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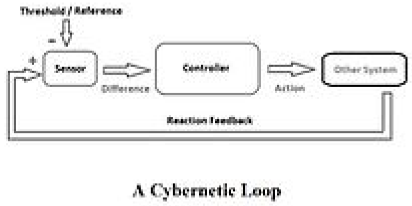
Cybernetics

Cybernetics is a transdisciplinary[1] approach for exploring regulatory and purposive systems—their structures, constraints, and possibilities. The core concept of the discipline is circular causality or feedback—that is, where the outcomes of actions are taken as inputs for further action. Cybernetics is concerned with such processes however they are embodied,[2] including in environmental, technological, biological, cognitive, and social systems, and in the context of practical activities such as designing, learning, managing, and conversation.



Principle diagram of a cybernetic system with a feedback loop

Cybernetics has its origins in the intersection of the fields of control systems, electrical network theory, mechanical engineering, logic modeling, fuzzy logic, evolutionary biology, neuroscience, anthropology, and psychology in the 1940s, often attributed to the Macy Conferences. Since then, cybernetics has become even broader in scope to include work in domains such as design,[3] family therapy, management and organisation, pedagogy, sociology, and the creative arts.[4] At the same time, questions arising from circular causality have been explored in relation to the philosophy of science, ethics, and constructivist approaches. Contemporary cybernetics thus varies widely in scope and focus, with cyberneticians variously adopting and combining technical, scientific, philosophical, creative, and critical approaches.

Contents

Overview

The essential goal of the broad field of cybernetics is to understand and define the functions and processes of systems that have goals and that participate in circular, causal chains that move from action to sensing to comparison with the desired goal, and again to action. Its focus is how anything (digital, mechanical or biological) processes information, reacts to information, and changes or can be changed to better accomplish the first two tasks.[5] Cybernetics includes the study of feedback, black boxes and derived concepts such as communication and control in living organisms, machines and organizations including self-organization.

Concepts studied by cyberneticists include, but are not limited to: learning, cognition, adaptation, social control, emergence, convergence, communication, efficiency, efficacy, and connectivity. In cybernetics these concepts (otherwise already objects of study in other disciplines such as biology and engineering) are abstracted from the context of the specific organism or device.

Studies in cybernetics provide a means for examining the design and function of any system, including social systems such as business management and organizational learning, including for the purpose of making them more efficient and effective. Fields of study which have influenced or been influenced by cybernetics include game theory, system theory (a mathematical counterpart to cybernetics), perceptual control theory, sociology, psychology (especially neuropsychology, behavioral psychology, cognitive psychology), psychoanalysis, philosophy, architecture, and organizational theory.[6] System dynamics, originated with applications of electrical engineering control theory to other kinds of simulation models (especially business systems) by Jay Forrester at MIT in the 1950s, is a related field.

Definitions

Cybernetics has been defined in a variety of ways, by a variety of people, from a variety of disciplines.

One of the most well known definitions is that of Norbert Wiener who characterised cybernetics as "the scientific study of control and communication in the animal and the machine".[7]

Another early definition is that of the Macy cybernetics conferences, where cybernetics was understood as the study of "circular causal and feedback mechanisms in biological and social systems".[8]

Cybernetician Stuart Umpleby reports some notable definitions:[9]

- "Science concerned with the study of systems of any nature which are capable of receiving, storing and processing information so as to use it for control."—A. N. Kolmogorov
- "'The art of steersmanship': deals with all forms of behavior in so far as they are regular, or determinate, or reproducible: stands to the real machine -- electronic, mechanical, neural, or

economic -- much as geometry stands to real object in our terrestrial space; offers a method for the scientific treatment of the system in which complexity is outstanding and too important to be ignored."—W. Ross Ashby

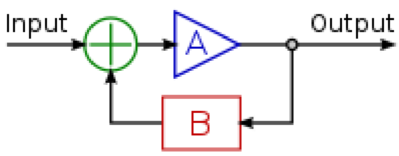
- "A branch of mathematics dealing with problems of control, recursiveness, and information, focuses on forms and the patterns that connect."—Gregory Bateson
- "The art of securing efficient operation [lit.: the art of effective action]."—Louis Couffignal[10][11]
- "The art of effective organization."—Stafford Beer
- "The art and science of manipulating defensible metaphors" (with relevance to constructivist epistemology. The author later extended the definition to include information flows "in all media", from stars to brains.)—Gordon Pask
- "The art of creating equilibrium in a world of constraints and possibilities."—Ernst von Glasersfeld
- "The science and art of understanding." – Humberto Maturana
- "The ability to cure all temporary truth of eternal triteness."—Herbert Brun

