Information in Biological Systems
Outline

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Introduction

The notion of information has developed in a number of different ways (as discussed in this volume), and many of them have been applied to biology, both usefully and gratuitously, and even misleadingly. These multiple notions of information have, not surprisingly, led to apparently contradictory claims by authors who have really been talking past each other, although there are also substantive issues at stake. The aim of this chapter is to review some of the ways that notions of information have been used in biology, to disentangle them, and to evaluate their implications and aptness, as well as to point out some of the more widespread confusions. In particular, I will compare the use of information as a technology of measurement, which does not imply that there is anything present that might be called 'information', with a stronger usage of information in biology that attributes information to biological systems in a non-instrumental way. This distinction between instrumental and substantive uses of information in biological studies often turns on the notion of information used, so it is important in each case to be clear what is at stake. It will be impossible to cover all the varied uses of information concepts by biologists, so I will look primarily at cases that seem to be historically significant or else philosophically pivotal (the two often correspond). I will not discuss what falls under the general heading of *bioinformatics* in this chapter, since I do not think that any special issues of philosophical interest are raised by biological systems, and the general topic is dealt with elsewhere in this volume [xx].

Information as a tool

DNA
Macromolecules, transcription, communication (Yates, Marijuan, Holzmüller, Yagil)
Cells (Maturana, Rosen)
Ecology (Ulanowicz)

Information storage and processing

Necessity of information storage to life (Gatlin, Barbieri, Rosen, Dubois)

Storage (Gatlin, Barbieri, Brooks and Wiley, Ulanowicz, Maynard Smith and Szathmàry)
Transmission (genetics, developmental systems, molecular signaling)
Information as a constraint (Shannon, MacLaurin)
Why information?

Information in hierarchies
An old problem, biology as a focal case (MacKay, Pattee)
Syntactic, physical (Shannon, Brillouin, Holzmüller, Layzer, Küppers, Ménant)
Extension of statistical mechanics (Smith, Brooks and Wiley, Kauffman, Collier)
Function and meaning (list problems)

Codes
What is a code? (Shannon, Barbieri)
Is the code concept required in biology? (Barbieri, Collier – physical information system, mechanism)

Information and meaning
Function (etiological versus autonomy views)
Representation (external versus internal perspectives, error, compare with signaling)
Recognition
Syntax, semantics and pragmatics (Küppers, Ménant)

Communication
Channels
Function
Closure

Representation and intentionality in biology
Immune system (Matthen, Levy)
Does DNA represent?
Molecular communication
Ecology and behaviour (Lorenz, Brooks and MacLennan)

Biosemiotics (Uexkull, Hoffmeyer, Emmeche, Sharov)

Closure

Autopoiesis (Maturana and Varela)
Functional closure (Rosen)
Closure to information
Biosemiotics
The significance of closure

Summary and conclusions

Partial Bibliography

Atlan, H. 1972. L'organisation biologique et la théorie de l'information. Herman, Paris.

Barwise, Jon and Jerry Seligman, 1997. *Information Flow: The Logic of Distributed Systems*. Cambridge: University of Cambridge Press.

Bateson, G. 1973. *Steps to an Ecology of Mind*. London: Paladin.

Brillouin, L. 1962. *Science and Information Theory, 2nd edition*. New York: Academic Press.

Brooks, D.R. 2000. The nature of the organism: life takes on a life of its own. *Proceedings of the New York Academy of Science*. **901**: 257-265.

Brooks, D.R. 2001. Evolution in the Information Age: Rediscovering the nature of the organism. *Semiotics, Energy, Evolution and Development*. [xx] http:// www.library.utoronto.ca/see

Brooks, D.R. 2002. Taking evolutionary transitions seriously. *Semiotics, Energy, Evolution and Development.* **2**, 21 pp. http://www.library.utoronto.ca/see

Brooks, Daniel R., J.D. Collier, B.A. Maurer, J.D.H. Smith and Edward O. Wiley. 1989. Entropy and information in biological systems. *Biology and Philosophy* **4**: 407-432.

Brooks, D.R. and D.A. McLennan. 1997. Biological signals as material phenomena. *Rev. pensee d'aujord d'hui* 25. pp. 118-127.

Brooks, D.R. and D.A. McLennan. 1999. The nature of the organism and the emergence of selection processes and biological signals. In E. Taborsky, ed. *Semiosis, Evolution, Energy: Towards a Reconceptualization of the Sign*. Aachen Shaker Verlag, Bochum Publications in Semiotics New Series. Vol. 3. 185-218.

Brooks, D.R. and E.O. Wiley. 1988. *Evolution as Entropy: Toward a Unified Theory of Biology, 2nd edition*. Chicago: University of Chicago Press.

