications with (ii) information-theoretical operationalizations of the possible synergies in Triple-Helix relations, and (iii) anticipatory mechanisms in cultural evolutions.

11.1 The Sociocybernetics of Scientific Knowledge

How are meaning and information processing related, and how are they re-combined in the shaping and self-organization of discursive knowledge? Whereas knowledge is often attributed to individuals in the history and philosophy of science or, from a sociological perspective, to communities as belief structures, a perspective on the sciences using communications as units of analysis enables us to proceed to measurement. The aggregated citation relations among journals, for example, can be used to visualize disciplinary structures (Chap. 2, Fig. 2.3). The journal network, for example, can be considered as a construct at the supra-individual level structuring the variation. A cognitive structure can be revealed that operates as a selection mechanism on the historical (bottom-up) generation of knowledge claims that feed the publication process. The knowledge claims in articles provide the variation; the cognitive, social, and textual contexts operate as selection environments.

When both variations and selections can operate upon each another and among themselves, one can expect the generation of both information (that is, uncertainty) and redundancy (that is, reduction of uncertainty). The evolutionary dynamics of

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interactions between selection environments are different from interactions among historical agents. The variations generate uncertainty (along the arrow of time). Interactions among selection mechanisms can also reduce uncertainty by generating redundancy (against the arrow of time).

In Chap. 3, I discussed how "heterogeneous networks" have been studied in terms of *practices* and *actor-networks* in the sociology of scientific knowledge and the sociology of translations, respectively. From these perspectives, authors, texts, cognitions (and in the case of the sociology of translation even the objects under study) have been analyzed as symmetrical sources for the construction of techno-scientific artefacts (e.g., Callon, 1986).

In my opinion, scholarly practices are intellectually structured by codes emerging in the communications. The codes operate as selection mechanisms by spanning horizons of meaning as selection environments. Different from the symmetry principle used as a normative yardstick in the constructivist sociologies of science, selections can be expected to generate *asymmetries* between selected and de-selected variations. Cognitive structures thus interact and co-construct the organization of scholars and discourses into research programs, specialties, and disciplines. In other words: the intellectual organization of the sciences adds to and asymmetrically feeds back on the configurations of authors and texts.

In Chap. 4, I proceeded to the operationalization and measurement of the interacting dynamics of communications and meanings using information theory. Shannon's co-author Weaver (1949, p. 8) warned against confusing information and meaning. He distinguished three layers which I further elaborated in a model: (i) at level A, events are sequenced historically along the arrow of time, generating uncertainty; (ii) the incursion of meanings at level B is referential to (iii) horizons of meaning spanned by codes in the communication at level C. I propose to distinguish accordingly: the interactive communication of information at level A, the organization (e.g., sharing) of meanings at level B, and the generation and self-organization of discursive knowledge at level C.

The three levels can be operationalized in a measurement theory, as follows: *relations* (at level A) can be distinguished from *correlations* among patterns of relations and non-relations at level B. The correlations span a vector space on the basis of a network of relations. Relations and relating nodes are positioned in this vector space and can then be provided with meaning. Different positions provide other horizons of meaning spanned by codes in the communication. The codes can interact and overlap (for example, in university-industry-government relations.) Overlapping codes may generate new codes and therefore redundancies—that is, options which are still open for realization. From this (evolutionary) perspective, the realized—that is, historically observable—networks can also be considered as retention mechanisms.

11.2 Synergy in Triple Helix Models

The Triple Helix of university-industry-government relations provides an empirical model combining the *vertical* differentiation among the levels in terms of relations, correlations, and eigenvectors (as operationalizations of the codes) with *horizontal* differentiation among the codes (e.g., markets, technologies, politics, etc., operating in parallel). The institutional TH model focuses on the observable relations among horizontal differentiations in the networks and the neo-evolutionary on interactions among selection mechanisms. The relative weights of the historical and evolutionary dynamics in generating information and redundancy can be measured as a trade-off in empirical configurations. The generation of redundancy in interactions among latent codes is a measure of the additional synergy in configurations of relations; options reduce uncertainty, as in a niche. In a knowledge-based economy, one can exploit this synergy as a source of wealth.