Other notable definitions include:

- "The science and art of the understanding of understanding."—Rodney E. Donaldson, the first president of the American Society for Cybernetics
- "A way of thinking about ways of thinking of which it is one."—Larry Richards
- "The art of interaction in dynamic networks."—Roy Ascott
- "The study of systems and processes that interact with themselves and produce themselves from themselves."—Louis Kauffman, President of the American Society for Cybernetics[12]
- "The science of design, purposeful activity, and accomplishment."—Angus Jenkinson, Secretary of the Cybernetics Society[13]
- "Cybernetics is a universal science of accomplishment, purposeful activity, design, and reflexive control. It explains manifold phenomena and aids the design and use of technologies and practice related to them."–Cybernetics Society[14]

Cybernetics evolved in ways that distinguish first-order cybernetics (about observed systems) from second-order cybernetics (about observing systems).[15] More recently there is talk about a third-order cybernetics (doing in ways that embraces first and second-order), being closely related to the autopoietic perspective, radical constructivism, or, more recently, to enactivism.[16]

Etymology



Simple feedback model. AB < 0 for negative feedback.

The word *cybernetics* comes from Greek κυβερνητική (*kybernētikḗ*), meaning "governance", i.e., all that are pertinent to κυβερνάω (*kybernáō*), the latter meaning "to steer, navigate or govern", hence κυβέρνησις (*kybérnēsis*), meaning "government", is the government while κυβερνήτης (*kybernḗtēs*) is the governor, pilot, or "helmsperson" of the "ship".

French physicist and mathematician André-Marie Ampère first coined the word "cybernetique" in his 1834 essay *Essai sur la philosophie des sciences* to describe the science of civil government.[17] The term was used by Norbert Wiener, in his book *Cybernetics*, to define the study of control and communication in the animal and the machine. In the book, he states: "Although the term *cybernetics* does not date further back than the summer of 1947, we shall find it convenient to use in referring to earlier epochs of the development of the field."[7]

History

Pre 20th Century

The word *cybernetics* was first used in the context of "the study of self-governance" by Plato in Republic [18] and in *Alcibiades* to signify the governance of people.[19] The word 'cybernétique' was also used in 1834 by the physicist André-Marie Ampère (1775–1836) to denote the sciences of government in his classification system of human knowledge.

James Watt

The first artificial automatic regulatory system was a water clock, invented by the mechanician Ktesibios; based on a tank which poured water into a reservoir before using it to run the mechanism, it used a cone-shaped float to monitor the level of the water in its reservoir and adjust the rate of flow of the water accordingly to maintain a constant level of water in the reservoir. This was the first artificial truly automatic self-regulatory device that required no outside intervention between the feedback and the controls of the mechanism. Although they considered this part of engineering (the use of the term *cybernetics* is much posterior), Ktesibios and others such as Heron and Su Song are considered to be some of the first to study cybernetic principles.

The study of *teleological mechanisms* (from the Greek τέλος or *télos* for *end*, *goal*, or *purpose*) in machines with *corrective feedback* dates from as far back as the late 18th century when James Watt's steam engine was equipped with a governor (1775–1800), a centrifugal feedback valve for controlling the speed of the engine. Alfred Russel Wallace identified this as the principle of evolution in his famous 1858 paper.[20] In 1868 James Clerk Maxwell published a theoretical article on governors, one of the first to discuss and refine the principles of self-regulating devices. Jakob von Uexküll applied the feedback mechanism via his model of functional cycle (*Funktionskreis*) in order to explain animal behaviour and the origins of meaning in general.

Early 20th century

Contemporary cybernetics began as an interdisciplinary study connecting the fields of control systems, electrical network theory, mechanical engineering, logic modeling, evolutionary biology and neuroscience in the 1940s; the ideas are also related to the biological work of Ludwig von Bertalanffy in General Systems Theory. Electronic control systems originated with the 1927 work of Bell Telephone Laboratories engineer Harold S. Black on using negative feedback to control amplifiers.

