CHAPTER TEN[*]

Homunculus' Quest for a Body

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I Introduction

Goethe's Faust strikes resonant chords in any thoughtful modern person, but for those of us employed in Faustian endeavors, it is difficult not to take the drama personally. Therefore, at the risk of adding to the numerous subjective interpretations of Faust, in this chapter I will explore some of its intimations and implications for several Faustian technologies with which I am involved: artificial intelligence, autonomous robotics, artificial life, and artificial morphogenesis. Faust has relevance to science and technology beyond these specific disciplines, of course, but they are beyond the scope of this chapter. First, however, it is necessary to define these technological pursuits and their goals.

Artificial intelligence (AI) is perhaps best known; it seeks to design artificial systems that have a behavior that would be called intelligent if exhibited by humans.[1] Much current research is devoted to relatively specific behaviors, such as recognizing faces, controlling vehicles, and scanning images or text for patterns of interest. This is largely an engineering activity, and greater insight into natural (human and animal) intelligence is neither an explicit goal nor an inevitable result. Nevertheless, research continues in artificial general intelligence (AGI), which refers to the creation of an artificial intelligence comparable to human intelligence in scope, flexibility, and generality.[2] Although we are still many years from developing an AGI, even the possibility raises questions in the philosophy of mind, such as whether such an artificial intelligence could or would exhibit consciousness or free will. Our inability to give clear, defensible answers to such questions reveals gaps and aporia in contemporary philosophy and psychology.[3]

Autonomous robotics is an active research area. Literally, an autonomous robot would be self-governing (autos + nomos), a law unto itself,[4] but in common usage the autonomy of a robot may be limited to its ability to operate without direct human control. In this context, "Autonomy refers to systems capable of operating in the real-world environment without any form of external control for extended periods of time."[5] The longer-range goal is to develop robots that are truly autonomous, able to take care of themselves, to pursue their own goals, and, to this end, to be able to cooperate with each other or with humans and other animals. Successfully implementing truly autonomous robots would help us to understand our own autonomy.

The discipline of artificial life (alife) seeks to create "sufficiently lifelike" artificial systems out of non-biological materials. In this it may be contrasted with synthetic biology, which seeks to re-engineer living matter for technological purposes. Some alife organisms are implemented with robotic technology, but many live in virtual environments that exist in a computer's memory (computer viruses and worms are simple, but all too familiar, examples). Current alife systems are not literally alive, but they display many lifelike attributes, such as reproduction, heritable traits, sensorimotor coordination,

[*] To appear in *Goethe's* Faust *and Cultural Memory: Comparatist Interfaces*, edited by Lorna Fitzsimmons. Bethlehem, PA: Lehigh University Press, 2012.

decision-making, competition, and cooperation. These life-like systems allow us to explore the characteristics and boundary conditions of life. Nevertheless, most alife researchers expect that, in the long run, true artificial life will be developed and that this accomplishment will help us to understand the necessary and sufficient conditions of life.

Artificial morphogenesis is a promising approach to nanotechnology.[6] Current nanotechnology focuses on the development of new, nanostructured materials, which, for the most part, are assembled into macroscopic products by conventional manufacturing techniques. Unfortunately, this approach is limited in its ability to assemble complex hierarchical systems with significant structure from the nanoscale up to the macroscale. Organisms display this hierarchical structure, with complex structures at every length scale, and we can anticipate that future autonomous robots and alife systems will have to be similarly structured (see below). Fortunately, nature shows an alternative assembly process in embryological morphogenesis, by which cells proliferate, differentiate, and coordinate their activity to create complex three-dimensional forms. Thus we expect future nanostructured systems to assemble themselves by processes of growth, differentiation, and self-organized motion.[7]