In Chap. 6, regional and national systems of innovations in Italy were analyzed as an empirical example. The Italian systems of innovation are interesting because the Italian economy is both knowledge-based and knowledge-intensive. Using firm-level data collected by Statistics Italy for 2008, 2011, and 2015, synergies among the geographical and size distributions of firms and technology classes can be measured at both national and regional levels. As against the statistical classification into twenty regions, or into Northern, Central, and Southern Italy, the greatest synergy is retrieved by defining the country in terms of Northern and Southern Italy as two sub-systems, with Tuscany included as part of Northern Italy.

Different innovation strategies could be developed for these two parts of the country. The current focus on twenty regions for innovation policies may to some extent be an artefact of EU policies. In terms of sectors, both medium- and high-tech manufacturing (MHTM) and knowledge-intensive services (KIS) are integrated proportionally in the various regions in Italy. In Spain, for example, the knowledge-based sectors are highly concentrated in Madrid and Barcelona as two metropolitan innovation systems (Leydesdorff & Porto-Gomez, 2019).

In Chap. 7, the Triple-Helix synergy indicator was formalized and generalized as a methodology for the measurement of synergy and systemness. A routine for this measurement is made available at https://www.leydesdorff.net/software/synergy.triads. The routine evaluates all possible permutations among three column vectors in terms of their contribution to synergy generation. This enables us to compare configurations in terms of possible synergies. Since the routine is based on the Shannon formula, synergies can be summed (after proper normalization). For example, one can compare two regions in Italy—e.g., Tuscany and Piedmont—in terms of the Triple-Helix dynamics of geographical, technological, and organizational variety (e.g., of firms). One could ask, for example, how much a change in one of these distributions would increase the number of options.

When policy-makers call for "interdisciplinarity," they often mean "synergy." In collaborations with third parties, however, "interdisciplinarity" can also be considered a means for creating "synergy. Synergy is generated when the whole offers more possibilities than the sum of its parts. I discuss recent advances in the operationalization and measurement of "interdisciplinarity" and propose a methodology for measuring "synergy." An increase in the number of options above the sum of the options in subsets can be measured as redundancy, that is, the number of not-yet-realized options. Increasing redundancy reduces the relative uncertainty. The operationalization of the two concepts—"interdisciplinarity" and "synergy"—as different outcome indicators enables us to distinguish between the effects and the effectiveness of interventions in research priorities.

11.3 Anticipatory Dynamics and Simulations

Knowledge bases can drive the transformation in the present from the perspective of expected states. In Chaps. 8 and 9, I analyze the *feedback* of an emerging communication dynamic as a local inversion of the arrow of time in terms of the theory and computation of anticipatory systems. Using a set of recursive, incursive, and hyper-incursive equations derived in Chap. 8, I specify *six* subdynamics of anticipation operating in the second contingency of knowledge-based systems in Chap. 9: (i) three coordination mechanisms among expectations at different levels of aggregation (interactions, the organization of meaning, and self-organization), and (ii) three further equations that operationalize "double contingency," "identity," and "reflection," respectively.

These subdynamics update one another dynamically in co-evolutions of historical recursions and anticipatory incursions. In this complex dynamics, vertical and horizontal differentiations can be expected to generate time differences (Δt) at interfaces. Interactions among time differences in horizontal and vertical *incursions* can be multiplied and generate hyper-incursivity. Hyper-incursion drives the layer of rationalized expectations. The social system of communications is unique in its ability to build on interactions among meanings in the second contingency.

11.4 Against Monism

In an epilogue (Chap. 10), I discuss, among other things, the differences between the dualistic sociology of science and the monistic program claiming a research perspective for a meta-science based on "big data." Both "big data" and "monism"—the program of reducing cultural and mental processes to computational and biological principles—reject a dualism between a physical and biological reality (*res extensa*) and our knowledge of this reality (*res cogitans*). However, I have argued throughout this study that on top of the manifest relations, a second contingency of possible relations and expectations can be envisaged. This second contingency is the proper domain of the social sciences, where the focus is on what things *mean* and how these appreciations can change. In other words, I have argued against monism and historicism.

In my opinion, a major contribution of this study is the focus on redundancy as a measure of the number of cases that could have occurred or the meanings that could have been provided. The possible meanings refer to "horizons of meaning." These horizons are contingent (for example) upon positions and perspectives. However, the second contingency operates differently from the first contingency, with a minus sign. A complication is the time factor; the linear arrow of time accords with the entropy law in thermodynamics, and thus with Shannon's probabilistic entropy. However, the *possible* states of a system cannot be learned from its history because a system's history is by definition only its genesis in a lower dimensionality. If one wishes to envisage the range of possibilities, one first has to specify expectations. In most boxes one finds a zero, indicating redundancy.

