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Crafted Bodies:
Interpretations of Corporeal Knowledge in Light of the Technological Imagination in Antiquity, the Renaissance and the Present

Master of Arts, 1995

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Abstract

This thesis is about Western scientific discourses, present and past, that structure and vitalize corporeal knowledge. My strategy for deciphering the body is to view it through the interpretive grid of everyday technologies. The ideas and conceptual categories suggested by certain technologies mobilize new understandings about the constitution, functioning, powers and limits of the body.

Every civilization, J. David Bolter writes, "possesses a characteristic set of materials, techniques and devices that help to shape its cultural outlook" (1984, p. 16). These he calls *defining technologies*: technologies that capture the imagination of thinkers and reform their ideas about nature. Defining technologies alter the physical means of life and establish new epistemological frameworks. Their effects are felt materially and symbolically.

In this thesis I recount the influence of three defining technologies — the manual crafts of Antiquity, the machine during the Renaissance, and the digital computer in the present — on Western scientific ideas of bodily structure and functioning. I describe the movement of technological ideas into scientific discourses and the concomitant merging of these technologies with our bodies. This thesis asks how technologies are represented linguistically, how new systems for making sense of our bodies are produced, and how the new representations/self-representations achieve the status of truth.

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Special thanks to my parents, Lee and Edith Cantor, whose encouragement and generosity helped make this thesis possible. Isaac, Sarit and Oren Cantor sparked my imagination by inviting me to join in their journeys to worlds of tall mountains, magical forests and humongous castles.

I dedicate this thesis to the memory of my grandmother, Fanny Chodorcove (1901-1988), who always believed in me.

Contents

Chapter 1

Introduction

I. The Problem and its Context

Ideas about the human body — its fabric, animating forces, capacities, and the relation of its "inside" to its "outside" — are products of culture. As a culturally mediated form, the body is subject to description and interpretation. In short, somatic knowledge is discursively crafted. The human body is an object of knowledge rendered intelligible by the sciences, philosophies, religions and mythologies of the people who imagine it, discuss it and plumb its mysteries.

This thesis is about Western scientific discourses, present and past, that structure and vitalize corporeal knowledge. My strategy for deciphering the body is to view it through the interpretive grid of everyday technologies — the machines, materials and techniques with which people amplify and extend their own powers. The ideas and conceptual categories suggested by certain technologies mobilize new understandings about the constitution, functioning, powers and limits of the body.

The most familiar example of a technology that informs knowledge of the body is the machine. Since the Renaissance a succession of mechanical technologies — the clock, the steam engine, and the factory — have served as descriptive keys for unlocking the secrets of anatomy and physiology. The machine-body entered Western thought with René Descartes (1596-1650), who, in several of his treatises, compared human and animal bodies to "clocks, artificial fountains, mills, and similar machines" (Descartes, 1972, p. 4). Descartes' premise was that all responses conventionally believed to require the intervention of the soul actually occurred without it; instead, he proposed that life was the consequence of the movements of solids and fluids in small physiological structures. Thus in Descartes' *Description of the Body* we read:

> Admittedly, it is hard to believe that the mere arrangement of the organs is sufficient to produce in us all the movements that are not determined by our thoughts. That is why I shall try to prove it here, and to explain the whole machine of our body in such a way that we shall have no more occasion to think that our soul excites the movements... than we have to judge that there is a soul in a clock which causes it to show the hours (Descartes, p. 115).

The details of Descartes' system of physiology were promptly rejected by his successors, but the general mechanistic orientation of his philosophy prevailed. In the 1600s, a tendency began to grow among natural philosophers to explain natural processes mechanically. One of the characteristics of the mechanical approach to the study of nature was the reduction of all phenomena to matter and motion. All activities — from the orbiting of planets to the beating of hearts to the collisions of atoms — were explained by the logic that accounts for the movements of machines.

For 300 years science has patterned the body on the machine. In its most stringent articulations, mechanistic science regarded mind as an epiphenomenon of material events, and life as the accidental by-product of physical processes. The "machine-body" was well illustrated in a 1975 National Geographical Society television program, *The Incredible Human Machine*:

> Set aside now the poet's passion in favour of the scientists' cold analysis. About two-thirds water, plus carbon, calcium, plus a few other chemicals, all worth about five dollars at the inflated prices of the mid-seventies. In one sense, that's all we are, all of us. But right now your body is performing amazing feats of engineering, chemistry and physics that no machine designed by man can duplicate (National Geographic Society, 1975).

In contemporary popular scientific portrayals of the body, the "parts" are often depicted as machine components or elements in an industrial process. From the same National Geographic program, the human hand receives a quintessentially mechanistic treatment:

> The unique engineering design of the human body reaches its apex in the hand. Powerful and precise, servant of the mind, creator of civilization and culture. Twenty-five joints give it fifty-eight distinctly different motions and make it the most versatile instrument on earth (National Geographic Society, 1975).

After three centuries of scientific biomedicine it is difficult to conceive of the body as anything but a living machine. The mechanistic outlook is so deeply engrained in the Western imagination that the idea of the body-as-machine structures commonsense knowledge to this day.

Ten years after the broadcast of *The Incredible Human Machine*, a very different hand was described in another National Geographic Society television program, *Miniature Miracle: The Computer Chip*. Robotics expert Ken Salsbury remarked:

> The human hand is really an amazingly complex and amazingly subtle piece of engineering in a sense. If you look at the amount of the human brain that's devoted to processing and controlling motion and information from the human hand, it's really a large proportion of our brain. And so it gives us some sense that to try and duplicate the capabilities of the human hand is not a simple task, and that's why working with this [robotic] hand we've had to use a fairly large computer with a large amount of memory and a large amount of computational capability in order to coordinate the fingers. There's a lot of processing necessary to make them move smoothly, make them move with good sensitivity (National Geographic Society, 1985).

Two hands, two discourses. The former hand acquires signification in the language of mid twentieth-century industrialism; the latter, in the patois of late twentieth-century cybernetics, computer science and information theory. The contrast hints at a metamorphosis underway in scientific thinking about corporeal functioning and constitution. A fundamental shift is occurring in the way the human body is conceived of, experienced, represented and regulated. The body, which for three hundred years was likened to the machine, is now increasingly compared to communication/computational technologies. A hybrid body, a fusion of the organism and the computer, is taking shape in scientific discourses. The flesh of late twentieth-century science coalesces around a quantity called information, and physiological functions are increasingly described in terms of the retrieval, input, storage, processing, and output of information.

The constitution of the modern individual as an information processor is an entirely new practice of the self. There was no possibility of a reading of self based on computer technology sixty years ago, for the technology did not exist. The digital computer is a product of cybernetics, the science of control and communication in the animal and the machine. The tendency to merge the organism with the computer is evident in the writings of the founder of cybernetics, Norbert Wiener (1894-1964):

> It is my thesis that the physical functioning of the living individual and the operation of some of the new communications machines are precisely parallel in their analogous attempts to control entropy through feedback (quoted in Roszak, 1986, pp. 9-10).

The computer is the most recent technology to redefine the boundary between technology and the human person. Every civilization, J. David Bolter writes, "possesses a characteristic set of materials, techniques and devices that help to shape its cultural outlook" (1984, p. 16). These he calls *defining technologies*: technologies that capture the imagination of thinkers and reform their ideas about nature. Bolter records the technologization of the human person by studying historically and culturally specific technological metaphors for the self: in Ancient Greece through to the Middle Ages, manual and craft technologies (spinning, pottery and carpentry); from the Renaissance until the mid-twentieth century, mechanical technologies (the clock, automaton, the steam engine, the factory); and, beginning in the late twentieth century, the computer. Bolter contends that throughout Western history certain materials, techniques and devices have acquired sufficient explanatory power to alter the metaphysical intuitions of a culture. Using the categories and concepts suggested by these technologies, people have produced new theories about self, nature and the relation between the two. Like all other technologies, defining technologies alter the physical means of life; but in addition, they establish new epistemological frameworks. Their effects are felt materially *and* symbolically.

In this thesis I recount the influence of three defining technologies — the manual crafts, the machine and the computer — on Western scientific ideas of bodily structure and functioning. I outline the movement and absorption of certain technological ideas into scientific discourses and the concomitant merging of these technologies with our bodies. This thesis asks how technologies are represented linguistically, how new systems for making sense of our bodies are produced, and how the new representations/self-representations achieve the status of truth. In short, this thesis chronicles technological interpretations of the human body.

II. A History of the Body

Since the seventeenth century the Western intellectual tradition has assumed that there exists an objective, substantive reality that may be divined by applying the analytical techniques of science. This assumption, which is rooted in the epistemology of René Descartes and has nourished the rationalistic branches of modern (Cartesian) philosophy, projects the human body into the realm of the material, the biologically given, and the natural (Jaggar & Bordo, p. 4). In the modern age the body is posited as a tangible "fact" whose secrets are revealed only to specialists in the life sciences.

But is a scientific description of the human body more privileged than others, or is it just one explanation among many (Jacobus, Fox Keller, & Shuttleworth, p. 7)? The idea that the body is amenable only to scientific analysis is deeply engrained in Western commonsense, and the notion that the body might be subject to historical analysis strikes many people as absurd. During an early stage of this research, I explained to a medical doctor my interest in historically-specific technological metaphors for the body. "In a sense," I said, "I'm studying the history of the human body." He shot back, "Rubbish! The human body has no history!" His objection was that only positivistic science could properly claim to investigate bodily phenomena. Further, he insisted that the body should no more be dignified with a history than animals, trees, or other "natural" objects. Histories are written about human beings, not human bodies. The vicissitudes of the lives of actual people living in the real world is the stuff of history. By virtue of its being a natural object amenable to the laws of physics and chemistry, the body is beyond the pale of history.

Over the past two decades, cultural critics, feminists, and artists have, without denying the merits of a scientific perspective on the body, emphasized the body's historicity. In so doing they have contested the naturalness of the bodies produced by scientific discourses. In body historiography the body is never coded as natural; it is understood as a historical category that must be interpreted through the lenses of the cultures that apprehend it. A history of the human body chronicles the modes by which the body has been socially constructed. This approach does not deny that "real" bodies exist, but reminds us that our beliefs about reality are grounded in the social organization of knowledge. Cultural practices lend the body shape and substance. Far from being a fixed biological reality or a part of nature, the body is studied as a cultural artifact and an object of knowledge. A history of the modes of its construction turns "the body into a thoroughly historicized and completely problematic issue" (Feher, 1989, p. 11).

Michel Feher suggests a double strategy for writing a history of the human body: (1) compare earlier and foreign constructions with those perceived today; and (2) study the transformations that affect body techniques and the new problems that these practices suggest. Thus the task ahead is to highlight cultural practices that have activated new ways to interpret the body; to show what knowledges have been produced; and to suggest the implications of these new knowledges.

III. Thesis Organization

This work is an attempt to build on Bolter's. I augment his notion of defining technologies by attending more closely to the processes by which social subjects "absorb" the technologies they encounter. The questions that interest me include: how is one version of commonsense knowledge (e.g., the body is like a machine) replaced by another (the body is like a computer)? What power animates an idea (the idea of the computer) so that it is able to reach into people's bodies, colonize them, and finally, be taken as natural? How is this "truth" about the self reinforced and extended?

I contend that new knowledge is generated in the borderlands between conceptual categories. In this thesis I attend to tensions between the dichotomies that structure scientific discourses. According to Bolter, defining technologies redraw the line between "person" and "nature" — this is Bolter's crucial demarcation. However, as Bolter points out, the categories "person" and "nature" are themselves slippery, and the very fluidity of the boundary evinces the historical and cultural specificity of the concepts. In this thesis I turn my attention to other dichotomies, their changing meanings, and the traffic of ideas across conceptual divides. Thus I attend to dichotomies such as vitalism/mechanism, animate matter/inanimate matter; science/mysticism; matter/mind; and, of course, technology and the body.

Each chapter represents a technological and epistemological shift. I show that knowledge about the structure and functioning of the body is organized by the ideas and categories suggested by the defining technologies of the age. However, somatic knowledge cannot be properly understood outside the context of the philosophy and science that gives rise to it. Thus a prerequisite for understanding the "bodyview" engendered by a particular technological imagination is to understand something of how authoritative discourses have construed "reality."

Thus, in each chapter, I locate bodyview within its worldview. I define worldview as the set of fundamental beliefs and practices that explain reality and delineate what knowledges are possible. The principles and practices that constitute a worldview establish the grid of intelligibility through which people interpret the cosmos, the world, and in general, why things are as they are. Similarly, I define bodyview as a collection of core beliefs and practices that turn the body into an object of knowledge. In each chapter I expose the connections between bodyview and worldview.

In this account there are no sudden "paradigm shifts" to a new normal science. At each juncture there are both continuities and disruptions. For example, the mechanical sciences that arose in the seventeenth century were built squarely on the foundations of the older organicist sciences. Organicist principles were, in some cases, merely translated into a mechanistic vocabulary. Yet the new mechanistic sciences suggested an entirely different way to perceive reality. Both the transitions and the continuities must be taken into account if historical theories of corporeality are to be properly understood.

I begin in the remote past. In Chapter 2, *The Pre-Mechanistic Body*, I illustrate the worldview and bodyview of ancient and medieval Europe through a reading of the *Timaeus*, Plato's cosmological myth. The myth is an early source of technological ideas about the cosmos and the body, one which profoundly influenced later thinkers. Plato invoked the craft technologies of his age — spinning, pottery, carpentry, and tool making — to explain the universal order. In Plato's creation story, the gods are artisans who fashioned the world and the bodies of men. The gods' knowledge of divine technologies — alchemy and magic — enabled them to enliven their handiwork. The universe and everything in it was compounded from elementary substances and brought to life by alchemist/magician-gods.

Chapter 3, *The Body as Machine*, is concerned with the discursive evolution of the human body from the supernatural product of manual technologists to a machine. This chapter is critical, for in it I depict the dominant Western worldview and bodyview from the seventeenth century until the present. Together, the mechanistic worldview and bodyview establish the epistemological ground from which the West tends to interpret reality. In this chapter I describe the symbolic reordering of reality occasioned by the change from a science based on animist principles to one founded on mechanism, and how this development affected notions about the structure and functioning of the human body.

In Chapter 4, *The Body as Computer*, is about twentieth-century scientific discourses that organize new corporeal understandings. Cybernetics posits that the human body, on a fundamental level, is a "machine" for processing information and therefore, analogous to the digital computer. I locate bodyview in the context of the emerging post-Newtonian worldview. My aim is to document the emergence of new understandings of somatic organization and operation that are informed by the conceptual categories suggested by late-twentieth-century information technologies.

I conclude, in Chapter 5, with a suggestion on how to enrich Bolter's notion of defining technologies. Applying the approach, I speculate on the implications of two different cybernetic repatternings of the human body.

IV. Limitations of the Study

In attempting this project, I was acutely aware of the problem of attempting to translate, as it were, the knowledges and beliefs of the cultures of other places and times into terms comprehensible to a reader living in the present. How can the theories of the distant past be faithfully represented in the languages and conceptual categories of the late twentieth century? Since I am not a scholar of the Classic, Medieval or Renaissance periods, my attempts to understand the various demarcations I explore in this thesis (nature/culture, human/non-human, technology/bodies, and so on) have been, of necessity, drawn principally from secondary sources. My readings of bygone interpretations are already interpretations.

Similarly, the meanings of the categories of which I speak — science, mysticism, nature, culture, technologies, bodies — are not fixed, but historically and socially specific. The meanings of each of these terms has shifted substantially over time, a problem compounded by the fact that the meanings of each have changed *in relation* to the others. Errors of presentism (the writing of past history in terms of the present) have, inevitably, crept into my writing.

To compensate for these limitations, I have attempted to research and write genealogically. Genealogy refers to the method of historical analysis employed by Michel Foucault in his later works to record the history of interpretations. Foucault emphasized that intellectual history is not a history of ideas, but the history of the rituals of power that uphold the valourized interpretations. While my method is probably best characterized as a critical reading of historical texts, my approach has been informed by Foucauldian analytics.

Much of this thesis consists of descriptive overviews of influential systems of thought that have produced new theories about the body. The desire to portray the whole of "Greek scientific thought" or "European Mechanistic Philosophy" is a danger. I know that I risk oversimplifying or essentializing diverse historical eras, peoples, philosophies, mythologies, cosmologies, sciences, and systems of knowledge. Undoubtedly, my choices of textual resources have skewed my interpretations. I cannot hope, nor do I claim, to provide a definitive reading of any past epoch. Foucault is helpful here, to a point, in his articulation of the power/knowledge nexus. A definitive reading is illusory; truth is never "outside power, or lacking in power." We always operate within ideology. Methodologically, this means shifting attention from the ideas themselves to the social relations that *produce* the ideas. Thus I have made little attempt to ferret out truths about the body. Instead I have tried to draw attention to the struggles over the meaning of the body.

In addition, my study is circumscribed by the gendered, Eurocentric biases of many of my sources. The texts I drew upon were mostly written by men or from a masculinist perspective, and few of the authors mention the contributions of Jewish and Islamic scholars on the development of Western scientific thought. I have tried to address these limitations by including, where possible, footnotes and parenthetical comments to draw attention to these absences.

Chapter 2

The Pre-Mechanistic Body

> He put bone together as follows. He sifted out earth that was pure and smooth, kneaded it and steeped it in marrow; next he placed it in fire and then again into water, then back into fire and then again into water, and by this repetition of the process tendered it insoluble by either. From the resultant substance he formed a spherical bony sphere to contain the brain...
>
> — Plato, pp. 101-2

I. Introduction: Chapter Overview

Chapter 2 is an encapsulated view of the body from Greco-Roman antiquity until the Renaissance. Both the subject and time frame are vast, and I do not pretend to present an encyclopedic history of the body for this period. My goal here is to portray, in broad strokes, what I believe to be the most salient features of the pre-mechanistic body. However, the human body cannot be deciphered outside of the system of rationality that makes it comprehensible. Therefore it will be necessary to sketch the contours of the pre-mechanistic worldview.

Characterizing a worldview, too, is a monumental task, but a simplification is possible. To illustrate the worldview and bodyview prevalent in Western Europe prior to the Renaissance, I consider the defining technologies of ancient and medieval Europe. Spinning, pottery and carpentry are Bolter's candidates for the defining technologies of the ancient world; to his list I add two other technologies that helped to organize pre-mechanistic discourses on nature: alchemy and natural magic — sublime technologies of physical and metaphysical mixing.

I illustrate the pre-mechanistic body primarily (but not exclusively) through a reading of the *Timaeus*, Plato's (ca. 428-ca. 348 BCE) cosmological myth. I chose the

Timaeus for three reasons. First, the myth is an early source of technological ideas about the cosmos and the body. Plato invoked the technologies of his age to explain the universal order. Throughout, God is described as a craftsman, a maker and a fashioner. He and his demiurges (lesser gods created by God) were spinners, potters, carpenters, farmers, and tool makers who first framed the body of the world, then the bodies of men. (Women and animals were made later.) But it was the demiurges' knowledge of alchemy and magic, I will argue, that enabled them to animate their handiwork. According to Plato, the world and everything in it was compounded from elementary substances by alchemist/magician-gods.

Second, Plato's cosmology affords a view (albeit distorted through the darkened lenses of time and place) of "science" (natural philosophy) prior to the rise of mechanistic philosophy. The *Timaeus* is Plato's rational account of a divine creation. Many of his ideas were derived or borrowed from earlier and contemporaneous thinkers, and as such, the *Timaeus* reflects, in the main, the assumptions that underwrite the physics, psychology, astronomy, physiology and medicine of his day. From the Hellenistic age until the Renaissance, natural philosophy was built on the organicist, animist and vitalist foundations reflected in the *Timaeus*. The universe was regarded as a living animal, and all it contained was seen as alive. These early ideas about nature stood in sharp contrast to those that emerged during the Scientific Revolution, when a new picture of reality gradually came into focus. Based on a philosophy of mechanism, nature was likened to a machine: the universe consists of lifeless matter and motion that obeys mathematical laws.

Third, the *Timaeus* was an extremely influential document in the development of European thought. The work was known in Antiquity, and two different Latin translations survived the collapse of the Roman Empire. Most important medieval libraries possessed one or both editions, and consequently, the *Timaeus* was studied and quoted throughout the Middle Ages. It was Plato's only dialogue — and one of the few works of Greek antiquity — known in the West during the "Dark" and early Middle Ages (Lee, in Plato, p. 7). For over a thousand years the work exerted greater influence than anything else in Plato. Both neo-Platonism (the dominant European philosophy between CE 250 and 1250) and early Christianity accepted the authority of the *Timaeus*. Despite Plato's polytheism, Church fathers easily assimilated Plato's creator-god into the god of Genesis. After the thirteenth century, when Platonism and neo-Platonism were eclipsed by Church Aristotelianism, Plato's theology remained vital in gnostic and hermetic thought. The humanist revival of classical scientific and medical texts was stimulated, in part, by the undercurrents of Platonic philosophy that had survived in the Latin West. The cosmological outlook of Renaissance luminaries the likes of Copernicus and Kepler can be traced, in part, to their familiarity with the *Timaeus* and/or Platonic philosophy (Klibansky in Plato, p. 22; Debus, 1978, p. 11). In addition to providing a creation myth, the *Timaeus* is the source of the Atlantis legend. Plato's precise descriptions of the antediluvian world incited the imaginations of hundreds of authors from the nineteenth century onward. Owing to its influence on ancient, medieval and modern European thought, the impact of Plato's cosmology can be said to be continuous from its publication until the present (Lee in Plato, p. 7; Russell, p. 157).

A cosmology, by definition a theory about the origins of the universe, is implicitly a theory of nature. The *Timaeus* is not scientific in the modern sense of the word, but the myth does suggest the epistemological ground from which people interpreted their world. Contained within Plato's creation myth, like tiny invisible seeds, are many assumptions out of which rational explanations of the world have grown. It is these germs of knowledge I consider here, for they imply culturally and historically specific ideas about *physis* (nature). What assumptions vitalized a pre-mechanistic discourse on nature? What are the unacknowledged knowledges — the unseen and unspoken beliefs — that lie buried in the pre-modern worldview and bodyview?

I use the *Timaeus* also to illustrate macrocosm and microcosm from the Hellenic period to the Renaissance. Conceptions of nature that originated with the Greeks coloured early Europe's understanding about the body. Plato's cosmology authorized the metaphysical presuppositions that underwrote these ideas. My object is to reveal the metaphysical "glue" that held together ancient and medieval theories about the universe and the body by enumerating the interlocking knowledges that lent them shape and substance. In this way, pre-mechanistic conceptions of bodily constitution and functioning are elucidated.

I do not regard this exercise as the search for the origins of the idea of the body as defined by a particular technological imagination. I view the *Timaeus* not as a source of technological metaphors, but as a point of discursive production. It is not the metaphors themselves that are of concern, but the grid of intelligibility and the rules for deciphering that the metaphors lay down. I assume that Plato's rhetoric reflects the requirements of a "rational" discourse on nature; it is Plato's system of rationality that I try to render intelligible

II. Theory of Ideas (Underlying Forms)

A key assumption of ancient Western philosophy is the belief in the reality of underlying Forms (or Ideas). Plato's theory was a synthesis of Heraclitus' doctrine that nothing is permanent in the sensible world, and Parmenides' belief in a timeless, changeless reality (Russell, p. 123). The Platonic theory of Ideas had enormous effect upon subsequent ages. The persistent dualism so deeply etched in the Western outlook continually affirms the influence of Plato's theory of Ideas on later thought: Aristotelian philosophy, neo-Platonism and Christianity are but three major philosophical systems that borrowed and built on Plato's dualistic doctrine.

The terms of Plato's theory of Ideas were set out in the beginning of the *Timaeus*. Plato distinguished two separate orders of reality: Ideas (or Being) — pure, eternal, unchanging thoughts in the mind of God; and Opinions (or Appearances) —

Ideas imperfectly perceived by mortals. To know reality, one must have knowledge of something that actually exists. Only that which is eternally unchanging is real. The world as presented to the five senses is not fully real, for sensory impressions are subject to interpretation. The physical world is but a secondary reality, and knowledge of it is bound to be imprecise (Lee, in Plato, p. 40). No knowledge of reality can be obtained empirically. On the other hand, Ideas are real, for they are eternally the same. Only intelligence, aided by reason, can apprehend truth (p. 40). Intelligence and reason are the organs of perception of the soul.

Ideas are archetypes of all that is experienced and known in the physical world. Consider an apple. It might taste sweet, or appear red, large or spherical; but these judgments say nothing of its reality. At other times, under different conditions, or to other people, the same apple might seem tart, or orange, or small, or pear-shaped. The senses provide opinions, not fixed knowledge about the apple. Its reality exists in the mind of God as the ideal, transcendental Apple; or as the irreducible qualities of Redness, Largeness, Roundness, and so on.

Plato writes of Ideas both as ideal models and as pure abstractions. In the *Timaeus* Plato portrays the created world as an imperfect copy of a divinely-conceived archetype. The world itself is not eternal, "for it is visible, tangible, and corporeal, and therefore perceptible by the senses" (Plato, p. 41). The demiurges who crafted the world looked to the celestial blueprint for guidance. The world was "constructed on the pattern of what is apprehensible by reason and understanding and eternally unchanging" (p. 41). Plato's heavenly ideals are numbers, triangles and geometric proportions, and things in the sensible world are replicas of or are made up of these perfect forms. Goodness, beauty, regularity and exactitude index the proximity of an object to its ideal, which is godly perfection (Dijksterhuis, p. 76).

Many pre-modern philosophical and religious systems adapted or modified Plato's theory of underlying forms. Aristotle, whose philosophical system formed the backbone of ancient and medieval science, rejected Plato's rationalism in favour of a more empirical approach to knowledge. He opposed Plato's dichotomy of perfect forms and imperfect appearances, proposing instead that form existed in individual objects rather than in a separate transcendent level of reality (Merchant, p. 13). Later, the contrast between eternal ideas and the transient objects of the senses became the starting point for much neo-Platonic speculative enquiry (Flew, p. 273). Christian beliefs about the immortality of the soul also had their origin in Plato. Both Platonism and Christianity regarded the sensible world of time and space as less substantive than a perfect level of reality. For Plato, otherworldliness was metaphysical: truth, beauty and wisdom were to be found in the suprasensible realm of ideas. For the Church fathers, otherworldliness was temporal: the afterlife.

A more enduring legacy of the ancient belief in underlying forms is the belief that mind (or soul) and body are separate. Implicit in the theory of Ideas is the view that there exists two independent, separable, irreducible, unique realms (Angeles, p. 66), one perceived by the mind or soul, the other by the bodily organs of perception. In the *Timaeus*, flesh is subordinate to the soul, for God created the soul before the body. Ancient and medieval science applied the doctrine of mind-body duality to all departments of nature. All matter, it was believed, consisted of a material substance infused with mind or spirit.

III. An Organicist Natural Philosophy

Natural philosophy before the Renaissance was, for the most part, animistic and organicist: animism assumes that matter is alive; organicism explains phenomena on the basis of an analogy to living things. Both imply that the cosmos is a vast creature; that everything is in some sense alive and sensitive; that matter is imbued with a vital, nonmaterial spirit (mind or soul); and that all objects possess psychologies (or consciousness). Organicism also implies that wholes cannot be broken down into pieces; that the function of the whole causes and coordinates the activity of the parts; and that the parts that constitute a whole (body, society, and so on) are crucially interdependent. These ideas were upheld, in various forms, by virtually all Greek, medieval and early Renaissance thinkers.

Technological Context of Ancient and Medieval Europe

My aim here is to show how the defining technologies of the ancient world substantiated a belief in a living universe. My argument will unfold in three stages: first, I will review the technological context of the ancient world and identify the defining technologies. Then, I will show how the character of these technologies substantiated a teleological understanding of nature. Finally, I will outline the implications of animistic natural philosophy on an understanding of the cosmos, the heavenly bodies, the earth, society and the human body.

Technology, as I use the word here, is to be understood as people's efforts to control the environment in which they live and work. All technologies have a source of power, and a means for regulating, controlling, or focusing the power in order to perform work. For example, a mechanical watch receives power from a tensed mainspring; the energy of the spring is controlled by an escapement or other mechanical regulator. A refrigerator is powered by electricity; its temperature is regulated by a thermostat. In purely instrumental terms, any technology can be resolved into vectors of power and control.

Consider both the technological landscape of Plato's Greece, and the means by which its technologies were powered and controlled. The intellectual and artistic achievements of the Hellenic Age notwithstanding, mainland Greece remained primarily an agricultural and seafaring civilization (Russell, pp. 29-30). Wheeled transportation was rare (Bolter, 1984). Devices to harness the energies of nature (power technologies) had not yet been invented. The clock and other autonomous technologies (machines that contain their own principle of motion (Beaune, p. 431)) were scarcely conceivable. Metallurgy was still in its infancy. The availability and cost of raw materials limited what could be conceived of and built. Iron was far scarcer in the south of Europe than in the north, and consequently, the metal was hardly used in Greece and Rome (White, p. 40). The basic concepts of Newtonian dynamics — mass, velocity and acceleration — would have been utterly incomprehensible (Lee, in Plato, p. 13). In other words, ancient Europe possessed little of the technological imagination of later times. The mental framework necessary to receive mechanical and industrial ideas simply did not exist; and once the ideas were glimpsed, they spread very slowly. Lynn White Jr. demonstrates that the incorporation of new technological innovations into people's ways of thinking sometimes required hundreds or thousands of years. The mechanical crank, for example, "is extraordinary not only for its late invention [between 816 - 834], or arrival from China, but also for the almost unbelievable delay, once it was known, in its assimilation to technological thinking" (White, p. 110).[1]

Ironically, the Hellenic age invented many of the technical aids that were to figure prominently in late medieval and early Renaissance reconceptualizations of nature. Hero of Alexandria constructed a miniature windmill and a working steam turbine, but these devices were regarded as little more than toys. The cam and the three basic gear systems (star, crown and worm) were devised by the Greeks, but were not developed into sources of power. These devices left no impression on subsequent technological developments (White, pp. 79-80), and were not defining technologies in their time.

What, then, were the defining technologies of the ancient world? What devices, materials and techniques sparked the imaginations of contemporary thinkers and suggested themselves as explanations for the workings of nature? In Greece and Rome, says Bolter, the defining technologies were those associated with the crafts —

[1] The conceptual difficulties posed by the crank might possibly relate to the ancient conviction that continuous rotary motion was appropriate only to heavenly bodies, while rectilinear and reciprocating motion were thought natural for things living in the sublunary plane. To use a crank, our tendons and muscles must relate themselves to the motion of celestial objects, an exercise from which humans long recoiled (White, p. 115). The technological imagination was bounded by the assumed predispositions and limitations of the flesh. (A description of sublunary-supralunary theory appears on page 69.)

the manual technologies. Greek artisans used potter's wheels, lathes, drop spindles and the like; their primary materials were clay, wood and wool. Carpentry, pottery-making and spinning are Bolter's candidates for the defining technologies of pre-Renaissance Europe. "In the ancient world," Bolter writes, poets and philosophers

> observed the drop spindle and potter's wheel and were struck by the use of rotary motion and of human or animal power. From these observations came support for the rotating universe, the animate nature of the stars, Aristotle's theory of form and matter (pp. 16-7).

