Tables Showing the Development of the *Body-Machine* Metaphor in the Life Sciences

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TABLE A: Techno-Cultural Orders and the Development of the *Body Machine* Metaphor

Techno-cultural order	Main Characteristics	Main Metaphors
The Organic Order Period / Culture: Preliterate culture and script culture	- Essence, - Wholeness, - Telos, - Holistic forces that regulate the body as a whole - The religious, mystic and animistic universe that resonated within the body	- The *psyche*, *soul*, the Chinese *qi* or equivalent holistic forces that *work through essence and purpose for the good of the living being* -The *macrocosm-microcosm* metaphor: the universe echoes in the human body and vice versa - *The body is an artifact designed by supreme forces and humanlike beings* - Early versions of the *body machine* metaphor under the *organic* perception; for example, when Aristotle describes the movement of the body as the movement of an automatic puppet working by springs, the movements described are still regulated by the *psyche*
The Mechanistic Order Period / Culture: Highly literate, industrial society 16^{th} – 20^{th} centuries	- Fragmentation (reductionism, specialization and atomism) - The efficient cause, chains of efficient causes - Sequential operation - Standardization (mechanical repetition of serial actions) - Determinism	- *The body is a mechanical automaton* : *The body is a clock* metaphor and simple mechanical models, such as pumps, sieves and grinding machines - *The industrialized body*: - *The body-engine* metaphor - *The cell-state* metaphor, cells as citizens/individuals in a nation-state /industrial society - *The division of physiological labor* - *Natural selection* and the logic of industrial capitalism

The Electronic Order Period / Culture: the cybernetic post-industrial society from the 20th century onwards	- Cybernetics and cybernetic implosion - Contemporary field and systems theories: totality, holism, systemic approach - Computerized systems, feedback, electronic *teleology* and flexibility	- *The body is a field* - *The body is a cybernetic-computerized system* and *the virtual body*: - *The body is an information pattern* - *DNA is the code of life*

TABLE B: The Proto-Mechanical Approach.

Period: The 16th Century

Prominent Representatives and Schools	**Main Metaphors, Paradigms and Trends**
Andreas Vesalius	

- Modern anatomy, print industry and print culture: The work of Vesalius and his colleagues in the field of anatomy was closely linked to print industry. As a student during the 1530s, Vesalius helped professor Guinther of Andernach who edited the important rediscovered work of Galen, *Anatomical Procedures*. Michael Servetus received the same assistant job after Vesalius, and in addition he also worked during the 1530s in a publishing firm as a book editor and proof reader. The mass and uniform production of old and new texts, of images and labels, and the rapid and efficient diffusion of knowledge – all these had promoted new forms of science and scientific communities, and the retrieval and standardization of the full Galenic corpus. The efficient and rapid diffusion of new data and the standardization of knowledge had led to the development of systematic research. Rigorous analysis and thorough comparison between old texts and new observations revealed discrepancies and anomalies. Ancient texts and traditional views were criticized and disconfirmed, contradictions were found and the authority of Aristotle, Galen and others was challenged

-The *macrocosm↔microcosm* metaphor: the human body corresponds to the structure of the universe

- The body as a *factory* (*fabrica*)

Ambroise Paré

- Illustration and design of mechanical limbs that work through gears and levers
- Diseases as lesions or mechanical malfunctions of the *body↔machine*
- *Jokes of nature* – a grand-metaphor that attributed to nature artistic skills and creative powers; residues of animistic thought that lasted until the 18th century

TABLE C: The 1st Mechanistic Phase: Early Mechanism and the Organo-Mechanical Approach.

Period: The 17th Century

Prominent Representatives and schools	**Main metaphors, paradigms and trends**
William Harvey	- Combining the traditional organic perception with the new spirit of the mechanical sciences - The proto mechanical paradigm: the circulation of blood as a piece of machinery in which one wheel gives motion to another in a successive manner; the heart as a mechanical pump - The *macrocosm↔microcosm* metaphor - The generation of the body is governed by the “foresight” and “intelligence” of nature / the Divine Architect / the formative faculty
Rene Descartes	- The body as a mechanical clock / automaton - Cartesian Philosophy, dualism, a body and a soul
Thomas Hobbes	- Materialism: the body is a mechanical automaton without an immaterial soul - Society or the state as a great *Artificial Man*