These disciplines—artificial intelligence, autonomous robotics, artificial life, and artificial morphogenesis—merge in the project of developing truly autonomous, intelligent robots able to behave independently and competently in the real world. Our current understanding of intelligence is that it depends on dense, intricately connected neural networks, which cannot be efficiently implemented on conventional digital computers. Conventional manufacturing techniques are unlikely to be able to assemble sufficiently intricate artificial neural networks, and therefore artificial morphogenesis will be required to "grow" (self-assemble) them. Furthermore, the creation of complex sense organs and effectors (such as artificial muscles) will require artificial morphogenesis. Research in autonomous robotics and artificial life will show us how to make these robots cooperate with each other and with us.[8]

These technologies promise many benefits, and so we might go groping blindly forward, like Faust, "foretasting such high happiness to come" ("Im Vorgefühl von solchem hohen Glück") (F, 11585) that we exclaim, "Abide, you are so fair" ("Verweile doch! du bist so schön!") (F, 1700),[9] and seal our fate. The Faustian character of these technologies is apparent; what might we have to bargain away to obtain them? What might machines with more than human intelligence mean for the future of humankind? What are the ethical implications of using autonomous robots in warfare?[10] What are the environmental implications of artificial organisms, which might be microscopic in size? And so on. Aside from their obviously Faustian character, these technological and social issues might seem remote from Goethe's drama, but his deep insights into nature and human nature allowed him to anticipate many of the problems and sometimes their solutions. In particular, Homunculus' quest for a body symbolically prefigures the history of AI in the twentieth century, including the emergence of theories of embodied and situated intelligence, and offers new insights into the relation of mind and matter. Therefore, in this chapter I will limit myself to this issue and leave Faust's broader implications to a book in preparation.

II Words and Deeds

Symbolic AI

The discipline of artificial intelligence arose in the late 1950s, although it has much deeper roots, stretching back through Aristotelian logic into Pythagorean numerology.[11] Its history may be divided into two overlapping phases, symbolic AI (also known as traditional AI or GOFAI, "good old-fashioned AI") and, since the mid-1980s, connectionist AI. The latter takes seriously the embodiment of natural intelligence, both in the brain and, as more recently recognized, in a body situated in its physical environment. These developments were impeded by background assumptions about the nature of intelligence that were grounded in European traditions such as rationalism, idealism, Cartesian dualism, and the mechanical philosophy. As a consequence researchers focused on human intelligence (supposedly the only intelligence truly worthy of study) and in particular on the faculties considered most characteristic of human intelligence: language and abstract reason. Symbolic AI gets its name from its focus on "symbols," in this context: words, concepts, and abstract categories.

Symbolic AI is a direct outgrowth of developments in symbolic logic and formalist mathematics in the late nineteenth and early twentieth centuries. For example, in his Investigation of the Laws of Thought (1854) George Boole expressed logic in a formal algebraic notation, which is the ancestor of modern symbolic logic as developed by Bertrand Russell, Alfred North Whitehead, and others. Further, in the years leading up to 1900 mathematicians were successful in reducing much of mathematics to a system of axioms from which, in principle, all the truths of mathematics could be deduced by formal inference expressible in symbolic logic. David Hilbert is well known for advocating a formalist philosophy of mathematics, in which the truths of mathematics consist entirely in the formal relations among contentless symbolic structures (words, sentences, formulas, etc.). Thus Ludwig Wittgenstein famously remarked, "all propositions of logic say the same thing, to wit nothing" ("Alle Sätze der Logik sagen aber dasselbe. Nämlich nichts") he called them senseless ("Sinnlos"), but not nonsense ("Unsinn").[12]

In the early twentieth century philosophers of science, especially those of the Vienna Circle, such as Rudolph Carnap, began to apply symbolic logic to scientific knowledge, thus laying the foundations of logical positivism and logical empiricism, which dominated the philosophy of science in the first half of the century. In this approach, the structure of knowledge is formal and logical, but the empirical content resides in primitive terms and properties defined in terms of physical measurement. Anything that could not be expressed in these logical-empirical terms was taken to be meaningless or at least nonscientific.