Typically, a spinner, potter, or carpenter worked a material by *setting it in motion*. Then, guided by an image of the desired product, the craftsperson drew out, cut, shaped, or otherwise modified the material until it conformed, more or less, to the original idea. Control over the creative process was exercised by the artisan's intellect. The power to set the material in motion was supplied by the artisan, slaves, or animals. The manual technologies were controlled by an exercise of the will; their ultimate source of power was the body of a living creature. Before machines developed into significant forms of power (during the late Middle Ages), the body was the prime technology in Western Europe.

Movement and Life

The living creature's ability to initiate motion was key in pre-mechanistic formulations of nature. Movement was seen as a sign of life. Humans or animals moved so long as they lived. Therefore, whatever moved — or whatever was capable of imparting motion — was alive. Viewed from the present, the link between motion and life seems simplistic because non-living locomotion is part of our daily experience; autonomous machines are integral to modern industrialized societies. But in the ancient world, all work was performed by virtue of muscles,[2] not mechanisms.

[2] Muscles are "the contractile fibrous bands or bundles that *produce movement in [the] animal body*" (Concise Oxford Dictionary, 1984, my emphasis).

The association between motion and vital activity carries with it the idea that movement must be caused: motion results from the application of a force to an object. Increase the force and the object moves faster; remove the force and motion stops altogether. This assumption is explicit in Plato: "For it is difficult, or rather impossible, for what is moved to exist without what causes its motion" (Plato, pp. 81-2).[3] Plato recognized both external and internal causes of motion. The external cause, *necessity* (or *mechanical necessity*), occurs when one body collides with and imparts its motion to a second. Things that happen by necessity are chaotic, are subject to no law, and serve no purpose or reason. The internal cause is self-propelled motion, motion originating in the thing itself and not imparted by any outside thing (Russell, p. 159; Angeles, p. 180). The internal cause of movement is the soul — movement initiated by an act of will (Plato, pp. 64-5, p. 96). Soul (or mind) is the only self-mover. Every self-moving body embodies a non-material principle which is regarded as the essence of its reality.

Plato accepted both necessity and mind as causal agents; but of the two, he ascribed greater importance to causes that operate intelligently (Plato, p. 64). Aristotle built his entire scientific edifice on the same assumption. He defined nature (*physis*) as "the source of movement of natural objects, being present in them either potentially or in complete reality" (Merchant, p. 11). The assumption that intelligent causes take precedence over mechanical causes persisted in Western science for the next 1500 years; it was overturned during the Scientific Revolution.

A Teleological Science

Thus the sciences of pre-Renaissance Europe constructed reality teleologically. Natural phenomena were explained not by means of prior causes, but by ends, aims,

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[3] Aristotle also took this position. He taught that a projectile launched at an angle to the earth follows a perfect straight-line trajectory. Vortexes in the air buoy it up to keep its path true. After reaching its zenith, the projectile immediately drops perpendicularly to the earth. In fact, a projectile follows a parabolic trajectory, and air hinders, not assists, its motion. The Greeks had no notion of momentum, i.e., a quantity of motion related to its mass, that keeps a body moving once the motive force is removed, nor could they conceive of air as a retarding force. In Newtonian physics, momentum keeps a body in linear motion *until* the body is disturbed by an external force.

or intentions. Nature does nothing in vain; nature is purposeful; nature always moves toward goals. Every object has its "natural" place, the place it belongs "by nature." It is the nature of heavy objects to seek the centre of the earth, and the nature of smoke to rise to the heavens. A body "knows" its place, and naturally endeavours to return there. An object accelerates as it approaches its destination. The sun's nature is to traverse the heavenly orb; a human's, to walk on the ground; a tree's, to be rooted in the earth. *Physis* also has to do with growth, with changes in size or quality. It is the nature of an acorn to grow into an oak tree; the oak tree is its end, the sake for which the acorn exists (Russell, p. 214). Nature belongs to that class of causes that operate for the sake of something (p. 215). In a sense, future events "cause" present ones. A will, mind, or intellect directs all of the processes of nature.

Nature was seen as a vital force, the source and fashioner of all living things (Taylor, p. 8). From the Hellenic era onward, nature was thought alive. Collingwood remarks:

> For the early Greeks quite simply, and with some qualifications for all Greeks whatever, nature was a vast living organism, consisting of a material body spread out in space and permeated by movements in time; the whole body was endowed with life, so that all its movements were vital movements; and all these movements were purposive, directed by intellect (quoted in Bolter, p. 23).

In general, the worldview of ancient and Medieval Europeans was animistic, organismic and vitalistic. "[O]ur world..." wrote Plato in the concluding paragraph of the *Timaeus*, "is a visible living creature, it contains all creatures that are visible and itself is an image of the intelligible; and it has thus become a visible god, supreme in greatness and excellence, beauty and perfection, a single, uniquely created heaven" (1981, p. 124).

IV. God as the First Cause

How did the living universe come into existence? In Plato's cosmology, the first cause is God. Movement (or activity) betokens life, and God is the originator of all movement. Plato believed in a complementary relationship between activity and repose; one cannot exist without the other (Plato, p. 82). Therefore the originator of motion must *itself* be unmoved. God is, in Aristotelian terms, the "unmoved mover" (Russell, p. 180) who created a living cosmos. The moving (and therefore living) universe is the handiwork of a divine artisan.

The *Timaeus* was the first Greek account of a divine creation (Lee, in Plato, p. 7). In describing the deity as a craftsman, Plato introduced a new image for God. Earlier Greek cosmologies had been either mythological (the origin and development of the universe were explained in the language of sexual reproduction and growth) or evolutionary (the universe was accounted for in terms of unplanned development arising from its material organization). Although elements of the earlier tropes survive in the *Timaeus*, Plato's myth introduced the idea that the cosmos was brought into existence by the deliberate, constructive activities of God (p. 8). The demiurges, using their hands or simple tools, worked the raw materials of the primordial universe to create order, symmetry, beauty, goodness and purpose. Drawing on the thoughts of earlier cosmologists, Plato synthesized an enduring divine artificer.

Mythological cosmologies were premised on the belief that matter grows into the world by virtue of an inherent reproductive power (Lee, in Plato, p. 8). Hesiod, for example, wrote of gods and goddesses who begat children, and of the earth who gave birth to "high mountains and unharvested sea" (quoted by Lee, in Plato, p. 8). Storyteller Beulah Swayze (p. 3) summarizes a number of early Greek cosmologies like this:

> Out of Chaos emerged Earth, the mother of all, Uranus the Sky and the depths of the Underworld. Earth, by her own efforts, caused the

> mountains, valleys, trees, beasts, birds and fishes to appear. But it was from the mating of Earth and Sky that the first monsters were born...

A different tradition, originating in the fourth century BCE, yielded an altogether different understanding of nature. Atomism was an early attempt to posit a naturalistic science free of supernatural and occult influences. Leucippus (450-420 BCE) and his younger contemporary Democritus (460-370 BCE) produced the first unequivocally atomistic cosmology (Flew, p. 203). The atomists sought to explain the world without introducing the idea of purpose or final cause (Russell, p. 84). To the atomists, the world and its processes are entirely attributable to lawfully operating material forces. Everything that occurs is due to necessity. Such accounts exclude the principles of intelligence or design from the worldview; the world is a product of unplanned development arising from its material organization.

The *Timaeus* is an assertion of the opposite view: the power behind the universe is divine purpose. Plato's cosmology is a theological and teleological account of the origins of the world and of the phenomena of nature (Lee, in Plato, p. 7). The story needs a creator to prove the intelligibility of the universe. Plato believed that the universe was comprehensible because we can, after all, understand it. Plato accounts for the intelligibility of the cosmos by positing a divine intelligent force underlying it.

God is the architect of the cosmos and its sustaining cause. His enduring existence guarantees the persistence of the universe; if God were to withdraw his support, everything both animate and inanimate, would "collapse into non-existence" (William Temple, quoted in Flew, p. 80).

In Plato's cosmology, God creates and sustains a living universe. The organicist and animistic predilections of pre-mechanistic science are apparent in Plato's descriptions of the creation of the cosmos, the heavenly bodies, the earth and the bodies of men and women.

The Cosmos

God "created a single visible living being, containing within itself all living beings" (Plato, p. 43). Like a living creature, the cosmos is "visible, tangible, and corporeal" (p. 41), but because of its excellence and completeness Plato ascribes it the status of "a blessed god" (p. 46). God ensures the continuity of his creation by making it totally self-contained, for "it was better for it to be self-sufficient than dependent on anything else." The creator gave the universe no eyes, for "there remained nothing visible outside it;" no ears, for there was nothing audible beyond its outer edge; no nose, for "there was no surrounding air which it needed to breathe in;" no mouth nor organs of digestion, for the animal "was designed to supply its own nourishment from its own decay." The universe needed no hands "as it had no need to grasp anything or defend itself," nor feet or legs, for its natural circular motion befits a god (pp. 45-6).[4]

God turned the body of the divine animal as a carpenter turns wood on a lathe. Thus he created an orbiting (i.e., moving and therefore living) sphere (p. 46), "a figure that has the greatest degree of completeness and uniformity... and gave it a perfectly smooth external finish all round..." (p. 45). The demiurge produced the material of the world-soul by a complex process of metaphysical and mathematical measuring, cutting and mixing. He wove together world-soul and body, thus diffusing the soul throughout the body (pp. 46-50).

The Heavenly Bodies

Plato describes the sun, the stars and the five planets as living creatures, and tells how the divine Artificer made and bound together their bodies and souls. The sun and planets exist for the purpose of marking time (Plato, pp. 52-5), to provide "a

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[4] There were for Plato seven distinct physical motions: uniform circular motion, up, down, forwards, backwards, right and left. Continuous circular motion, as exhibited by the heavenly orb, the stars, the sun and the moon, was deemed perfect and eternal, and therefore a godly prerogative (Lee, in Plato, p. 45). By contrast, the six rectilinear motions were thought proper and correct for sublunary bodies, i.e., anything that moved within the atmosphere of the Earth, including animals and humans. See also page 69.

moving image of Eternity" (p. 51). The retrograde motion of the planets is accounted for, partially, by the independent exercise of their wills (Lee, in Plato, p. 14).

The Earth

The living Earth, too, was created by God, and acts as foster-mother to the creatures who inhabit it (Plato, p. 55). She is "the first and oldest of the gods born within the heaven" (p. 56). From Greek antiquity until the Renaissance the geocosm (earth) was regarded as alive. It was commonly held that the world-organism reasons, has sensations, and generates other living beings. Springs were likened to blood vessels, and other fluids to sweat, saliva, mucus and other lubricants. Metals and minerals were thought to grow in its veins. A widely held alchemical[5] belief was that base metals grow into gold in the earth's matrices (wombs) (Merchant, pp. 20-7). The earth even had its own elimination system. "The tendency for both [the earth and the human] to break wind caused earthquakes in the case of the former and another type of quake in the latter" (p. 24).

The Bodies of Men and Women

God ordered his demiurges to create man, saying "turn your hands, as is natural to you, to the making of living things, taking as your model my own activity in creating you" (Plato, p. 57). The divine artificers began by binding the immortal soul to the mortal body:

> [They] took the immortal principle of the mortal creature, and in imitation of their own maker borrowed from the world portions of fire and earth, water and air — loans to be eventually repaid — and welded together what they had borrowed; the bonding they used was not indissoluble, like that by which they were themselves held together, but consisted of a multitude of rivets too small to be seen, which held the part of each individual body together in a unity. And into this body, subject to the flow of growth and decay, they fastened the orbits of the immortal soul (Plato, p. 59).

[5] Alchemy is described on page 29.

Evoking images of potters engaged in their craft — or alchemists practising theirs — Plato describes how the demiurges created the human body, starting with the marrow (which is regarded as the substance that houses the soul), the bones and the skull:

> [T]he purest fire, water, air and earth... he mixed in due proportion to produce marrow, as a kind of universal seed for mortal creatures of every kind... and he moulded into spherical shape the part of the marrow... that was to contain the divine seed and called it the brain, indicating that when each creature was completed the vessel containing the brain should be the head... And round brain and marrow, for which he first constructed a bony protective covering, he went on to frame our whole body...
>
> He put bone together as follows. He sifted out earth that was pure and smooth, kneaded it and steeped it in marrow; next he placed it in fire and then again into water, then back into fire and then again into water, and by this repetition of the process tendered it insoluble by either. From the resultant substance he formed a spherical bony sphere (sic) to contain the brain... (Plato, pp. 101-2).

In a similar vein, Plato details how the demiurges put together the rest of man's body. The image of man that emerges is that of a privileged creature. He is the handiwork of alchemist-gods; his structure reflects both the form of the universe (e.g., both skull and universe are spherical) and its composition (e.g., both are made of the same materials). In death, righteous men become one with the stars. Cowardly or immoral men are reincarnated as women. Women's bodies were constructed by the demiurges by piercing a channel through men's bodies. In this view, women are flawed men, both morally and physiologically.[6]

V. The Structure of Matter and Technologies of Mixing

Divine intelligence is at the root of Plato's conception of the universe. The visible cosmos — the heavenly orb, the stars, the sun, the planets, the earth and its inhabitants — were brought into existence by God. But divine purpose alone cannot account for all of creation. Intelligence pervades and vitalizes everything, but there

[6] An incisive analysis of the relationship between scientific conceptions of women's bodies and cultural attitudes toward women appears in Martin (1987). See also Lange (1983); Harding (1986); Jacobus, Fox Keller & Shuttleworth (1990).

is more to the universe than mind-stuff. God crafted the cosmos from physical matter. In pre-mechanistic natural philosophy, matter was utterly unlike its modern counterpart. I will discuss the constitution of matter in a moment, but first, I will consider the ontological status of matter in a living universe.

Ontological Status of Matter

In Plato's portrayal of the universe, matter has its own integrity. Matter is malleable, but not infinitely so. The recalcitrance of matter constrains even God. Unlike the omnipotent God of Genesis who created the universe ex nihilo, the Demiurge manufactured the living cosmos by refashioning the materials found in the primordial chaos. In Plato's philosophy divine purpose and necessity are cooperative causes. Necessity is subordinate to divine purpose, but matter establishes the parameters within which God can operate (Plato, p. 96). Like a human craftsperson, the gods did the best they could given the materials available to them.

The Demiurge and the lesser gods do not transcend the universe, but are rooted in it and bound by its laws. In contrast, the biblical God stands outside of Nature, and nothing limits his sovereignty (Tambiah, pp. 6-7). Intimate knowledge of the laws of nature enabled Plato's deities to shape the universe. In some of the scientific traditions indebted to Platonism, the secrets of nature known to the gods were also intelligible to humans of religious and philosophic miens. Direct apprehension of the super-sensible, unchanging, eternal realm of *Ideas* gave philosophers access to God's thoughts, and thus to godlike powers. Magic and alchemy are examples of divine-sciences practised in ancient, medieval and Renaissance Europe.

Natural Magic and Alchemy

Natural or ritual magic (theurgy) was the empirical science of the properties and uses of plants, herbs, stone and other natural substances (Dijksterhuis, p. 158).

In Renaissance Europe, magicians were charged with the task of explaining the seemingly inexplicable forces of nature — magnetism, magnification and steam power. Magic was integral to neo-Platonism, the dominant European philosophy between circa 250 - 1250 (Flew, p. 244). Neo-Platonic natural magic presupposed a hierarchically structured cosmos, and assumed that terrestrial changes were influenced by the celestial heavens and could be produced artificially by human manipulation of natural objects, in which these influences inhered (Merchant, p. 105). Renaissance magicians conceived of nature as a vital or magic force that could be tapped and directed to achieve practical goals. The magician's powers were thought to be natural, God-given and available to all (Boas, p. 21). Magic was closely associated with religion, for the search for the hidden truths in created nature led the practitioner to greater knowledge of the Creator (Debus, p. 137).

Alchemy was an ancient and medieval philosophy combining an occult cosmology with practical chemical experimentation. It originated independently in China and Hellenistic Egypt, and remained a legitimate and recognized branch of philosophy in Europe and the Islamic world for more than 1500 years. Alchemists attempted to replicate the chemical keys of life. The universal panacea, the elixir of life, and the means of transmuting base metals into gold were three of the powers sought by practical alchemists (Flew, pp. 8-9).

In the *Timaeus* the demiurges were alchemists and magicians, masters of matter, and interpreters of the secrets and hidden powers of Nature. The deities' knowledge of metaphysical, numerological and physical mixing enabled them to enliven the chaos. A complex technology of combinatorials explains how the cosmos was made. In describing the manufacturing of nature, Plato demonstrates an overarching concern for proportion and number. In a living universe, all parts must hold together if the integrity of the whole is to be maintained. Therefore constituent elements must be present in proper mathematical and geometrical balance. Mixing and blending describe how matter holds together. Magic and alchemy were technological explanations of the way nature was thought to work.

Plato's origin story lies within the organicist framework of the mythological cosmologists, but also rests partially outside it. The traditional gods of Greek religion were the progenitors of nature; nature was borne of their bodies. Plato shifted the emphasis from the reproductive capacities of divine bodies to the productive possibilities of divine hands and minds. Plato ascribed to God the power to fashion a living universe. The artisan metaphor is compatible with the organicistic framework, but marks a decisive break with it: nature is no longer born alive; it is *made* alive.

Plato retained the animistic and pantheistic flavours of the mythological cosmologists, but merged them with the evolutionary cosmologists' belief in mechanical necessity. The effects of this synthesis were far-reaching, for Plato assigned to matter a new ontological status. In a purely organicistic framework, matter was inherently alive; now, matter was only potentially alive. Plato's philosophy deprived matter of some of its former vitality, rendering it passive, modifiable by human agency. The *Timaeus* authorized the belief in a kind of Nature that could be technologically altered.

Neo-Platonic natural magic and alchemy are two expressions of the urge to manipulate Nature that flourished during the Middle Ages. Beginning in the Renaissance, the project of control over nature assumed a new direction when Humanist scholars overlaid the old sciences with a new mechanistic understanding. Modern science was the eventual outcome of the grafting of mechanistic sensibilities onto a devitalized Nature. Both the ancient occult practices and modern science sought to tap the inherent energies of nature (Berman, 1990, pp. 222-3).

In Plato we see an early instance of science's propensity to blur and blend *physis* (all that occurs in the natural order of things) and *techne* (all which is created by humans) (Angeles, p. 213). Technologies — artifacts, materials and techniques — become incorporated into discourse on nature; but by the same token, the discourses became ontologically dependent on these technologies. A culture's defining technologies become so deeply etched into its explanatory strategies that it becomes difficult to construct rational explanations of nature in any other terms.

The Constitution of Matter

Let us return now to the question of the composition of matter to observe how knowledge about matter, from Greek antiquity until the Renaissance, was justified in terms of alchemical and magical mixing.

Elementalism

The handiwork of God — the physical universe — was understood by Plato to be composed of elaborate mixtures of four mystical elements: Earth, Air, Fire and Water. Elementalism was a key assumption of ancient and medieval natural philosophy, and remained pivotal to explanations of the physical world until the seventeenth century. A fifth element, variously known as ether, quintessence, pneuma, or the non-limited, was believed to be latent in, or a pure substratum of, the others. Alchemists equated the fifth element with the *prima materia* (first matter) from which the rest of the world was made. Another alchemical interpretation, Aristotelian in origin, posited the fifth element as the material from which the heavenly bodies were made. This "substance" was contrasted with the four mutable elements of the sublunary world. To draw celestial influences to bear upon the earth, alchemists attempted to distill quintessence from the other elements (Taylor, p. 8; Flew, pp. 8-9; Amber & Babey-Brooke p. 13).

The elements were considered primary and irreducible constituents of matter, but were not themselves physical. As fundamental units of matter, elements were unlike atoms. Leucippus and Democritus described atoms as indivisible and impenetrable physical entities that arrange themselves geometrically to give an object its outward form. For Plato, the material world was only an imperfect reflection of the real and eternal world of Ideas or Forms. Whereas atoms were constituent *parts* of matter, elements were constituent *qualities*. Elements were metaphysical, not physical. In the *Timaeus*, the elements were associated with pure Ideas: number, geometry and proportion:

> So god, when he began to put together the body of the universe, made it of fire and earth. But it is not possible to combine two things properly without a third to act as a bond to hold them together. And the best bond is one that effects the closest unity between itself and the terms it is combining; and this is best done by a continued geometrical proportion (Plato, p. 44).

Like numbers and geometric primitives, elements are bridges to a more authentic reality than can be perceived by the senses, and thus forge a link between the suprasensible and sensible planes. One's experience of a hard object speaks only of its appearance. Only the quality "hardness" is real. Hardness, tangibility, and immovability were qualities associated with the element Earth; visibility and movement with Fire (Plato, p. 44). The engrained mathematical and geometrical structure gives matter the illusion of permanence.

All things in the world consist of mixtures of the four elements. There are no unalloyed substances; every material object represents a fusion of the four elements. The elements are not absolute versions of earth, fire, air and water (Grossinger, p. 132). For example, fire (the substance) is not comprised solely of Fire (the element). A flame gives off heat and light because it partakes in elemental Fire's hotness and visibility; but mixed in with the flame is a scintilla of the other three elements.

The unique blend of elements gives an object its distinctiveness. Metals, for example, were thought to consist principally of elemental Water, for heated metals partake in Water's fluidity. Particular metals are influenced by the presence or absence of elements. Gold, for example, is ductile because Fire penetrates the basic structure and makes it mobile; copper is harder than gold because it contains more

Earth, the element associated with solidity (Plato, pp. 83-4).[7] The twinkling of fireflies is attributed to the Fire contained in their bodies (Hall, p. 23). An object's character is entirely determined by the blend of elements. The brittleness of mica, the taste of beets, the scent of hyacinths, the darting flits of hummingbirds, or the lilt in a laugh are all manifestations of the constituting elements (Grossinger, p. 132).

Substances are subject to cyclical transformations, gaining or losing elements as conditions change. The substance water is an amalgamation of elemental Water with lesser quantities of Fire and Air. Atmospheric water joins with elemental Air to give hail; ground water, nearer to elemental Earth, makes ice (Plato, p. 85). In this science, the distinction between object and environment is indeterminate. Objects are always in relation to other objects; matter is continuous with, not separate from, its surroundings. Matter assumes a local aspect based on the relative proportions of occult constituents. The redistribution of elements did not require physical contact between substances. In the same way that a lodestone attracted iron, alchemical reactions and sympathetic magic could occur at a distance. In contrast, atomism always assumes contact between particles, and change is the result of collisions between elementary particles. The "holistic" orientation of Greek science is consistent with the underlying principle of all of the organicistic systems: everything is held together by vital (non-physical) forces. Atomism begins from a different premise: everything may be broken apart.

Humourialism

In the same way that elementalism formed the basis of Western cosmology and science for two thousand years, humourialism beat at the heart of Western

[7] There appear to have been a number of rival element theories in ancient, medieval and Renaissance Europe. A system based on the trinity of Fire, Air and Earth was adhered to by a number of Renaissance luminaries, including Descartes. Both Indian and Chinese science upheld different element theories. Chinese elementalism substituted Wood for Air and added a fifth element, Metal. I speculate that the inclusion of elemental Metal reflects China's relatively advanced level of metallurgical understanding compared to that of ancient Greece (Grossinger, p. 137; Hall, 1970, p. 23).

physiological theory and medical practice. Elementalism was the system by which alchemists explained the composition of matter; humourialism was the strategy by which physicians interpreted health, diseases of the mind and body, and temperament.

The theory originated with the Hippocratic school (ca. 400 BCE), and was later modified by the influential Roman medical writer Galen (ca. 129-ca. 200). Humourial theory was a central doctrine in Galen's medical system, which was practised, both in the remnants of the Roman Empire and in the Islamic world, throughout the medieval period and into the Renaissance. Humourial theory survived into the nineteenth century (Delaporte, p. 94), and endures linguistically in words such as sanguine, cholera, melancholic and phlegmatic.

Humourial theory held that the four elements expressed themselves in the human person through the four humours or cardinal fluids: blood, phlegm, choler (yellow bile) and melancholy (black bile). Blood, phlegm, choler and melancholy are each associated with a quality: wet, dry, hot and cold, respectively (Danciger, p. 13). Like the elements, humours were metaphysical or spiritual entities. In Galenic medicine nature was conceived of as a vital force, with respiration connecting the human body to the cosmic life force. A vital spirit, the *vis medicatrix naturae*, was said to be the restorative power that rejuvenated sickened or weakened organs (Taylor, p. 105). The nature, or purpose, of this spirit was revealed through the humours. Humourial pathology was vitalist and teleological. Galen rejected the theory of atoms, and thus denied mechanical necessity and chance as causes of disease. Galen strove to determine the final cause, or purpose, of a disease, for therein lay its explanation and the possible cure (Taylor, pp. 105-111). In Galenic medicine the physician was a cryptographer, a semiotician of disease, who, having divined its reason, interceded to stimulate the body's vital spirits. The *vis medicatrix naturae* would then directly act on the excess humour to restore the humourial equilibrium in the organism (Grossinger, p. 149).

Whereas elements were purely metaphysical, humours were conceived of as both metaphysical and organic. Humours were regarded as actual fluids in the body (Delaporte, p. 128) whose circulation, distribution and elimination could be inferred, observed and predicted. Health could be strengthened by redressing humourial imbalances. Disease was always attributed to humourial excesses, imbalances among the humours, or disruptions in their flow through the body. In the Hippocratic corpus one reads:

> The human body contains blood, phlegm, yellow bile, and black bile: these constitute the nature of the body, and through them a man suffers pain or enjoys health. A man enjoys the most perfect health when these elements are duly proportioned to one another in power, bulk, and the manner of compounding, so that they are mingled as excellently as possible. Pain is felt when one of these elements is either deficient or excessive, or when it is isolated in the body without being compounded with the others (quoted in Grossinger, p. 133).

The Galenic apothecary consisted primarily of medicines of plant and animal origin — organic substances like the humours themselves (Danciger, p. 16). The restorative power of the body could also be activated by exercise, massage, hot and cold baths, sweating, darkness, quiet, changes in diet and, in cases of sanguine temperament, bloodletting (Merchant, p. 84).

The body was conceived of as a kind of alembic in which alchemical transmutations occurred. Digestion was seen as an alchemical reaction (Danciger, pp. 39-40). Healing was referred to as "coction" (boiling) or "pepsis" (cooking). The sick organism was said to be "raw," at which time visible or subtle sediments were deposited in the urine, stools, sputum, vomit, perspiration and menstrual blood. As the disease "cooked" the precipitates gradually disappeared. Diarrhea was interpreted as the ripening of white phlegm (Grossinger, pp. 149-150); cholera, as the thickening and congealing of blood (Delaporte, p. 159) (which implies that elemental Fire evaporates elemental Water). The physician's skill lay in determining the nature of the coction, choosing an intervention, and introducing it at precisely the correct moment in the disease's natural cycle.

In humourial conceptions of health, disease and disposition, the physical boundaries of the body were far looser than they would become after the Renaissance, for organicism defined subject-object relationships differently than atomistic or mechanical science. Disease and temperament reflected changes in elemental relations inside and outside the body. Humours responded to variations in diet, habits, climate, weather, environment and system of governance. Climate and government were external signs that revealed the internal constitution of the individual (Delaporte, p. 18). Meteorological factors — sunshine, clouds, wind, rain and fog — influenced the humours for better or worse. In nineteenth-century France, humourial pathologists claimed that southern Europeans were lazy and cowardly because they lived in hot climes under the rule of tyrants; and that northern Europeans were bellicose, active and enterprising owing to the tranquil rule of their monarchies and to the regular cycle of the seasons.

Hippocratic/Galenic notions that people and the environment exist in harmony, and that disease is a consequence of humourial imbalances, must be understood in the context of the belief in a hierarchically-structured, living cosmos: everything, by its nature, achieves its proper place and its proper relation to everything else. Personal identity, in these terms, does not necessarily end where skin meets air. Knauft (p. 201) argues that modern scientific knowledge has shaped the body as a genetic-physical-chemical entity, and that this widespread belief is at the very root of the modern self-concept. In pre-mechanistic Europe, identity was rooted in an affiliate relationship with, rather than a separate relationship from, the cosmos. "Throughout the Middle Ages," writes Berman, "men and women continued to see the world primarily as a garment they wore rather than a collection of discrete objects they confronted (1984, p. 61)."

A sublime technology of mixing described how bodily health and functioning were explained. Humouric concoctions were organic and material, but also spiritual and metaphysical. "Reality" lay not in the corporeal world of appearances, but in the suprasensible realm of pure abstractions: qualities, numbers, proportions and geometric forms. Fire, Water, Air and Earth were the spiritual qualities that gave shape, substance, and permanence to matter. Similarly, blood, phlegm, yellow bile and black bile were the physical manifestations of invisible structures whose blends determined the state of the living creature. The mixing of humours was not conceived of chemically, for there was no chemistry in the modern sense. Humours combined symbolically. Causation and etiology were not based exclusively on deterministic (cause-and-effect) relationships between microscopic, interacting particles, but on complex admixtures of signs, both internal and external to the body.

Pneumology

Blended elements and humours were transformed by heat to produce new substances and qualities. An alchemical theory of heat, *pneumology*, was a central tenet in pre-mechanistic European physiology. Pneuma, the spirituous component of the air, is a form of heat containing celestial (not sensible) Fire. From the time of the Greeks until the Renaissance, physicians generally assumed that the body was animated by three distinct spirits, or *pneumata* — animal, vital and natural. The pneumata were variously conceived, but were generally understood to be instruments of the soul and agents responsible for physiological processes such as digestion, growth, reproduction, and blood flow (Hall, in Descartes, p. 72; Keele, p. 173).

In ancient, medieval and Renaissance texts digestion is persistently linked to heat. In the *Timaeus* Plato wrote that the sharp edges of Fire chop up food in the stomach and drive it into the body. To Aristotle and Galen gastric alteration of food, or "cooking" (pepsis), prepares it for incorporation into the tissue. Writing in the 1500s, Paracelsus viewed the stomach as a vessel in which poisonous and non-poisonous parts of food are separated by heat. The agent responsible for this process is "an alchemist" who uses the stomach as a workshop in which "he labors and boils" (Hall, in Descartes, pp. 6-7).

