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Giovanni Sommaruga (ed): Formal Theories of Information: From Shannon to Semantic Information Theory and General Concepts of Information

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A unifying theory of information is a constantly returning theme for the sciences of the information age. The starting problem of this volume is the quest for a notion of information flexible enough to be used by each discipline and general as to satisfy the unique requirement of each individual science. "No theory can fulfil these two requirements other than a formal (mathematical) theory of information" (Sommaruga, Introduction, p. 3). Reflecting Weaver's (1949) famous tripartite definition, the volume starts with a philosophical analysis (Floridi), then explores a significant range of syntactical (Bavaus, Calude), semantical (Kohlas and Schneuwly, Kohlas and Eichenberger, van Rooij, Seligman) and pragmatical (Devlin) approaches, aiming at a non-elusive philosophy of the information sciences. To us, this comprehensive collection offers the opportunity of reconsidering some of the recurrent themes in this area, with the restricted objective of finding a few of the items that might shape the future research agenda.

A general notion of information, "notoriously a polymorphic phenomenon and a polysemantic concept … associated with several explanations, depending on the level of abstraction … requirements and desiderata" (Floridi, p. 13), starts certainly from a Shannonian description of well-structured data neutral with respect to typology, support and origin (Floridi, subsecs. 2.4–2.7). Such an account, eventually revisited as in Bavaus' contribution from a statistical inferential perspective, leads to the additional take on semantic content. When this happens, information comes in two varieties: factual and functional. The basic disagreement with respect to veridicality for semantic information can be explained reconsidering this distinction: on the one hand, information is crucially different from knowledge precisely because only the latter qualifies as true; on the other hand, semantic information needs to add truthfulness to meaningful data, otherwise can be at most qualified as

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misinformation (Floridi, subsec. 4.2.3). The misunderstanding arises precisely when the distinction between factual and functional information is neglected. Whereas logical model-theoretic approaches can only deal with the factual format, in many distinct contexts—and especially in computer science—information comes in a functional vest, expressing sets of conditions on epistemic states: information is what needs to be known (executed), in order to acquire (perform) certain knowledge (programs). This notion of functional information requires ascription of truth rather than truthfulness. This allows us to analyze a number of aspects of epistemic functional theories of information.

Let us consider the relation between information and truth as the computational problem of informational gain (Calude, sec. 4), an algorithmic version of the 'scandal of deduction'. Interpreted in terms of Turing computability, "to create information means to start with an input x and produce an output y which has more information than x" (Calude, p. 85). If this is provably impossible, then one can still ask *how much* information can we gain in computation. Not much either, as there is a (Gödelian) bound for any finitely-specified, arithmetically sound, consistent theory strong enough to formalize arithmetic. It is interesting that incompleteness via Chaitin's theorem (every Gödelian theory cannot determine more than a finite number of bits in the list $\omega_1, \omega_2, \ldots, \omega_n, \ldots$) relates to algorithmical randomness in the total information of a system. To establish how much of this uncertainty is effective, one needs a user-oriented epistemic perspective.

The issue of uncertain information is therefore crucial. A methodology for computing uncertainty is possible by approximating infinite by finite information in an algebraic approach (Kohlas, Schneuwly and Kohlas, Eichenberger), where pieces of information refer to precise questions and can be combined to refer to other questions. Uncertainty arises when "information is known to be valid under certain assumptions, but it is not altogether sure that these assumptions really hold" (Kohlas, Eichenberger, p. 128), which leads us back to the basic issue of truth vs. ascriptions of truth, in terms of an analysis of the logical role of assumptions. In the algebraic framework, the degree of support of a piece of information can be measured in terms of the degree of probability of those assumptions with respect to that piece of information and in interaction with consequences: "The degree of support of [hypothesis] H is the probability of the assumptions that are capable of proving H. Such assumptions are called arguments for the validity of H" (p. 134). This problem, which has a clear connection with argumentation systems for propositional languages, with non-monotonic reasoning, creativity and information gain, is therefore approached as the relation in an erotetic model between a question (parameter) and an answer (data): it uses a *hint* as a mapping of an assumption to the smallest set of possible answers to a given question containing the right answer. It is not just a coincidence that in a constructive user-based logic, assumptions are the bearers of functional information and that the erotetic model finds more than one implementation in the context of defining information. This stresses the need for a dynamic framework to define both functional and factual information.