Furthermore, this study contributes to the construction of a relation between social theory, on the one hand, and the specification of a measurement theory in terms of information, redundancy, and meaning, on the other. The relations between these discourses have hitherto been scarce. In artificial intelligence, the main focus has been on relating biology and psychology at the level of individuals and with the purpose of explaining agency. Agency can be observed as behavior (of, for example, persons, institutions, or principal agents). Behavior provides us with a point of entrance to study individual intentions. However, the relations between science, technology, and society are structural at the above-individual level. Structures can be expected to operate as selection mechanisms on both variation (e.g., actions) and on interactions among differently coded structures (e.g., co-evolutions, Triple- and Quadruple-Helix models, etc.). Since one can no longer expect a single ("natural") selection, the interactions among selection mechanisms can also become sources of variation in a complex dynamic.

At the level of above-individual expectations, selection mechanisms can also be considered as coordination mechanisms. Codes can be expected to emerge in the communications when selections operate on other selections or previous selections, Selections which operate on selections, may lead to stabilization and also globalization. Codes provide meta-stable selection criteria which operate in parallel. In addition to a horizontal differentiation in terms of codes, structures are differentiated vertically in layers (e.g., information, meaning, and knowledge). Organization is a specific function and a layer, and thus links the vertical and horizontal differentiations.

Simon (1973, pp. 19f.) hypothesized that there might be an alphabet of possible codes. For example, other dimensions of the communication are backgrounded when we focus in scholarly discourse on substantive issues or in policy-making on choices. The routines can be interrupted by otherwise coded communications. The interruptions disturb system-building and thus shape a "fractal manifold" (Ivanova & Leydesdorff, 2014). In sum, one expects neither Triple nor Quadruple helices of co-evolutions (Carayannis & Campbell, 2009), but one can expect fractals and fragments; for example, a dimensionality of 3.1. In this domain of incompleteness, the derivatives from the Latin verb *esse* ("to be," "exist," and "ontology") are superseded by derivatives of *frangere* such as "fractal," "fragment," "fragile."

Add to the dynamics of the second and first contingencies—and their interactions—the possibility to invert the time-axis to different degrees in each receiving systems. Meanings incur on events against the arrow of time, and interactions among incursions can induce hyper-incursive operations (Chaps. 7 and 8). For example, expectations organized in models enable us to add new dimensions to the communication. Whereas agency constructs piecemeal, along historical trajectories, the social can be expected to self-organize and hyper-incursively reconstruct virtual structures of expectations.

The codes emerge over time in a morphogenesis, but when sufficiently populated, the next-order can take over control *because it is based on selections.* These asymmetrical transformations of contents between the level of incursive individuals and hyper-incursive expectations show the operation of communications as mediating structures with the potential of control. Measurement is needed for the specification of the extent to which organization or self-organization prevail.

I have used the three, in my opinion, most relevant theories for addressing these dynamics at the supra-individual level: Luhmann's sociology, Shannon's information theory, and Rosen's and Dubois's theory of anticipatory systems. These theories enabled me to approach the problems from different angles. However, the objectives of these theories are very different: information theory is operational and provides primarily a measurement theory (Theil, 1972); Luhmann's (1997a, 1997b, 1984, 1995, 2012) sociology has remained theoretical and sometimes even speculative. In my opinion, the latter has been hitherto the most systematic effort to remain at the level of a *second-order* cybernetics of communication while specifying a sociological dynamics; Rosen's (1985) theory and Dubois' (1998) computation of anticipatory mechanism are expressed in algorithms that can be simulated.

I submit that only the social system can be hyper-incursive—that is, without historicity, since operating hyper-incursively from the perspective of the future. In the computation of anticipatory systems (CASYS), one may therefore need this focus on the social as a unique example of strong anticipation. A research program can here be envisaged.

The objective of this study has been to make the three perspectives of communication theory, information theory, and socio-cybernetics relevant for one another. Reading these sociological and computational theories together can broaden the scope for each of them. The focus shifts from explaining what "is" to what "might be" or "could have been"; that is, from information to redundancy. However, the surplus of combining these approaches is first analytical; the focus is on the specification of expectations. The purpose is to provide suggestions for further research. These theories had not yet been brought together with a perspective on further research—operationalization and measurement—because of their very different theoretical backgrounds and respective semantics.

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