Pneumology is central to Aristotle's theories of reproduction and growth. The degree of vital heat in the body determines the kinds of concoction produced. By virtue of the abundance of heat, men's bodies are presumed to yield a more "perfect" reproductive agent than women's bodies. Aristotle considers "semen" the most highly refined concoction of the blood, and "catamenia" (menses) as a less thorough concoction. Being less spiritous than the semen, the menses contribute only the physical matter necessary for the generation of new life, while the semen endows it with soul[8] (Lange, pp. 4-5).

Heat in the heart causes the blood to flow. The heart is considered an inherently "hot" organ. Inspired air, which contains celestial Fire, is cooked by the innate heat of the heart to produce vital pneuma, and blood is bonded to pneuma. By virtue of the motive power of the soul contained in the pneuma, the blood pulses through the body (Hall, in Descartes, p. 10; Keele, pp. 109-117).

In Chapter 3 I will speak more about blood and blood flow in relation to the mechanization of worldview and bodyview.

VI. Symbolic Correspondences

Causation

Modern science and medicine posit purely material links between antecedent causes and their effects. Science rules out spiritual causes. The development of modern clinical medicine, observes Foucault, required that everything be subject to the doctor's gaze (1973, p. 128). Whatever cannot be seen (or more precisely, identified, isolated, broken down into measurable units, and analysed) is disqualified

[8] This is entirely in keeping with Aristotle's belief in the natural inferiority of women. Like Plato, Aristotle considered women to be flawed versions of men. See also Martin, 1987, especially pp. 27-31.

as a causal agent. A very different logic of causation reigned during the age before mechanistic notions came to possess scientific discourses. The calculus was less concerned with the co-ordinated functioning of component parts than with the blending and balance of qualities. Qualities were attributes that achieved signification through a vocabulary of sympathies, antipathies, signatures, correspondences, vicinities, homologies, appetites and natural tendencies (Foucault, 1973, p. 3; Hall, 1970, p. xxii).

The living, hierarchically structured cosmos was order exemplified. In this closely knit universe, everything held together exactly as it should. All things were either in, or in the process of returning to, their natural places. A theory of symbolic correspondences described how the various objects in the cosmos related to one another. Things behaved in particular ways due to their elemental composition, but also because of their affinities with other things. Each item was endowed with an intrinsic nature or quality that determined its behavior or temperament. Things of a certain class could and would affect others of the same class. Essential harmonies permeated the cosmos; and these ensured that all departments of nature were linked to all others, and that each fragment served its purpose as part of the complete and ongoing whole (Amber & Babey-Brooke, p. 35; Debus, p. 133).

Belief in the symbolic correspondences is fundamental to the idea of a hierarchically-structured, organic universe. God, the first cause, arranged the preexisting chaos into a coherent and stratified whole. Everything in the universe is an emanation, or manifestation, of God's creative impulse. A "chain of being" was the metaphor for the order, unity, and completeness of God's created world. With God at its apex, the chain extends "downward" to include the entire physical world and all possibilities for existence. The idea of the chain of being entered Western thought with the *Timaeus*, and formed the basic medieval and Renaissance image of a hierarchical universe (Flew, p. 60). Implicit in both Christianity and neo-

Platonism was the belief in a unity of nature encompassing God and the angels at one extreme and humans and the terrestrial world at the other (Debus, p. 12).[9]

Symbolic correspondences imply the unity between celestial objects and humans, and suggests that humans reflect all that exists in the cosmos (Danciger, p. 20). More generally, the correspondences imply that a web of relationships underlies all. The body reflects the greater universe, but so does everything else, for the great chain of being vibrates through every department of nature and resonates in every object. Everything is interconnected, and all things exist in relationship to everything else. Things draw significance from other things, whether they exist in the visible world or in an occult or metaphysical one. The world duplicates and reflects itself in a network of similarities and differences, and knowledge consists of interpreting the complex system of non-discursive messages laid out by God. To the initiated, the world is an open book "bristling with written signs" (Berman, 1984, p. 62).

Doctrine of Signatures

In medieval medicine, the belief in correspondences lent credence to a method of discovering pharmaceutical value known as the doctrine of signatures. The doctrine holds that everything in the universe is bound together, partially because of mechanical causes, but mainly by hidden affinities (Koestler, p. 665). The healing qualities of plants were established, in part, on the basis of clues suggested by the shape or name of the substance. The medicinal effectiveness of mandrake root, for example, was attributed to its resemblance to the form of a human body (Lewontin, 1990). Grossinger notes that as recently as three hundred years ago, the herbals of Europe recommended walnuts for the treatment of head ailments because walnuts

[9] The "Great Chain of Being" was used to justify race hierarchies in Europe during the Renaissance and the Enlightenment. Africans ranked lower on the chain than Europeans because the "nature" of Africans prevented them from exploring the secrets of nature as did their northern neighbours (Adas, p. 118).

> have the perfect Signatures of the Head: The outer husk or green Covering, represents the pericranium, or outward skin of the skull, whereon the hair groweth, and therefore salt made of these husks or barks, are exceeding good for wounds to the head. The inner shell hath the Signatures of the Skull, and the yellow skin, or Peel, that coverth the Kernell, of the hard Meninga & Pia Mater, which are the thin scarfes that envelope the brain. The Kernel hath that very figure of the brain... For if the Kernel be bruised, and moystned with the quintessence of Wine, and laid upon the Crown of the Head, it comforts the brain and head mightily...

Similarly, Saint John's Wort was believed effective for the treatment of skin conditions because

> The little holes whereof the leaves of Saint Johns wort are full, doe resemble all the pores of the skin, and therefore it is profitable for all hurts and wounds that can happen thereunto (quoted in Grossinger, p. 113).

Macrocosm-Microcosm Analogy

Hidden affinities existed between different things in the natural world, but the most fundamental correspondence was between the cosmos and the human body. The macrocosm-microcosm correspondence was an interpretation of natural phenomena based on an organic analogy between the world as a whole and the living creature. The human body, or microcosm, was considered a miniature replica of the greater universe, or macrocosm. The structure and behaviour of the larger world reflects in and through the body, and similarly, the body mirrors all that exists in the cosmos. Both macrocosm and microcosm are composed of a physical body, a soul obtained from God, and an astral spirit (Merchant, p. 119). From Greek antiquity until the Enlightenment, the dominant Western philosophical systems upheld the veracity of the macrocosm-microcosm interrelationship. After the Scientific Revolution, explanations of natural phenomena took a mechanistic turn. Descriptions in terms of chains of signs and associations yielded to explanations in terms of chains of material causes and effects.

Belief in the macrocosm-microcosm analogy implied the unity of celestial objects and humans. In the *Timaeus*, planets, stars and human bodies were all wrought of the same material by the same divine craftsmen. The gods "copied the shape of the universe and fastened the two divine orbits of the soul into a spherical body which we now call the head..." (Plato, p. 61). The human soul, which resides in the spherical head, and the world-soul, which inhabits the sphere (or dome) of the heavens, were made of the same mixture, and therefore shared an identical structure.

The belief in the macrocosm-microcosm correspondence fitted in with the view of nature as "a designed hierarchical order existing in the cosmos and society corresponding to the organic integration of the parts of the body — a projection of the human body onto the cosmos" (Merchant, p. 6). All parts of the cosmos are connected and interrelated in a living unity. All parts of nature are mutually interdependent, and therefore each part reflects changes in the rest of the cosmos. The organic unity of the cosmos derives from its being perceived as a living animal (pp. 103-4). Conceptualizations of the cosmos began with the prime technology of the ancient world: the body. The universe possesses body, soul and spirit. The cosmos is the body, in its largest manifestation. The implication is that matter is sensible and intelligent. Thus the line between animate and inanimate matter was drawn differently than after the Renaissance, when vital forces were excised from matter.

Belief in the macrocosm-microcosm analogy illustrates the centrality of the body in the ancient worldview. The body was the most obvious source of power and control in pre-mechanistic Europe. The body was the locus through which knowledge was formulated; a background against which nature was understood.

VII. Chapter Summary

In this chapter I have looked to Plato's cosmology (and to other writings of or about ancient, medieval, and Renaissance natural philosophy) to discover what scientific knowledges were sanctioned by the early-European technological imagination. Let us summarize a few key ideas suggested by pre-mechanistic scientific discourses about the functioning and constitution of the human body, and more generally, about the nature of reality.

The dominant natural philosophies were animistic and organicist rather than mechanical. The machine was not part of the technological landscape of ancient and medieval Europe and so could not be grafted to the technological imagination. When constructing theories of nature, philosophers interpreted the world through a grid of familiar technologies powered by the bodies of humans or animals and controlled by acts of will. In the exercise of magic and alchemy the practitioner's body was itself a channel through which nature was controlled. Wherever natural scientists observed uninitiated movement, they projected life. Thus science was teleological and anthropomorphic, and interpretations of natural phenomena depended on knowledge of a living creature. The body itself was a theoretical resource for constructing rational discourses on nature.

The defining technologies of this period were the manual and divine crafts of pottery, carpentry, spinning, alchemy and magic. The composition and vitality of the body were described in terms of elaborate admixtures of matter and signs. Shaping, stirring, chopping, heating, boiling, fermenting, concocting, sublimating, precipitating, and bringing supernatural forces to bear were the operations that explained the creation of the crafted body, and guaranteed its ongoing existence.

Perhaps the most enduring somatic legacy incited by the image of the body as a product of craft technologies has been the persistent tendency of Western science and philosophy to dichotomize psyche and soma. In the *Timaeus* the Great Artificer established the primacy of spirit by fabricating it first, thus subordinating flesh to mind or soul. Although Plato did not invent the dualism, his influence on later generations ensured its perpetuation.

Beyond this conclusion, my analysis has pointed to the difficulties in disentangling somatic from extrasomatic phenomena in pre-mechanistic science. In ancient and medieval Europe, body and universe cleaved together in ways that are quite alien to the modern Western mind, for discourses on nature were ontologically wed to the defining technologies.

Chapter 3

The Body as Machine

Let us conclude bravely that man is a machine; and that there is in the universe only one kind of substance [i.e., matter] subject to various modifications.

— Julien Offray de la Mettrie (1709-1751)
(quoted in Bolter, p. 205)

I. Introduction: Chapter Overview

Chapter 3 is concerned with the discursive evolution of the human body from the product of manual technologies to a machine. I describe the symbolic reordering of reality occasioned by the change from a science based on animist principles to one founded on mechanism, and how this development affected notions about the structure and functioning of the human body. My aim in this chapter is to expose the metaphysical presuppositions that lend shape and substance to the body portrayed by modern (i.e., mechanistic) science and biomedicine.

The sweep of this chapter encompasses the European Renaissance (beginning about 1300) until the concluding years of the Scientific Revolution (about 1725). It was during this period that the mechanical reconceptualization of reality was first articulated, promoted, and finally, consolidated as scientific "fact."

In this chapter, as in the last, I locate bodyview within its worldview. In Chapter 2 I discussed the centrality, in pre-mechanistic natural philosophy, of the correspondences that were presumed to exist between the human body (microcosm) and the greater universe (macrocosm). I begin, therefore, by regarding worldview and bodyview as inextricably linked, and consequently, in this chapter, I highlight how macrocosmic and microcosmic phenomena were reinterpreted mechanistically during the early modern period.

In addition, I once again assume that it is generative to contextualize and historicize the body by refracting it through a culture's ambient technologies — in Bolter's terms, its defining technologies. Philosophy, cosmology, science, medicine and art are reflected in and through a culture's technological imagination. Technologies have implications both for cultural practice (ways of living) and for discourse (ways of structuring knowledge). Cosmology and somatic history can be read through the categories and ideas suggested by a culture's machines, devices and techniques. Beginning in the late Middle Ages, two classes of machines appeared and spread across Europe: power technologies, devices that tap the forces of nature (e.g., windmills); and autonomous technologies, mechanisms that contain their own principle of motion (e.g., clocks). By the eighteenth century the ideas suggested by mechanical technologies had developed into comprehensive explanations of nature.

Mechanical philosophy, the scientific explanation of natural phenomena in terms of matter and motion, has, since the eighteenth century, formed the core of Western scientific discourses. Mechanism rendered the older, organicist sciences largely irrelevant, for animist and vitalist notions could not be assimilated into the modern scientific framework. Though at the height of the Renaissance in 1600 the mental attitude of Europeans was still largely medieval, by 1700 it was recognizably modern: educated Europeans were more likely to believe in atomism than in elementalism and humourialism; they accepted the reality of a heliocentric solar system rather than an earth-centred universe; they regarded the solar system as a vast machine held together by the forces of gravity rather than as orbs presided over by God or kept in motion by angelic intelligences; and they acknowledged God less as the creator and sustainer of the cosmos than as the engineer who had built a clockwork universe that unwinds in obedience to "natural laws." The notion of the experiment as a controlled test of theory, although generally not well understood, had changed the criteria by which factual evidence and true explanation were judged (Smith, p. 32). By the late 1700s the metaphysical intuitions that flowed out of organicist natural philosophy had been largely abandoned and replaced by a set of mechanized presuppositions.

A mechanistic conception of the body took root at this time. The works of three sixteenth- and seventeenth-century anatomists associated with Padua University, Andreas Vesalius, Hieronymus Fabricus and William Harvey, primed the Western imagination for mechanistic reinterpretations of the body. Harvey's contemporary, René Descartes, conceived the human body as a machine composed of microscopic parts too small to be seen. Descartes' intellectual heirs, the iatromechanists, successfully challenged vitalist theories of life while extending the range of corporeal phenomena that could be interpreted in terms of matter and motion.

My argument will unfold as follows:

I begin by locating the ascent of mechanistic thinking in its historical context. Technological developments in the years leading up to the seventeenth century inspired a mechanistic repatterning of reality, culminating, in the late 1600s, in the elevation of mechanical invention to the level of epistemology. *Technology and Epistemology* is concerned with the technological ideas that precipitated the mechanical reconstruction of reality; and with the assumptions underlying the new interpretations of reality that were consistent with the structure and logic of machines.

Before a mechanical reconstruction of reality could be fully realized, it was first necessary to sever the strands that for thousands of years had bound body to universe. During the sixteenth and seventeen centuries, the linkages between the somatic and extrasomatic realms began to loosen. In *The Failing Plausibility of Macrocosm-Microcosm Theory*, I describe the breakdown of celestial and corporeal correspondences. In discussing dissection, blood circulation, René Descartes' automaton-like body, iatromechanism, and the evolution of the machine-body, I stress the discourses that organized mechanistic theories of the flesh and the forces that vitalized it.

Today, modern (mechanistic) science plays a pre-eminent role in making the body knowable. The body that modern science recognizes is underwritten by four metaphysical presuppositions: objectivism, materialism, reductionism and determinism.

II. Technology and Epistemology

Modern Science and Mechanistic Philosophy

The main tenets of modern science were gradually established during the sixteenth, seventeenth and early eighteenth centuries, a period referred to as the Scientific Revolution. This period witnessed the renewal of Hellenic scientific scholarship; the erosion of the influence of the Church; the rejection of medieval sources of scientific authority; the growing reliance on observation, experiment, and mathematics as tools of science; and the articulation, diffusion, and general acceptance of a mechanical approach to the study of nature. Modern science succeeded scholastic philosophy[10] and completely destroyed Aristotelian physics (Butterfield, p. 7). Organicist natural philosophy was overturned by an experimental, observational, mathematical study of matter in motion.

The mechanical technologies developed during the Middle Ages and Renaissance profoundly affected the conditions of life in Western Europe, and, as I will show, helped reshape the contours of Western thought. With new technologies

[10] Scholasticism, the kind of philosophy taught and studied in the universities of medieval Europe (Flew, p. 315), respected only the authority of the scriptures, certain biblical commentators, and, after the twelfth century, Aristotle (Peirce, in Spicker, p. xi). Scholastics adopted the Aristotelian method of reasoning as a means of arriving at theological and scientific certainty (Flew, p. 316; Hall, 1970, p. 5). Truth could be reached, scholastics believed, through a process of rational argument. Precise definitions, deductions from dogma, and logical subtleties were central to this method.

conspicuous on the landscape of Renaissance Europe, mechanistic ideas came to occupy — and in some ways, to preoccupy — the modern scientific imagination. How did the idea of the machine become the basis for a philosophy of nature? To answer this question, let us turn to the subject of Renaissance mechanical technologies.

Technology and Power

The Renaissance witnessed impressive advances in technology and instrumentation. The microscope and the telescope revealed the existence of things that nobody had even dreamed possible. The discovery of two previously unknown realms began to awaken the suspicion that Nature might be far richer than the human imagination had previously allowed. Other instruments also had the effect of challenging the assumptions of pre-mechanistic science. Demonstrations of the vacuum pump furnished evidence that Aristotle's rejection of the void was wrong. Other technologies — gunpowder, distillation, the stern-rudder, the printing press, paper making, the magnetic compass, and the astrolobe — were diffused into Western Europe from the East, principally through the Arabs. The thermometer, the barometer, and many other devices had no historical antecedents (Dijksterhuis, pp. 390-1).

Mechanical technology represented a new power in the world. This fact was obvious to contemporary scholars, many of whom attributed the growing cultural and political hegemony of Western Europe to the new technologies. Writing in the *Novum organum* (1620), Sir Francis Bacon (1561-1626) observed that

> it is well to observe the force and virtue and consequences of discoveries; and these are to be seen nowhere more conspicuously than in those three which were unknown to the ancients...; namely, printing, gunpowder, and the magnet. For these three have changed the whole face and state of things throughout the world; the first in literature, the second in warfare, and the third in navigation; whence have followed innumerable changes; insomuch that no empire, no sect, no star seems to have exerted greater power and influence in human affairs that these mechanical discoveries (quoted in Debus, p. 1).

Bacon advocated the advancement of scientific learning and mechanical invention as the surest means of improving the lot of humankind (Mumford, p. 6). Bacon was neither the first nor the last to make such a statement. A French physician writing in 1545 rhapsodized

> The world sailed round, the largest of Earth's continents discovered, the compass invented, the printing-press sowing knowledge, gun-powder revolutionising the art of war, ancient manuscripts rescued and the restoration of scholarship, all witness to the triumph of our New Age (quoted in Boas, p. 17).

These statements capture the spirit of confidence and optimism that permeate the writings of the mechanical philosophers and prophets of science, but also advertise their prejudices. The "mechanical discoveries" lauded by Bacon and his contemporaries did as much to advance science and "civilization" as they did to make possible the imperializing aims of Western Europe. Superior technology, it was believed, set Europeans apart from other civilizations. The above quotations illustrate the great importance attached to technological innovation in producing Western Europe's sense of superiority over non-Europeans. It was at this time that scientific and technological achievements became measures of civilization (Adas, p. 3). Consequently, the pace of Western expansionism, colonialism and enslavement quickened during the 1500s and 1600s, abetted by the devices, techniques, and ways of thinking that arose in the wake of mechanical science (Bleier, p. 57).

Defining Technologies in the Modern Age

The deployment of mechanical invention garnered for Western Europe unprecedented physical and political leverage, both over the natural environment and over subjugated peoples. Mechanical technologies, originally conceived of as instrumental means to achieve power, gradually evolved into explanations of nature. The categories and ideas suggested by the machines, devices and techniques of the Renaissance became integrated into discourses of nature.

I turn my attention from the cultural effects to the discursive effects of the new technologies: the link between the development of mechanical technologies and the scientific project of control over the production of truth. How did the machine become the basis for a philosophy of nature? To this end, I return to the notion of a defining technology.

Bolter identifies two defining technologies for the modern age: power technologies (machines that harness the energies of nature); and autonomous technologies (machines that are self-propelled). By the late fifteenth century Europe was equipped with sources of power far more diverse than those known to any previous culture (White, p. 128; Merchant, pp. 216-7). Mechanical invention reshaped the mental contours of the West by providing new strategies by which the forces of nature could be altered, controlled, measured and — perhaps most significantly — mimicked.

Power Technologies

Between the eighth and fifteenth centuries a new class of machines driven by gravity, running water, wind and steam gradually came into common use in Europe. These were the power technologies — continuously operating machines that perform work by tapping and directing the forces of nature. Examples of power technologies include the watermill, windmill, tidal mill, air gun, gunpowder gun, rocket, cannon, pump and steam engine. These devices substituted gravity, wind, water and expanding gas for muscle power.

Watermills were the earliest power technology. First introduced during Roman times, their use gradually spread across Europe, reaching Great Britain by the eighth century and Scandinavia by the twelfth. For many centuries watermills were used solely for grinding grain; thereafter there is evidence of their use in fulling cloth, tanning leather, sawing timber, making paper, driving the trip-hammers of iron forges, and extracting oil from olives (White, p. 84; Merchant, p. 45; Adas, p.

27). Along the coasts and in marshy estuaries where streams could not drive a watermill, inhabitants constructed tidal mills (White, pp. 84-5). In regions lacking running rivers and changing tides, the power of the wind was first harnessed during the twelfth century. By the sixteenth and seventeenth centuries, windmills were draining fens and marshes in England, France, and the Low Countries (Merchant, p. 45). Windmill-driven bellows and forges contributed to advances in tool making in the North Sea region (Adas, p. 27). By the eleventh century the whole population of Europe was living in the constant presence of at least one major item of power technology, and the implications of these devices were beginning to be recognized (White, pp. 83-5).

Autonomous Machines

Automata are machines that contain their own principle of motion (Beaune, p. 431). Renaissance automata took two forms: clocks, and working models of living organisms (Wiener, 1985, p. 39). The latter are devices that imitate nature — or more accurately, technologies that incarnate historical and cultural notions of the nature of nature. Thus Renaissance automata moved of themselves. Automata constructed before 1600 were primarily powered by water, and thereafter, by springs. The sixteenth, seventeenth and eighteenth centuries saw the proliferation of ingenious mechanical animal and human simulacra, many of which achieved considerable fame. Jacques de Vaucanson's self-propelled duck and his mechanical flute player[11] were demonstrated throughout Western Europe in the 1730s (Beaune, 1989; Quantz, p. 54; Bolter, 1984, pp. 204-5). As European science inched closer to adopting non-vitalist interpretations of nature, the fascination with autonomous technologies expressed the flourishing traffic of mechanistic ideas.

No autonomous technology better exemplifies the transition from Plato's living cosmos to Newton's mechanistic universe than the clock. The purely mechanical

[11] A fascinating first-hand account of the mechanical flute player is found in Johann Joachim Quantz's 1752 *On playing the flute.*

clock, driven by lead weights, was an invention of the thirteenth century. The first clocks were intended less as chronometers than as astronomical indicators. Early clocks had only an hour hand, and were so inaccurate that they had to be reset daily with the aid of a sundial (Merchant, p. 220). Their main purpose was to demonstrate the celestial wanderings of the sun, the moon, and the five planets according to the Ptolemaic system (White, p. 119, p. 122; Bolter, p. 26). The first public clock to strike the hours was heard in Milan circa 1335, and thereafter, the clock quickly spread across Europe. Before the middle of the fourteenth century,

> the mechanical clock seized the imagination of our ancestors. Something of the civic pride which earlier had expended itself in cathedral-building now was diverted to the construction of astronomical clocks of astounding intricacy and elaboration. No European community felt able to hold up its head unless in its midst the planets wheeled in cycles and epicycles, while angels trumpeted, cocks crew, and apostles, kings, and prophets marched and countermarched at the booming of the hours (White, p. 124).

The clock suggested a universe in miniature to medieval thinkers, but not the living, enchanted cosmos of Plato or Aristotle. The clock divided days and nights into uniform yet arbitrary mathematical units. The marking of time, historically rooted in the cycles of the seasons and the positions of the heavenly bodies, was transformed into an abstract and measurable quantity. Technical refinements to the clock over the following 350 years included the addition of a minute hand and pendulum regulation. By 1700 the clock had become an accurate timekeeper; but long before the turn of the eighteenth century the idea of the clock was deeply engrained in the European psyche as a model of the cyclical processes of nature (Bolter, p. 26).

As the clock came to symbolize cosmic order, the assumptions that underwrote an animistic universe became less tenable. Nature, in a living universe, was intelligent, willful, erratic, even whimsical. The emerging picture of nature was that of a predictable, ordered, and precise creation. The clock did not mark time in reference to seasonal, religious, or ritual cycles; it was a secular machine (Adas, p. 61).

The clock was obviously not alive. As early as the 1200s thinkers began to speculate whether God had constructed a clock that exhibited the characteristics of the cosmos. Writing in the fourteenth century, Jean Buridan (ca. 1295-1356) posited a parallel between the movements of mechanical devices and the planets. Remarking that the only force that appears to slow a rotary grindstone is mechanical friction, Buridan questioned whether, as it was long believed, angelic intelligences were needed to move the celestial spheres. He suggested instead that the spheres rotate because they were supplied with an initial impulse (White, p. 174), and that the grindstone, rather than moving by virtue of an applied force, actually stored power (*vis impressa*) (pp. 115-6). It is in the writings of the fourteenth-century ecclesiastic and mathematician Nicholas Oresmus (d. 1382) that the universe and clock were first compared. Oresmus likened the cosmos to a machine created and set in motion by God so that "all the wheels move as harmoniously as possible" (quoted in White, p. 125).

The Articulation of Mechanistic Philosophy

As the machine loomed larger in the technological imagination of late medieval and early Renaissance Europe, mechanistic descriptions of reality began to appear with increasingly regularity. As people became power- and machine-conscious, scholars began to think of the cosmos as a vast reservoir of energies to be tapped for human purposes (White, p. 137). Between the thirteenth and the fifteenth centuries there were clear signs of an approach to a mechanistic philosophy of nature. A mechanical theory of impetus that eliminated the teleological elements of Aristotelian kinematics (the science of motion) was first articulated during the thirteenth century. The rediscovery, in 1417, of what was later recognized as the sole surviving copy of Lucretius' poem about Greek atomism, *De Rerum Natura (On* *the Nature of Things*), stimulated the seventeenth-century revival of atomic theory by Gassendi.

Mechanism finally became fully awake as a philosophy of nature in the writings of the English empiricist Sir Francis Bacon. Bacon promoted a new natural philosophy based on the careful observation of the physical properties (size, shape, weight, and so on) and motion of matter. In contrast to the deductive propensities of scholastic philosophy, Bacon advocated an inductive approach to the study of nature: general laws were to be inferred from particular instances. Bacon objected to the scholastic monopoly on scientific knowledge; the study of nature should not be restricted to a coterie of scholars. The science he sought to establish would enable all persons to verify truth for themselves. Bacon's aim was to reform all knowledge and create a new learning in place of the old (Merchant, p. 80).

Bacon regarded the scholastic mode of thought as useless to the advancement of natural philosophy. Although the revival of Hellenic scholarship had had an invigorating effect on scholarship in general, Bacon believed that the foundations of Greek science were crumbling and in need of replacement. The emerging observational sciences, he wrote, furnished a way to revitalize knowledge. Recent advances in mechanics, cosmology and anatomy threw into doubt many of the unassailable truths of ancient and scholastic scholarship. Kinematics, in Aristotelian physics, held that the ultimate source of all movement was the soul; yet the activities of autonomous machines seemed to render this principle irrelevant. The heliocentric system promoted by Copernicus, Kepler and Galileo simplified and improved the accuracy of the Ptolemaic system. The Padua anatomists — Vesalius in particular — discovered that the anatomical and physiological pronouncements of Aristotle and Galen were not supported by empirical evidence (Dubos, p. 18). Observation and experience were overturning ancient authority.

Bacon held that the sciences had profited less from the revival of ancient learning than had all of the other areas of scholarship. Science could produce little that was new while natural philosophers continued to adhere to the teachings of the ancients. Aristotle may have been a great scientist, Bacon argued, but the early seventeenth century knew little more than Aristotle had known:

> The sciences stand where they did and remain almost in the same condition, receiving no noticeable increase, but on the contrary. thriving most under their first founder, and then declining. Whereas the mechanical arts, which are founded on nature and the light of experience, we see the contrary happen, for these (as long as they are popular) are continually thriving and growing, as having in them a breath of life; at first rude, then convenient, afterwards adorned, and at all times advancing (quoted in Boas, p. 250).

Bacon saw in mechanism a model for science to emulate. The idea that the crafts and trades had something to teach science was revolutionary, for scholars had traditionally disdained practitioners of the "useful arts." Artisans and mechanics were considered "vile personnes" who had little to offer philosophy (Adas, p. 29).

Bacon promoted a model for the systematic and deliberate study of nature patterned after the study of mechanical systems. Natural philosophy, he concluded, must be empirical, materialist, cumulative and pragmatic.

First of all, science, like mechanics, must be founded on the real; the real, according to Bacon, is that which may be verified by the senses. Thus observation and experience, not speculation, is the means by which to arrive at certainty. True knowledge is to be found in the world of senses, not in a suprasensible world of Ideas. Bacon was one of the first to adopt and publish the view that one of the fundamental problems for natural philosophy was to explain occult properties in sensible terms (Boas, p. 260). An experimental science, Bacon wrote,

> shall not vanish in the fume of subtle, sublime, or delectable speculation, but such as shall be operative to the endowment and benefit of man's life; for... it will give a more true and real illumination concerning causes and axioms than is hitherto attained (quoted in Boas, p. 253).

And like mechanics, science should deal exclusively with matter and its physical properties. In the same way that expert mechanics master their materials and tools, scientists must be intimate with physical nature. For "men" to know nature, it must be subdued; nature would yield its secrets only when coerced. To force nature to reveal "her" secrets (Bacon personified nature as female), scientists must vex nature[12] (Merchant, p. 198).

Scientific knowledge, like mechanical know-how, should be cumulative and practical. Master artisans passed on their knowledge to their apprentices and advanced their crafts by trial-and-error experimentation. Bacon held that natural philosophy should be built upon past experience so that scientists may learn from the mistakes and successes of other practitioners.

Thus for Bacon mechanical technology was a source of a new epistemology. His influence ensured that the mechanical arts were elevated to the level of a philosophy of nature (Berman, 1984, pp. 16-17).

The Spread of Mechanical Philosophy

Bacon himself was not a practising scientist. The "experimental" approach he advocated was less experimental than investigative, amounting to little more than an exercise in amassing and classifying observations. Truth, he believed, would reveal itself amid the assemblage of data. Bacon never put his method to the test, and his followers soon realized that the method was unworkable. By emphasizing experiment and devaluing mathematical interpretation, Bacon's empirical and inductive approach to science did not generate new knowledge in the manner he had predicted. Whatever the weaknesses of Bacon's methodology, however, his writings inspired countless others to construct a new science built on the bedrock of mechanism (Debus, pp. 102-5).

[12] In exploring the nature/woman relationship, Merchant (1989) has detailed the detrimental consequences of the tendency of the Western scientific tradition to personify nature as savage and female, including the persecution of witches and the slaughter and enslavement of non-European peoples.