Chaitin, Gregory J. 1987. *Algorithmic Information Theory*. Cambridge: Cambridge University Press.

Collier, John D. 1990a. Intrinsic information. In Philip Hanson (ed) *Information, Language and Cognition: Vancouver Studies in Cognitive Science, Vol. 1*. Oxford: Oxford University Press: 390-409.

Collier, John D. 1990b. Two faces of Maxwell's demon reveal the nature of irreversibility. *Studies in the History and Philosophy of Science* **21**: 257-268.

Collier, John. 1998. Information increase in biological systems: How does adaptation fit? In Gertrudis van der Vijver, Stanley N. Salthe and Manuela Delpos (eds) *Evolutionary Systems*. Dordrecht, Kluwer. pp. 129-140.

Collier, John D. 2003. Hierarchical dynamical information systems with a focus on biology. *Entropy,* **5**: 100-124.

Collier, John D. and C.A. Hooker. 1999. Complexly Organised Dynamical Systems. *Open Systems and Information Dynamics*, **6**: 241-302.

Gatlin, L.L. 1972. *Information Theory and the Living System*, New York: Columbia University Press.

Holzmüller, Werner. 1984. *Information in Biological Systems: The Role of Macromolecules*, translated by Manfred Hecker. Cambridge: Cambridge University Press.

Kolmogorov, A.N. 1965. Three Approaches to the Quantitative Definition of Information. *Problems of Information Transmission* **1**: 1-7.

Küppers, Bernd-Olaf. 1990. *Information and the Origin of Life*. Cambridge: MIT Press.

Layzer, David. 1990. *Cosmogenesis: the Growth of Order in the Universe*. New York: Oxford University Press.

MacKay, Donald M. 1969. *Information, Mechanism and Meaning*. Cambridge, MA: MIT Press.

Maturana, Humberto R. and Francisco J. Varela. 1980. *Autopoiesis and Cognition*. Dordrecht: Reidel.

Maynard Smith, J. and E. Szathmàry. 1995. *The Major Transitions in Evolution*. Oxford: W.H. Freeman Spektrum.

Rissanen, Jorma. 1989. *Stochastic Complexity in Statistical Inquiry*. Teaneck, NJ: World Scientific.

Rosen, R. 1991. *Life Itself*. New York: Columbia University Press.

Salthe, S.N. 1985. *Evolving Hierarchical Systems*. New York: Columbia University Press.

Salthe, S.N. 1993. *Development and Evolution: Complexity and Change in Biology*. Cambridge, MA: MIT Press.

Schneider, Eric and J.J. Kay. 1994. Life as a Manifestation of the Second Law of Thermodynamics. *Mathematical and Computer Modeling*. **19**, No. 6-8, 25-48.

Schrödinger, Irwin. 1944. *What is Life?* Reprinted in *What is Life? And Mind and Matter*. Cambridge: Cambridge University Press.

Shannon, C.E. and Weaver, W. 1949. *The Mathematical Theory of Communication*. Urbana: University of Illinois Press.

Ulanowicz, R.E. 1997. *Ecology, the Ascendant Perspective*. New York: Columbia University Press.

Wallace, C.S. and P.R. Freeman 1987. Estimation and Inference by Compact Coding. *Journal of the Royal Statistical Society, Series B, Methodology* **49**: 240-265.

Weber, Bruce, David Depew, and James D. Smith (eds.) 1988. *Information, Entropy and Evolution*. Cambridge, MA: MIT Press.

Weber, Bruce, David J. Depew, Chuck Dyke, Stanley N. Salthe, Eric D. Schneider, Robert E. Ulanowicz and Jeffrey S. Wicken. 1989. Evolution in thermodynamic perspective: an ecological approach. *Biology and Philosophy* **4**: 373-406.

Wicken, Jeffrey S. 1987. *Evolution, Thermodynamics and Information: Extending the Darwinian Paradigm*. New York: Oxford University Press.

Wolfram, Stephen. 2002. *A New Kind of Science*. Wolfram Media.

Yagil, Gad. 1993a. Complexity analysis of a protein molecule, in J. Demongeot, and V. Capesso (eds) *Mathematics Applied to Biology and Medicine*. Winnipeg: Wuerz Publishing: 305-313.

Yagil, Gad. 1993b. On the structural complexity of templated systems, in L. Nadel and D. Stein (eds) 1992 Lectures in Complex Systems. Reading, MA: Addison-Wesley.

Yagil, Gad. 1995. Complexity analysis of a self-oganizing vs. a template-directed system, in F. Moran, A. Moreno, J.J. Morleo, and P. Chacón (eds.) *Advances in Artificial Life*. New York: Springer: 179-187.