Logical empiricism provided what seemed to be an ideal foundation for artificial intelligence, since it was supposed that any "genuine knowledge" could be expressed in these symbolic structures and that cognition was essentially reasoning, which could be reduced to the mechanical manipulation of formal symbols.[13]

Formal logic and formalist mathematics do not depend on empirical data; they are purely formal. Thus, as Wittgenstein observed, the knowledge structures in a purely symbolic AI system are apparently not about anything. Stevan Harnad has called this the

symbol grounding problem: how do the symbols in an AI system—or in our minds, if we suppose they are like a symbolic AI system—get their meanings? One answer is that there is no primary content, and the only meaning resides in the formal (contentless) relationships among "ungrounded" symbols. In the words of the "formalists' motto," widely accepted in AI, "If you take care of the syntax, the semantics will take care of itself."[14] Or as Mephistopheles wisely observes, "Men usually believe, if only there be words, / That there must also be some sort of meaning" ("Gewöhnlich glaubt der Mensch, wenn er nur Worte hört, / Es müsse sich dabei doch auch was denken lassen") (F, 2565–66).[15] However, when applied to human cognition this is an unsatisfactory resolution, and Harnad and others have argued that symbols are grounded ultimately in sensory perception. Goethe, too, observed, "How difficult it is . . . to refrain from replacing the thing with its sign, to keep the object alive before us instead of killing it with the word" ("Jedoch wie schwer ist es, das Zeichen nicht an die Stelle der Sache zu setzen, das Wesen immer lebendig vor sich zu haben und es nicht durch das Wort zu töten").[16] This issue brings us back to Faust.

Word and Sense

The drama regularly reminds us of the power and limitations of senseless discourse. Examples include the familiar parodies of the Schoolmen's logic-chopping and of the Humanists' empty rhetoric and pedantic antiquarianism;[17] both are examples where form dominates content. In contrast Faust understands that meaningful language, significant speech, is grounded in one's inmost understanding.[18] Sometimes the substitution of form for meaning is successful, at least for a time, as in Mephistopheles' institution of fiat money to cure the Emperor's economic woes and his use of illusion to rout the rival emperor.[19] In both cases we have only the appearance of something real, but the appearance is sufficient to the purpose.

But the problems in symbolic AI were not limited to senseless knowledge structures, but also stemmed from formal logical deduction as a model of cognition. Mephistopheles accurately describes the limitations of sequential formal reasoning in his colloquy with the Student in Part I, "Study" ("Studierzimmer II"):

> My friend, I shall be pedagogic,
> And say you ought to start with Logic.
> For thus your mind is trained and braced,
> In Spanish boots it will be laced,
> That on the road of thought maybe
> It henceforth creep more thoughtfully,
> And does not crisscross here and there,
> Will-o'-the-wisping through the air.
>
> (Mein teurer Freund, ich rat' euch drum
> Zuerst Collegium Logicum.
> Da wird der Geist euch wohl dressiert,

In spanische Stiefeln eingeschnürt,
Daß er bedächtiger so fort an
Hinschleiche die Gedankenbahn,
Und nicht etwa, die Kreuz' und Quer,
Irrlichteliere hin und her.) (F, 1910–17)[20]

Creeping along the "Gedankenbahn" ("road of thought") has proven to be the Achilles' heel of many symbolic AI systems, for the more the knowledge in the system, the more the combinations of formulae the reasoning engine must sequentially evaluate. This is called the problem of combinatorial explosion, and it defeats even the fastest computers. Early robots were extremely slow, sometimes taking an hour to make a movement, because they used sequential, discursive logic, analysis, and planning to coordinate their behavior, but animals and insects with very simple brains behave competently and quickly in the world. As Mephistopheles recognizes, sometimes we must resort to such tortured methodical and analytical reasoning, but it is inefficient, and in most cases we are better served by holistic embodied behavior:

They teach you for a year or so
That what you did all at one go,
Like eating and drinking, fancy-free,
Needs stages one, and two, and three.