If Bacon is seen as the architect of modern worldview, its edifice was gradually constructed during his lifetime and over the following 150 years by generations of mechanical philosophers. The mechanistic foundations of modern science were laid by Johannes Kepler (1571-1630), Galileo Galilei (1564-1642) and William Harvey (1578-1657). Mechanism as a philosophy of science was given discursive shape by René Descartes (1596-1650), Marin Mersenne (1588-1648), Pierre Gassendi (1592-1655), Thomas Hobbes (1588-1679) and John Locke (1632-1704). Mechanism was extended and refined by Giovanni Alfonso Borelli (1608-1679), Robert Hooke (1635-1703) and Robert Boyle (1627-1691); and finally elevated to the status of a philosophy of nature by Denis Diderot (1713-1784), Friedrich Hoffman (1660-1742), Paul Heinrich Dietrich d'Holbach (1723-1789), Albrecht von Haller (1708-1777), Julien Offray de la Mettrie (1709-1751), Gottfried Wilhelm Leibniz (1646-1716) and Sir Isaac Newton (1642-1727).

The two central problems addressed by seventeenth- and eighteenth-century mechanical philosophers were the development of an explanatory framework based solely on the nature of matter and the origins and transmissions of motions amongst component parts (Merchant, pp. 206-7); and the elimination of vital, animistic and magical forces from theories of nature.

The new definition of reality in seventeenth-century science and philosophy was consistent with the structure and logic of machines. In ancient and medieval Europe the defining technologies had been the manual crafts and the occult sciences. Pottery, carpentry, spinning, alchemy and magic were the theoretical resources out of which thinkers had fashioned rational explanations of nature. Organicist science was ontologically rooted in the body, for the universe itself was likened to a living creature. As the symbolic force of the organism declined in plausibility, clocks and machines developed into the underlying models for Western philosophy and science. Perhaps the most significant effect of the Scientific Revolution on Western thought was the decentring of the living creature from philosophy and science, and its replacement by the machine.

Let us enumerate the key assumptions about the structure of being, knowledge, and method that were consistent with and analogous to the defining technologies of the late Renaissance:

Ontological Assumption

The ontological foundation of mechanistic science is that all phenomena may be explained in terms of physical properties and motion. Seventeenth-century science required no explanatory principles other than the concepts employed in mechanics — geometric concepts such as size, shape and quantity. These concepts were treated mathematically; the specific subject of study was motion (Dijksterhuis, pp. 414-5).

The organic philosophies had explained motion or outward change in terms of invisible correspondences, homologies, appetites and tensions between sympathies and antipathies. All change was presumed to begin from the inside, spontaneously, in response to a sign, command, or exhortation (Dijksterhuis, p. 148). Teleological science was necessarily psychological; it sought to identify the motive for motion. All matter was seen as alive — or in Platonism and neo-Platonism, as potentially alive. The principle of change was vital and incorporeal.

Mechanical philosophy appropriated the Platonic notion of passivity of matter (Merchant, p. 20, p. 277) and transformed it into an ontological imperative. Machines powered by wind, water, metal springs, and the like, were not easily incorporated into the organic framework, and accounting for inanimate sources of motion was a central problem addressed by mechanical philosophers. The eventual resolution was to do away with the immortal soul as the agent of change; instead change was explained in terms of external mechanical forces. In *Principles of Philosophy* Descartes wrote:

> I openly state that the only matter that I recognize in corporeal things is that which is subject to every sort of division, shape, and movement — what geometers call quantity and take as the object of their demonstrations. Moreover, I consider nothing in quantity apart from these divisions, shapes, and movements; and I admit nothing as true of them that is not deduced, with the clarity of a mathematical demonstration, from common notions whose truth we cannot doubt. Because all the phenomena of nature can be explained in this way, I think that no other principle of physics need be admitted, nor are to be desired (quoted in Hoenen, p. 355).

Mechanical philosophers denied that matter possessed mind or soul. Change was the result of material interactions between inanimate bodies. All vestiges of consciousness and of vital activity — animation, internal spontaneity, and purpose — were excluded from the purview of the new sciences. Mind and soul were gradually squeezed out from the scientific picture, leaving only fragments of inorganic matter pushed blindly by external forces.

Whereas the teleological sciences understood the universe as a complete and enduring whole, Renaissance mechanistic science explained the cosmos as an assemblage of discrete bits of matter connected in a causal nexus that sequentially transmitted motion from one part to another (Merchant, p. 228). Renaissance scholars found in Greek atomism a theory to elucidate the machine-like nature of matter. Atomism, until the Renaissance, was condemned as heretical because the theory contradicted church teachings and Aristotle. Classical atomism held that atoms were eternal; that atoms have always existed; that the motion of atoms was governed by chance or necessity; and that atoms were infinite in number. The Church held that God alone is eternal; that God created the universe ex nihilo; that God's will prevails over everything in creation; and that there could be no physical object infinite in number (Dijksterhuis, p. 425; Angeles, p. 134).

A number of Renaissance scholars endeavoured to harmonize pagan atomism with church teachings. Noteworthy is Descartes' theory of corpuscular physics, which presumed that the universe was composed of a fixed quantity of microscopic corpuscles created by God at the moment of creation (Kuhn, p. 41). Also influential was Gassendi's reinterpretation of classical atomism. Gassendi's atoms, like those of Democritus and Epicurus, possessed size, weight and form; were invisible, firm and impenetrable; were physically indivisible but mathematically divisible; and were identical to one another in every respect. Gassendi "Christianized" his atoms by asserting that they do not exist eternally, but will one day be destroyed; that their numbers were finite; and that their motions were not governed by chance, but were controlled by God's ongoing intervention (Dijksterhuis, p. 425). Atoms, wrote Gassendi, were created by an incorporeal Christian God who "pervade[s] and support[s] the universal machine of the world" (quoted in Merchant, p. 201).

Epistemological Assumption

The conviction that everything consisted of atoms was applied by mechanical philosophers to theories of knowledge. If the structure of reality was atomic, then sensory data must be atomic too. This assumption was explicit in the writings of the British empiricists Hobbes, Hume and Locke. Sensation arises, explained Hobbes, from the motions of particulate matter impinging on the sense organs, either directly, as in taste or touch, or indirectly, through a material medium such as light, sound, or smell. Sensory impressions were then recombined and manipulated in the mind to produce speech (Merchant, p. 232).

The mind itself was viewed by Hobbes as a kind of machine, a view that gained plausibility with the invention of working mechanical calculators during the seventeenth century.[13] In the mechanical worldview, reasoning was reduced to mathematical operations performed on sensory information. "For reason..." wrote Hobbes, "is nothing but reckoning, that is adding and subtracting" (Merchant, pp. 232-3).

Mathematical reasoning was paradigmatic in Descartes' system of knowledge (Flew, p. 89). Knowing was the apprehension of clear and distinct ideas. A *clear* idea,

[13] These devices, precursors to the modern computer, were built by John Napier (1550-1617), Blaise Pascal (1623-1662) and Leibniz.

Descartes explained, is one that is "present and open to an attentive mind, just as we say that we see things clearly when they are before our open eyes and have a sufficiently strong and direct impact on our vision." A *distinct* perception "is marked off and sharply divided from all others in such a way that it contains (in itself) only what is clear." Of corporeal things Descartes wrote, "At least everything that I understand clearly and distinctly — that is, everything, generally speaking, that is included in the object of pure mathematics — is found in them [i.e., in corporeal things]" (quoted in Hoenen, pp. 363-4).

Descartes believed that at least some mental episodes represent direct and unchallengeable cognition. Collisions of atoms on the organs of perception, mathematically rearranged by the mind, were thought by Descartes to furnish unerring truth. Such knowledge could be expressed without ambiguity or need for interpretation.

The epistemological assumption may be stated thus: The goal of science is to eliminate moral, intellectual, and practical risks to knowing. Knowledge about the world can be abstracted from the world itself; all relevant information about the world must be analyzable as context-independent determinant elements. Clarity, certainty and control are guaranteed by this philosophy. Real knowledge is rule-governed; what cannot be articulated is merely belief. The conviction that knowledge is atomistic and situation-independent eventually achieved the force of commonsense (Dreyfus & Dreyfus, pp. 41-42).

Methodological Assumption

The third assumption shared by seventeenth-century natural philosophy and machine technology was the assumption that problems can be broken down into constituent parts. Mechanistic science is premised on the belief that any problem can be divided into smaller problems, and that each individual part may be operated under guidance of a set of mathematical rules (Merchant, p. 232). The machine is paradigmatic here. Knowledge of the operation of a machine depends upon a detailed understanding of the design and arrangement of its constituent parts.

The methodological assumption is well-illustrated by Descartes' method, four logical steps that (purportedly) lead to certainty. His method was intended as a rational system for the interpretation of nature, relying completely on mathematical and mechanical conceptions (Dijksterhuis, p. 409). Descartes believed that the whole of human knowledge could be obtained by strictly adhering to his method:

1. Accept as true only that which is so clearly and distinctly presented before the mind's eye that there is no occasion to doubt it;
2. Divide every problem into as many parts as needed to resolve it;
3. Begin with the parts that are simple to understand, and rise by degrees to the most complex;
4. Make so general and complete a review of the problem and its parts that no detail is overlooked (Merchant, p. 231).

Descartes' method was seized upon by contemporary and later writers as a means for procuring exact knowledge about the world. Writing in 1642, Hobbes advocated Descartes' method for the analysis of society:

> For everything is best understood by its constitutive causes. For as in a watch, or some such small engine, the matter, figure, and motion of the wheels cannot well be known except it be taken asunder and viewed in parts; so to make a more curious search into the rights of states and duties of subjects, it is necessary, I say, not to take them asunder, but yet that they be so considered as if they were dissolved (quoted in Merchant, p. 232).

Hobbes and his contemporaries championed a mechanical approach to the study of grammar, logic and ethics (moral philosophy) (Adas, p. 32). The Royal Society of London went so far as to promote the development of a purely denotative language based on mechanistic ideals. The adoption of a language free of metaphors and linguistic ornamentation was seen as a way to set philosophy free. Abraham Cowey, a seventeenth-century scientist, eagerly anticipated a future when all knowledge would be collected "the mechanic way" (Sawday, pp. 23-4).

The Mechanical Reeducation of Europe

Mechanical philosophy reached the minds of Europeans beginning in the seventeenth century and continued throughout the eighteenth. The breakthroughs of the early modern scientists, culminating in Newton's experiments and writing on optics, mathematics and mechanics, left little doubt in the minds of educated Europeans that a decisive break with the past had occurred, and that the key to the new understanding of reality was based on mechanistic precepts. Eighteenth-century Western Europe was confident that the mechanical outlook elevated their civilizations above all others that had ever existed (Adas, pp. 99-118). Mechanism was actively promoted by prestigious scientific societies on both sides of the Atlantic, such as the Royal Society of London and the American Philosophical Society (Sawday, p. 24; Smith, p. 122). The upper classes participated in the currents of modern thought by reading the works of Newton, Diderot, Voltaire, Hobbes, Locke and Hume. The public's appetite for information on Newtonian science was so voracious that within a century after the publication of the *Principia*, over 70 treatises about it had been published in six languages, for both professional and lay audiences (Smith, p. 50, p. 136). Noteworthy as vehicles of popular education were almanacs written for the lower-middle classes. In the seventeenth and eighteenth centuries, almanacs were the only books, besides the Bible, that everybody bought. Almanacs diffused scientific information, corrected morals, and satirized the belief in astrology, amulets, and the like (Smith, pp. 338-9).

With the ascent of mechanistic science, the older organicist and vitalist sciences — alchemy, natural and sympathetic magic and humourial medicine — began to lose credibility. The conviction grew that only that which could be described in terms of matter and motion is real. As a positivistic mindset came to possess Europe, the belief in spirits, angels, and other occult phenomena went into decline. Voltaire, one of the more elegant propogandists for enlightenment sensibilities, wrote:

> Witchcrafts, divinations, and possessions were for a long time universally accounted the most certain things in the world. What numberless crowds have seen all those fine things! But at present such certainty begins to lose its credit (Smith, p. 459).

Our commonsense reality has been shaped by the symbolic reordering of reality wrought by the mechanical philosophers during the Scientific Revolution. We believe that matter consists of atoms; that sensory experience is caused by particulate matter impinging on the nervous system; that the perception of colour is the reflection of light waves of different wavelengths; that bodies obey the law of inertia; that the sun is at the centre of the solar system; that the universe is a clockwork of inconceivable size and amazing regularity; and that clear thinking is mechanical. By the eighteenth century, almost everything was interpreted in light of Newtonian mechanics. "From this science," writes Preserved Smith (1966),

> were derived the widely accepted ideas that everything is subject to natural law, and hence susceptible to scientific treatment, and that the proper method is the isolation, abstraction, and definition of universal forces and the deduction from them, by pure reasoning, of their consequences. That men and nations act under the push and pull of general attractions and repulsions, that all societies are machines, and that the art of politics is the proper balancing of opposite tendencies in a perfect equipoise, were the corollaries of such a conception (pp. 172-3).

Summary: The Mechanical Repatterning of Reality

To summarize a few key conceptual categories that were reinterpreted in light of mechanical philosophy:

Power: The machine shifted the source of power from the living tissue to inanimate matter. Ancient and medieval technologies derived their motive power from animal and human muscle controlled by acts of will. The coming of the machine invalidated this logic. The new source of power was nature itself, and its regulation was achieved mechanically. As power became dissociated from the body, nature was increasingly viewed as a vast reservoir of energies to be harvested for human needs.

Order: Order in pre-mechanistic science was unpredictable. Mechanism rejected animistic sources of change. Order came to be seen as the predictable behaviour of individual parts obeying mathematical law.

Motion: Motion was no longer regarded as an organic process, but as a temporary state of a body relative to the motion or rest of other bodies (Merchant, p. 277).

Causation: Modern science banished final causes. Motion was no longer explained in terms of sympathies, antipathies and correspondences, and change was no longer presumed to occur in response to a sign. In the mechanistic worldview all change was explained as efficient material causes obeying mathematical law. Mechanism banished will, purpose, adaptive and goal-seeking behaviour, agency and telos as recognized principles of causation, and reduced causation to collisions (and other material interactions) between constituent parts. The new sciences sought to determine "how" things happen. In contrast, the sciences of Plato, Aristotle and Galen sought to know "why" things occur.

Theory of matter: Pre-mechanistic Western science held that all things are comprised of four metaphysical elements. The blend of elements determined the physical characteristics of an object. Mechanistic philosophy stripped away the vitalist core of elementalism, replacing the elements with material atoms as the building blocks of the physical universe.

Ontological status of matter: During the Scientific Revolution matter began to lose its vitality. Science banished from matter its capacity for activity, thinking and feeling. Matter became passive, dead, stupid. Mechanism relegated the so-called secondary qualities of matter to mere states of consciousness (Dijksterhuis, pp. 414-5).[14]

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[14] Primary qualities, according to John Locke, are those which things actually have; secondary qualities are those which produce experience in us. Locke lists solidity, extension, shape, motion, rest, and number as primary qualities, and sounds, tastes, colours, and smells as secondary (Flew,

The heavenly bodies: The natural philosophers of antiquity attributed soma and psyche to the living universe. Mechanistic science replaced the living body and soul of the cosmos with matter in motion. Similarly, Kepler argued that the earth could not possibly be considered alive for it lacked organs of perception. "My aim," wrote Johannes Kepler in 1605, "is to show that the celestial machine is to be likened not to a divine organism but to a clockwork" (Merchant, pp. 128-9).

The image of and role for God: Robert Boyle noted that God's continuing presence is not needed to explain a clockwork universe (Merchant, pp. 225-6). The early exponents of mechanistic philosophy retained a place for God in their vision of the cosmos. The God of the Middle Ages was a supernatural magician who created and sustained the universe. The God of the Enlightenment was a mathematician and engineer who fashioned a material universe, and then either operated it from the outside, or stepped back to watch it unwind. The mechanistic God revealed His perfection by the formulation and application of universal laws (Smith, p. 411). Over the following two centuries, science gradually eased out God from the picture of the universe.[15]

Natural law: The Scientific Revolution fostered the popular belief in natural law — a single set of immutable, universal principles that account for all phenomena. The conviction that the universe was bound by natural law weakened the ancient and medieval tendency to bifurcate reality into discrete domains, each governed by a unique set of principles. This development led to science's eventual rejection of macrocosm-microcosm theory. The growing stature of natural law in seventeenth- and eighteenth-century scientific thought also had the effect of diminishing the plausibility of natural magic and miracles. The purported ability of

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p. 287). Twentieth-century physics has demonstrated that the primary *and* secondary qualities are forms of perception.

[15] The mechanistic sciences gave impetus to an important eighteenth-century religious movement, *Deism*. (Smith, p. 240, p. 411). Deism held that God created a mechanical universe that obeys mathematical law. Deist Thomas Paine (1737-1809), for example, characterized God as the "first mechanic" (Deutsch, 1968, p. 388).

magicians to bring macrocosmic forces to bear upon the microcosm was inconsistent with the unalterability of natural law. Similarly, Baruch (Benedict) de Spinoza (1632-1677) argued that miracles were impossible because God's laws are absolute and irrevocable (Levy, p. 57).[16]

III. The Failing Plausibility of Macrocosm-Microcosm Theory

The sixteenth century witnessed the dissolution of old assumptions regarding the nature of reality, and the ascent of new methods and approaches to the study of nature. The new sciences found their ontological, methodological, and epistemological justification in mechanical technologies.

In their application of mechanical natural philosophy, an number of early-modern scientists noticed cracks forming in the ontological cornerstone of ancient and medieval science: the macrocosm-microcosm analogy.

The dominant organicist natural philosophical systems of Renaissance Europe upheld, in some form, the veracity of the macrocosm-microcosm analogy. In this philosophy, world and body were sewn tightly together to form a seamless whole. More generally, the macrocosm-microcosm analogy implied that all parts of God's creation were interconnected, and that each object incarnated the structure of the whole. As seventeenth-century vitalist Jean Baptiste van Helmont explained, "all particular things contain in them a delineation of the whole universe" (quoted in Debus, pp. 126-7).

The human person, in macrocosm-microcosm theory, was constituted as an exact replica, in miniature, of the greater universe. The characteristics and activities of the one perfectly mirror the other. The correspondences that were presumed to

[16] Renaissance and Enlightenment savants may have found substantiation for natural law in Jewish sacred texts. According to the Babylonian Talmud (completed circa 6th Century CE), the world always "functions in its normal way." This passage has been interpreted to mean that the lawfulness of the world applies equally to the material, moral and biological realms, and is unaffected by what people do. See Levy, p. 51.

exist between the two realms provided theoretical justification for ancient and medieval science and medicine.

Although heavenly and terrestrial phenomena were linked, a unique set of principles governed each realm. The supralunary plane — the region beyond the moon — was unchanging, perfect and eternal. The sublunary plane — the region below the moon — was subject to change, decay and death. The supralunary plane was associated with the divine; the sublunary, with terrestrial life. God dwelled in the ethereal reaches beyond the moon; creatures lived their mortal lives on the Earth.

The two realms were subject to different laws of motion. Ancient astronomers witnessed the uniform and predictable movements of the heavenly bodies, and from their observations concluded that the supralunary realm was unchanging and flawless. Celestial motion, being perpetual and circular, was "perfect." The motion of the planets and stars exemplified the superiority of the macrocosmic realm. In contrast, terrestrial motion was "imperfect" because it lacked the timeless quality of celestial motion. Terrestrial motion always had a definite start and finish. According to the theory, an object partakes only in motion that is appropriate to its "nature." Celestial objects "naturally" trace circles, while sublunary objects "naturally" move in straight lines. Curvilinear motion, when it occurred on or near the earth, was judged "violent" or "unnatural" (Hall, 1970, p. 18).

The Breakdown of Macrocosmic Theory

The investigations and findings of sixteenth- and seventeenth-century astronomers had the effect of diminishing the credibility of macrocosmic theory. The methods and techniques of modern science — accurate measurement, meticulous observation, and mathematical exactitude — furnished Renaissance astronomers with evidence that the celestial region was not as the ancients had imagined it.

The detection of nova ("new stars") and comets during the sixteenth and seventeenth centuries challenged the orthodoxy that the cosmos was forever unchanging. Changes in the heavens were inconceivable to Christian astronomers, for Scripture decreed that the stellar reaches were created by God at the dawn of creation. Medieval astronomers regarded falling stars, comets and nova as transient disturbances in the region between the earth and the moon (Hall, 1970, p. 17). Aristotle's theory of comets, which was still upheld during the Renaissance, attributed their radiance to atmospheric friction (Boas, p. 332). Using measuring devices of his own design, Tycho Brahe (1546-1601) tracked a series of comets between 1577 and 1596, and calculated that their trajectories lay entirely beyond the sublunary region (Debus, pp. 89-91). Faced with this conclusion, he questioned whether crystalline spheres existed. Ptolemaic astronomy held that the planets were fastened to translucent orbs. Tycho Brahe argued that a comet would burst or shatter crystalline spheres as its orbit intersected the spheres, an event that could not go unnoticed by terrestrial observers.

While some astronomers recognized that the "unchanging" heavens were in fact mutable, others found evidence that the heavens were far from perfect. Galileo argued that sunspots, rather than being satellites of the sun (as some of his contemporaries claimed) were actual blemishes or imperfections on the surface of the sun, a notion, which if true, falsified Aristotle's theory of celestial perfection (Boas, p. 325). Especially noteworthy is Kepler's derivation of the equations of planetary motion, which demonstrated that the positions of the planets could be pinpointed with greater precision if their orbits were assumed to describe imperfect ellipses rather than perfect circles.[17]

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[17] However, one should not think of Galileo and Kepler as modern scientific reformers, for both straddled the border of occult philosophy and modern science. Kepler's outlook was deeply influenced by his neo-Platonic beliefs. His "scientific" laws resulted from his mathematical attempt to circumscribe the orbit of the each planet within a different Platonic solid (tetrahedron, cube, octahedron, dodecahedron and icosahedron.) Similarly, Galileo's adherence to the idea of the perfection of the heavens (an implicit acceptance of macrocosm-microcosm theory) prevented him from conceiving of non-circular planetary motion (Debus, p. 11). When Galileo saw lunar mountains, plains and seas through his telescope, he believed that he had substantiated Pythagoras' mystical belief that the moon is another Earth (Boas, p. 318). The demarcation between mystical and mechanical interpretations of nature was less clear-cut during the

Traditional macrocosmic theory became even less tenable in light of Galileo's telescopic discoveries. For ancient and medieval sky-watchers, the number of heavenly bodies was constant: exactly seven planets plied the skies, and a fixed quantity of stars studded the celestial orb. When Galileo trained his telescope skyward, he saw more stars than any Western astronomer had ever seen. The Milky Way, he noted, seemed to consist of countless stars. Turning his telescope toward the moon, Galileo saw structures that he took to be mountains, plains and seas. The existence of terrestrial features on the surface of the moon, he believed, proved that the moon was another Earth-like planet, not a divine body. The outer planets, seen through his telescope, appeared as "globes perfectly round and definitely bounded, looking like little moons flooded all over with light" (Boas, p. 318). Galileo observed previously unknown moons encircling Mars and Jupiter, and discovered that Venus, like the moon, exhibited phases.

Taken together, the observations of early modern astronomers argued against the traditional understanding of the twofold division of the universe into terrestrial and celestial regions (Boas, pp. 317-8). Over the course of the 1600s and 1700s, explanations of macrocosmic phenomena were increasingly relegated to the theoretical umbra of celestial mechanics. With Newton's unification of celestial and terrestrial mechanics — the theory that all matter, wherever it occurs, is governed by universal law — the theoretical threads that for thousands of years had bound universe to human body finally began to unravel.

The Breakdown of Microcosmic Theory and the Mechanical Repatterning of Life

By adhering to the "mechanical" methods and techniques of the nascent modern sciences, astronomers overturned prevailing beliefs about the constitution,

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Renaissance than it would later become. Early modern scientists found magic, alchemy and astrology no less stimulating than their interest in experiment and mathematical abstraction (Debus, p. 2). For many early modern scientists, the new techniques of science served to further both "occult" *and* "scientific" ends.

size and arrangement of the macrocosm. In the wake of the revolution in astronomy precipitated by Copernicus, Kepler, Brahe and Galileo, the image of a living cosmos created and sustained by God grew less plausible. It was not necessary to predicate the movement of the heavens on underlying spiritual forces. The study of matter in motion was sufficient to explain the workings of the greater universe.

Similarly, the study of matter and motion, when applied to human physiology, anatomy and psychology, discursively siphoned spirit out of the body. What early modern astronomers did to the image of the larger universe, the anatomists did to the conception of the "little universe."

The experimental anatomists of the sixteenth and seventeenth centuries primed the Western imagination for mechanistic reinterpretations of the body. The scholars mentioned in this section represent three generations of anatomists who were affiliated with Padua University in northern Italy; each contributed significantly to the development of a fully articulated mechanical bodyview: (1) Andreas Vesalius demonstrated that the medical authorities of antiquity possessed faulty knowledge about bodily structure and functioning; (2) Hieronymus Fabricus propelled Renaissance medicine toward a mechanical conception of body parts; and (3) William Harvey proved that blood is impelled by a pump-like heart rather than by vital spirits.

Humanist Challenges to the Tradition Sources of Medical Authority

Early Renaissance anatomical and physiological knowledge was based almost wholly on Greek and Roman texts that had survived the Middle Ages, had been transmitted to Europe via the Arabs, or had been revived or newly translated into Latin. In the early 1500s, Greek assumptions about human physiology still dominated, but had been modified by thinkers who had combined the ancient ideas with elements of alchemy, astrology, magic, logic, and the doctrines of the church (Hall, in Descartes, p. xxxvi). In general, the prevailing medical theories of the

Renaissance affirmed a vitalist interpretation of nature, and accepted the veracity of the macrocosm-microcosm analogy. Beating at the heart of Renaissance medicine were humourialism, Aristotelian or Paracelsian elementalism, and pneumatism (theories of heat). In short, the prevalent medical theories of Renaissance Europe were ontologically rooted in the same organicist presuppositions that had directed the thinking of biological writers for over two thousand years.

Medical humanists especially venerated the biological works of Aristotle and Galen (Debus, p. 54). Given the respect accorded the ancient authors, it is not surprising that attempts to reform medicine were often met with fierce resistance. The professional societies that governed the conduct of physicians tolerated only minor corrections to the ancient texts. Thus in 1559, when Dr. John Geynes dared to suggest that Galen may not be infallible, he was sharply rebuked by the London College of Physicians, and was forced to sign a recantation before being received again into the company of his colleagues (Debus, p. 4).

Andreas Vesalius (1514-1564) was one of the medical humanists whose application of the observational method proved decisive in overturning the hegemony of the Greek and Roman schools. Vesalius' painstaking dissections of human corpses led him to conclude that Galen had been entirely incorrect in his description of the heart and the arterial and venous systems. Galen had taught that blood passed from the right to the left ventricle through invisible pores in the septum.[18] The pores serve an indispensable function in Galen's cardiovascular scheme: As blood passes through the pores, it bonds with vital spirits. The vital spirits cause blood to flow through the veins. Without the enlivening power of the spirits, there could be no blood movement; without blood movement, there could be no life (for movement indicates life). If the invisible interventricular pores do not exist, Galen's theory crumbles.

[18] The right side of the septum is, in fact, pitted with crevices from interlacing muscle bands, but there are no interventricular pores, visible or invisible (Keele, pp. 113-4).

Vesalius was unable to detect the pores. In the 1552 edition of *De fabrica* we find Vesalius reluctant to accept the evidence of his senses:

> The septum is formed from the very densest substance of the heart. It abounds on both sides with pits. Of these none, so far as the senses can perceive, penetrate from the right to the left ventricle. We wonder at the art of the Creator which causes blood to pass from right to left ventricle through invisible pores (Debus, pp. 60-3).

Vesalius' rejection of experience in favour of authority attests to the prestige that Galen still commanded in mid-sixteenth-century Europe (Debus, p. 63).

When Vesalius returned to the problem of interventricular pores in the second edition of *De Fabrica* (1555), he observed that "although sometimes these pits are conspicuous, yet none, so far as the senses can perceive, passes (sic) from right to left ventricle." Here, Vesalius has broken with tradition. He adds:

> Not long ago I would not have dared to turn aside even a hair's breadth from Galen. But it seems to me that the septum of the heart is as thick, dense and compact as the rest of the heart. I do not see, therefore, how even the smallest particle can be transferred from the right to the left ventricle through the septum (quoted in Debus, p. 63).

This observation was confirmed by contemporary anatomists, and was to result in a complete rethinking of blood flow (p. 63). The new conception was less dependent on animating forces. I will return to this subject shortly.

The Body in Pieces: Dissection

With faith in the medical authorities of antiquity in doubt, Renaissance medical theory was in a state of flux (Hall, in Descartes, p. xxxvi). In this climate of theoretical uncertainty, many medical writers emphasized the need to turn to the senses to obtain fresh and reliable knowledge about the body. Increasingly, this was accomplished by dissection and vivisection. In their efforts to describe their observations, many medical humanists invoked a mechanical vocabulary to make their findings intelligible. By doing so, they forged an entirely new understanding of body "parts."

Dissections had been performed in ancient Greece and Rome. Both Aristotle and Galen dissected animals, but neither thought it necessary to anatomize humans. To gain anatomical knowledge, it is sufficient, wrote Aristotle, to analyze the bodies of animals:

> There is doubt and ignorance about the internal parts of man, wherefore it is necessary to study in other animals those parts which bear a similarity to the parts of man (quoted in Keele, p. 87).

Since medical physicians regarded Aristotle and Galen as infallible, they had little incentive to substantiate the ancient opinions. For over 1400 years, scholars did not seek direct knowledge of physiology and anatomy, but instead, sought to refine the venerated teachings. Thus medieval Galenists codified and abridged their master's works; and Arab physicians, who had inherited the Galenic corpus, strove to improve his work by identifying the causes of and cures for diseases (Debus, p. 57).

As well, social and cultural taboos against disturbing human remains were strong in Renaissance Europe. In 1500, dissections were strictly supervised by the Church of Rome (Hall, 1970, p. 2). In any event, European scholars showed little enthusiasm for sullying their hands in pursuit of knowledge. Scholars studied books, not bodies; eviscerating cadavers was a task befitting surgeons, butchers, barbers, and other manual labourers who wielded sharp tools.

Dissection did not suggest itself to medieval scientists as a worthwhile way to learn about corporeal structure and functioning. The rationalistic bias of medieval philosophy, coupled with the "holistic" logic of organicist natural philosophy, rendered the practice irrelevant to science. The organic cosmos was a living whole; breaking it down into constituent pieces was inconceivable. With the exception of the atomists, philosophers did not conceive of reality as divisible, or that each of the divided pieces might have consequences for the whole (Lewontin, 1990).