Pierre Gassendi	- Atomism: although Gassendi believed that in the beginning of the universe God created and scattered on earth the germs which are responsible for the phenomenon of spontaneous generations (pre-existence), he also promoted the view that inheritance and embryonic development take place by the motion and action of atoms in the seed.
Jan Swammerdam Claude Perrault Nicolas Malebranche	- Preexistence: machines cannot organize themselves; the organized structure of all *body↔machines* was created by the Supreme Artificer; the embryos develop by mechanical enlargement and unfolding
Giovanni Alfonso Borelli Marcello Malpighi Lorenzo Bellini The English physiologists of the *Royal Society* and the medical writers of the *Royal College of Physicians*	- Italian iatro-mechanism - English iatro-mechanism (By the 1750s and 1760s the mechanical philosophy of the first phase lost its power in England)

TABLE D: The 1st Mechanistic Phase.

Mechanism in the 18th Century

Prominent Representatives and schools	Main metaphors, paradigms and trends
Friedrich Hoffmann	- Iatro-mechanism
Herman Boerhaave	- The leader of the conservative Christian mechanists - Iatro-mechanism - Explanations of how the *body↔machine* works via mechanical models, such as *pullies* and *sieves*
Giovanni Morgagni	- The *seat* of diseases, i.e., diseases as mechanical malfunctions in specific parts of the *body↔machine*
The successors of Boerhaave - Conservative Christian mechanists : Albrecht von Haller Rene de Réaumur Lazzaro Spallanzani Charles Bonnet	-The forces of *sensibility* and *irritability* - Early models of *artificial digestion*: this new technique, which was developed by Réaumur and Spallanzani, reconstructed in the laboratory a physiological function which was separated and taken out of the living body as a fragment - From the strict *mechanical* approach to the *mechanistic* approach - Preexistence

Caspar Wolff	- Epigenesis and the quasi-mechanistic *essential force* - The Haller-Wolff debate: Preexistence vs. Epigenesis
Jacques Vaucanson Pierre Jaquet Droz	- The android; mechanical figures of humans and animals; the mechanical duck of Vaucanson and the writing boy of Droz

Carl Linnaeus

- Mechanistic classification using fragmentation and *primary-objective* qualities; the aim of the empirical study in the Linnaean program was to (a) define and isolate some important characters from the inclusive pattern of the plant or the animal (b) make visual comparisons between the isolated characters of a plant or an animal and the corresponding characters of a plant or an animal from another species.

- Print culture, science and systematic classification:

print promoted standardization, abstraction and dichotomy, and a new analytic mentality. The printed page enabled and encouraged the formation of complex lists, charts and indexes. Modern scientific communities depended on the conditions which the new environment provided: systematic collection and classification of data, comparative analysis, efficient diffusion of new observations, standardization and the mass and uniform production of journals, textbooks, images, illustrations etc. By the mid 16^{th} century, new schematic illustrations, which were based on technical advances in print, facilitated the efficient classification of the rapidly expanding data pool. Pocket editions of the new guides were prepared for field trips. Print shops in Europe were engaged in a large-scale program of botanical publications. Famous editors received new seeds, specimens, reports and drawings from distant regions Uniform texts and images had become available to many readers whose comments and observations helped to revise later editions. If the ancients had described about 600 plants, by 1623 the number grew to 6,000. Modern botanists challenged the authority of the ancients, but more gradually than their colleagues in the field of anatomy (e.g. Vesalius's critique of Galen). As part of the trend that began by 16^{th} century book editors, Linnaeus received packages of seeds from members of the reading public who wished to be immortalized in the next volume of his work. To deal with the overload of data,

<table>
<tr><td colspan="2">Linnaeus developed a classification system that resembled a system of index cards. The technique involves keeping information on particular subjects on separate sheets; as a result Linnaeus was able to reshuffle the sheets and add new sheets when needed.

- Linnaeus wished to develop botanical calligrams which would translate the structure of the plant into the printed text or vice versa</td></tr>
<tr><td>Georges Buffon</td><td>- The internal mould that directs particles to their place in the body in a mechanical way, as bronze fills the smelter’s mould through the action of weight
- The proto-mechanical theory of degeneration</td></tr>
<tr><td>Pierre Maupertuis

The radical materialists:
Denis Diderot
Julian Offray de La Mettrie
Baron d’Holbach</td><td>- A strong mechanistic approach although the generation and organization of the body↔machine could be explained “only by analogy” to notions like intelligence, desire, aversion, memory and instinct

- An attempt to achieve a complete reduction of the body to a machine

- L' Homme Machine</td></tr>
</table>

TABLE E: The 1st Mechanistic Phase.