(Dann lehret man euch manchen Tag,
Daß, was ihr sonst auf einen Schlag
Getrieben, wie Essen und Trinken frei,
Eins! Zwei! Drei! dazu nötig sei.) (F, 1918–21) [21]

Mephistopheles next uses the metaphor of weaving for thinking, which reminds computer scientists of the Jacquard loom (dating from 1801), which used punched cards to control an automatic weaving machine. Charles Babbage intended to use this technology to control his "analytical engine," perhaps the first automatic computer (under development from 1837 to 1871), and punched card technology continued to dominate automatic data processing through much of the twentieth century. But this is what Mephistopheles says:

Yet the web of thought has no such creases
And is more like a weaver's masterpieces:
One step, a thousand threads arise,
Hither and thither shoots each shuttle,
The threads flow on, unseen and subtle,
Each blow effects a thousand ties.

(Zwar ist's mit der Gedanken-Fabrik
Wie mit einem Weber-Meisterstück,
Wo Ein Tritt tausend Fäden regt,
Die Schifflein herüber hinüber schießen,

Die Fäden ungesehen fließen,
Ein Schlag tausend Verbindungen schlägt.) (F, 1922–27)[22]

This does not describe the slow sequential mechanism of a symbolic AI system, but rather the spreading activity in a connectionist neural network (a web of thought), in which thousands of nerve fibers converge on each neuron, which then influences thousands of others, to create a continuous field of activity in the cortical "Gedanken-Fabrik" ("thought factory").[23] Thus in his 1937–38 Gifford Lectures on Natural Religion the pioneer neurophysiologist Sir Charles Sherrington, whose own poetry was inspired by Goethe's, described the brain as "an enchanted loom where millions of flashing shuttles weave a dissolving pattern, always a meaningful pattern though never an abiding one; a shifting harmony of subpatterns."[24]

Logos — Idea — Dynamis — Energeia

Faust's efforts (F, 1224–37) at translating logos in the first verse of the Gospel of John are not unprecedented; Jantz observes, "he was being an excellent classical philologist, solidly traditional and thoroughly grounded in the history of the concept from Heraclitus to St. John."[25] His attempts reflect, according to Jantz, a progressively deeper penetration into the phenomenology of the symbol ("Wort"), the comprehension ("Sinn") of which gives the Renaissance mage power ("Kraft") over nature, which is actualized ("Tat") in the magical operation.[26] Faust's successive translations also anticipate the use of computational models in AI and cognitive science, for computing submits a formal symbolic structure (the program) to a mechanical interpreter (the computer) so that, ex opere operata, the potential computation is actualized in specific behavior to achieve some end: word, interpretation, power, action.

The semiotician and logical empiricist Charles Morris divided semiotics into syntax, semantics, and pragmatics; the first studies the structure of linguistic forms independently of their meanings, the second studies their relationships to their meanings, and the third addresses the effects of linguistic expressions on interpreters in the context of communicative situations. Formal syntax and semantics have been studied extensively by logicians and, when semantics is grounded in measurement, syntax and semantics correspond to the "logical" and "empirical" parts of logical empiricism. Pragmatics, due to its resistance to mathematical analysis, has been the neglected stepchild.[27]

Following in this tradition, symbolic AI at first adopted the formalists' motto; that is, if the semantic relations are completely encoded by the syntax (formal relations), then, from a formalist perspective, there is no further need to consider semantics. This is ideal from the perspective of symbolic AI, since computers are purely syntactic: the symbols in the computer are meaningless (to the computer); they lack original intentionality.[28] Likewise, the computer's "thinking" is purely formal, like formal logic, and depends only on the formal structure of knowledge representations (their syntax), not on their meanings. Similarly, early attempts at machine translation focused on syntax to the exclusion of semantics.