When body "parts" were described by medieval and early Renaissance medical writers, they were not conceived of mechanically. The parts served as vessels and channels for vital spirits; they were not, as they would later become, elements in a complex array of interrelated material components. All living things were said to be imbued with an innate spiritous essence, *pneuma*. Aristotle characterized pneuma as a form of heat, "made" of celestial (i.e., not sensible) Fire, and therefore, governed by divine law (Keele, p. 173). Pneuma permeated and enlivened the body (Singer, p. xvii, p. 1). Individual body "parts" served as pneuma conduits, conveyors and receptacles. Andreas Vesalius wrote:

> There is in the substance of the heart the power of *vital spirit*. In the liver is the faculty of the *natural spirit*. The liver produces thick dark blood and from that the natural spirit; while the heart produces [thin light] blood which impetuously rushes through the body with the vital spirit, from which the inner organs draw their proper substances, by channels appropriate to all the bodily parts. So too the brain — containing a matter appropriate to its own function — produces, at the proper places and by those instruments which serve its function, the finest and subtlest of all [the three spirits, namely] the *animal spirit*. This it uses partly for the divine operations of the Reigning Soul, partly however it distributes it continuously to the organs of sense and motion through the nerves, as through little tubes. These organs are thus never without the spirit which is the chief author of their function... (Singer, pp. 1-2).

Vesalius' description of body parts bolstered a vitalist interpretation of nature. Anatomists who followed Vesalius, however, used a very different vocabulary when describing body parts. There grew a tendency for sixteenth-century Padua anatomists to parallel the activities of the body with the mechanical artifacts of Renaissance Europe. For example, Vesalius' younger contemporary Hieronymus Fabricus of Aquapendente (ca. 1533-1619) described what would later be regarded as venous and arterial valves, thus:

> The mechanism which Nature has here devised is strangely like that which artificial means have produced in the machinery of mills. Here millwrights put certain hindrances in the water's way so that a large quantity of it may be kept back and accumulated for the use of the milling machinery. These hindrances are called... sluices and dams... Behind them collects in a suitable hollow a large head of water and finally all that is required. So nature works in just the same way in the veins (which are just like the channels of rivers) by means of floodgates, either singly or in pairs (quoted in Boas, p. 277).

The application of machine analogies to describe arterial and venous valves evinces the propensity of Renaissance anatomists to reorganize biological knowledge mechanistically. Within this explanatory framework, the role of spiritual forces that enliven the body was downplayed, and the arrangement of material parts was emphasized. A body part, within a system of teleological medicine (like Galen's), was a "seat" for disease, i.e., a point at which celestial or divine influences touched the flesh. Vitalist medicine sought to identify the final cause of a disease (its purpose or motivation), not its material cause.

The mechanistic penchant for interpreting body functioning in terms of the material organization of constituent parts can be clearly seen in the writings of William Harvey (1578-1657). He declared, "The goal of anatomy is understanding the necessity and use of the part" (Keele, p. 88). Like other medical scholars of his age, Harvey focused on the observable (i.e., sensible) effects of a disease on the organs. His approach was different from that of his adversaries. His purpose was not to indicate

> the seats of diseases from the body of healthy subjects... but that I may relate from the many dissections I have made of the bodies of persons diseased how and in what way the internal organs were changed in their situation, size, structure, shape, consistency and other sensible qualities from their natural forms and appearances such as they are usually described by anatomists (Keele, pp. 88-9).

Harvey's field of study was morbid anatomy — the study of the palpable effects of disease on dead bodies. In Harvey, we witness the early murmurings of a medical discourse in which the human body is stripped of vital forces, and explained entirely in terms of the observable properties of matter.

With the advent of mechanical philosophy, medical humanists did not cease to believe in spiritual forces; they merely translated them into a materialist vocabulary. Harvey, like his contemporary Bacon, sought naturalistic explanations for the spirits. "Persons of limited intelligence," wrote Harvey, "when they are at a loss to assign a cause for anything very commonly reply that it is done by the spirits"

(Keele, p. 149). Harvey and Bacon, like many of their contemporaries, likened the spirits to the mechanical technologies of Renaissance Europe, particularly those powered by wind and magnet (Keele, p. 200).

The Circulation of Blood

The discursive hemorrhaging of spirit from soma was further sanctioned by the mechanization of the blood and the heart. The blood was of central symbolic significance in vitalist medicine. Life itself resided in the blood, an understanding promoted by Galen and justified by Scripture (Leviticus Chapter 14, verses 11-14). Blood bonded soul to body because the blood contained the soul. Blood was charged with a spiritous ingredient whose power to rouse the flesh derived from its macrocosmic origin.[19]

The mechanization of the heart and blood was set in motion by William Harvey. In 1628, writing in *Exercitatio Anatomica de Motu Cordis et Sanguinis in Animalbus*, Harvey advanced the opinion that: (1) The heart is a pump; (2) the quantity of blood in the body is definite and measurable; and (3) the blood is in circulation. As knowledge of Harvey's treatise on the mechanical movement of the heart and the blood was disseminated throughout Western Europe, Galen's vitalistic explanation of blood flow began to lose merit.

Galen's cardiopulmonary theory is quite elaborate; it is set out in outline here:

1. The liver converts food (the *ingesta*) into fresh blood.

2. The lungs draw air through the lungs and into the right ventricle of the heart.

3. In the heart, pneuma, the spiritual component of air, mixes with the blood.

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[19] The spiritous fraction of the blood was variously conceived by the different schools of vitalist medicine — as *pneuma* (Aristotelian), *anima* (Galenist), or *archeus* (Paracelsian).

4. Pneuma and blood are concocted (cooked) in the heart, a process that bonds the two. The heart, being an innately "hot" organ, is the source of heat. The vitalized blood "sweats" through the invisible pores from the right to the left ventricle.

5. Finally, the vitalized blood passes from the heart into the veins. The venous system distributes the blood throughout the body. Blood ebbs and flows through the veins, in the manner of air moving in and out of the windpipe. Blood vessels diminish in size further from the heart until their thread-like ends become flesh, muscle and organs (Keele, pp. 109-110, pp. 113-4, p. 117; Lee, in Plato, pp. 97-8).

A number of vitalist and organicist ideas are implicit in Galen's theory of cardiovascular physiology:

1. Celestial influences enliven the flesh. Vital spirits enter the body with each breath and are incorporated into the blood. Blood flow creates, nourishes and sustains the body.

2. The motion of the blood is consistent with the logic of Aristotelian physics. All movement is initiated by a thought, command, or exhortation. Therefore, blood moves through the body by virtue of the God-given soul amalgamated with the blood.

3. Also in accord with Aristotelian physics, blood travels in straight paths through the body. Sublunary objects, by nature, partake in linear motion only; they have definite starting and ending points. Blood originates in the liver and terminates in the skin, flesh and organs. The passage of blood through the veins is oscillatory: it alternates directions as it works its way toward its final destination.

4. The heart is primarily a respiratory organ; it is the spirits that are responsible for blood flow, not the heart. The chief function of the heart is to exchange fresh air for stale. The arteries contain air; the veins, blood.

5. Two kinds of blood flow in the body. The heat of the heart transforms new blood, which is dark purple, into vivified blood, which is bright red. This blood is carried through the veins to the rest of the body by an irrigatory current. The pulse is caused by a special property, *vis pulsifica*, which originates in the heart and creeps along the walls of the arteries (Keynes, pp. 169-170).

6. The body continually produces a fresh supply of blood from the ingesta.

Writing in *de Motu Cordis*, Harvey corrected several of Galen's physiological errors by employing the observational and experimental methods of the nascent mechanical sciences:

1. Although Vesalius had 70 years earlier published the opinion that the interventricular pores did not exist, belief in them persisted. On the strength of his own experimental evidence, Harvey refuted the existence of the pores: "But, damme, there are no pores and it is not possible to show such" (Keynes, p. 179).

2. The arteries contain blood only, not air. He demonstrated this by inflating the lungs of a corpse, and observing that air did not enter the pulmonary arteries (Keele, p. 126).

3. There is but one kind of blood. By removing arterial and venous blood from the body, pouring them into separate basins, and comparing their colours, Harvey observed no difference. He attributed the difference in colouration *in situ* to the fact that arterial blood, having passed through the heart, is under greater pressure than venous blood. Vitalists accounted for the difference in colour by hypothesizing that the more florid blood contained vital spirits. Harvey's explanation was purely mechanical.

Through experimentation and mechanical analogy, Harvey contributed a new understanding of the action of the heart. He was the first to describe the synchronized movements of the auricles and the ventricles. Earlier anatomists (including Galen) were unable to differentiate the phases of the cardiac cycle. The action is extremely quick in humans and warm-blooded mammals. By performing vivisections on animals with slow heart rates (e.g., reptiles and dying mammals) he saw and felt (with his fingers) cardiac rhythms (Keynes, p. 127). Harvey used a technological example to illustrate the difficulties detecting the phases. He compared the rapid movements of the heart to those of a firearm, in which the pulling of the trigger, the striking of a spark from the flint, and the ignition of the powder all seem to take place simultaneously, but do not (p. 180). From these experiments Harvey argued that the heart expels blood during systole, and refills passively during diastole. The pulse, he conjectured, is produced by the passive filling of the arteries during systole.

The secret of the complexity of the movement of the heart, Harvey wrote, was that the heart is a pump (Keynes, p. 141). "From the structure of the heart it is clear that the blood is constantly carried through the lungs into the aorta as by two clacks[20] of a water bellows to raise water." Harvey also likened the heartbeat to a "piston of a forcing pump, forcing water aloft" (p. 124). His conception of the cardiovascular structure as a hydraulic system, in both terminological detail and general framework, owed much to the work of hydraulic engineers who were active at that time in devising structures using valves and water under pressure (Webster, in Sawday, pp. 26-7).

Fabricus' notion of mechanical "floodgates" in the veins was refined by Harvey into a theory of mechanical valves. Fabricus knew that venous blood flowed in one direction only. Harvey advanced the view that the membranes in the veins and the heart that regulated the blood supply acted like the valves of pumps (Boas, pp. 279-80). Harvey reached his understanding of the valves by means of a series of experiments with arm ligatures; he reported his findings in *de Motu Cordis*.

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[20] A clack is a part of a mechanical pump common in seventeenth-century European mines. Harvey probably learned of clacks during his travels to the continent (Keynes, pp. 123-4).

Although the details of Harvey's experiments that led him to adopt a mechanical understanding of the blood vessels are prominently featured in *de Motu Cordis*, the book is best remembered today because in it, Harvey proved that blood circulates. Harvey's hypothesis was that blood is impelled by the heart, passes through the lungs, flows through the arteries, and returns to the heart through the veins.

> It is certain... that there is a passage of the blood from the arteries to the veins. And for this reason it is certain that the perpetual movement in a circle is caused by the heart beat... I am obliged to conclude that in animals the blood is driven round in a circuit with an unceasing, circular sort of movement, and this is an activity or function of the heart which it carries out by virtue of its pulsation, and that in sum it constitutes the sole reason for that heart's pulsatile movement (Keynes, pp. 182-5).

In fact, Harvey did not "discover" cardiopulmonary circulation. Arab medical scholars proposed the theory during the so-called "Dark Ages," a period, Les Levidow reminds us, that appears dark only when viewed through the distorting lenses of Eurocentric history (1988, p. 102). There is evidence — disputed by some — that the theory was articulated in the fourth century BCE by Hippocrates of Cos (ca. 460-370 BCE) (Keynes, p. 169). Hildegard of Bingen (1098-1179) may have also discussed the circulation of blood (Howe, p. 14). Whatever the origin of the idea, what is salient here is the two strategies by which Harvey justified his theory.

Harvey's work confounds the modern reader precisely because it blends the contemporary interest in experimentation, observation, quantification, and mechanical analogies with what modern science would now dismiss as metaphysical or occult. Harvey saw things partially in a new way, and partially in an old. Both in his training and in his overall scientific orientation Harvey was an Aristotelian and a Galenist. Despite his deep reverence for the ancients, Harvey professed "both to learn and to teach anatomy, not from books but from dissection; not from the positions of philosophers, but from the fabric of nature" (quoted in Debus, p. 102).

Let us consider Harvey's two strategies for proving blood circulation: quantification and mystical analogies.

Quantification began to develop as a tool of science during the Renaissance, and even then, not every early modern scientist was convinced of the merit of describing natural phenomena mathematically.[21] Teleological natural philosophers were concerned with ascertaining qualities of the self-acting soul, not with the measurement of physical quantities. Harvey's medical writings reveal no great interest in quantification. In examining a patient, Harvey might note an accelerated pulse rate, but he would not count the beats per minute. Similarly, Harvey gauged fever by feeling a patient's skin, but he would not measure the temperature. In Galen's time, there were no instruments for measuring heart rate or temperature. During Harvey's lifetime, timepieces for measuring short intervals and instruments capable of registering minute changes in body temperature were first becoming available. In Padua, Sanctorius and Galileo developed the pulsilogium, a pendulum with an adjustable arm (similar to a metronome) for measuring heart rates. The thermoscope, invented by Galileo and improved by Sanctorius, initiated a method for measuring body temperature. Harvey knew of Galileo through their mutual association at Padua, but the latter's influence came too late to alter Harvey's essentially Aristotelian approach (Keele, pp. 76-7).

Although Harvey showed little enthusiasm for quantification as a tool of science, he advanced a mathematical argument, in *De Motu Cordis*, to substantiate his theory of cardiopulmonary circulation. On the basis of animal examinations, vivisections and dissections, he made a telling argument: Assume that the left ventricle contains two ounces of blood, and that the heart beats 72 times per minute. A simple calculation shows that in one hour the left ventricle forces over 500 pounds of blood into the arteries. Since animal bodies contain only a few pounds of blood,

[21] Bacon stated that the investigation of nature was best conducted by applying mathematics to physics, but complained that mathematics could be used to excess. He deplored the fact that mathematicians were beginning to dominate physics (Debus, p. 104).

one must ask where all this blood comes from and where it goes (Debus, p. 67). Harvey argued that there are insufficient ingesta to produce a continuous supply of blood. Therefore, the modest quantity of blood contained in the animal must circulate unceasingly through its body (Keele, pp. 136-8).

Harvey's mathematical demonstration of circulation is crude by the standards of the science of today, but we easily recognize the system of rationality underlying it. However valid his reasoning appears to us in the present, many of Harvey's contemporaries remained unconvinced. And many who did accept the veracity of the circulation were persuaded by a very different rationale. In addition to his mathematical and physiological demonstrations, Harvey proved the circulation of blood by reference to the mystical analogies between macrocosm and microcosm.

Because celestial bodies always partake in unceasingly circular motion, and terrestrial motion always originates at one point and ends at another, blood circulation was inconceivable to early Renaissance scholars (Danciger, pp. 15-6). The heliocentric worldview was gaining plausibility in Harvey's time, and one of the effects of the Copernican revolution was the destabilization of traditional macrocosmic theory. But rather than discard the pivotal doctrine of Aristotelian science, Harvey found a new way to link macrocosm to microcosm: He endowed the heart with macrocosmic capacities. The heart, he wrote,

> is triply in the middle, and all dimensions are taken from it, above, below, to the front, to the rear; to the right and to the left. Therefore it is the principal part because it is in the principal place, as in the centre of a circle... (Keele, p. 122).

He likened the heart to the sun, supplying blood, spirit, and heat to the body:

> The heart of animals is the foundation of their life, the sovereign of everything within them, the sun of their microcosm, that upon which all growth depends, from which all power proceeds. The King in like manner is the foundation of his Kingdom, the sun of the world around him, the heart of the republic, the fountain whence all power, all grace, doth flow (Keele, p. 55).

The reactions of Harvey's contemporaries to his theory of cardiopulmonary circulation evince the impossibility of delineating "scientific" from "mystical/ religious" thought during the early modern era. Alchemist Robert Fludd was the first to publicly support Harvey's theory of cardiopulmonary circulation. Harvey's anatomical evidence had merely confirmed Fludd's deeper mystical realizations. For Fludd, "circulation was a fact, but one that could, and had been, postulated by him on the basis of cosmic truths prior to Harvey's lesser — but no less convincing — physiological evidence" (Debus, p. 70).

From the vantage of the present, it is perhaps most surprising that one of the apostles of mechanical philosophy rejected outright Harvey's theory. Gassendi argued that Vesalius, Harvey and Fludd had failed to invalidate Galen's system of cardiopulmonary physiology. The (invisible) interventricular pores denied by Vesalius and Harvey, did, in fact, exist, for Gassendi had seen them with his own eyes. If the pores existed they must serve a purpose, and that purpose could only be the formation of the arterial blood as described by Galen (Debus, p. 72).

Although Harvey offered both mystical and mathematical proofs for his theory of cardiopulmonary circulation, the mathematical-mechanical explanation eventually prevailed. Harvey's theory marked a turning point in the development of modern science and medicine. The heart and the blood, traditionally associated with life itself, began, after Harvey, to move gradually under the symbolic umbra of mechanism, and therefore, toward a mechanical explanation for life itself. Despite the great many accommodations to mechanism made by vitalist medicine during the eighteenth century, vitalism was eventually forced to cede blood as a symbol of life.

René Descartes and *Treatise of Man*

From the vantage point of the present, Harvey's work on blood flow seems to bolster a modern "scientific" interpretation of physiology and anatomy. From the perspective of the past, however, this judgment is inaccurate. The demarcation between "science" and "mysticism" was drawn very differently during the Renaissance than it is now. For Harvey and for a great many of his contemporaries the circulation of blood affirmed a vitalist theory of nature, and upheld the Aristotelian belief in mystical correspondences between the heavens and the human person. The break with the anatomical and physiological traditions of Galen and Aristotle — and, not coincidentally, the birth of modern philosophy — began with René Descartes.

Descartes' description of physiology, biology, and psychology are contained in two works, *l'Homme* (*Treatise of Man*) and the *Description of the Body*. In the *Treatise*, Descartes proposed to consider the bodies of humans and of animals as machines. Animals are automata; their bodies are governed entirely by the laws of physics, and they are devoid of feelings or consciousness. Humans are different; they have a soul. The soul meets the body in the pineal gland, and through this contact body and soul interact (Russell, p. 545). Two assumptions underlie Descartes' new theory of life: mind and body are separate; and the body is a machine and can be studied as such.

Few ideas in Descartes have lingered in Western thought as have his ideas on body and soul, their ontological separateness, and their modes of interaction (Hall, in Descartes, p. 2). Contemporary theories of the soul were Greek in origin and regarded the soul as the motive cause of physiological function and as the conscious agent of perception, volition, and reason. Descartes eliminated the physiological role of the soul altogether, and limited its cognitive role to humans.

L'Homme parallels Plato's *Timaeus*. Plato's cosmology centred on the image of the demiurge who constructed the body and soul of the universe and the bodies of humans from materials he found in the primordial chaos. Plato used the craftsperson analogy not to specify exactly what happened at the dawn of time, but to illustrate why things are as they are. In other words, the *Timaeus* encapsulates Plato's requirements for a rational discourse on nature. In the same way, *l'Homme* established Descartes' prerequisites for natural philosophy. Whereas Plato's cosmology was founded on organicist presuppositions, Descartes' origin story was deliberately mechanistic.

In the *Timaeus* the Supreme Artificer first constructed soul, then body, and then wove them together. Like Plato, Descartes has God construct separate body and soul; but each author proposes a different dualism. For Plato the body is dependent on the soul. In the *Treatise on Man*, Descartes dispensed of the soul as *causa vitae*, and showed what the body can do entirely on its own. He emphasized exactly what *res extensa* (the body) can do independently of *res cogitans* (the soul). Descartes' premise is that all responses conventionally believed to require the intervention of the soul actually occur without it (Descartes, p. 108).

In Cartesian philosophy, mind was not amenable to mechanical description. Descartes' innovative theory of the relationship between bodies and minds endures, in Gilbert Ryle's terminology, as the "Dogma of the Ghost in the Machine" (Ryle, p. 343). The "official doctrine" of this modern orthodoxy Ryle distills down to three points:

1. Every human person has both a body and a mind. The two are harnessed during life, but after death the mind may continue to exist and function.
2. Human bodies occupy space and are subject to identical mechanical laws that govern other bodies in space. Bodily states are subject to external examination; mental states are not. Only the self is privy to the activities of the mind. Therefore people occupy two independent spheres: a public physical world and a private mental world.
3. At least some mental episodes represent direct and unchallengeable cognition. Self-consciousness and introspection present the subject with direct and authentic awareness of the present state and operation of the mind (Ryle, pp. 338-40).

Herein lies an explanation for the pervasive form of individuality of a subject who inhabits a body defined by mechanistic sensibilities. Until Freud — who bestowed upon Western thought the notion of the unconscious — epistemological certainty became associated with a sovereign, self-knowing self. According to the

Cartesian formulation, consciousness engenders no illusion. The inner eye is capable of registering authentic knowledge. The nature and existence of present thoughts, emotions, desires, perceptions, remembrances, and imaginings are intrinsically reliable sources of knowledge. Unlike sense perception, consciousness and introspection cannot be mistaken or confused (Ryle, pp. 340-4).

The second assumption underlying Descartes' new theory of life, that the body may be regarded as a machine, has guided Western medical theory for three hundred years. Descartes' argument hinges on the denial of self-movement as the criterion for life:

> We see clocks, artificial fountains, mills, and similar machines which, though made entirely by man, lack not the power to move, of themselves, in various ways (Descartes, p. 4).

The difference between these devices and the human form is their relative degree of complexity. The body, having been created by God, is more ingenious than things created by humans, and therefore capable of greater freedom of movement (p. 4). Despite its complexity, the human body can be studied as an automaton:

> you may have observed in the grottoes and fountains in the gardens of our kings that the force that makes the water leap from its source is able of itself to move divers machines and make them play certain instruments or pronounce certain words according to the various arrangements of the tubes through which the water is conducted.
>
> And truly one can well compare the nerves of the machine that I am describing to the tubes of the mechanisms of these fountains, its muscles and tendons to divers other engines and springs which serve to move these mechanisms, its animal spirits to the water which drives them, of which the heart is the source and the brain's cavities the water main. Moreover, breathing and other such actions which are ordinary and natural to it, and which depend on the flow of the spirits, are like the movements of a clock or mill which the ordinary flow of water can render continuous... And finally when there shall be a rational soul in this machine, it will have its chief seat in the brain and will there reside like the turncock who must be in the main to which all the tubes of these machines repair when he wishes to excite, prevent, or in some manner alter their movements (Descartes, pp. 21-2).

Rather than invoking the soul as the source of vital activity, Descartes likened the body to familiar mechanical technologies: clockworks, automated fountain-figures, and systems of pulleys. He endorsed the theory of cardiopulmonary circulation, but only after stripping away all vestiges of Harvey's vitalistic explanation. Descartes compared the heart and lungs to a mechanical distillation unit: The heart heats the blood; the intake of air cools the lungs. The blood naturally circulates through the body because the heart operates at a higher temperature than the lungs, and its flow is naturally regulated by the valves (Debus, p. 70).

But it was not on the level of the observable organs that Descartes considered humans to be machines. In *Treatise on Man*, he makes clear on page after page that the mechanics of physiology is the mechanics of very small things, from somatic structures just below the threshold of visibility, down to the elementary particles of matter (Descartes, p. xxvix). All physiological and psychological functions — digestion, respiration, the functions of the heart and nerves, sensory awareness, memory, instinct and emotions — are explained as the mechanics of subvisible mechanics (p. 80). Finally, even "heat" he reduced to corpuscular motion (pp. xxvii-xxviii).

Descartes lived during the era when it was first becoming possible to seek optical evidence for his physiological claims. The telescope had been used earlier by Galileo, and the microscope, although not yet invented, was prefigured by the use of magnifying lenses in anatomical examination by both Harvey and Descartes himself. He attempted to account for the visible actions of the visible organs in terms of the invisible actions of structures below the threshold of visibility (Descartes, p. 5).

The subvisible world was as fundamental to Descartes' physiology and psychology as it was to his physics and cosmology. Descartes adhered to the alchemical-Paracelsian three-element theory (Fire, Air and Earth) but ultimately, he believed there existed only one kind of particulate matter. These particles, corpuscles, were created by God at the beginning of time along with a fixed quantity of motion. Thereafter, motion has transferred from particle to particle by collision without loss. Identical laws apply to every particle in the universe, whether in the heavens or in the living tissue. In this manner, Descartes linked physics, cosmology, psychology and physiology, giving the mystical relationship between heaven and earth a mathematical, non-vitalist treatment (Berman, 1990, p. 247).

The Ascent of the Machine-Body

Iatromechanism

The details of Descartes' explanation of physiology were rejected by his successors, but his general mechanical orientation prevailed (Hall, in Descartes, p. xxvii). Mechanical scientists found the machine analogy conducive to the creation of new medical knowledge. The iatromechanists (medical mechanists) produced good results during the 1600s and 1700s precisely because of their insistence on attending solely to observable and quantitative aspects of physiological functioning (Moravia, p. 46).

If Descartes deemed it necessary to distinguish mind from body, his intellectual heirs often did not. For many iatromechanists, mind, too, was reducible to matter in motion. The "Bible of Materialism" was Paul Heinrich Dietrich d'Holbach's (1723-1789) *Système de la Nature* (Smith, p. 170). D'Holbach rejected all occult causes, and explained everything — including consciousness and thought — in terms of matter and its fundamental property, motion (p. 170). D'Holbach attributed human existence in its entirety to the lawful forces acting on molecular parts:

> His visible actions, as well as the invisible motion interiorly excited by his will or his thoughts, are equally the natural effects, the necessary consequences, of his peculiar mechanism... All that he does, all that he thinks, all that he is, all that he will be, is nothing more than what Universal Nature has made him (d'Holbach, p. 11).

Iatromechanism had its detractors. Anti-mechanistic sentiment of the seventeenth and eighteenth century found expression through the iatrochemical school of medicine. The iatrochemists promoted a vitalist and religious understanding of nature based on the harmonies binding macrocosm to microcosm. Like the iatromechanists, the iatrochemists likened the cosmos and the body to the technologies of their day; but unlike the mechanists, the iatrochemists refracted the organism through the interpretive grid of Renaissance occult technologies — defining technologies of an earlier era. The followers of alchemist Paracelsus, the sixteenth-century progenitor of iatrochemistry, understood the entire universe as a chemical reaction. He regarded the Creation as a divine chemical process (Danciger, p. 19), and the stomach was a vessel in which poisonous and non-poisonous parts of food were separated by heat. Central to iatrochemistry was the concept of the *archeus*, the invisible, innate life force, the inner healer of the being, and the immaterial principle of life. Baptista Van Helmont (1578-1644) likened the archeus to an alchemist who separates the useful from the useless in food, and transforms nutrients into tissue (Danciger, pp. 38-40).

Critics of the mechanical school tended to challenge iatromechanism's exclusively materialist orientation. Some proponents of mechanism conceded that a life science based solely on the physics of machines and mathematics was untenable. Even Descartes admitted to the limitations of the purely mechanical perspective (Moravia, p. 45). Yet iatromechanists, swept along by the surging tide of mechanistic ideology, celebrated their triumphs despite evidence of the difficulties of their enterprise. Thus Giorgio Baglivi, writing in 1696, declared:

> Whoever examines the bodily organism with attention will certainly not fail to discern pincers in the jaws and teeth; a container in the stomach; watermains in the veins; sieves or filters in the bowels; in the corner of the eye, a pulley, and so on. So let the chemists continue to explain natural phenomena in complex terms such as fusion, sublimation, precipitation, etc., thus founding a separate philosophy. It remains unquestionable that all these phenomena must be seen in the forces of the wedge, of equilibrium, of the lever, of the spring, and of all the other principles of mechanics. In short, the natural functions of the living body can be explained in no other way so clearly and

easily as by means of the experimental and mathematical principles with which nature herself speaks (quoted in Moravia, pp. 47-8).

Iatromechanism and iatrochemistry were based on incompatible theories of life. The "life force" that was key to chemical explanations of life was entirely dispensed with by the mechanists. With the publication of Robert Boyle's (1627-92) *The Sceptical Chemist* (1661, 1680), mechanistic natural philosophy began to embrace and absorb chemical explanations. Boyle contrasted the simplicity of mechanical natural philosophy with the older natural philosophies. He criticized the idea of quality or form (conceived of as a kind of independently existing soul), showed the untenability of Aristotelian and Spagyristic (magical) theories on the grounds of experiment, and advanced his own corpuscular theory of matter. As the influence of Boyle's work spread, elementalism, both in its Platonic/Aristotelian and Paracelsus/alchemical guises, slowly passed into disuse in favour of a mechanistic and corpuscular/atomic theory of the structure of matter[22] (Dijksterhuis, pp. 433-7).

The Evolution of the Machine-Body

The machine has been the dominant metaphor for describing human body functioning for over three hundred years. Mechanical biomedicine first assimilated chemistry and, over the following centuries, incorporated electrical, thermodynamic, cellular and genetic phenomena (Merchant, p. 287). Over the years, Western science has fine-tuned the analogy of the machine-body: originally conceived of as a clockwork or automaton, the body evolved into a heat engine, a small business, a factory, and an industrial process.

As the Industrial Revolution transformed the patterns and conditions of Western life, new metaphors based on power technologies seemed better suited to describe the workings of nature than the simple clock had been. The steam engine, a

[22] Given the impossibility of demarcating mystical from mechanical thought in Renaissance science, it should come as no surprise to learn that Robert Boyle was a practising alchemist. Boyle laboured mightily to create the universal panacea, and was convinced that his attempts to transmute base metals into gold indicated that a solution to the problem was imminent (Dijksterhuis, p. 439).

device for transforming heat into mechanical energy, relied on the universal principles of thermodynamics (Bolter, p. 31). Writing in 1824, Sadi Carnot, one of the founders of this new science, explained meteorological and geological processes by comparing natural and synthetic steam engines·

> It is to heat that we must attribute the great and striking movements on the earth. It causes atmospheric turbulence, the rise of clouds, rain and other forms of precipitation, the great oceanic currents... lastly it causes earthquakes and volcanic eruptions. From an immense natural reservoir we can draw the motive power we need... To develop that power, to appropriate it to our own use is the purpose of fire-engines (quoted in Cardwell, 129).

If the universe appeared to seventeenth-century philosophers as a gigantic clockwork, to nineteenth-century thinkers the cosmos seemed to share many of the attributes of a heat engine (Cardwell, p. 130). And if macrocosmic processes could be accounted for in terms of power technologies, so could microcosmic phenomena. For nineteenth-century physiologists, "The living organism is above all a heat engine, burning glucose or glycogen or starch, fats, and proteins into carbon dioxide, water, and urea" (Wiener, 1985, p. 42). Writing in 1961, Wiener maintained that this scientific posture guided the thinking of many classically-trained physiologists living at the time (p. 42).