Vitalism in the 18th Century

Prominent Representatives and schools	Main metaphors, paradigms and trends
Georg Ernst Stahl	- Strong vitalism: the body is "a mechanical structure", but the mechanical principles and the mechanical activities of the body always remain under the guidance of the spiritual soul
The school of Montpellier: Francois de Sauvages Théophile de Bordeu Paul Barthez	- The rejection of the models of Boerhaave - The forces of sensibility and irritability - the mechanical characteristics of animated machines are regulated by vital forces
The school of John Hunter Matthew Baillie	- The body as a machine regulated by the vital principle - Diseases as local lesions
Johann Blumenbach	- The *teleo-mechanical* force - Epigenesis - The body as both a *laboratory* and a *chemist*

Immanuel Kant	- A soft mechanist who influenced the teleo-mechanical tradition; sympathetic towards the teleo-mechanical approach
Johann Reil Carl Kielmeyer Johann Meckel	- The teleo-mechanical tradition, between the last decades of the 18^{th} century and the first decades of the 19^{th} century -Romanticism, Naturphilosophie - *Progress* - Schelling's idea of *polarity* in the universe
Erasmus Darwin	- Combining vitalism and mechanism - *Progress*, transformism and teleology - Anticipation of the idea that the transmutation of species occurs through competition between individuals

TABLE F: The Beginning of the 2nd Mechanistic Phase / The Industrial-Chemical Phase.

Period: from the end of the 18th Century until the Early Decades of the 19th Century

Prominent Representatives and schools	**Main metaphors, paradigms and trends**
Antoine Lavoisier Pierre Laplace	- The roots of the *body↔engine* paradigm: respiration and chemistry - Exploring the body as a steam engine, i.e., as a combustion mechanism producing physiological work equivalent to the work of the machine
The Paris School of Medicine: Xavier Bichat Jean Corvisart Rene Laennec	- Mechanistic Vitalism: fragmentation of the body -The tissue doctrine and the atomistic approach of Lavoisier - The *seat* of diseases in specific tissues - The stethoscope (an invention of Laennec): a mechanical extension of the ear that enables the mechanistic analysis of the living body and the finding of the *seat* of diseases - The industrial-chemical program, the beginning of specialization in medicine and the modern state: The infrastructure of the modern state and the trends of industrial society were the background on which the new medicine appeared. Fragmentation, centralization, standardization, the bureaucratic surveillance on populations, systemic surveys, and new systems of analyses and classification - play a major role in all aspects of modern life. The bureaucratic-medical surveillance on the body and the education of the public by doctors are an integral part of these developments. The new form of organization in the hospitals of industrial society was based on fragmentation, specialization and standardization and it resembled the organization in the factories that were described by Adam Smith in the 18th century

The mechanistic pathologists : Léon Rostan Jean Bouillaud	- Mechanistic organicism - Anti-vitalistic approach - Reduction of diseases to organic lesions
Jöns Berzelius Friedrich Tiedemann Leopold Gmelin	- The body as a *chemical laboratory* which is regulated by the vital force - Standardized , systematic analysis of body fluids and tissues using chemical techniques
William Beaumont	- The exemplar of *artificial digestion*; fragmentation and mechanistic physiology
Phrenology: Franz Gall Johann Spurzheim George Combe Orson Fowler	- The brain and the characteristics of industrial society -The *division of labor* in the brain: the mind is composed of distinct innate faculties and each faculty has a distinct seat or a corresponding part in the brain - Hereditarianism and proto-eugenic ideas
Jean Baptiste Lamarck Georges Cuvier	- The body as a mechanical automaton; mechanistic-materialistic physiology - *Progress* and teleological transformism - Soft mechanism; “Every animal may be considered as a particular machine, having certain fixed relations to all the other machines, that together form the Universe”. - The teleological design of the *body↔machine* does not coincide with the idea of transformism - Functional analysis of organs and comparative anatomy