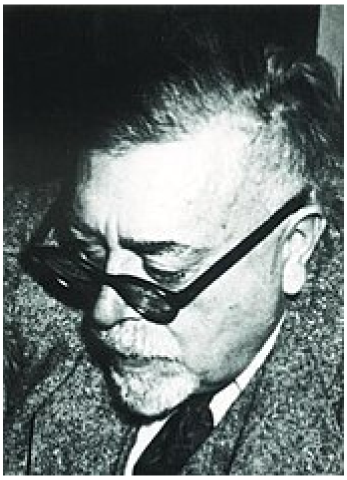
Early applications of negative feedback in electronic circuits included the feedback amplifier and the control of gun mounts and radar antenna during World War II. The founder of System Dynamics, Jay Forrester, worked with Gordon S. Brown during WWII as a graduate student at the Servomechanisms Laboratory at MIT to develop electronic control systems for the U.S. Navy. Forrester later applied these ideas to social organizations, such as corporations and cities, and he became an original organizer of the MIT School of Industrial Management at the MIT Sloan School of Management.

W. Edwards Deming, the Total Quality Management guru for whom Japan named its top post-WWII industrial prize, was an intern at Bell Telephone Labs in 1927 and may have been influenced by network theory; Deming made "Understanding Systems" one of the four pillars of what he described as "Profound Knowledge" in his book *The New Economics*.

Numerous papers spearheaded the coalescing of the field. In 1935 Russian physiologist P. K. Anokhin published a book in which the concept of feedback ("back afferentation") was studied. The study and mathematical modelling of regulatory processes became a continuing research effort and two key articles were published in 1943: "Behavior, Purpose and Teleology" by Arturo Rosenblueth, Norbert Wiener, and Julian Bigelow –based on the research on living organisms that Arturo Rosenblueth did in Mexico–; and the paper "A Logical Calculus of the Ideas Immanent in Nervous Activity" by Warren McCulloch and Walter Pitts.

In 1936, Ștefan Odobleja published "Phonoscopy and the clinical semiotics". In 1937, he participated in the IX International Congress of Military Medicine with "Demonstration de phonoscopie"; in the paper he disseminated a prospectus announcing his future work, "Psychologie consonantiste", the most important of his writings, where he lays the theoretical foundations of generalized cybernetics. The book, published in Paris by *Librairie Maloine* (vol. I in 1938 and vol. II in 1939), contains almost 900 pages and includes 300 figures in the text. The author wrote at the time that "this book is ... a table of contents, an index or a dictionary of psychology, [for] a ... great Treatise of Psychology that should contain 20–30 volumes". Due to the beginning of World War II, the publication went unnoticed (the first Romanian edition of this work did not appear until 1982).

Cybernetics as a discipline was firmly established by Norbert Wiener, McCulloch, Arturo Rosenblueth and others, such as W. Ross Ashby, mathematician Alan Turing, and W. Grey Walter. In the spring of 1947, Wiener was invited to a congress on harmonic analysis, held in Nancy (France was an important geographical locus of early cybernetics together with the US and UK); the event was organized by the Bourbaki and mathematician Szolem Mandelbrojt.


Norbert Wiener

During this stay in France, Wiener received the offer to write a manuscript on the unifying character of this part of applied mathematics, which is found in the study of Brownian motion and in telecommunication engineering. The following summer, back in the United States, Wiener decided to introduce the neologism *cybernetics*, coined to denote the study of "teleological mechanisms", into his scientific theory: it was popularized through his book *Cybernetics: Or Control and Communication in the Animal and the Machine*.[7] In the UK this became the focus for the Ratio Club.

In the early 1940s John von Neumann contributed a unique and unusual addition to the world of cybernetics: von Neumann cellular automata, and their logical follow up, the von Neumann Universal Constructor. The result of these deceptively simple thought-experiments was the concept of self replication, which cybernetics adopted as a core concept. The concept that the same properties of genetic reproduction applied to social memes, living cells, and even computer viruses is further proof of the somewhat surprising universality of cybernetic study.


John von Neumann

In 1950, Wiener popularized the social implications of cybernetics, drawing analogies between automatic systems (such as a regulated steam engine) and human institutions in his best-selling *The Human Use of Human Beings: Cybernetics and Society* (Houghton-Mifflin).

Split from artificial intelligence

Artificial intelligence (AI) was founded as a distinct discipline at the Dartmouth workshop in 1956. After some uneasy coexistence, AI gained funding and prominence. Consequently, cybernetic sciences such as the study of artificial neural networks were downplayed; the discipline shifted into the world of social sciences and therapy.[21]

Prominent cyberneticians during this period include Gregory Bateson and Aksel Berg.