The attributes of nineteenth-century power technologies did not always inspire confidence in the future of humankind. The second law of thermodynamics suggested that the universe was an inefficient steam engine, gradually running down, and giving up its energy as wasted heat. Death and dissolution were inevitable. The savagery of this metaphor reflected the brutalizing conditions to which the working classes of the industrialized world were subjected (Bolter, p. 32).

In her recent study of historically- and culturally-specific medical metaphors, Emily Martin has traced the discursive evolution of the body during the last century from small business to factory or industrial process. In contemporary accounts of physiology, the

> imagery of the biochemistry of the cell [has] been that of a factory, where functions [are] specialized for the conversion of energy into particular products and which [has] its own part to play in the economy of the organism as a whole (Lewontin et al, 1984, quoted in Martin, 1987, p. 37),

These images have an obvious relation to the dominant form of social organization in late nineteenth- and early twentieth-century industrial societies.

The Body of Modern Science

Despite the evolution of the idea, the fundamental characteristics of the machine metaphor have not changed significantly over the centuries. The body recognized by science is purely physical, consists of atoms, and is subject only to the empirically verifiable laws of nature. The machine metaphor, which originated in the physiology of René Descartes, was enlarged by his successors and eventually became the basis of a comprehensive philosophy of nature.

Modern science has modified the basic Cartesian framework, but accepts, by and large, Descartes' key assumptions about the nature of nature. Four tightly intertwined metaphysical stances hold together the modern scientific framework: materialism, objectivism, reductionism and determinism. Here is a summary of how these stances are applied to the body:

Materialism assumes the primacy of matter (as opposed to the primacy of mind, consciousness, or spirit). Matter is held to be an inert substance possessing no inherent purpose, awareness, intention, meaning, intelligence, or will. All phenomena can be explained in terms of the play of natural forces acting on matter; religious and metaphysical interpretations have no place in materialist science. The pervasiveness of materialist assumptions on scientific medicine is evinced by the belief that the body is a purely physical system which responds only (or most effectively) to material interventions: surgery, drugs, radiation, and approved forms of physical manipulation.

Objectivism (or *metaphysical realism*) implies the existence of an objective reality "out there" whose nature or structure is unaffected by or independent of human understanding (Jaggar & Bordo, p. 3). Exact knowledge of objective reality may be approached by the application of pure reason guided by empirical evidence. The downplaying of the effects of mental state on health, and the reliance on double-blind experiments in determining the effectiveness of medical interventions, are expressions of the commitment of medical science to objectivism.

Reductionism implies that a complex whole can be explained in terms of the description of its parts or causes. Biological activity explained entirely in physicalist terms is an example of reductionism.

Determinism is the belief that every event is governed by, or operates in accordance with, causal laws. In science, determinism generally implies a lawful, material relation between the cause and the event. The belief that microbes "cause" disease reflects science's determinist bias.[23]

Together, these metaphysical stances lend shape and form to the machine-like body of modern science. The machine view assumes that

1. Life is movement of solid and liquid parts. All body functions are explained as the push and pull of material forces. Disease is caused by physical factors only.
2. Mind does not inhere in matter. Organic matter is identical to inert matter.
3. Living beings are devoid of active forces and principles. Recourse to an animating soul is unnecessary to account for somatic phenomena.

In other words, humans are machines who function according to universal physical laws. Homer W. Smith emphasizes the centrality of mechanistic thought in twentieth-century life sciences:

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[23] Richard Lewontin (1990) observes that most modern medical textbooks teach that microbiolcgical agent "X" causes disease "Y." Etiology, Lewontin argues, is far more complex and must take social factors into account. Many people carry the tubercle bacillus, but few who live in affluent surroundings contract the disease. Yet scientific medicine does not suggest poverty as the "cause" of tuberculosis.

> I would define mechanism, as we use the word today, as designating the belief that all the activities of the living organism are ultimately to be explained in terms of its component molecular parts. This was Descartes' greatest contribution to philosophy... Abandon Cartesian mechanism and you will close up every scientific biological laboratory in the world. At once, you will turn back the clock by three full centuries (quoted in Dubos, p. 115).

After three hundred years of mechanistic biomedicine, it is hard to conceive of the body as anything other than a living machine. The mechanistic outlook is so deeply engrained in the Western imagination that the idea of the body-as-machine structures Western commonsense knowledge to this day.

IV. Chapter Summary

In the modern West the body we are most intimate with is the one revealed by technological medicine. Dissected, probed, measured, vaccinated, drugged, X-rayed, CAT-scanned, and otherwise infiltrated, exposed, and rendered transparent, modern scientific and medical discourses presume a high level of confidence in their ability to provide true, objective descriptions of the structures and functioning of the human body. This confidence is partially warranted: In many ways, Western hygienic and medical practices are astonishingly effective in protecting health, curing illnesses, and averting death — at least as measured by medicine's own benchmarks of life expectancy, infant mortality rate, survival-years, and the like. In the spheres in which scientific medicine has been less successful — and here I would include the persistent tendency of Western medicine to overlook political, social and cultural determinants in their models of health and disease — we are promised, at least on the ideological level, that given sufficient time and funding, scientific medicine will eventually cure all ills, extend life, and perhaps even conquer death.

The widespread cultural authority wielded by science makes it virtually impossible to deny Western biomedical "facts." Few would dispute that the heart pumps blood; that blood circulates throughout the body via a network of blood vessels; that food is converted to energy as it traverses the alimentary canal; that the nervous system has an electro-chemical basis; and that our bodies are composed of chromosomes, cells and other genetic and biological building blocks. The reality of microscopic agents that promote or threaten health — bacteria, viruses, parasites, and the like — cannot easily be dismissed. Nobody who has been raised in the Western tradition seriously doubts that our bodies, at their most fundamental level, consist of atoms, which themselves consist of swirling clouds of subatomic particles. All of these familiar examples come out of the Western scientific and biomedical traditions. In the West, what counts as authoritative knowledge about the structure and functioning of the body is revealed through the researches of scientists, doctors, and medical investigators.

The cultural authority now enjoyed by science began to amass during the late Renaissance and the Enlightenment, circa 1600-1775, a period corresponding to the articulation, dissemination, and growing acceptance of mechanistic philosophy. With the advancement of scientific explanations of natural phenomena in terms of matter and motion, the groundwork for modern science was laid. All phenomena, the living organism included, were accounted for by the same principles by which machines were explained. Over the centuries, mechanical technologies evolved into explanations for bodily structure and function, and a means for fashioning corporeal truths.

Chapter 4

The Body as Computer

> Today we are coming to realize that the body is very far from a conservative system, and that its component parts work in an environment where the available power is much less limited than we have taken it to be. The electronic tube has shown us that a system with an outside source of energy, almost all of which is wasted, may be a very effective agency for performing desired operations, especially if it is worked on a low energy level. We are beginning to see that such important elements as the neurons, the atoms of the nervous complex of our body, do their work under much of the same conditions as vacuum tubes, with their relatively small power supplied from outside by the circulation, and that the bookkeeping which is most essential to describe their function is not one of energy. In short, the newer study of automata, whether in the metal or in the flesh, is a branch of communication engineering, and its cardinal notions are those of message, amount of disturbance or "noise" — a term taken over from the telephone engineer — quantity of information, coding technique, and so on.
>
> — Norbert Wiener (1985, p. 42)

I. Introduction: Chapter Overview

Chapter 4 focuses on twentieth-century scientific discourses that organize new understandings of corporeal structure and functioning. Cybernetics and its successor sciences posit that the human body, on a fundamental level, is a "machine" for processing information and therefore, analogous to the digital computer. My aim in this chapter is to document the emergence of new understandings of somatic organization and operation that are substantiated by the conceptual categories suggested by late-twentieth-century information technologies. The question that will guide this enquiry is: what ideas vitalize a body redefined by cybernetic sensibilities?

The discursive shift from machine to computer[24] is not a *fait accompli*. I do not claim that science describes (or will describe) all corporeal aspects cybernetically, in the manner that biomedicine has sought to depict life mechanistically. I believe that "bio-mechanical" explanations will continue to account for the makeup and workings of, say, the musculoskeletal system. Notwithstanding the continuities with the past, I contend that the capacities and possibilities of the digital computer add to, and in some instances, supplant existing knowledge about human bodies and their processes.

As in the preceding chapters, I locate bodyview within its worldview. By worldview I am referring to the set of fundamental beliefs and practices that explain reality and delineate what knowledges are possible. Similarly, bodyview consists of the core beliefs and practices that turn the body into an object of knowledge. I argued in Chapter 2 that worldview and bodyview are inextricably linked. In ancient and medieval European natural philosophy, the body was a theoretical resource out of which rational accounts of nature were fashioned. This propensity is exemplified by macrocosm-microcosm theory. The Scientific Revolution fostered the idea of universal law, i.e., a single set of mechanical principles that explain the behaviour of all particles in all parts of the universe. The effect of universal law on Western thought was to weaken the tendency to bifurcate reality into two discrete domains, each governed by a unique set of principles. In the new order, the definition of reality was consistent with the structure and logic of machines.

Beginning in the early years of the twentieth century, the appropriateness of mechanism as a philosophy of science came into doubt. With the articulation of novel theoretical perspectives, the image of the universe as a smoothly functioning machine appeared increasingly untenable. In *Three Post-Newtonian Sciences* I

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[24] Provisionally, I define *computer* as a device for manipulating logical operators to achieve an end. By contrast, a machine is an apparatus consisting of several parts, each with a definite function, for applying mechanical power. Unlike a machine, a computer does no physical work itself; a computer embodies a set of rules that enable specified tasks to be performed. John von Neumann (1903-1957) referred to the computer as the "general purpose machine," a term that denotes the theoretical ability of a computer to perform the work of any other machine.

sketch the contours of the emerging worldview. Quantum mechanics, special relativity and General Systems Theory (GST) are three theoretical approaches that undermine the plausibility of the mechanistic worldview. In the emerging picture of reality, the organization of complex systems, rather than the organization of matter, becomes the most compelling problem of study.

Cybernetics is a theory of organized complexity in machines and living creatures. The digital computer is the most visible example of a cybernetic machine. In *Control and Communication in the Animal and the Machine* I outline "the science of communication and control," and argue that the computer supersedes the machine as defining technology. Cybernetic redefines "machines" as operational descriptions written in the language of logic, and applies the definition to computers *and* living creatures.

Cybernetic "machines" have three properties: they are purposeful, complex and probabilistic. In the final section I describe this trinity of properties in detail, and in the process, enumerate how cybernetic discourses lend shape and substance to the body in the present.

II. Three Post-Newtonian Sciences

> So the second scientific revolution has abandoned the hidden tenets of the first. Its model of nature no longer assumes that she must be causal, continuous, and independent. These assumptions were idealized from everyday experience, and they were right, and splendidly successful, during two centuries when physics worked and measured on the everyday scale. They have turned out to be false on the small scale of the atom and on the large scale of the nebulas, and at least inappropriate to studies of the living (Jacob Bronowski quoted in Foss & Rothenberg, p. xv).

The Demise of Mechanism as a Philosophy of Nature

In Chapter 3 I noted that modern science is guided by four metaphysical principles: *objectivism* (or *metaphysical realism*), the belief that an objective reality exists independent of human understanding, and that knowledge of this reality may be gained through dispassionate observation and the exercise of reason; *materialism*, the assumption that the ultimate ground of reality is matter; *determinism*, the doctrine that every event is governed by, or operates in accordance with, causal laws; and *reductionism*, the belief that all phenomena, without exception, are analyzable in terms of the physical interplay of constituent parts. In this section I outline three key developments in twentieth-century science that invalidated the metaphysical underpinnings of the mechanistic worldview.

The mechanistic foundations of modern science were laid by its founders. "Out of Galileo's discoveries and those of Newton in the next generation there evolved a mechanical universe of forces, pressures, tensions, oscillations, and waves" (Einstein, in Barnett, p. 15). Over the next three centuries mechanism proved to be an astonishingly robust analytic approach. "There seemed to be no process of nature," observed Einstein, "which could not be described in terms of ordinary experience, illustrated by a concrete model or predicted by Newton's amazingly accurate laws of mechanics" (p. 15).

Life, too, seemed amenable to mechanistic explanation. The iatromechanists of the eighteenth and nineteenth centuries extended and refined the works of the early medical mechanists, and as a consequence, vitalist interpretations of life lost merit. Vitalism continued to be a force in Western medicine and biology, but by the early twentieth century, scientists were expressing confidence that the laws of physics and chemistry had yielded a definitive materialist explanation for life (Brillouin, 1968a, p. 147).

Cracks in the mechanistic worldview began to appear around the turn of the twentieth century. Scientists noticed that Newton's equations failed to predict the behaviour of very small and very large objects. In particular, the activities of objects on the scale of atoms and nebulae deviated from what Newton's laws said they should be. Although slight, the aberrations were of such a fundamental nature that the edifice of Newton's machine-like universe threatened to topple (Einstein, in Barnett, pp. 15-6).

Rifts in the mechanistic worldview also appeared in biology and the social sciences. Organisms and social systems do not abide by Newtonian standards. The belief that living creatures and their societies were subject to deterministic laws was especially dubious. Determinism implies that time is, in theory, reversible. A complete description of a system should yield precise knowledge of its history and future. Given the exact positions and speeds for the sun and its satellites at one instant, astronomers can use Newton's laws to calculate the exact state of the solar system for all time (Hawking, p. 53). While determinism guarantees accurate knowledge of the arrangement of planets, the phenomenon of life is at odds with Newtonian physics.

Furthermore, the second principle of thermodynamics seemed incommensurate with life. The law of entropy holds that chaos and dissolution are inescapable. Order is ephemeral; disorder is inevitable. Yet the animal, so long as it lives, attests to increasing orderliness by growing, healing itself, reproducing and evolving. If this interpretation is accurate, then life may be an exception to the entropy principle.

Despite these problems, confidence in Newtonian mechanics remained strong well into the twentieth century. Lacking an alternative framework, most scientists believed that ways would be found to account for the aberrations. During the final quarter of the nineteenth century, all attempts to fit the observed inconsistencies into the Newtonian framework failed (Hawking, p. 156).

The break with the past came with the acknowledgment that the Newtonian worldview lacked the explanatory power to account for certain phenomena. With the theories of Max Planck, Werner Heisenberg, Niels Bohr, Albert Einstein and others, the era of post-Newtonian science began. As post-Newtonian perspectives gained acceptance within the scientific community, the image of nature as a smoothly functioning machine began to break down. Newtonian mechanics yielded to a constellation of successor theories and sciences, including quantum mechanics, the uncertainty principle, the special and general theories of relativity, irreversible (statistical) thermodynamics, general systems theory (GST), information theory, games theory, cybernetics and complexity theory. In this section I will examine quantum mechanics, the special theory of relativity, and GST as examples of twentieth-century sciences that undermined Newtonianism.

Quantum Mechanics

Quantum theory is a system of mechanics advanced by Max Planck (1858-1947) in 1900 as a means to account for certain problems that had arisen in the study of radiation. Unexpectedly, quantum mechanics also had the effect of problematizing the appropriateness of determinism, objectivism and materialism as bases for science.

Heated metals emit electromagnetic energy, a phenomenon well-illustrated by the behaviour of an electric lightbulb. Electricity flowing through the metal filament causes it to glow. The glowing filament releases energy in two forms: visible light and radiant heat. Physicists at the turn of the century assumed that electrons were solid, material spheres; and that metal, when heated, shed electrons in an unbroken stream. Newton's laws predicted the release of more energy than was actually measured. Planck found a mathematical means to fit the observed facts to the experimental data by assuming that electrons were liberated from heated bodies in discrete parcels which he termed *quanta*. Planck's equations yielded the frequency and amplitude of radiation emitted by the excited atom with great precision (Barnett, p. 23; Flew, p. 297; Hawking, p. 54).

The implications of Planck's quantum hypothesis for the Newtonian worldview was not recognized until 1926 when Werner Heisenberg (1901-1976) formulated his uncertainty principle (Hawking, p. 54). Heisenberg was interested in the problem of calculating the exact position and momentum[25] of individual electrons. Heisenberg's principle states that the more you know about the momentum of a subatomic particle, the less certain you are about where it actually is, and vice versa. If its position is measured, determining its momentum is uncertain; if its momentum is measured, determining its position is uncertain (Angeles, p. 301). Heisenberg demonstrated that this indeterminacy had nothing to do with the inaccuracies of his measuring instruments, but was an ultimate barrier of nature (Barnett, p. 33).

Heisenberg illustrated his thesis by means of an imaginary experiment. A physicist, equipped with a powerful microscope, wants to measure the speed and position of an electron. To observe the electron, the physicist must somehow illuminate it; to illuminate it, the physicist shines a light on the electron. But "adding" light to the experiment disturbs the electron, for electromagnetic energy of all kinds (whether visible or invisible light, x-rays, or gamma-rays) affects the behaviour of subatomic particles. The act of observing electrons alters their velocity and position (Barnett, pp. 33-4).

Quantum physics rendered the Newtonian conception of determinism obsolete. Heisenberg's principle implies that physicists should not be concerned with the behavicur of individual particles, but with the behaviour of populations of particles. The subatomic realm can be described only in terms of probabilities, not cause and effect relationships. In dealing with atomic phenomena probabilistically, physicists were forced to abandon the notion that nature exhibits an inexorable sequence of cause and effect relationships. The Newtonian dream of being able to forecast the history of the universe at any instant based on its present position and velocity was dispelled (Barnett, p. 30, p. 34).

[25] Momentum is the product of velocity and mass, and implies a directional vector.

Quantum mechanics also cast suspicion on Newtonian notions of objectivism and materialism. To the physicist studying the inner realm of the atom, the "objective" world of solid objects could no longer be said to exist. Atoms were not actual objects, but statistically likely states. Werner Heisenberg wrote:

> When we get down to the atomic level, the objective world in space and time no longer exists, and the mathematical symbols of theoretical physics refer merely to possibilities, not to facts (quoted in Foss & Rothenberg, p. 144).

Special Relativity

The plausibility of the Newtonian worldview became even less certain in light of Albert Einstein's theory of special relativity. Whereas Quantum Mechanics redefined the inner limits of scientific knowledge, the theory of relativity reshaped scientific knowledge about the structure of the universe as a whole.

Relativity is the scientific principle established in two parts by Einstein in the opening years of the twentieth century. *Special Relativity* (1905) deals with non-accelerated systems; *General Relativity* (1915) deals with relative motion between accelerated systems. Both parts of the theory had the effect of upending the ordered mechanistic world picture. In the interest of brevity I will confine my discussion to special relativity and its implications for the Newtonian worldview.[26]

Einstein showed that Western intuitions about of the nature of mass, space and time were flawed. Mass, space and time are absolute quantities in Newton's mechanistic universe; in Einstein's, they are elastic. "Newtonian matter" is always everywhere the same: a one-kilogram object occupies a definite volume of space, has a constant mass, and ages in synchrony with all the universe. Einstein challenged these commonsense assumptions, asserting that size, mass and time are functions of

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[26] The second part of Einstein's theory, general relativity, makes further modifications to Newtonian notions of space and time, treating them as a non-Euclidean continuum, "curved" by the presence of matter in such a way that gravitation appears as a consequence of the geometry of the universe (Flew, p. 304).

velocity. Although everything is subject to relativistic effects, the effects are noticeable only when the speed of an object approaches that of light.

The speed of light has special significance in Einsteinian physics. The importance is illustrated by comparing Newtonian and Einsteinian conceptions of relative velocity. Newtonian mechanism offered a simple view of relative velocity: imagine two bodies, A and B, moving at different velocities V_a and V_b. The body travelling at velocity V_b appears to an observer travelling at velocity V_a to move at velocity $V_{ab} = V_a - V_b$. For example, to passengers in a car moving at 100 km/hour, the relative velocity of another vehicle passing at 110 km/hour is 10 km/hour. This "intuitive" understanding was cast into doubt in 1887, when Michelson and Morley performed an experiment that proved that light is an exception to the rule of relative velocity. They found that the velocity of light was constant (approximately 300,000 km/hour) regardless of the speed and direction of the light source with respect to other moving objects.

Seizing on the discovery of Michelson and Morley, Einstein ventured that the velocity of light establishes the upper limit at which objects may travel. Einstein showed that Newton's equations were approximations only valid for bodies travelling much slower than light (Smith, p. 148; Flew, p. 303; Brillouin, 1968a, p. 148).

Because relativistic effects are noticeable only at near-light speeds, there appear to be few (if any) practical consequences of Einstein's theory. The significance of special relativity lies in its implications for our everyday understanding of the nature of time and space. Space and time are concepts at the very root of our commonsense pictures of reality. Relativity theory argues that our taken-for-granted models are wrong because they are underwritten by Newtonian presuppositions. Relativity discards the concepts of absolute space and time. Space can no longer be regarded as everywhere the same; and a steady, unvarying universal time flow streaming from the infinite past to the infinite future is no longer plausible. Space and time, like the sense of colour, are forms of perception. Just as colours are meaningless without eyes to discern them, so space and time are nothing without events to mark them (Barnett, pp. 46-7). Imagine a terrestrial astronomer observing an event on Jupiter through a telescope. The event seems to occur "now." However, the light conveying information to the astonomer's eye takes 35 minutes to cross the interplanetary gulf. To an observer on Jupiter "now" occurred 35 minutes earlier. The special theory of relativity implies that there is no universal clock that guarantees that a single event observed from two different locations occur "simultaneously." Thus the experience of time is subjective.

Relativity neutralized the scientist's claim to dispassionate, value-free observation. Because time and space are relative rather than absolute quantities, there is no vantage point from which to observe "objective" reality. The scientific detachment guaranteed by modern science is shown to be chimerical. In Einsteinian physics, the scientist is an active participant in the system under study, and the mind of the observer appears as a necessary element in the structure of theory (Foss & Rothenberg, p. 144). Observers who move with respect to one another perceive the world differently and therefore establish physical reality differently (pp. 303-4).

To recapitulate the argument thus far: relativity and quantum mechanics draw the intellect away from the Newtonian conception of the universe as rooted in immutable time and space and functioning like a giant, unerring machine (Barnett, p. 66). Quantum theory, which deals with the fundamental units of matter and energy, and relativity, which deals with time, space, and the structure of the universe as a whole, describe phenomena in terms of consistent mathematical relationships. They do not answer the Newtonian "how" any more than Newton's laws answered the Aristotelian "why." Instead, they specify equations that define with great accuracy the laws that govern phenomena in the realm of the atom and in the depths of intergalactic space. Both theories are emblematic of the turning of science away from mechanical explanations of reality and toward completely mathematical descriptions of reality (pp. 17-23).

General Systems Theory (GST)

A third line of retreat from mechanical explanation toward mathematical abstraction is General Systems Theory, or GST. Ludwig von Bertalanffy (1901-1972) began advocating for a general theory of systems in the 1920s and 1930s to redress the failure of mechanistic science to explain biological phenomena and social activity (von Bertalanffy, 1968, pp. 11-2). The following four decades saw the rise of the systems approach and its incorporation into disciplines as diverse as physics, biology, ecology, meteorology, the earth sciences, psychology, sociology, economics, history and philosophy. Summarizing his life's work in 1968, von Bertalanffy wrote that systems theory "is operative with varying degrees of success and exactitude, in various realms, and heralds a new world view of considerable impact" (p. vii).

The impetus for a general theory of systems arose from two main sources. Von Bertalanffy, as a biologist and philosopher of science, regarded science as an inexhaustible wellspring of inspiration and insight. He was dismayed that barriers had grown up between the various branches of science. By the 1920s and 1930s many physicists had recognized the far-reaching implications of quantum mechanics and relativity. As a result, they were questioning the appropriateness of mechanism as a philosophy of science and were beginning to reformulate fundamental questions in terms of the wholeness of systems and the dynamic interactions of parts. Outside the field, however, the implications of the new physics were scarcely felt. Simultaneously and independently, comparable problems and conceptions were evolving in widely divergent fields. Parallel efforts to develop more holistic, interactive theories arose in the life, behavioural and social sciences. It appeared to von Bertalanffy that specialists in different fields were struggling to construct a new conceptual framework, but lacking a common language, they toiled in isolation. The interdisciplinary gulfs had grown so wide that scientists working in related subspecialties were sometimes unable to communicate with one another (von Bertalanffy, 1969, pp. 30-2). The edifice of science, von Bertalanffy feared, threatened to turn into "an unfinished Tower of Babel" (Rapoport, 1988, p. 5). Von Bertalanffy conceived of GST as a bridge across disciplinary schisms that would facilitate the building of a post-Newtonian worldview.

The second source for GST was von Bertalanffy's input into a now almost-forgotten controversy that polarized biologists early this century. The debate pitted neo-vitalists against the mainstream mechanistic school. Neo-vitalist Hans Driesch (1867-1941) thought he had incontrovertibly refuted the mechanistic interpretation of life. In his crucial experiment he cut a sea urchin embryo in two and saw it develop into two normal embryos. If embryonic development was governed by purely mechanical laws, Driesch argued, then the two fragments would have grown into two halves rather than two wholes. He hypothesized that the activities that characterize a living creature — growth, reproduction, healing, and so on — were due to *entelechies*: autonomous, mind-like, non-physical entities that direct organic processes (Flew, p. 107, p. 370). Driesch claimed that his experiment established the principle of *equifinity*, a teleological principle present only in living bodies.

Von Bertalanffy pointed out that equifinity was not confined to living matter, but characterized *open systems* in general (Rapoport, 1988, p. 5). He advanced the concept of the open system to explain "the rather trivial fact" that organisms exchange matter and energy with their surroundings (von Bertalanffy, 1969, p. 13). Conventional physics and physical chemistry explicitly dealt with closed systems, i.e., systems isolated from their environments (von Bertalanffy, 1969, p. 32; Kremyanskiy, p. 78). On the basis of the distinction between open and closed systems, von Bertalanffy refuted the neo-vitalist claim that life was incompatible with the second principle of thermodynamics. The second principle (the law of entropy) implies that orderliness is unstable; a state of orderliness naturally decays into a state of chaos. Yet the living creature attests to increasing orderliness by growing, healing itself, reproducing and evolving. Von Bertalanffy noted that a rigorous formulation of the second principle presupposes a system isolated from its environment, a condition that is not met by living organisms in particular, or open systems in general (Rapoport, 1988, p. 5).

By distinguishing open from closed systems von Bertalanffy pointed the way toward a new development in science: the investigation of systems of all kinds. General Systems Theory is a leading theory of organized complexity. A system is defined as a collection of items that interact. GST holds that certain principles apply to all systems, irrespective of type, composition, or nature of the forces that bind its components. GST discusses all systems equivalently, whether physical, biological, psychological or sociological. Systems are classified primarily by their degree of complexity, not by whether they are large or small, animate or inanimate, constructed of steel or represented mathematically (Beer, p. 7). Identical laws and principles apply for a machine, a living creature, a pair of scissors, a game of billiards, an economy, a language, a quadratic equation, a solar system or an atomic nucleus. All systems are related by virtue of the fact that they are *organized.*

Systems theorists represent "reality" as an immense hierarchy of superimposed organized entities (von Bertalanffy, 1969, p. 87). Every system is itself an element in a system. A pair of scissors is a system, as is the expanded system of a person cutting with a pair of scissors. The person using the scissors may be part of a manufacturing system, an industrial system, or an economic system. The scissors themselves consist of systems of blades and rivets; the blades consist of molecules, atoms and subatomic particles. The person wielding the scissors consists of systems of organs, nerves, muscles, tendons, blood vessels, cells, genetic material, molecules, and so forth. On the macrocosmic level, the universe may be thought of as a complex of interlocking systems (Beer, pp. 9-10).

All systems are subject to the principle of *mathematical isomorphism* (structural similarity). The law of exponential growth, for example, predicts the rate of bacterial reproduction; the spread of epidemics; the growth rate in animal populations; the quantity of gas released during a chemical reaction; and the progress of scientific research as measured by the number of journal articles published. The entities in question, whether microbes, creatures, gases or articles are unique, as are the causal mechanisms responsible for their growth. Nevertheless, the mathematical laws that predict their behaviour are of the same form (von Bertalanffy, 1968, p. 33). Ultimately, any system may be expressed as a system of differential equations (p. 83).

Although a system can be described as an aggregate of components — this is the strategy of "mechanistic" science — GST deems the approach inappropriate for the study of complex phenomena. Systems theorists hold that systems may only be properly understood when the connections between the parts are made the subject of study (Beer, p. 9). Mechanistic science presupposes that the forces of interaction between components are non-existent or weak (Rapoport, 1988, p. 7). Systems theory begins from the premise that the forces of interaction are strong. GST regards classical mechanics as a special case of systems theory applicable for objects for which the forces of interaction between components are negligible.

The fact that a system consists of strongly interacting parts accounts for its distinctiveness. GST posits that organized pockets exist in the universe. These pockets, by virtue of their organization, tend to preserve their identities. In contrast to Driesch's neo-vitalistic assumption that a non-material soul guides organic development, GST assumes that complex systems are organismic by nature. Living creatures are the most obvious examples of organismic systems, but there are others — the subsystems of organisms: cells, organs and tissue; the more-or-less integrated collections of social animals that function like organisms: anthills, beehives, flocks, pods and herds; groups that coalesce in human societies: families, tribes, nation-states, institutions and religions. Ecosystems, too, are living systems, consisting of plant and animal life, soil, air and water. On the terrestrial scale, the biosphere is a living system encompassing everything on Earth (Rapoport, 1988, p. 9).

Vitalists argue that the living creature is more than the sum of its parts, while mechanists (like the Greek atomists before them) maintain that the organization of matter is sufficient to explain life. Vitalism needs its soul; mechanism, its palpable matter. GST steers a different course through the vitalist-mechanist controversy. It regards life as intrinsic to complex systems, and seeks confirmation for this hypothesis by noting that both organic and inorganic forms tend to retain distinctive identities. Substituting one set of clock gears for another does not alter the function of the timepiece. Similarly, the inhabitants of a city live and die, yet the city's unique civic culture may endure for centuries. Driesch's sea urchin embryo was cut in two, yet each half retained the individuality of the whole. When a person loses a limb, life is disturbed but not destroyed. The iatromechanists, in asserting that life is purely a function of material organization, were clearly wrong. Cells in our bodies continually die and are replaced. Materially, we are never the same person twice.

Vitalism *and* mechanism ignore or neglect problems of organization. To systems theorists, it is neither the soul that lends a living system its individuality, nor the fact that the creature is a complex material entity. Life is a natural consequence of being organized on many levels: atomically, materially, neurologically, anatomically, socially, psychologically, politically, and so forth.