Etienne Geoffroy Saint-Hilaire	- Transformism and the progressionist worldview -The Cuvier–Geoffroy debate
Henri Milne-Edwards	- Contribution to the synthesis between the approaches of Cuvier and Geoffroy - Industrial vitalism: *progress* and *the division of physiological labor* (following Adam Smith)
Conservative teleologists: Charles Lyell Adam Sedgwick vs. Non-teleologists: Richard Owen Robert Grant Robert Chambers	- Followers of Cuvier - A gradual decline in the power of teleological explanation in Britain of the 30s and 40s - The organization of the body cannot be explained solely in terms of adaptation to function - The body as an organized set of machines - A follower of Lamarck, Erasmus Darwin and Geoffroy -Transformism , progress and social change - Popularization of mechanistic and transformist views
Johannes Müller Ignaz Döllinger Karl Ernst von Baer	- A teleo-mechanist who prepared the ground for the predominance of the second phase - Teleo-mechanists who were influenced by Cuvier and combined the approaches of Blumenbach and Haller

TABLE G: The Predominance of the 2nd Mechanistic Phase / the Industrial-Chemical Phase.

Period: 1840s - 1900

Prominent Representatives and schools	Main metaphors, paradigms and trends
Germany:	
Justus von Liebig	-Fertilizer and meat industries
and the students of Johannes Müller (along with Carl Ludwig and others), especially ------>	- Reduction of all biological phenomena to fragments which work according to chemical and physical forces
Hermann Von Helmholtz	- The *body↔engine* metaphor and the law of conservation of energy
Matthias Schleiden	- Cell theory, the *cell↔state* metaphor, the *individual* cell
Theodor Schwann	
Rudolf Virchow	-Cellular pathology
Emil Dubois Reymond	- The electric telegraph and the nervous system
	- Specialization of research
The medical materialists:	- Materialism and reductionism
Carl Vogt	- Darwinism

Jacob Moleschott Ludwig Buchner	
France: Claude Bernard Louis Pasteur Étienne-Jules Marey	- A soft mechanistic approach: on the one hand, an analysis of physiological functions as separate fragments, following the exemplar of artificial digestion; on the other hand, reaching a conclusion about a physiological function only "in relation to its effects in the whole". Thus, the *living machine* must be analyzed like a "crude machine whose parts also have their role to play in a whole." - Materialism and anti-vitalism - *Internal milieu* and engineering concepts: the ability of the body to maintain internal stability in different environmental conditions; *equilibrium*, *compensation*, *regulation* and the steam engine; the idea did not make a significant impact during the 19th century, but it influenced the theory of homeostasis which developed in the 20th century - Industrial-chemical program: microorganisms, wine and milk industries, pasteurization - A soft mechanistic approach: unlike Liebig and Helmholtz, Pasteur thought that some chemical processes of the living cell, such as, fermentation, cannot be further reduced to simpler fragments - Reductionism and the strong mechanistic approach - The *body*↔*engine* metaphor
Paul Ehrlich	- The dyestuffs industry and the reduction of the *unit* of the cell to the functions of its components

Charles Darwin & Alfred Wallace	- *Natural selection* and the political economy of industrial society - Competition between individuals of the same species - Thanks to the *division of labor*, the *economy of nature* is just as efficient as the physiological economy of organs and as social economy - Gemmules: reducing heredity to specialized atomic particles; reducing development to a linear chain of efficient causes - Natural selection and the rejection of the mechanism of inheritance of acquired characters
Different followers of Darwin Thomas Huxley Samuel Butler Francis Galton	 - Promoting the strong mechanistic program and professionalism in biology - Nature as a *gladiators' show* - *Darwin among the Machines* - The *autonomy* and *independent* life of organs and cells as the starting point for developing a new theory of heredity - Biometrics; statistical tools for isolating, quantifying and standardizing mental and physical characters; the separation between heredity and embryology - The sum-total of hereditary factors as a "post office" - Eugenics and hereditary determinism

Ernst Haeckel	- A mechanical-pantheistic view - Recapitulation theory: "Phylogenesis is the mechanical cause of ontogenesis"
Asa Gray	- The Divine *Industrialist*: a compromise between natural selection and the belief in the Divine Artificer
Peter Kropotkin and the Russian Darwinists Karl Marx	- *Mutual aid* - The rejection of the capitalist interpretation of Darwinism
Examples of non-Darwinian hypotheses of evolution:	
Albert von Kölliker	- Kölliker accused Darwin of being a "Teleologist" who believes that every part in the structure of the body was created for the benefit of the animal; he suggested that an unknown general law determines the organism's course of development. Under certain circumstances an alternate generation may take place, thus producing new forms of organisms
Alpheus Hyatt	- Evolution occurs through acceleration of development via the inheritance of acquired characters, but in the process degenerative characteristics appear as a usual mode of development: "progressive specializations" which increase the functional powers of the living being are eventually followed by degeneration