Late 20th century

Cybernetics in the Soviet Union was initially considered a "pseudoscience" and "ideological weapon" of "imperialist reactionaries" (Soviet Philosophical Dictionary, 1954) and later criticised as a narrow form of cybernetics.[22] In the mid to late 1950s Viktor Glushkov and others salvaged the reputation of the field. Soviet cybernetics incorporated much of what became known as computer science in the West.[23]

Published in 1954, Qian Xuesen published work "Engineering Cybernetics" was the basis of science in segregating the engineering concepts of Cybernetics from the theoretical understanding of Cybernetics as described so far historically.

While not the only instance of a research organization focused on cybernetics, the Biological Computer Lab at the University of Illinois at Urbana–Champaign, under the direction of Heinz von Foerster, was a major center of cybernetic research for almost 20 years, beginning in 1958.

New cybernetics

In the 1970s, new cyberneticians emerged in multiple fields, but especially in biology. The ideas of Maturana, Varela and Atlan, according to Jean-Pierre Dupuy (1986) "realized that the cybernetic metaphors of the program upon which molecular biology had been based rendered a conception of the autonomy of the living being impossible. Consequently, these thinkers were led to invent a new cybernetics, one more suited to the organizations which mankind discovers in nature - organizations he has not himself invented".[24] However, during the 1980s the question of whether the features of this new cybernetics could be applied to social forms of organization remained open to debate.[24]

In political science, Project Cybersyn attempted to introduce a cybernetically controlled economy during the early 1970s.[25] In the 1980s, according to Harries-Jones (1988) "unlike its predecessor, the new cybernetics concerns itself with the interaction of autonomous political actors and subgroups, and the practical and reflexive consciousness of the subjects who produce and reproduce the structure of a political community. A dominant consideration is that of recursiveness, or self-reference of political action both with regards to the expression of political consciousness and with the ways in which systems build upon themselves".[26]

One characteristic of the emerging new cybernetics considered in that time by Felix Geyer and Hans van der Zouwen, according to Bailey (1994),[27] was "that it views information as constructed and reconstructed by an individual interacting with the environment. This provides an epistemological foundation of science, by viewing it as observer-dependent. Another characteristic of the new cybernetics is its contribution towards bridging the *micro-macro gap*. That is, it links the individual with the society".[27] Another characteristic noted was the "transition from classical cybernetics to the new cybernetics [that] involves a transition from classical problems to new problems. These shifts in thinking involve, among others, (a) a change from emphasis on the system being steered to the system doing the steering, and the factor which guides the steering decisions; and (b) new emphasis on communication between several systems which are trying to steer each other".[27]

Recent endeavors into the true focus of cybernetics, systems of control and emergent behavior, by such related fields as game theory (the analysis of group interaction), systems of feedback in evolution, and metamaterials (the study of materials with properties beyond the Newtonian properties of their constituent atoms), have led to a revived interest in this increasingly relevant field.[5]

Cybernetics and economic systems

The design of self-regulating control systems for a real-time planned economy was explored by economist Oskar Lange, cyberneticist Viktor Glushkov, and other Soviet cyberneticists during the 1960s. By the time information technology was developed enough to enable feasible economic planning based on computers, the Soviet Union and eastern bloc countries began moving away from planning[28] and eventually collapsed.

After the fall of the Soviet Union a proposal for a "New Socialism" was outlined by the computer scientists Paul Cockshott and Allin Cottrell in 1995 (Towards a New Socialism), where computers determine and manage the flows and allocation of resources among socially owned enterprises.[29]

On the other hand, Friedrich Hayek also mentions cybernetics as a discipline that could help economists understand the "self-organizing or self-generating systems" called markets.[30] Being "complex phenomena",[31] the best way to examine market functions is by using the feedback mechanism, explained by cybernetic theorists. That way, economists could make "pattern predictions".[32]

Therefore, the market for Hayek is a "communication system", an "efficient mechanism for digesting dispersed information".[33] The economist and a cyberneticist are like garderners who are "providing the appropriate environment".[33] Hayek's definition of information is idiosyncratic and precedes the information theory used in cybernetics and the natural sciences.

Finally, Hayek also considers Adam Smith's idea of the invisible hand as an anticipation of the operation of the feedback mechanism in cybernetics.[34] In the same book, *Law, Legislation and Liberty*, Hayek mentions, along with cybernetics, that economists should rely on the scientific findings of Ludwig von Bertalanffy general systems theory, along with information and communication theory and semiotics.[34]

Subdivisions of the field

Cybernetics is sometimes used as a generic term, which serves as an umbrella for many systems-related scientific fields.