The dynamics of *relevant* questions and answers is taken over in van Rooij's article: "[W]e might say that with respect to a certain question, an assertion is relevant if it is (i) consistent, (ii) informative, and (iii) is about the question. …

[A]ny contingent proposition satisfies the first two constraints … But some … are irrelevant because they are already entailed by, or inconsistent with, what is already believed by the participants of the conversation." (p. 167). To understand the notion of relevance, the relativization to information states of the agents involved and to *other questions* becomes essential: the informational value of an answer q to question B is the reduction of entropy of B upon learning q, and the informational value of question Q with respect to question B is the average reduction of entropy of B upon learning an answer to Q. But "suppose that we need not to know how exactly the world looks like, but rather just want to find out which of the mutually exclusive and exhaustive set of hypotheses H … is true" (p. 177): uncertainty affects the way we determine the informational value of Q by determining the validity of H. The problem of a purely quantitative approach with respect to entropy is that a question might still be relevant, even if not reducing the hypothesis space. Determination of the expected utility of a question from statistical decision theory is a step forward in the jungle of semantic information when deciding *which* question should be asked, with a perspective in an embedding into general game theory.

The assumption that information arises in conditions of uncertainty is also at the basis of Seligman's contribution. It embeds the standard frame of situation semantics in the Barwise-Seligman account of information flow using structures called 'classifications', maps between classifications called 'infomorphisms' and combinations of infomorphisms called 'channels'. The contextual and modal flavour of agent-based information processing are at stake: "Whereas actual events are expected to respect logical or probabilistic constraints between types, they cannot be used to define them if … there are unactualised possibilities. I'll call this the Modality Problem. … [I]nformation flow in concrete event channels depends on conditions being just right. … But actual events can violate these presuppositions. … I'll call this the Context Problem." (p. 207). Regularities among types in the core of a channel are obtained via the formal notion of *link*, which serves Tarski theories for entailment, Dretske theories for probability space and Gentzen theories as a generalization of the previous two (Theorem 3.3., p. 211). From this framework, three major consequences are derived: "Firstly, the linking relation … deems that what is logically necessary or already known is not information. … Secondly, [it] provide[s] an umbrella for different ways of deriving the linking relation …. And lastly, the account of information flow in [Barwise and Seligman's system] has a quite different view of what happens when information flows." (p. 224). In particular, flowing information comes in different varieties: its generalization considers appropriately defined normal tokens under constraints (Definition 6.1, p. 224). Here completeness corresponds to satisfaction of all constraints in the theory by the normal tokens, and soundness corresponds to normality of every token in the theory. Partiality of these properties leads to an ordering relation on local logics that allows them to move "from one classification to an equivalent logic in the other classification" (p. 226) in order to provide a more coherent model of information flow in concrete channels.

Uncertainty and constraints dependence are thus at least two of the major problems that information sciences are dealing with. Devlin's contribution faces them by designing a mathematical model for real-life logical reasoning. He

maintains that reasoning is information gathering and processing: "[R]eal-life reasoning is … about marshalling evidence to arrive at a conclusion. … [For this, one] must keep track of the sources of all the evidence used, the nature and reliability of those sources, and the reliability of the reasoning steps used in the process" (p. 235). Hence, context-dependency, non-linearity, dynamic source selection, data-incompleteness, hypothesis check, conflicting information, back-tracking, background tacit knowledge and trusting relations are all fundamental properties to be described in determining aspects of the notion of information. Devlin's thesis is that our need for a precise, representation-free definition of information requires us to focus on the regularities whereby things in the world represent information: reformulating typological neutrality and abstracting from the channel-like structure, he argues in favour of situation theory (sec. 3). Its representational means focus on the contextual nature of a situation to provide support for a fact or statement on the basis of evidential reasoning elements: "[A] basic evidential reasoning step consists of the application of the logical operator to one or more constituents of the evidential reasoning elements. … An evidential reasoning process is a finite sequence … of basic reasoning steps such that each element is either evidential (i.e., an input to the reasoning process) or else the output of some previous (in the sequence) evidential reasoning step, or else … is the final element in the process" (p. 244). The representation of evidence in the information processing is certainly an effective move that mimics similar process-based descriptions, e.g. in epistemic logics, allowing a description of reasoning rules associated with operations such as making choices, retracting back to previous sources, expanding data, breaking tasks and the like: "Above all, our framework makes it clear that reasoning involves three components: facts, sources, and indicators. Real-life reasoning typically involves all three" (p. 251).

It seems that the search for a unifying notion of information is today a less urgent problem: each language and model preserves its peculiarities, its advantages and scope, possibly lost in a unified framework. To put it in the editor's words: "An examination of the possibility to make out a reductionist approach in the theoretical study of information yields a negative result: There is no such reductionist way. Thus, the answer to the initial question (**Q**) [How many informal theoretical concepts of information are there?] is: several. The answer to question ($\mathbf{Q}^*$) [How many formal theoretical concepts of information are there?] is: at least several" (p. 264). But, as this collection shows, there is certainly a unified need for understanding what makes information a central notion at the syntactic, semantic and pragmatic levels. In other words, what makes information the basis of both processes and situations? The new struggle of both quantitative and logical models of information is finding the linking step between the abstract description of factual information and the semantical, intentional, contextual nature of functional information, where agency is the common trait to all theories and information is the content of directed processing.