Carl von Nageli	- Cell theory and the new approaches to heredity - The *idioplasm*: a distinct substance that carries the factors of heredity and controls the processes of development and differentiation - Fragmentation and the complex problem of generation: promoting the separation between heredity and embryology
Gregor Mendel	- The new paradigm of hereditary analysis; - A particulate model of heredity: discrete, atomic units in the cell determine the characters of the organism
August Weismann	- Reductionism: the chromosomes contain specialized hereditary determinants, which are responsible for the formation of the characters and components of the cell; when embryonic cells divide into daughter cells, each of the two daughter cells receives different set of determinants and the result is differentiation of cells; in other words, the special set of determinants received by the cell determines its course of development. -The distinction between germ cells and somatic cells; rejection of the mechanism of inheritance of acquired characters - Neo-Darwinism - Using the images of a cotton factory and a phonograph in the discussion about the complexity of the mechanism of heredity - The telegraph and hereditary *transmissions*
Wilhelm Roux	- Reductionism following Weismann: the *mosaic* theory of development; hereditary particles in the fertilized egg are unevenly divided between daughter cells during cell divisions; different types of tissues develop from cells which contain different sets of hereditary particles. - Experiment: destroying one of the two blastomers (cells) of a developing frog embryo. Result: the second blastomere developed only into a half embryo, while the other parts of the embryo did not develop from the deficient blastomere. Conclusion: organs develop to a mature state from elementary, independent units

Hans Driesch	- The anomalies of the mechanistic approach. - Experiment: separating the two blastomeres of a sea urchin embryo. Result: each blastomeres developed to a complete small embryo. Conclusion: the fate of the blastomeres depends on their relative position in the developing embryo. Driesch thought that the result of the experiment was as a dead end for the mechanistic program despite its successes
Hugo de Vries Carl Correns Erich von Tschermak	- Finding the particulate elements of life, according to the mechanistic model of physics and chemistry - Confirmation and acceptance of the Mendelian paradigm around 1900 (de Vries, Correns and Tschermak)

TABLE H: Electro-Mechanistic Hybrids - The Appearance of the Electronic Order.

Period: 1910s until the beginning of the 1940s

Prominent Representatives and schools	**Main metaphors, paradigms and trends**
Jacques Loeb - Organisms as *chemical machines* - The artificial reconstruction of life or the engineering of life: "...we must either succeed in producing living matter artificially, or we must find the reasons why this is impossible." - Artificial parthenogenesis: a chemical treatment that leads to the beginning of embryonic development of unfertilized egg cells - *The Mechanistic Conception of Life*: materialism; the sum of all life phenomena can be unequivocally explained in physico-chemical terms. - "That a part is so constructed that it serves the "whole" is only an unclear expression for the fact that a species is only able to live—or to use Roux's expression—is only durable, if it is provided with the automatic mechanism for self-preservation and reproduction." - Determinism: "We eat, drink, and reproduce not because mankind has reached an agreement that this is desirable, but because, machine-like, we are compelled to do so." - *The Organism as a Whole:* influenced by the appearance of the post-mechanistic wave, which was represented by biologists like Boveri and Child (see below), Loeb rejected the complete reduction of the developing organism via "Mendelian heredity, according to which each character is transmitted independently of any other character." The organism is not "merely a mosaic of independent hereditary characters": "...the unity of the organism is due to the fact that the egg (or rather its cytoplasm) is the future embryo upon which the Mendelian factors in the chromosomes can impress only individual	