In art

Nicolas Schöffer's *CYSP I* (1956) was perhaps the first artwork to explicitly employ cybernetic principles (CYSP is an acronym that joins the first two letters of the words "CYbernetic" and "SPatiodynamic").[35] The prominent and influential Cybernetic Serendipity exhibition was held at the Institute of Contemporary Arts in 1968 curated by Jasia Reichardt, including Schöffer's *CYSP I* and Gordon Pask's *Colloquy of Mobiles* installation. Pask's reflections on *Colloquy* connected it to his earlier *Musicolour* installation and to what he termed "aesthetically potent environments", a concept that connected this artistic work to his concerns with teaching and learning.[36]

The artist Roy Ascott elaborated an extensive theory of cybernetic art in "Behaviourist Art and the Cybernetic Vision" (*Cybernetica*, Journal of the International Association for Cybernetics (Namur), Volume IX, No.4, 1966; Volume X No.1, 1967) and in "The Cybernetic Stance: My Process and Purpose" (*Leonardo* Vol 1, No 2, 1968).

Art historian Edward A. Shanken has written about the history of art and cybernetics in essays including "Cybernetics and Art: Cultural Convergence in the 1960s"[37][38] and *From Cybernetics to Telematics: The Art, Pedagogy, and Theory of Roy Ascott* (2003),[39] which traces the trajectory of Ascott's work from cybernetic art to telematic art (art using computer networking as its medium, a precursor to net.art).

In architecture and design

Cybernetics was an influence on thinking in architecture and design in the decades after the Second World War. Ashby and Pask were drawn on by design theorists such as Horst Rittel,[40] Christopher Alexander[41] and Bruce Archer.[42] Pask was a consultant to Nicholas Negroponte's Architecture Machine Group, forerunner of the MIT Media Lab, and collaborated with architect Cedric Price and theatre director Joan Littlewood on the influential Fun Palace project during the 1960s.[43] Pask's 1950s Musicolour installation was the inspiration for John and Julia Frazer's work on Price's Generator project.[44]

There has been a resurgence of interest in cybernetics and systems thinking amongst designers in recent decades, in relation to developments in technology and increasingly complex design challenges.[45] Figures such as Klaus Krippendorff, Paul Pangaro and Ranulph Glanville have made significant contributions to both cybernetics and design research. The connections between the two fields have come to be understood less in terms of application and more as reflections of each other.[46]

In biology

Cybernetics in biology is the study of cybernetic systems present in biological organisms, primarily focusing on how animals adapt to their environment, and how information in the form of genes is passed from generation to generation. There is also a secondary focus on combining artificial systems with biological systems.[47] A notable application to the biology world would be that, in 1955, the physicist George Gamow published a prescient article in *Scientific American* called "Information transfer in the living cell", and cybernetics gave biologists Jacques Monod and François Jacob a language for formulating their early theory of gene regulatory networks in the 1960s.[48]

In computer science

Computer science directly applies the concepts of cybernetics to the control of devices and the analysis of information - examples being cellular automatons and decision support systems.

In engineering

Cybernetics in engineering is used to analyze cascading failures and system accidents, in which the small errors and imperfections in a system can generate disastrous outcomes.

An artificial heart, a product of biomedical engineering.

In Earth system science

Geocybernetics aims to study and control the complex co-evolution of ecosphere and anthroposphere,[49] for example, for dealing with planetary problems such as anthropogenic global warming.[50] Geocybernetics applies a dynamical systems perspective to Earth system analysis. It provides a theoretical framework for studying the implications of following different sustainability paradigms on co-evolutionary trajectories of the planetary socio-ecological system to reveal attractors in this system, their stability, resilience and reachability. Concepts such as tipping points in the climate system, planetary boundaries, the safe operating space for humanity and proposals for manipulating Earth system dynamics on a global scale such as geoengineering have been framed in the language of geocybernetic Earth system analysis.

In law

As a form of regulation, cybernetics has been always close to law, specially in regulation and legal sciences.

In management

Management as a field of study covers the task of managing a multitude of systems (often business systems), which presents a wide natural overlap with many of the classical concepts of cybernetics.

In mathematics

Mathematical cybernetics focuses on the factors of information, interaction of parts in systems, and the structure of systems.

In psychology

In science, the human mind and individuals are often observed as autonomous and interconnected systems, allowing the cybernetic approach to be leveraged in those fields of study as well.