Systems theory dissolved the boundary between living and non-living entities, not by reducing all sciences to physics and chemistry, but by identifying the structural uniformities underlying the different levels of reality (von Bertalanffy, 1969, p. 87). GST showed that many concepts that had been classified as anthropomorphic, metaphysical, or vitalistic were amenable to exact scientific formulation (p. 86). As Buckley (1968) observed,

> A long, hard scientific struggle was required to recognize that the difference between inert matter and living materials does not lie in

any inherent qualitative differences in the substance as such, but in the way it is *organized* (p. 37).

GST rendered the notion of a life-force irrelevant while legitimating purposefulness and adaptiveness in nature. Living systems are regarded as hierarchically organized open systems that maintain themselves or develop toward a steady state (equilibrium). In this view, healing is the regulatory process that brings the organism toward normalcy after being disturbed. In this view, the *vis medicatrix natura* of vitalist medicine is divested of its metaphysical basis; it is not a conscious agent, but an expression of the dynamics of living systems that maintain and re-establish the steady state (von Bertalanffy, 1968, p. 18).

The emphasis on generalized living systems heralds the return to organismic science and medicine. Unlike the organicist sciences of ancient, medieval and Renaissance Europe, the systems approach does not imply vitalism. General Systems Theory holds that systems are not literally organisms, but are nevertheless crucially like them. As a living entity, the parts can only be understood in relation to their functions in the complete and ongoing whole (Flew, p. 152). The Greeks conceived of a living cosmos created, permeated and sustained by God. In contradistinction the systems approach seeks explanations for life not in the divine realm, but in the dynamic interactions that characterize all complex systems (von Bertalanffy, 1969, p. 88).[27]

Until recent times science was practically synonymous with theoretical physics, and the material world was the only reality vouchsafed by science. The consequence of this was the postulate that all phenomena are best depicted by the

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[27] The Gaia Hypothesis advanced by James E. Lovecock and Lynn Margulis proposes that the Earth lives. Simply expressed, the hypothesis states that the activities of life regulate terrestrial surface conditions, and vice versa (Joseph, p. 86). The theory is not as vitalistic as is sometimes imagined, and certainly does not signal a return to the geocosmic beliefs of the Renaissance. Lovecock and Margulis are less interested in determining whether the earth is alive than whether the planet is more subject to the generative processes of biology than the mechanical forces of geology. They emphasize that the line dividing living entities from the inanimate environment cannot be clearly drawn. The appropriate question is not *Is the Earth alive*? but *How alive is it*? (pp. 52-3). The suggestion that life may not be absolute parallels the argument advanced by cyberneticians in the 1940s that purposefulness may not be absolute. By this reasoning, computers are construed as self-regulating and goal-seeking machines. This question will be discussed on page 127.

paradigm of physics, and are therefore reducible to physical concepts and entities (von Bertalanffy, 1969, pp. 91-2). Owing to developments in modern physics, the physicalist and reductionist theses of classical science became problematic. The entities that science discusses — molecules, atoms and elementary particles — turned out to be more ambiguous than previously supposed. Once considered the metaphysical building blocks of reality, elementary particles are now thought of as mathematical models invented to account for observed phenomena (p. 92).

Although many modern sciences retain much of their mechanistic orientation, systems theory has altered the course of development in a number of material, social and biological sciences. With the approach of systems theory, the "dethronement of material substance as the only reality, the bedrock, has shifted the focus to the fact of *organization* per se as the more fundamental problem for study" (Buckley, p. xxiv). With the systems reorientation, Newtonian assumptions became less plausible.

For example, the image of the human psyche in the psychological theories of the early twentieth century had its origins in the physical-technological picture of the universe. The "robot model," which regards humans as reactive to their environment, found expression in Pavlov's notion of acquired and conditioned responses; in Skinner's theory of operant conditioning by reinforcement; and in Freud's concept of early childhood experiences being the basis for personality. The systems outlook lent psychology a holistic orientation by bringing into focus the psycho-physiological organism as a whole, emphasizing its autonomous functioning, creativity and distinctiveness. This development is conspicuous in Maslow's concept of "self-realization" and in Rogers' "client-centered approach." Gestalt psychology argued for the primacy of psychological wholes that are not a summation of elementary units and are governed by dynamic laws (von Bertalanffy, 1969, p. 31). The new breed of psychologies regard humans as active personality systems, not as reactive automatons (pp. 188-193, p. 207). "It appears," wrote von Bertalanffy, "that internal activity rather than reaction to stimuli is fundamental" (p. 106).

In the social sciences it has become admissible to regard social entities as systems. The tendency to consider economies, societies and nations as dynamic, organic wholes competes with the concept of a society as the sum of individual "social atoms" (von Bertalanffy, 1969, p. 25, p. 31). The intellectual heirs of historian Oswald Spengler (1880-1936) have seized upon the idea that "civilizations" are systems that obey general systems principles of decay and growth (Flew, p. 334). In so doing they have shifted the emphasis away from the study of the decisions of significant persons to the systems that produced them. In sociology, "Quasibiological functions are demonstrable in organizations," said Rapoport and Horvath:

> They maintain themselves; they sometimes reproduce or metastasize; they respond to stresses; they age, and they die. Organizations have discernible anatomies and those at least which transform material inputs (like industries) have physiologies (quoted in von Bertalanffy, 1968, p. 30).

In biology, the mechanistic procedure resolves life phenomena into atomic entities and partial processes. The living creature is resolved into cells, which in turn are resolved into physiological, and ultimately, physico-chemical processes. Its behaviour is reduced to unconditioned and conditioned reflexes, and its temperament and personality are sought in its genes. In contrast the organismic conception of life sees it necessary to study not only parts and processes in isolation, but also to solve the problems found in their organization and order that result from dynamic interactions between parts, and that make the behaviour of the parts different than when studied in isolation (von Bertalanffy, 1969, p. 31).

In summary, quantum mechanics, special relativity and GST are three twentieth-century theories that undermine the plausibility of the mechanistic worldview. Evidence for the inadequacies of Newtonianism slowly began to amass in the late 1800s and, a century later, there is no doubt that a major reorientation in scientific thought is underway. The founders of twentieth-century science have broken through the epistemological limits erected by the founders of modern science and have demonstrated the inappropriateness of objectivism, materialism, reductionism and determinism as metaphysical commitments. The emerging worldview is organismic rather than mechanistic.

The organicist orientation of twentieth-century science may be summarized thus: open systems are organized things, and the scientist must account for their order, organization, maintenance in the face of change, regulation, and apparent teleology. The envisaging of such factors as multivariate interaction, organization, self-maintenance, and directiveness represents new categories and directions of scientific thought and research.

III. Control and Communication in the Animal and the Machine

Defining Technologies in the Late Twentieth Century

With the breakdown of the Newtonian worldview, the image of the universe as a smoothly running machine is in need of revision. J. David Bolter nominates the computer as the defining technology for this age. In the same way that the categories and concepts suggested by Renaissance mechanical technologies challenged the metaphysical intuitions underlying ancient and medieval organicist science, the categories and concepts suggested by the computer challenge the metaphysical intuitions undergirding the mechanistic worldview. "It is not that we cannot live without computers," Bolter writes, "but that we will be different people because we live with them" (p. 10).

The principal symbolic effect of a defining technology is to modify dominant understandings of nature, the human person and the relation between the two. With the arrival of the computer as defining technology, nature and the living creature have reunited: the human person is an information processor, and nature is information to process (Bolter, p. 13).

The propensity to regard the living creature as a communication system linked to its environment is implicit in the new science of cybernetics. The emerging picture of the body is no longer based on nineteenth-century power engineering, but on twentieth-century communication theory. In establishing the science of cybernetics Norbert Wiener wrote that

> the newer study of automata, whether in metal or in flesh, is a branch of communication engineering... In such a theory, we deal with automata effectively coupled to the external world, not merely by their energy flow, their metabolism, but also by a flow of impressions, of incoming messages, and of the actions of the outgoing messages. The organs by which impressions are received are the equivalents of the human and animal sense organs. They comprise photoelectric cells and other receptors for light; radar systems, receiving their own short Hertzian waves; hydrogen-ion-potential recorders, which may be said to taste; thermometers; pressure gauges of various sorts; microphones; and so on. ... The [incoming] information fed into this central control system will very often contain information concerning the function of the effectors themselves..." (Wiener, 1985, pp. 42-3).

Cybernetics proposes the tightest discursive coupling of technology and the human body to date. Constituting the living creature as an information processing system is an entirely new representational practice. Neither computers nor the conceptual categories that the technology suggests existed a half-century ago.

My thesis is that cybernetic ideas are augmenting, and in some cases superseding, mechanistic conceptions of the body. In the remainder of this section I will show that cybernetic discourses reconstitute living and non-living systems according to a "machine" logic; however, the machine of cybernetics has little in common with the mechanical technologies that inspired the revisioning of reality during the Renaissance. A cybernetic machine is an operational description written in the language of logic.

Background to Cybernetics

One of the influential theories of complexity to be advanced this century was cybernetics. Conceived of by its founders as a universal science, its methods proved less useful to the study of biological and social systems than to the problems of contemporary physics and communication science (Kuhns, p. 217). Cybernetics was quietly abandoned as a legitimate science in the 1960s when its hypotheses proved to be untestable (Kelly, 1989b, p. 94). Shortly after Wiener's death in 1964, Jarislov Bronowski wrote:

> [T]he heroic dream is over. Cybernetics remains in the best sense a fundamental idea as well as a popular one, but it has turned out to be less embracing and, in an odd way, less interesting than we had hoped 20 years ago when it was conceived (quoted in Kuhns, p. 217).

Before its demise, cybernetics, in union with computer science, spawned a generation of new disciplines: General Problem Solving (GPS) in the 1950s; Artificial Intelligence (AI) in the 1950s and 1960s; and more recently, Complexity or Chaos Theory. In these second-generation disciplines, the architecture and capacities of the computer suggest a novel approach to representing complexity. Weaving mathematical structures with logical operators, computer programmers code the behaviour of complex systems and observe the results. The code of a program that fails to imitate the target behaviour is tweaked until it does. Computer programs are "testable" in ways that cybernetic speculations were not.

The empirical basis of the second-generation disciplines grants them a scientific legitimacy that cybernetics did not possess. Notwithstanding the higher status ceded to the progeny, the newer disciplines have inherited cybernetic creeds. The bases for computational reinterpretations of bodily structure and functioning were clearly set out in the writings of the cyberneticians of the 1940s, 1950s and 1960s.

Like General Systems Theory, cybernetics is an organismic approach to the study of intrinsically complex systems. Cybernetics is a special case of GST founded on the concepts of information and feedback (von Bertalanffy, 1969, p. 17). The systems studied by cybernetics exhibit purposeful behaviour. In describing teleological systems, the principles of communication and control take precedence over the laws of physics and chemistry (Foss & Rothenberg, p. 160).

The science was established in the late 1940s by a group of scientists centred around the figure of Norbert Wiener. The appellation, coined by its founder, derives from the Greek *kubernetes*, or steersman, the word from which we derive our word "governor." The name connotes the interest of the founders in pursuing the ultimate source of control in natural processes (Wiener, 1968, p. 31; Beer, p. xiv).

The control problem first arose during the Second World War in response to the military demand for more accurate ground-to-air artillery. An aircraft is a difficult target to hit because both the shell and target move fast, and the aircraft travels a considerable distance after the gun is fired. Wiener and his associates solved the problem by linking the motion of the target to the firing of the gun. As the gunner tracked the aircraft, the motion of the gun was translated into a mathematical forecast of the trajectory of the target. Information about the trajectory was returned to the tracking mechanism, and the aim of the gun was automatically adjusted. Using control mechanisms of this kind ("servo-mechanisms") Wiener and his associates increased the probability of a shell striking its target (Beer, p. 1).

Simultaneously, specialists working in other fields were also discussing problems of control and communication. Electrical engineers were designing servo-mechanisms and other electronic control systems; mathematicians and communication engineers were describing the coding and decoding of information within these mechanisms; and biologists and biostatisticians were discussing information flow within the body of the animal as the basis of physiological control.

United by their interest in problems of control and communication, engineers, logicians, mathematicians, biologists, and others inaugurated the new science of cybernetics in the 1940s (Beer, pp. 1-2).

Cybernetics is the science of communication and control in systems that are coupled to the environment. "Communication" refers to the transfer of "information," both between system and surroundings and within the system itself. "Control" refers to the tendency of the system to regulate its behaviour on the basis of external and internal information returned ("fed back") into the system (von Bertalanffy, 1969, p. 21). Examples of self-regulating systems include heat-seeking missiles, auto-pilots, electronic computers and living organisms.

Cybernetic "Machines"

Cybernetics is a theory of machines. The machines that cybernetics discuss have little in common with the machines of industrialism, i.e., apparatuses consisting of individual parts each of which has a definite function within the whole. A cybernetic machine is not an object, but a strategy for representing a particular behaviour. A machine does something specific; it is a system organized to achieve some end (Beer, p. 25).

The machine of cybernetics is an operational description of a purposive system written in language of logic (Beer, p. 88). The materiality and energetics of "machines" are totally irrelevant. A cybernetic machine is not bound by the laws of physics or chemistry (Ashby, p. 1). It does not even have to exist physically; what is important is that its behaviour is regular and reproducible (Ashby, p. 60). A cybernetic machine may be discussed formally, independent of its appearance or the materials out of which it is constructed (Beer, p. 7). A cybernetic machine, whether it exists concretely or in the abstract, embodies a process. It consists of two things:

rules of operation; and data upon which to operate (Bolter, p. 47). Ultimately, a cybernetic machine is "made" of logic[28] (Turkle, p. 274).

The archetype of the cybernetic machine is the *Turing Machine*, a concept that came out of the work of mathematician and logician Alan M. Turing. In his 1936 paper *On Computable Numbers* Turing established the nature and theoretical limitations of logic machines — what would later be called computers. A decade before the first programmable computer was tinkered together, Turing provided its symbolic description. His portrayal revealed only the logical structure of the computer; it said nothing about how to realize the structure (in relays, vacuum tubes, transistors, or integrated circuits, for example). A Turing Machine, as his description came to be known, exists only as a set of specifications. No computer built during the intervening decades has surpassed these specifications; all have at most the computing power of Turing's "machine" (Bolter, p. 12).

The special property of a Turing Machine (of which the digital computer is an example) is that it can mimic any discrete machine. Any complex process may be simulated by the machine if the process is expressible in a finite number of logical operations. Writing in 1950 Turing made the extraordinary claim that computers

> are *universal* machines. The existence of machines with this property [i.e., the ability to imitate any other machine] has the important consequence that, considerations of speed apart, it is unnecessary to design various new machines to do various computing processes. They can all be done with one digital computer, suitably programmed for each case. It will be seen that as a consequence of this all digital computers are in a sense equivalent (Turing, p. 56).

Turing's declaration of the equivalence of logical machines seems rather less remarkable today than it did 45 years ago, for its truth is confirmed daily by hundreds of millions of people. A programmable computer functions as a machine for writing, editing, calculating, sorting and storing; the same machine sends and receives voice messages, data transmissions and facsimiles; and it may be operated

[28] Turkle wrote that computers are made of logic, but the description is valid for cybernetic machines.

by voice, keyboard, or pointing devices. The key to understanding the functional diversity of the computer lies not in its material structure, but in its organizational structure. By virtue of its programmability, a computer is transformed into other machines without altering a single molecule.

IV. Cybernetic Interpretations of the Body

I now turn my attention to cybernetic interpretations of bodily constitution and functioning. In the following discussion I show three theoretical strategies by which cybernetics dissolve the boundaries between information technologies and living organisms.

Cybernetic systems have three properties: they are self-regulating; probabilistic; and extremely complex. I will review each characteristic and show its role in vitalizing the body in the present.

1. Cybernetic Systems are Purposeful

Cyberneticians claim that living organisms and computers are examples of purposeful machines. Purposefulness refers to the intrinsic ability of a system to react to its environment in ways that are favourable to its continued operation. A cybernetic system functions as though directed toward a specific end, and in spite of adverse environmental conditions, its behaviour brings it ever closer to its goal (Hall & Fagen, p. 87). In cybernetics the concept of purposefulness is also discussed as *directiveness* and *adaptability*; and as *self-regulating, goal-seeking, self-controlling, decision-making* or *teleological behaviour*.

In developing the new phyla of goal-seeking machines, cybernetics made teleology scientifically respectable and analytically useful (Rapoport & Horvath, p. 74). The recognition that mechanical behaviour can be purposeful is unavoidable. A heat-seeking missile is purposeful because the output from its infrared sensor prompts the missile to alter its course toward its target. On the other hand, a clock is not purposeful because its output (the display of time) does not affect its future action (Rosenblueth, Wiener & Bigelow, p. 235). The application of teleological thinking to mechanical systems clarifies their operation without introducing vitalistic explanations (p. 234).

Feedback

Purposefulness in the cybernetic machine is exemplified by the *feedback loop*. Feedback is the key explanatory mechanism of control and communication in the animal and the machine. Cybernetic control is based on its actual rather than its expected performance. Feedback counteracts the natural tendency of a system toward disorganization by producing a temporary, local reversal in the normal direction of entropy (Wiener, 1968, p. 35). A feedback loop carries a continuous flow of information between a system, its parts, and its environment (Buckley, p. xxiv).

The concept of feedback renders obsolete the philosophical problems of Newtonian causality and Aristotelian teleology. In seeking goals, causes are arranged in loop patterns that feed back into the system, leading to a sequence of corrections that bring the system ever closer to its goal (Deutsch & Rapoport, 1975). Purpose is not the consequence of material arrangement of parts, nor is it spurred by a soul. Purpose is controlled by feedback, and is a consequence of the organization of a system.

There are two kinds of feedback: in *negative feedback* the difference between actual and expected performance is detected as a positive deviation; the action of feedback counteracts this tendency. In *positive feedback* the difference is detected as a negative deviation which the control mechanism amplifies (Beer, p. 30).

Feedback is ubiquitous, and important in every context. Positive and negative feedback loops are pervasive in mechanical,[29] computational[30] and biological

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[29] Machines taking advantage of the feedback principle were first constructed during the Industrial Revolution. James Watt's mechanical governor, developed during the 1700s, illustrates negative feedback in simple deterministic systems. Mounted on an engine shaft are weighted arms. The

systems (Beer, pp. 7-8).

Biological Feedback

Biological feedback plays an essential role in the cybernetic understanding of somatic functioning. Cyberneticians speculate that the organizational principles that allow computers to approach goals and modify themselves are similar to those in living organisms. Let us examine examples of physiological, behavioural and neurophysiological feedback.

Physiological Feedback: Physiological feedback, or homeostasis, refers to the tendency of an organism to achieve a state of physiological equilibrium. Homeostasis maintains physiological variables such as temperature, humidity and pressure within the limits necessary to biological survival. The classic example of mammalian homeostasis is blood temperature, which remains constant across a wide-range of environmental conditions.

Homeostatic mechanisms are extremely complex. This quotation, taken from a popular book about the functioning of the human body, describes the endocrine glands in terms of positive and negative feedback loops:

> Together with the nervous system, the hormones control and regulate the functions of metabolism, growth and reproduction... Large sections of the hormonal system are under the overall control of the cerebrum... [The pituitary and peripheral endocrine] glands with their hormones... not only act upon "target" organs but also exercise feedback control upon the pituitary and other controlling centers. For instance, a pituitary hormone stimulates the thyroid gland to secrete thyroxine; but if too much thyroxine is secreted, it suppresses this

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arms are mounted on pivots so that they may rise by centrifugal force as the shaft spins. The faster the shaft rotates, the higher the arms rise. The arms actuate the valve that admits power to the engine. The valve closes in proportion to the height of the arms. Thus the speed of the engine is controlled through self-regulation: below a certain speed, the energy supply to the engine is increased; above the critical speed, the energy supply is decreased (Beer, p. 29).

[30] A "system" consisting of a human operating a computer furnishes many examples of feedback, one of the more striking of which is voice recognition technology. A speech recognition system "adapts" *to each individual's vocal mannerisms; the performance of the system improves, to a point,* with use. When a user utters a word, the system either recognizes or misrecognizes it. If the former, the user continues dictating. If the latter, the user corrects the error by typing or spelling the word. The user's negative feedback causes the program to modify itself. As the gap between error (the guess) and goal (the word) narrows, the ability of the program to recognize words increases. If errors are not corrected the performance of the system degrades (positive feedback).

> stimulation action of the pituitary gland, so that thyroxine secretion is adjusted to the correct required level. This feedback mechanism... is the general regulating principle for keeping the various hormones at their correct level in the blood, which, in turn, is determined by the nervous system in any given circumstances (Van Amerongen, p. 350).

The feedback principle is as pervasive in lower animals as in mammals. The stimulation of nerves in the gut of earthworms increases the production of digestive enzymes — an example of positive feedback. A similar cycle is seen in protozoa and bacteria. In vertebrates there are complicated connections in which the flow of gastric juices is brought about by feedback induced by direct physical and chemical stimuli, hormones and nerve impulses (Beer, pp. 31-2).

Behavioural Feedback: Behavioural feedback refers to the variety of positive and negative feedback loops involved in kinesthesia, proprioception and motor-coordination. Feedback is responsible for ensuring that the creature's physical balance is maintained in rapidly changing, unpredictable circumstances:

> If someone, quite unexpectedly, were to throw a ball to me, I should probably succeed in catching it. In order to do so, however, my body must engage in an extremely large number of events. My whole being must turn itself into "a machine for catching a ball". I become a vast information network involving thousands upon thousands of decision functions. Consciously, I suddenly see a ball coming towards me, I determine to catch it and I do so. Little else about this process percolates to my consciousness. Consider, however, what is going on inside the ball-catching-machine. A general purpose visual-scanning system, on a constant watch, first detects the ball: a complex set of inductions in the brain very quickly hypothesises what is happening and puts a volitionary system into operation. As a result of this volition (itself a mysterious psychological process), special visual tracking mechanisms come into play and another set of motor events begins. Somehow, my fingers (which must clutch the ball at exactly the right moment) have to be brought into the ball's path in time. This may well involve my flinging my body into the air. To do this exactly, and without falling flat on my face, I shall have to make all sorts of postural adjustments to my stance, flinging out arms and legs in exactly the right way to avoid equilibrial disaster. These manoeuvres in turn demand special physiological measures: unusually large supplies of oxygen will be gulped in, muscle tone will change, and general "attentiveness" of the whole nervous system will alter its balance and so on (Beer, pp. 20-1).

Neurophysiological Feedback: As the previous quotation demonstrates, neurophysiological functioning is also said to be under the control of feedback. In this view

> The central nervous system no longer appears as a self-contained organ, receiving inputs from the sensors and discharging into the muscles. On the contrary, some of the most characteristic activities are explicable only as circular processes emerging from the nervous system into the muscles, and re-entering the nervous system through the sense organs, whether they be proprioceptors or organs of the special senses (Wiener, 1985, p. 8).

The feedback principle sheds light on normal neurophysiology, and on at least some neurophysiological pathologies. In *Behavior, Purpose, and Teleology* (1968), Rosenblueth, Wiener and Bigelow discussed the disastrous effects of "undamped feedback" on inadequately controlled machines and creatures. The authors illustrate the former by means of a heliotropic device. The path followed by the machine is controlled by the direction and intensity of a light source. If in moving toward the light, the machine significantly deviates from its path, the control mechanism must compensate by delivering a strong stimulus to turn the machine in the opposite direction. If that movement causes the machine to overshoot the path, negative feedback turns to positive feedback, and a series of increasingly large oscillatory motions results. The machine will miss its goal.

This picture of the consequences of undamped feedback resemble those observed during the performance of voluntary acts by persons with cerebellar disorders. No obvious motor disturbances are evident when the person is at rest. However, when asked to take a glass of water from a table and drink from it, the hand carrying the glass executes a series of increasingly large oscillations as the glass approaches the mouth. The water spills and the purpose is not fulfilled (pp. 222-3). "The analogy with the behavior of the machine with undamped feed-back is so vivid," the authors write, "that we venture to suggest that the main function of the cerebellum is the control of the feed-back nervous mechanisms involved in purposeful motor activity" (p. 223).

The significance of feedback is that a purposeful system cannot help but control itself, so long as it works. The underlying mathematical theories that gave rise to cybernetics hold that a feedback mechanism should be able to handle *all* types of disturbances, not just one kind, for it is the system's natural tendency toward chaos that actuates the self-regulatory mechanism. In other words, a feedback controller cannot fail to succeed (Beer, pp. 29-30).

A second consequence of feedback is that function and structure are reciprocal. Systems with feedback do not adapt to their environment; systems and environment interactively adapt to each other (Foss & Rothenberg, p. 161). Categories of "subject" and "object," "self" and "other" begin to break down.

A third, more general consequence of the feedback principle is that it suggests that there are degrees of purposefulness. A computer is more constrained in its decision-making and goal-seeking capacities than a person, yet both exhibit a modicum of purposefulness. In this view, purpose "is not absolute, but relative; it admits degrees" (Rosenblueth, Wiener & Bigelow, p. 235). In this way cybernetics dispenses with vitalistic principles. Purpose is explained entirely in terms of physical and organizational laws.

2. Cybernetic Systems are Extremely Complex

Cyberneticians regard the computer and the organism as examples of extremely complex machines. Complexity in living creatures and computers is illustrated through the concept of the black box. The black box represents the unknown or unknowable control mechanism of a cybernetic machine (Beer, p. 8), and serves as a theoretical resource for explaining the activities of the brain and the central nervous system. Similarly, the cybernetic perspective on "error" sheds light on the comparability of well-designed, reliable computer systems and healthy living bodies.

Historically, modern science has confined its investigations to simple systems. The methods of science are not well suited to studying intrinsically complex systems such as patterns of traffic flow, the behaviour of populations or the evolution of ecosystems. The choice of subject matter is a direct consequence of the natural scientific paradigm, which hypothesizes a universe composed entirely of interacting bits of particulate matter. This conviction implies a pair of metaphysical presuppositions: all natural phenomena are explainable in terms of the interactions between constituent material units; and that the forces of interaction between these parts are negligible. The scientific method reifies these assumptions, and the scientific experiment is its primary expression. An experiment in physics or biology is designed to control all factors except one; by varying the one factor, the underlying causal mechanisms of the system are revealed. However, this method cannot be applied to phenomena where a range of factors are simultaneously at play. Because extremely complex systems do not easily yield to the analytical method, its application to the study of life has been limited (Ashby, p. 5; Rapoport, 1968a, p. xiv).

Cybernetics offers the hope of providing effective methods for understanding intrinsically complex, self-regulating machines (Ashby, p. 5). Cybernetics accepts complexity as a given, affirming this characteristic to the point of indefinability. It embraces phenomena as they are found, not as they are imagined. Complexity is not regarded as a consequence of interacting parts, but as a property in its own right.

Black Box Theory

Cybernetics approaches extreme complexity through *black box theory*. The black box is the control mechanism of an exceedingly complex system whose inner structure and operational details are unknown. The black box is analogous to an unbreakable opaque case with wires entering one end and wires exiting the other. The behaviour of the system is studied by examining the logical and statistical relationships that hold between the information entering the box and the information that emerges. The wires convey the input and output of the machine (von Bertalanffy, 1969, p. 22; von Neumann, p. 98; Beer, p. 8, p. 49). In the living organism the input consists of sensory data from within and without the body, and the output may be any number of voluntary, unconscious, instinctual or conditioned responses.[31]

Because the black box is assumed to be absolutely inaccessible, cyberneticians use the technique of *model-building* to study complexity. The aim of modelling is to reproduce the behaviour of the system under study. The successfully modelled system behaves in all basic respects like the original (Beer, pp. 49-52).

The principle means of modelling complex behaviour is the computer program. "A computer scientist," said Leonard Adleman, "quickly learns that any sort of system where you... have organized, predictable actions or reactions can be parlayed into a computational system" (quoted in Kolata, 1994).

The central nervous system (CNS) is the prototypical black box. Because comparatively little is understood about the actual functioning of the brain and the central nervous system, they are prime candidates for computer simulation. The complexity of the CNS is rivaled only by that of the computer. John Von Neumann (1903-1957) analysed brain functioning in the operational terms of the digital computer. He noted that

> The number of neurons in the central nervous system is somewhere of (sic) the order of 10^{10}. We have absolutely no past experience with systems of this degree of complexity. All artificial automata made by man have numbers of parts which by any comparably schematic count are of the order 10^3 to 10^6 (quoted in Ashby, p. 62).

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[31] The black box of cybernetics is not analogous to the black box of Behaviorism. The behaviorists declared the workings of mind off-limits because mind is not directly observable. Cyberneticians and their intellectual heirs acknowledged the indefinability of the actual structure of the brain and central nervous system, but then set about to simulate their observed behaviour. Behaviorism and cybernetics remain, overall, mechanistic and deterministic sciences: "The only difference between Skinner's position and that of [Newell and Simon and their coworkers]," wrote Weizenbaum, "...is that Skinner refused to look inside the black box that is the person, whereas the theory [General Problem Solving] sees the inside as a computer" (Weizenbaum, p. 175).

In cybernetic explanations of the central nervous system, computational techniques mimic function, not structure. The brain is regarded "as an organization of symbol-manipulating processes, rather than a physiological structure" (Simon & Newell, p. 281). Black box theory implies that the heterogeneity of neural matter and electronic components is altogether irrelevant.

The operating characteristics of the CNS was assumed to be a natural outgrowth of its complex organization. Early cyberneticians believed they could construct artificial brains by building devices with a comparable level of complexity. Norbert Wiener based his model of the brain on the electro-mechanical devices on which he had worked during the Second World War, with vacuum tubes substituting for neurons, and servo-mechanisms replacing the nerves. His followers designed machines to mimic the functions of the brain through the application of neural network theory. In a neural network information is distributed across an extensive web of interconnected neuron-like components. The ability to mimic the brain was thought to be a function of the number of connections — itself a measure of system complexity. Neural networks did not prove workable, and projects to construct electronic brains were largely abandoned in the early 1950s.[32] Meanwhile, a novel approach to "brain-making" gained adherents. This approach, which eventually evolved into Artificial Intelligence, programs digital computers to simulate cognitive functions (Bolter, pp. 192-3). In AI theories of mind, organizational complexity in the form of program supplanted the physical complexity of electro-mechanical brains.

Complexity and Error

The property of complexity in relation to the body is further explained by the cybernetic outlook on "error." Real systems, whether natural or artificial, are likely to fail. Machines wear out and break; organisms become diseased and die. Orthodox science and medicine tend to regard errors as lapses from a preconceived ideal.

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[32] Neural Network research experienced a renaissance during the late 1980s. See Gorman (p. 46).