characteristics, probably by giving rise to special hormones and enzymes.” According to Loeb’s hypothesis, “the genus- and species-heredity are determined by the cytoplasm of the egg”	
The continuity of the mechanistic trends: Wilhelm Johannsen Bateson... Thomas Morgan and his students: Alfred Sturtevant Calvin Bridges Hermann Muller George Beadle and Alfred Tatum	- The distinction between *genotype* and *phenotype*; mechanistic fragmentation: the clear distinction between heredity and development - The Mendelian paradigm - The *Drosophila* model: mapping discrete genes on the chromosomes - Linear chains of reactions lead from the gene to the phenotype - *Variation due to Change in the Individual Gene*; *The Gene as the Basis of Life* - “One gene-one enzyme” hypothesis: each gene controls/produces one enzyme
Fritz Kahn	- *Man as Industrial Palace* and other illustrations which presented the industrial view of the body to the general public
The appearance of the post-mechanistic wave: Alexander Gurwitsch Theodor Boveri William E. Ritter	- *Field* theory, totality/holism, *gradients* and the regulation of developmental processes; the elements of the field, e.g., cells, interact according to their relative position in the whole - *Organicism*, as defined by Ritter: “the organism in its totality is as essential to an explanation of its elements as its elements

Charles Manning Child John Scott Haldane Ross Harrison Joseph Needham	are to an explanation of the organism." - The organism as a total entity in relation to its parts and its environment; the principle of fragmentation and the mechanistic approach are not the right way to analyze and understand the biological machine
Hans Spemann and Hilde Mangold	- Field theory, the *organizer* and the development of the body
Paul Weiss and Ludwig von Bertalanffy	- Electrical engineering and the roots of *systems theory* in biology
Richard Goldschmidt C. H. Waddington	- Fields, embryology and genetics: "the activation of the gene"
Richard Woltereck	- *Norm of reaction*: the interrelationship between the entire genotype and the environment

Walter Cannon

- Homeostasis / the homeostatic automaton: influenced by the *organicist* view of John Scott Haldane and the ideas of Claude Bernard, Cannon argued that the body is regulated by "automatic control" mechanisms, that respond to changes in the environment and maintain the necessary conditions for the operation of the system, e.g., maintaining glucose levels in the blood, oxygen supply or levels of body temperature
- Homeostasis theory was a prototype of the materialistic, post mechanistic view of the body; the body as an automatic regulated system; flexible reactions, interdependence and circular activity of different mechanisms
- *Margin of safety*; an addition to the engineering concepts that were used by Bernard to perceive and depict the *body↔machine*

- “Relations of Biological and Social Homeostasis”: the importance of physiological and social stability	
Hans Selye	- *Stress* and the *general adaptation syndrome*; from diseases as malfunctions in specific parts of the *body↔machines*, i.e. local lesions, to a general reaction of the homeostatic system to different stressors; “the syndrome of just being sick”; or “the pharmacology of dirt”, as the post-mechanistic approach of Selye was described from a mechanistic point of view by one of his colleagues
R. A. Fisher J. B. S. Haldane Sewall Wright Theodosius Dobzhansky Sergei Chetverikov Edmund B. Ford Ernst Mayr George Gaylord Simpson George Stebbins	- The *modern evolutionary synthesis* of natural selection and Mendelian genetics via population genetics; evolution as changes in gene frequency; following the synthesis, neo-Darwinian reductionism and the industrial-mechanistic worldview peaked in the 20^{th} century
Robert Yerkes Clarence Ray Carpenter	- Darwinism and social order: male dominance, sexual activity and reproduction; *trading* sex for privileges; the body politic and the reflection of male dominance in primatology; the “economic link of physiology and politics”, as Donna Haraway defined it (Haraway 1978) - Eugenics: primates as an experimental model for human progress -Fields, gradients and systems theory as applied to primate societies; primate societies as developing embryos; influenced by Yerkes, Carpenter described *gradients* of social dominance (the reflection of male dominance in primatology); male

Solly Zuckerman	dominance is strongly correlated with sexual activity and therefore, probably, gives an evolutionary advantage - Political economy, market competition and natural selection: when the group loses its alpha male, the competitiveness of the group declines and the result is an evolutionary disadvantage - The Social order of primates is based on dominance, sexual physiology and reproduction; hormones and mechanistic physiology as the basis of behavior and society - Darwinism and the logic of industrial capitalism: male competition; females as resources and as the means of (re)production - The *hunting hypothesis*

TABLE I: Electro-Mechanistic Hybrids - The Electronic Order in the Cybernetic-Computerized Environment.