In philosophy

In his 1990 essay "Postscript on the Societies of Control" Gilles Deleuze argues that society is undergoing a shift in structure and control. The author claims institutions and technologies introduced since World War II have dissolved the boundaries between these enclosures. As a result, social coercion and discipline have moved into the lives of individuals considered as "masses, samples, data, markets, or 'banks'" to be controlled cybernetically. These mechanisms of modern **societies of control** are described as continuous, following and tracking individuals throughout their existence via transaction records, mobile location tracking, and other personally identifiable information.[51]

Gregory Bateson saw the world as a series of systems containing those of individuals, societies and ecosystems. Each of these systems has adaptive changes which depend upon feedback loops to control balance by changing multiple variables. He saw the natural ecological system as innately good as long as it was allowed to maintain homeostasis, and that the key unit of survival in evolution was an organism and its environment.[52]

Bateson, in this subject, presents western epistemology as a method of thinking that leads to a mindset in which man exerts an autocratic rule over all cybernetic systems and in doing so he unbalances the natural cybernetic system of controlled competition and mutual dependency. Bateson claims that humanity will never be able to control the whole system because it does not operate in a linear fashion, and if humanity creates his own rules for the system, he opens himself up to becoming a slave to the self-made system due to the nonlinear nature of cybernetics. Lastly, man's technological prowess combined with his scientific hubris gives him the potential to irrevocably damage and destroy the "supreme cybernetic system" (i.e. the biosphere), instead of just disrupting the system temporally until the system can self-correct.[52]

In sociology

By examining group behavior through the lens of cybernetics, sociologists can seek the reasons for such spontaneous events as smart mobs and riots, as well as how communities develop rules such as etiquette by consensus without formal discussion. Affect Control Theory explains role behavior, emotions, and labeling theory in terms of homeostatic maintenance of sentiments associated with cultural categories.

The most comprehensive attempt ever made in the social sciences to increase cybernetics in a generalized theory of society was made by Talcott Parsons. In this way, cybernetics establishes the basic hierarchy in Parsons' AGIL paradigm, which is the ordering system-dimension of his action theory. These and other cybernetic models in sociology are reviewed in a book edited by McClelland and Fararo.[53]

In sport

A model of cybernetics in Sport was introduced by Yuri Verkhoshansky and Mel C. Siff in 1999 in their book *Supertraining*.

In Technology

Cybernetics has been used as a general reference for the science between the interjection of disciplines Medicine and technology. This involves sciences such as Bionics, Prosthetics, Neural network, Microchip implants, Neuroprosthetics and Brain-computer interface.

Cybernetics is a major theme in the implementation of transhumanism and androids.

See also

- Autonomous agency theory
- Complex systems
- Cybernetics Society
- Gaia hypothesis
- Industrial ecology
- Principia Cybernetica
- Ratio Club
- Superorganisms
- Synergetics (Haken)
- Tektology
- Variety (cybernetics)
- Viable system theory
  - Viable system model
  - Viable systems approach

External links

General

- Norbert Wiener and Stefan Odobleja - A Comparative Analysis (http://www.bu.edu/wcp/Papers/Comp/CompJurc.htm)
- Reading List for Cybernetics (http://bactra.org/notebooks/cybernetics.html)
- *Principia Cybernetica Web* (http://pespmc1.vub.ac.be/DEFAULT.html)

- Web Dictionary of Cybernetics and Systems (https://web.archive.org/web/20091213161047/http://pespmc1.vub.ac.be/asc/indexasc.html)
- Glossary Slideshow (136 slides) (http://www.gwu.edu/~asc/slide/s1.html)
- "Basics of Cybernetics" (https://web.archive.org/web/20100811013353/http://www.smithsrisca.demon.co.uk/cybernetics.html). Archived from the original (http://www.smithsrisca.demon.co.uk/cybernetics.html) on 2010-08-11. Retrieved 2016-01-23.
- What is Cybernetics? Livas short introductory videos (https://www.youtube.com/watch?v=_hjAXkNbPfk) on YouTube

Societies

- American Society for Cybernetics (http://www.asc-cybernetics.org/)
- IEEE Systems, Man, & Cybernetics Society (http://www.ieeesmc.org/)
- International Society for Cybernetics and Systems Research (https://web.archive.org/web/20150226115753/http://3rd-street.net/Group/index.php/index.php?topic=68.msg216#msg216)
- The Cybernetics Society (http://www.cybsoc.org)

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