Mechanical breakdown and biological dissolution are undesirable and therefore must be avoided. In contrast, cybernetics regards error as endemic to real life. An aberration in a system is not viewed as the process gone awry, a blemish to be excised, or an accident to be glossed over. Errors are natural and inevitable, and their occurrences are governed by the laws of statistics (Beer, pp. 98-9). "Error" is one systemic behaviour amongst many.

In the 1940s mathematician John von Neumann investigated the risks of error in complex systems and proposed methods for controlling error (Beer, p. 99). Von Neumann identified two ways that error may arise in a cybernetic machine. First, a communication pathway may fail. For example, in a mechanical system a lever, relay, circuit board, or microchip may malfunction; in a biological system, a bone may break, a nerve may be severed, or a pathological condition may develop that prevents neurons from firing.

Alternatively, the transmission of information along a communication pathway may fail. Reasons for the second kind of failure include electromechanical interference; a stripped gear-train; a cut wire; an overheated component; a blocked artery; a damaged nerve; or a ruptured synapse. Von Neumann showed that the risk of error is decreased by building sufficient redundancy into a system, and that a well-designed cybernetic machine can cope with any degree of error. In other words, deliberately introducing redundancy into a system keeps error under control. Von Neumann's theory explained why natural cybernetic machines are as reliable as they are, and suggested a strategy that would lead to the construction of extremely reliable artificial cybernetic machines (Beer, pp. 99-100).

Von Neumann noted that the complexity of the body ensures that there is a great deal of built-in redundancy, and suggested that the operation of autonomous machines (computers) mirrors the inner-workings of the animal:

> Natural organisms are, as a rule, much more complicated and subtle, and therefore much less well understood in detail, than are artificial

> automata. Nevertheless, some regularities which we observe in the organization of the former may be quite instructive in our thinking and planning of the latter; and conversely, a good deal of our experiences and difficulties with our artificial automata can be to some extent projected on our interpretations of natural organisms (von Neumann, p. 97).

In summary, the cybernetic characteristic of complexity bolsters computational interpretations of the body. The emerging image of the human person is that of the biocomputer or cyborg: "a hybrid of machine and organism, a creature of social reality as well as a creature of fiction" (Haraway, p. 191).

3. Cybernetic Systems are Probabilistic

Cybernetic systems are self-regulating, extremely complex and probabilistic. The first property is approached through feedback and homeostasis. The second, through the study of the black box. This section is about the third property, probabilism, and its elucidation through information theory. Information theory provides an entirely new conceptual framework for making sense of the functioning of the body.

Probabilism (or indeterminacy) represents a crucial metaphysical reorientation in scientific thought. With advances this century in the study of extremely complex phenomena, the 300-year-old commitment of science to determinism is disintegrating. Explanations of atomic structure, teleological machines and biological organisms require more sophisticated analytical techniques than the methods that mechanistic science allow. Newtonian principles yield satisfactory results when analyzing closed systems, but not open ones (i.e., systems that exchange matter and energy with their environments and whose constituent parts interact). The new sciences reject the possibility of explaining complex behaviour in terms of causal chains, arguing instead for a statistical approach to the study of densely interconnected systems.

Information Theory

Probabilism in cybernetics is approached through *information theory*, the statistical science of messages. The science was an outgrowth of Claude Shannon's influential 1948 paper *A Mathematical Theory of Communication*. In his paper Shannon defined the fundamental concepts of information theory — bits, noise, redundancy and entropy (Roszak, pp. 11-12). The theory was intended to aid in the design of mechanical communication systems, but it has great relevance to cybernetic systems as well (Beer, p. 43). In addition, Shannon's theory revolutionized the way scientists and technicians wielded the word "information," and ultimately, sowed the seeds for its many non-technical reinterpretations (Roszak, p. 11).

In Shannon's theory, *information* is a purely quantitative measure of communicative exchanges. In this context information is a technical term completely divorced from its conventional meanings; it says nothing about the content, semantics, value, truthfulness or purpose of messages. Even gibberish is information if somebody cares to transmit it (Roszak, p. 12; Miller, p. 123). Shannon, who worked out of the Bell Laboratories, was less concerned with what messages travelled over telephone lines than with how clearly and economically the messages were transmitted.

A communication system is visualized as a vast collection of individual components (nodes) linked together by communication channels to form a network or web. The channels conduct messages from one node to another. The linkages themselves may be mechanical, electrical or magnetic. The nature of the couplings is irrelevant; what is essential is that messages flow from node to node. The state of the connections at any given moment reflects the amount of information in the system. By virtue of its complexity and interconnectedness, the precise distribution of information within a network cannot be known in advance. The distribution of information may only be discussed probabilistically.

The standard unit of information is the *bit* (from *binary + digit*), a measurement expressed as a choice between two possibilities. The bit relates to the decision-making capacity of a system. Decisions are the events that occur in the nodes. At every instant the state of the network is governed by the results of "either-or" decisions made at the nodes. All decisions are in binary form, yielding either a "yes" or a "no." The concept of the binary bit is convenient when building machines because a bit can be represented as an on-off switch.

Neurons exhibit a similar "all-or-nothing" property. Below a certain level of stimulation a neuron does not respond at all. At the threshold level it suddenly begins to fire. As the stimulus increases in intensity the neuron fires more often, but its strength remains unchanged (Wooldridge, pp. 4-5). The discovery of the "either-or" character of neurons lent support to the idea that at least on the neurological level, the body operates in a manner analogous to communication devices and computers. To information theorists, "switches" made of protoplasm are conceptually identical to switches made of metal or plastic (Beer, p. 11, p. 46). Claude Shannon alluded to the parallels when he stated that "the human being acts as an ideal decoder" (quoted in Foss & Rothenberg, p. 297). To Wiener, the switching devices of computers represent almost ideal models of the synapses (Wiener, 1985, p. 14).

A network that "makes decisions" is a system that in some sense "chooses" between alternative forms of organization. Information is a measure of that organization, and therefore, a substitutive measure of its disorganization, or entropy (Wiener, 1968, p. 11). The second law of thermodynamics predicts that a transmitted signal will tend to degrade as its passes through a communication channel. Shannon's theory was designed to enquire into the conditions that make for efficient transmission of signals over a channel. Information counters the system's natural drift toward chaos. Information (order) injected into a system decreases its entropy (disorder), and entropy controlled by a system increases the information content. Although the overall disorganization of a system must, inevitably, increase, information theory demonstrates how to recoup part of the loss (Rapoport, 1968b, p. 139; Brillouin, 1968b, p. 161).

A Body Structured by Information

The challenge of extending the concepts of information theory from the context of communication engineering to computing machines and automation is traceable to the writings of its founders (Rapoport, 1968b, p. 137). Attempts to enlarge the purview of information theory into the social sciences during the 1950s met with mixed success. Von Bertalanffy noted that the application of information theory to psychology was limited "to rather trivial applications such as rote learning, etc." (von Bertalanffy 1969, p. 100).[33]

If the impact of the science of communication on the social sciences is inconclusive, the merging of information theory with the biological and medical sciences is very clear.

To Wiener information was the very essence of life: "To live effectively is to live with adequate information," he wrote.

> Man is immersed in a world which he perceives through his sense organs. Information that he receives is co-ordinated through his brain and nervous system until, after the proper process of storage, collation, and selection, it emerges through effector organs, generally his muscles. These in turn act on the external world, and also react on the central nervous system through receptor organs such as the end organs of kinaesthesia; and the information received by the kinesthetic organs is combined with his already accumulated store of information to influence future action (Wiener, 1968, p. 32).

One work was especially influential in lending credence to the idea that the functioning and structure of the body and the computer were analogous. In 1952 microbiologists James Watson and Francis Crick announced that they had "cracked" the genetic code. According to their theory, DNA molecules contain coded information that control specific physical processes during biological replication. The

[33] Von Bertalanffy appears to have ignored or downplayed the centrality of information theory in General Problem Solving, artificial intelligence, and cognitive science.

principles of the new "science of life" entered public discourse via a series of magazine articles, popular books and television programs. For example, in a 1960 television documentary on CBS, John Pfeiffer described the function of DNA this way: "The program's patterns of chemical bases may be compared to patterns of holes or magnetic spots on paper tapes fed into electronic computers" (Roszak, p. 17).[34] By the late 1950s or early 1960s "the DNA came to be universally seen as something like a tiny cybernetic apparatus that stored and processed microscopic bits of chemically encoded data" (Roszak, p. 17). Wiener's proposition appeared to have been substantiated: computer science and biology were both branches of cybernetics (p. 19).

The conviction that information theory was pertinent to biology was not universally recognized. Von Bertalanffy maintained that the application of the term "information" to describe DNA was inappropriate. When molecules of nucleic acids are spoken of as "coded information," and the revealing of their structure is described as "breaking the code," "information is a *façon de parler* rather than application of information theory in the technical sense as developed by Shannon and Weaver" (von Bertalanffy, 1969, p. 100). Subsequent microbiological studies demonstrated that the DNA "program" was more complex — and less like a computer program — than first imagined (Roszak, p. 17). "Information theory," wrote David Bell (1962), "although useful for computer design and network analysis, has so far not found a significant place in biology."

Notwithstanding the uncertainties as to whether information theory aptly characterized the neurological and genetic foundations of life, the idea that the body is structured by information has taken root and flourished. Information storage, transmission, exchange and retrieval emerge as pre-eminent explanatory strategies of corporeal functioning and constitution. Information is viewed as the third basic

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[34] Watson and Crick's vainglorious self-promotion of their "discovery" also helped cement the notion of the programmed gene in the public imagination. See, for example, Sarah Brooks Franklin's *Life Story: the gene as fetish object on TV*, her critique of the 1987 biographical docudrama about Watson and Crick's discovery of the double helix.

dimension to physical matter beyond mass and energy, and therefore, contributes to general notions of the structure and organization of organisms (Boulding, p. 6). Physicist Ernest Hutten referred to the performance of an organized system, the biological activities of an organism, and the behaviour of a human person as follows:

> The most general model of a natural process on which scientific explanation may be based is no longer the movement of a particle under the action of a force, but the storage (or organization) and transmission of information within a system (quoted in Foss & Rothenberg, p. 182).

In her study of body metaphor and imagery in medical literature, Emily Martin observed that the development of molecular biology has contributed to a shift from industrial to information processing metaphors. Modern medical textbook authors emphasize the flow of information from one part of the body to the other, and the control exerted from the processing centres of the body. Martin cites many examples, including this excerpt from a college physiology text:

> All the systems of the body, if they are to function effectively, must be subjected to some form of control... The precise control of body function is brought about by means of the operation of the nervous system and of the hormonal or endocrine system... The most important thing to note about any control system is that before it can control anything it must be supplied with information... Therefore the first essential in any control system is an adequate system of collecting information about the state of the body... Once the CNS knows what is happened, it must then have a means for rectifying the situation if something is going wrong... (quoted in Martin, 1987, pp. 37-8).

A body redefined by cybernetic sensibilities is a "machine" for handling information. It is analogous to a communication system or computer, and as such, obeys the laws that govern all such systems. Laurence Foss and Kenneth Rothenberg have attempted to describe this newly construed body in *The Second Medical Revolution* (1987). They argue for a paradigm shift in medicine paralleling the twentieth-century revolution in science. Their successor model to traditional biomedicine is "infomedicine." The transformation of medicine they call for is based on twentieth-century cybernetics rather than nineteenth-century power engineering, on a self-organizing system infrastructure rather than a mechanistic system infrastructure (p. 3). Infomedicine is "based on the premise that the patient is at minimum a biopsychosocial system or, in information theory terms, an information-processing system" (p. 12). Throughout, the language of information theory is used to capture the strategic advantages of a cybernetic approach (p. 192).

In infomedicine both somatic and exosomatic events have consequences for health and disease. Infomedicine expands the etiological scope of biomedicine beyond genetic and pathogenic factors, and embraces environmental, sociological, psychological and lifestyle factors. In so doing infomedicine "change[s] the boundaries of the patterns we call disease." The infomedical model regards the human organism as a complex system embedded in an expanding web of cybernetic circularities — a system within a system within a system (p. 17), and the whole of nature as a self-regulating and recycling system of patterned energy and information. Life is cast as a circular process in which genes, cells, organisms, minds, ecosystems, and the wider environment continuously exchange information (pp. 172-3).

One consequence of the centrality of "message" in twentieth-century science and medicine is the blurring of somatic and exosomatic distinctions. In the cybernetic reordering of nature, information is a measure of the entropy-resisting properties of the system. Information is that which reduces uncertainty, and efforts to keep entropy at bay are played out on every level of somatic/exosomatic organization. Thus in cybernetic descriptions of the body there has been a marked tendency to reduce physical, chemical, cellular and genetic phenomena to information. Richard C. Raymond stated that

> Relations between the control of sugar metabolism and insulin have reached a point where individuals who would otherwise die from a lack of this information may inject the information into themselves as required... Any stimulus applied to the cell,... even if it is only a change in the food supply, represents a transmission of information to the cell, and is used together with the stored information in the structure of the cell in the determination of the new state of the cell which results from the stimulus. Organisms which contain the sufficient amount of information appropriately keyed to facilitate

> rapid adjustment to a wide variety of information inputs, are said to be readily adaptable to their environments, and these have historically been the most successful organisms from the point of view of biology and evolution (Raymond, p. 160).

Raymond's claim that insulin and food are "information" demonstrates that the lines separating communication technologies from the body, and the body from the environment, are thoroughly breached. Late-twentieth century machines, Donna Haraway (1990) notes, render ambiguous the dichotomies of natural and artificial, mind and body, and self-development and externally designed. Many other traditional distinctions between organisms and machines are less certain than in the past. Now, says Haraway, "our machines are disturbingly lively, and we ourselves [are] frighteningly inert" (p. 194).

The emergent human body acquires signification in its relation (or non-relation) to the concept of pure "information." By extending the etiological reach of biomedicine to include environmental, sociological, psychological and lifestyle factors (i.e., variables that may be amenable to probabilistic analysis), the information processing model may lead to fresh understandings of health, safety, disease and hygiene. But there is a danger: the cybernetic discourse threatens to turn the body invisible. "Our best machines," writes Haraway, "are made of sunshine; they are all light and clean because they are nothing but signals, electromagnetic waves, a section of a spectrum" (p. 195). But only fictional cyborgs exist so ethereally; real people live in a world where matter still matters. To the person whose body is disabled by disease or injury, for example, suffering is not just coded simulacra; physical pain becomes the very condition of existence.

I will speculate further on implications of cybernetic reinterpretations of the human body in Chapter 5.

V. Chapter Summary

The human body, when interpreted through the grid of cybernetic discourses, is structured and vitalized by information. This assumption legitimates very different kinds of bodies than did the assumptions that informed the theories of mechanistic science. Until earlier this century, science explained the body as a product of power engineering. In cybernetics we find new conceptions of the body based on twentieth-century communication theory. The transition from mechanistic to computational metaphors represents a fundamental shift in the way the body is conceived of, experienced, represented and regulated. In only a generation, a new body metaphor has acquired the force of the real. Entirely new forms of selfhood are emerging. With little fanfare, the image of the human body as mechanism has begun to give way to the image of the body as computer — the most conspicuous cybernetic technology of the late twentieth century.

In accounting for the structure and organization of the body, computational conceptions subsume rather than replace mechanistic ideas. The parts of the body (e.g., bones and other solid "components") are reinterpreted as bio-mechanical conduits for conveying kinesthetic and sensory information to the central nervous system.

The capacities and possibilities of the digital computer add to our understanding of the function and structure of bodies. The computer-body is governed by a "central processor," structured by "information," and "programmed" to think. This body receives "input" from its internal and external receptors, processes "coded messages," and "outputs" its responses through its effectors. Its chemical, behavioural, hormonal and environmental equilibria are controlled homeostatically — by "feedback." Bodies are hardware, minds are software. The emerging picture of the body is that of a purposeful, extremely complex, and probabilistic cybernetic machine.

Chapter 5

Conclusion: The Body Under the Sign of Information

> The computer is more than an object, it is also an icon and a metaphor that suggests new ways of thinking about ourselves and our environment, new ways of constructing images of what it means to be human and to live in a humanoid world.
>
> — Bill Nichols, p. 22

I. Introduction

As a science of organized complexity, cybernetics constructs the body according to a different logic than the body described by mechanistic science. As somatic theory begins to slip under the discursive umbra of cybernetics, there is evidence of the approach of computational explanations for life. Computational interpretations of life revolve around the concepts of *feedback*, *program* and *information*. The same organization principles that describe the functioning of the body apply to the study of the new phyla of communication technologies. The science of control and communication completely dissolves the boundary between living creatures and cybernetic machines. In establishing the science of cybernetics, Norbert Wiener wrote:

> It is my thesis that the physical functioning of the living individual and the operation of some of the new communications machines are precisely parallel in their analogous attempts to control entropy through feedback (quoted in Roszak, pp. 9-10).

The emerging metaphor for the human body is the computer — a purposeful, extremely complex and probabilistic "machine." The shift from mechanical to cybernetic machine parallels the earlier discursive metamorphosis of the body from the product of divine handiwork to a self-acting clockwork. Yet the conceptual categories and ideas suggested by the computer imply a very different body than the one depicted by mechanistic science. What "kind" of body are we enticed into acquiring? What forms of selfhood do cybernetic understandings engender? What meanings are sanctioned — and what meanings are disallowed — when cybernetic discourses are sutured to living bodies?

These questions cannot adequately be addressed while adhering to Bolter's notion of defining technologies. Bolter's emphasis on *material* technologies blunts the theoretical edge of the concept. To sharpen it, I propose to regard technologies as "social" or "human" as well as material — i.e., as forms of power that establish the conditions and possibilities under which truth may be produced. By this definition, technologies are social and cultural forces that make possible (but do not cause) particular knowledges, practices and social relations. This is a Foucauldian notion of technology. In describing sexuality as a "technology of sex," for example, Michel Foucault is claiming that sexuality is not natural, but is constituted in social relations. Similarly, Teresa de Lauretis speaks of gender as "the product of various social technologies such as cinema, as well as institutional discourses, epistemologies, and critical practices" (1987, p. ix). Sexuality and gender are not properties of bodies, but historical achievements. Each is a "set of effects produced on bodies, behaviors, and social relations" by the deployment of "a complex political technology" (Foucault, 1980, p. 127).

By zeroing in on technological reinterpretations of the body, another Foucauldian spin is imparted to Bolter's idea of defining technologies. In Foucault's social analyses, the body is the locus of power through which subjectivity is constructed. Foucault links the mechanics of power to the body:

> When I think of the mechanics of power, I think of its capillary form of existence, of the extent to which power seeps into the very grain of individuals, reaches right into their bodies, permeates their gestures, their posture, what they say, how they learn to live and work with other people (quoted in Martin, 1988, p. 6).

By splicing Bolter (focus on material technologies) with Foucault (stress on social technologies), I produce a hybrid concept that enriches Bolter's original idea while enlarging the scope of questions that may be asked of it.

I conclude this thesis by applying this blended approach to discuss the implications of a body whose nature is informed by cybernetic sensibilities. I examine two different bodies that assume intelligibility "under the sign of information:" the "New Age" body; and the body of the Artificial Intelligentsia. Defining technologies, in addition to crystallizing new "truths" about the body, suggest new configurations of selfhood. In the ensuing discussion, it will become apparent that the computer metaphor is taken up in diverse, sometimes contradictory ways. Different groups impute different meanings to the cyborg-body.

II. The "New Age" Body and the Cosmic Computer

Cybernetic descriptions of the body are common in "New Age" writings. The New Age movement was born of the counter-culture generation of the 1960s and came of age in the 1970s and 80s. New Agers believe that the epoch of rampant materialism is nearing an end; at hand is a spiritual renaissance and a new social order. The name "New Age" hints at the utopian and millenniumistic tendencies of the movement. Marilyn Ferguson, whose *Aquarian Conspiracy* (1980) is considered a New Age manifesto of sorts, compares the renewal of society underway to the transition between the Middle Ages and the Renaissance. Ferguson writes that the New Age is an emergent culture that is paving the way to a new social order (p. 38). The world will not be a perfect place in the New Age, but will be, according to Corinne Cullen Hawkins, "a world with a healthier set of assumptions. The universe as an organism, not [as] a mechanism (handle with care); body/mind as an unbroken connection..." (Hawkins, p. 29). Andrew Ross estimates that several tens of million people worldwide are active in this burgeoning consciousness-raising movement (Ross, p. 8).[35]

The New Age bailiwick embraces humanistic psychologies; Eastern, African, and Aboriginal philosophies and religions; Western mystical teachings; alternative medical therapies; and sundry occult practices. Despite the diversity of New Age practices and beliefs, adherents are almost unanimously united in their conviction that the conceptual framework supporting the modern scientific enterprise is deeply flawed. In general, New Age proponents brand Western science as too materialistic, too unfeeling, too analytical, too clinical, too "left-brained."

Thus it is ironic that many New Age advocates have discovered in the computer an apt symbol and explanation for the body. The discursive grafting of the computer to the body in New Age writing is a rather curious development, given the overriding concern of New Age adherents to matters "natural," "organic" and "spiritual;" and their often ambivalent relationships to science and technology (Ross, 1990). Despite the body's purported affinity with the divine, many New Age proponents weave the products of positivist science into the fabric of the spiritualized body.

Many "alternative" health guides use computational metaphors to bolster vitalist interpretations of life.[36] For example, in a recent series of best-selling books, Deepak Chopra (1987, 1989) promotes a form of Ayurvedic medicine called

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[35] One measure of the breadth of New Agedom is the number of periodicals the movement supports: Ulrich's International Periodicals Directory (1990-91) lists over one hundred English language "New Age" publications, and categorizes many others under "Astrology" and "Parapsychology and Occultism." There are publishing houses that cater to New Age readers (e.g., Shambhala Publications). At least one mainstream publisher markets a line of New Age books (Bantam New Age Books: "A Search for Meaning, Growth and Change"). There are New Age bookstores, growth centres, conventions, workshops, radio and television shows, computer bulletin boards, and newsletters. The movement has even spawned a musical genre.

[36] In contrast, the founders of cybernetics were unequivocally anti-vitalist. Norbert Wiener (1985, p. 38), for example, charged vitalists with needlessly erecting barriers between life and physics. The new statistical and information sciences, he wrote, build walls that encompass both matter and life by offering an interpretation of matter, both living and non-living, founded on the concept of the cybernetic "machine."

Maharishi Ayur-Ved[37] (Mader, p. 4). Maharishi Ayur-Ved is premised on the belief that nature is an intelligent, conscious force. The human body is permeated by this same consciousness (Chopra, 1987, p. 221), and in fact, the body is said to be fashioned by consciousness. "Consciousness," Chopra explains, "conceives, governs, constructs and becomes the human body" (Mader, p. 4). Intelligence/consciousness plays an essential role in the maintenance of health:

> As we probe deeper into the pathogenesis of disease... a primary truth comes to light: all disease results from the disruption of the flow of intelligence. When people speak of intelligence, they refer almost automatically to the intellect and its dealing in concepts. Intelligence is not simply in the head, though. Its expression may be at the subcellular level, at the cellular or tissue level, or at the level of the central nervous system. Enzymes, genes, receptors, antibodies, hormones, and neurons are expressions of intelligence (1987, pp. 83-4).

The body depicted by the *Maharishi Ayur-Ved* system is endowed with intelligence and structured, at every level, by information. The universe, in this view, is an extension of the self, and under the conscious control of each individual. Chopra seeks confirmation for this outlook in the Hindu scriptures, and communicates his findings to his (predominantly affluent Western) audience in the upbeat patois of cybernetics and computer science:

> Veda [as a system of knowledge] represents an immense expansion of the human mind. The best way to describe it is that Veda is the total content of the cosmic computer. All the input of nature is channeled into it, and out of it flows all natural phenomena. The control over this computer is located in the human brain, whose billions of neural connections give it enough complexity to mirror the complexity of the universe (1989, p. 184).

In Chopra's system every event is precipitated by conscious or unconscious "information" originating in the brain. The brain, which is likened to the black box of cybernetic theory, orchestrates the ebb and flow of creation. All natural phenomena begin with a thought.

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[37] *Ayurveda*, Sanskrit for "the science of life," originated about 4000 years ago in India, and may be the oldest medical system still practised today. The Maharishi Mahesh Yogi personally selected Chopra to head the Maharishi's global campaign to promote Ayurveda. *Maharishi Ayur-Ved*, Dennis Mader charges, represents an attempt "to corner the ayurveda portion of the holistic health market" by the *Transcendental Meditation* organization (p. 4).

Maharishi Ayur-Ved is a teleological medical science; explanations for health and disease are sought (primarily) in the psyche.[38] Although Chopra does not disqualify purely material causation from his model of health and disease, he cannot easily admit to events initiated without consciousness or purpose. Thus there can be no accidents, coincidences or random events, and there is a marked tendency to (mis)diagnose social and cultural determinants of health and disease as self-inflicted mental wounds. *Maharishi Ayur-Ved* promotes a form of social-Darwinism — Nature smiles on the strongest, most resourceful individuals:

> In the scheme of things, what is useless soon dies out. Nature, and this includes our inner nature, has no room for what is useless. It promotes health only in those things that contribute to growth and increased development. To progress is to survive (1987, p. 127).

Chopra's discourse presents a (supposedly) radical retreat from the materialism of Western science. The recoil from materialism is not unique to *Maharishi Ayur-Ved*, but is in keeping with the idealist core of the dominant strains of New Age philosophy. This outlook subscribes to an ideology of rugged individualism, and holds that each individual is the sole author of his or her existence. "You create your own reality" is a popular New Age mantra. But as Bronwyn Drainie observes,

> New Age is the perfect cultural correlative for a neoconservative era... The irony of New Age thought is that, in spite of its professed desire for wholeness and oneness with the universe, it is relentlessly egotistical (quoted in Dale, p. 12).

Maharishi Ayur Ved is but one example of a New Age practice of the body that borrows heavily from cybernetic discourses. "Information" and "intelligence" emerge as key categories in this holistic health system — as do "programming," "feedback," and "central processing" in other alternative health models. In the case of *Maharishi Ayur Ved*, the marriage of computational ideas to Vedic erudition serves, first, to

[38] The teleological aspect of the *Maharishi Ayur-Ved* system resembles the teleological attitude of pre-modern European science and medicine. Galenic medicine, for example, sought to determine the motive for a disease rather than its material cause. See page 34.

oversimplify — and possibly to distort — the message of Vedas; and second, to naturalize a pernicious form of Western individuality by making it a property of healthy bodies. The self-absorbed individualism championed by some New Agers can hardly be construed as part of "a healthier set of assumptions" (Hawkins, p. 29).

III. The Obsolete Body of the Artificial Intelligentsia

Living systems and computing machines have special relevance for computer scientists and Artificial Intelligence (AI) workers. Organisms and computers are regarded as successful cybernetic systems: they respond quickly and accurately to internal and external stimuli; process information; integrate new information into their operating schemas; and induce trustworthy conclusions from incomplete information (Beer, p. 21). Organisms and computers act upon incoming information to preserve their organization and keep entropy at bay.

Living creatures are rather more impressive examples of cybernetic systems than are computers, but to the early AI workers, the gap between computers and humans was quickly narrowing. In 1958 Alan Newell and Herbert Simon announced that

> There are now in the world machines that think, that learn, and that create. Moreover, their ability to do these things is going to increase rapidly until — in the visible future — the range of problems they can handle will be co-extensive with the range to which the human mind has been applied (quoted in Roszak, p. 10).

Artificial Intelligence is one of the more prominent disciplines spawned by Cybernetics. AI begins from the premise that humans and computers are information-processing systems, and therefore, cognitive processes can be understood in terms of computer programs. According to AI theorists, programs are a means of positing and testing psychological theories:

> We use the term "program" exactly as it is used in the digital computer field, to denote an organized sequence of instructions, executed serially in a well-defined manner (Newell & Simon, p. 176).

A computer program is both a theory and a model; a computer program that successfully simulates a cognitive function is taken as evidence for the veracity of the theory (Reitman, 1964/1965). Simon and Newell found the homology between computer programs and human thinking so persuasive that they proclaimed: "the programmed computer and the human problem solver are both species belonging to the genus 'Information Processing System'" (quoted in Roszak, p. 10).

The body has a rather ambiguous status in the thinking of the artificial intelligentsia. At first glance the body appears to be absent as an object of theoretical and practical interest. According to Newell, Simon and Shaw, information processing descriptions of the operations of the mind are theories of psychology, not physiology (Dreyfus, 1965, p. 61). There are no implications of resemblance between protoplasm and electronic components (Simon & Newell, pp. 283-4). The actual material organization of the body is irrelevant, for mind can be replicated outside of and independently of the body. Gerald Jay Sussman of M.I.T. writes:

> If you can make a machine that contains the contents of your mind, then that machine is you. The hell with the rest of your physical body, it's not really very interesting. Now, the machine can last forever (quoted in Kelly, 1989a, p. 17).

Some computer scientists go further and insinuate that the body is — or is on the verge of becoming — obsolete. Marvin Minsky, for example, heralds the dawn of a post-biological future:

> If it was possible, I would have myself downloaded [into a machine]... And there's no reason the systems should break down if you use modern reliability techniques because you could replace each of the parts. The trouble with biology is that it tries to fix things, but it isn't very good at it. If you look at the error checking in the cell-repair part of the genetic code, it's really contemptibly low-grade compared to what we could do now if we redesigned the whole thing... I think the importance of downloading is just allowing evolution to proceed. And evolution seems to be leading us to a machine consciousness (quoted in Carstensen & Kadrey, p. 37).

Computational theories of the mind are implicitly computational theories of the body. The leap is unavoidable, for Western science and philosophy have not adequately dealt with — much less resolved — the implications of the dualistic legacy bequeathed by Plato and canonized by Descartes. Theories of machine intelligence preserve two longstanding assumptions of the Western intellectual tradition: the ontological separateness of mind and body; and the conviction that knowledge can be expressed in terms of logical operators (i.e., the belief that all knowledge may be formalized). Cybernetic discourses lend credence to both. Computing machines are Cartesian in two senses: they attest to the belief that the body interferes with reason and intelligence; and they deal only with determinate and discrete bits of information — what Descartes called "clear and distinct ideas" (Dreyfus, 1972, p. 147). The ghost in the machine has transmogrified into programmed code; but in the process, the machine, too, has been reconstituted. The absent yet implied body has discursively mutated into a variety of matter capable of processing information.

Artificial Intelligence retools the body as it recreates the mind outside the body. In the presence of cybernetic discourses living matter acquires a new ontological status. Neither infused with vital spirits nor defined by its atomic constituents, organic materials possess a property neither Plato or Descartes could have imagined: the power to control entropy through feedback.

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