Period: From the 1940s on

Prominent Representatives and schools	**Main metaphors, paradigms and trends**
Erwin Schrödinger	- *What is Life?* The chromosomes as *law-code* and *executive power*; the translation of the body into an *information* pattern
The cyberneticists and the biologists who worked with them: Norbert Wiener Arturo Rosenblueth Julian Bigelow	- The body as an electronic, information processing machine - The cybernetic approach united the *negative feedback* and *homeostasis* under the *teleological* principle - The Macy conferences and World War II: The Macy conferences created a trans-disciplinary program that united many disciplines under the cybernetic program: engineering, physics, biology, sociology, psychology linguistics, philosophy etc. Furthermore, the development of cybernetics was related to World War II. Many cyberneticists and biologists participated in the war efforts. The academic-military-industrial program influenced the perception of the body. Communication systems and electronic circuits that control the firing of missiles became a model for understanding and explaining different aspects of the body
Ross Ashby	- The *homeostats*: cybernetic systems that receive feedback from one another (the environment), while trying to maintain stability; self regulating, flexible, decentralized, non-linear, non-hierarchical systems
Claude Shannon	- Information Theory, communication systems and the *electronic rat* which was based on the homeostat
Warren McCulloch and	- The electronic computer and the nervous system: neural networks and information processing

Walter Pitts Alan Turing Stafford Beer and Gordon Pask John Von Newman Manfred Clynes and Nathan Kline Ludwig von Bertalanffy	 - The Turing machine and the Turing test: human intelligence and artificial intelligence - Influenced by the work of Ashby, Beer and Pask created models of flexible *artificial neurons* that can develop and adapt to different functions in different environmental conditions - Artificial life: chromosomes as *information tape*, self replication and evolution via cellular automata and computer simulations - The prototype of the cyborg, e.g., a rat with an implanted osmotic pump that injects chemicals to the rat's body with the purpose of modifying and regulating its homeostatic states - Biology and systems theory in the cybernetic age
James Watson and Francis Crick Marshall Nirenberg and Heinrich Matthaei Har Gobind Khorana Robert Holley	- DNA: the *genetic code* - The central dogma: a linear model of the action of genes: the one-way flow of information from genes to proteins, i.e., the synthesis of proteins according to the assembly line logic - C*odones*: the translation of the *genetic code* into proteins

C. H. Waddington	- *The Cybernetics of Development*; development as an epigenetic phenomenon regulated by feedback systems
Jacques Monod and François Jacob	- The *Lac operon*; genetic regulation and the *computer program*; the body as a cybernetic system; regulatory systems of genes and enzymes as electronic circuits that control the firing of missiles
Michael Apter Lewis Wolpert	- The *genetic program* and the *developmental program*; the entire developing embryo as a system of computer programs; "the system acts as a dynamic whole" - *Positional information*: a field theory developed by Wolpert; the theory explains the development of the embryo as a function of cells which respond to signals and differentiate according to their relative position in the system; following Alan Turing, Wolpert suggested that cells determine their position according to the concentration gradients of *morphogens*;
Christiane Nüsslein Volhard Eric Wieschaus Edward B. Lewis	- *Maternal-effect genes*: the interdependence of genes and proteins and the regulation of embryonic development in *Drosophila* and multi-cellular organisms
	- Other phenomena that contradict the reductionist models of genetics, e.g., position effect, the expression of genes in different genomes, alternative splicing and epigenetic inheritance
Edward De Robertis et al. 1991	- *Morphogenetic gradient fields* and their connection to homeobox genes: the new developmental biology synthesizes fields and genetics
J.B.S. Haldane and Helen Spurway	- Dancing bees as a cybernetic system / communication system

Primatologists: Sherwood Washburn David Hamburg	- Neo-Darwinism and the logic of industrial capitalism: the social order of primates is based on hierarchy that depends on male aggression, competition between individuals and competition between groups - *Feedback* of genotype, behavior, culture and environment: the genotype limits cultural possibilities, cultural changes create environmental changes and influence the selective pressure, leading to a change in the gene pool... - Tool use and the evolution of the human body - *Man the hunter*: production and the sexual division of labor; men specialize in hunting, women and children in gathering - New alternatives, for example, the feminist alternatives: Thelma Rowell replaced Zuckerman's concept of *dominance* with *stress*; dominance and aggressive behavior do not give an evolutionary advantage; emphasizing the importance of cooperation between all members of the group. Sally Slocum, Adrienne Zihlman and Nancy Tanner suggested *Woman the Gatherer* as a countertheme to Washburn's *Man the hunter*; an adaptation to this diet does not create selective pressure towards aggressive behavior; under these circumstances, cooperation is beneficial and women have an important role
The Sociobiologists: Edward Wilson Stuart Altmann and Peter Marler	- Sociobiology: analysis and explanation of social behavior combining the industrial-mechanistic approach of neo-Darwinism / modern evolutionary synthesis with the cybernetic approach - Fire ants as a cybernetic system / communication system - Primatology and cybernetics: animal societies as communication systems

Richard Dawkins	- *The Selfish Gene*; genetic reductionism and neo-Darwinism; the DNA as a computer program; the separation between genetics and development - The body as a *vehicle* of the genetic *replicator* - "It is raining DNA outside…it is the DNA that matters...it's raining programs; it's raining tree-growing, fluff-spreading, algorithms."

Stephen Gould
Richard Lewontin

- The post mechanistic approach: adopting the critique of the mechanistic-reductionist approach; the body is not a mechanical automaton which is composed of separate specialized fragments but an *integrated entity*
- *The Spandrels of San Marco and the Panglossian Paradigm*: rejection of the reductionist *adaptationist programme*, which characterizes modern evolutionary synthesis and sociobiology; rejection of the idea that natural selection works on *unitary traits*
- The *feed back* and *reciprocal* interaction between the organism and its environment: critique of the mechanistic-reductionist approach in ecology that defines the interaction between the species and the environment as unidirectional, while ignoring that the environment changes and evolves under the influence of the species; the activity of the organism shapes the environment; the organism and the environment are not separate entities
- The foundations of *Evo-Devo*: evolution and embryonic development

Scott Gilbert et al. 1996

- Evolutionary developmental biology: *Evo-Devo* is based on the new developmental biology and on the *field* view; macroevolution, homology, genetic regulation, gene *networks* and embryonic development; the process of development as the link between genotype, phenotype and evolution
- *Morphogenetic fields* mediate between genotype and phenotype; developmental biology mediates between functional biology and evolutionary biology;

<table>
<tr><td colspan="2">- “The morphogenetic field thus unites the atomism of the genetic and biochemical pathways within the wholism of the developmental pathway.”
- The homology of the developmental process: homology of structures is replaced by the homology of process and dynamic interactions; for example, the homeotic genes that regulate the formation of the anterior–posterior axis in animals are homologous and they appear in vertebrates as well as in flies.</td></tr>
<tr><td>James Lovelock
Lynn Margulis</td><td>- Gaia in the satellite and spaceflight era
- Earth as a homeostatic-cybernetic system, or, as Lovelock defined it, a “complex entity involving the Earth's biosphere, atmosphere, oceans, and soil; the totality constituting a feedback or cybernetic system which seeks an optimal physical and chemical environment for life on this planet.”</td></tr>
<tr><td>Miguel Nicolelis and his colleagues</td><td>- The new generation of Cyborgs</td></tr>
<tr><td>John Conway

Christopher Langton and his colleagues</td><td>- The Game of Life: cellular automata, computer simulations and the evolution of life

- Genetic algorithms, artificial life; virtual entities as examples of life itself</td></tr>
<tr><td colspan="2">- Genetic engineering and synthetic biology: the body is perceived as a system that belongs to the field of information processing; the motivation behind the Human Genome Project

- Recombinant DNA technology turns the body into an imploded technological prosthesis of itself

- Recombinant DNA technology and biotechnology have transformed micro-organisms into micro-factories that produce materials for the medical industry.</td></tr>
</table>

The insertion of human genes into bacteria and plants enables the mass-production of interferon, hormones like insulin and other materials.

- Through cloning the body can replicate itself like products on an assembly line - a function that could have never existed under the conditions of sexual reproduction

- Interspecies implosion: the creation of human-animal hybrids through genetic engineering, synthetic biology and stem cells transplantation, e.g. microbes and rabbits with human genes or insects and goats with spider genes, or, alternatively, the injection of human neural stem cells into the brains of mice, rodents, monkeys, and the injection of human stem cells from bone marrow of adults or from embryo lines into fetal sheep. Inter-species implosion serves the medical and biological research, medical industry, food industry and it has other industrial applications, e.g., organisms with spider genes that produce spider silk for different purposes.