To make a long story short, it was eventually discovered that syntax was insufficient on its own, and that machine translation and other AI applications had to take mean-

ing into account. As Faust recognized, "das Wort" ("word," Gk. logos) was overvalued until the importance of "der Sinn" ("sense," "meaning," Gk. idea) was recognized. However, while syntax and semantics may be adequate for disembodied cogitation (itself a debatable supposition),[29] they are pragmatically impotent. Thus Faust anticipates recent work in AI, cognitive science, and philosophy showing that true intelligence is embodied and situated in a pragmatic background of concerns, purposes, needs, etc.[30] This corresponds to the last two refinements in Faust's translation: "die Kraft" ("force," "power"), which expresses the power of the Logos as potentiality (Lat. potentia, Gk. dynamis), and then "die Tat" ("deed," "act"), which expresses it as purposeful activity or effect (Lat. actio, Gk. energeia). AI and cognitive science are following a similar path, from the superficiality of syntax, through disembodied semantics, to pragmatic, goal-directed action in the world: "striving" ("Streben"). As for Faust and Mephistopheles, so for AI, Homunculus lights the way toward embodiment (F, 6987).

III The Little Man Within

The Modern Quest for the Homunculus

The economist Hans Christoph Binswanger, with explicit reference to Faust, has described the modern economy as "a continuation of alchemy by other means."[31] The same description applies to AI and alife, for they effectively seek to create a homunculus, an artificial mind or person. More generally the goal of alchemy may be described as the materialization of spirit and the spiritualization of matter.[32] That is, spirit is to be drawn down into matter at the same time as matter is spiritually elevated. Thus base prima materia (symbolized by lead) is purified, ennobled, made incorruptible (symbolized by gold).

In AI the goal is to arrange material processes (e.g., by programming a computer) so that they exhibit genuine intelligence. According to the criteria of strong AI (reflected in the well-known Turing Test and ultimately rooted in logical empiricism), if an AI system is behaviorally indistinguishable from a human, then we are scientifically obliged to consider it genuinely intelligent and literally to have a mind.[33] From this perspective, the goal of AGI is to "spiritualize" matter, in the sense of imparting a mind to otherwise mindless matter. Conversely, such an artificial intelligence would accomplish the materialization of spirit by producing mind through material processes.

The goals of artificial life are similar: the animation of matter and the materialization of life. In one sense this has been accomplished already, for the techniques of synthetic biology have been used to assemble two viruses according to their genetic codes.[34] This in vitro creation of life is only a beginning, however, since viruses occupy a gray area between living and nonliving and because organic materials were used as a basis. More generally alife is directed toward the creation of definitely living artifacts from non-biological materials, perhaps within a computer.

Nowadays we commonly distinguish in vivo ("in life") and in vitro ("in glass") experiments, but many scientists now describe three sorts of experiments: in vivo, in vitro, and in silico ("in silicon"). The latter refers to computational science: the simulation of actual or hypothetical physical systems in a computer. This method has become the indispensable third branch of twenty-first-century science, complementing theory and

experiment (whether in vivo or in vitro).

Traditionally alchemy has sought to create the homunculus in a hermetically sealed alchemical vessel (symbolically spherical—a microcosm—or egg-shaped), such as we find Wagner using in the Laboratory of Act II.[35] Synthetic biology still seeks in vitro creation of life, but AI and alife make greater use of in silico methods. In some cases these are mere simulations of intelligence or life, but the more ambitious goal is to make the real thing. However, the fact that a process takes place in silico does not imply that it is a simulation and thus unreal. It's important to keep in mind that computers are physical devices and that computations are physical processes. If a computer (or robot) exhibits genuine intelligence or life, then it is physically real intelligence or life.

Some 35 years ago I was given a tour of Intel's fabrication facilities. At one place my guide introduced me to a highly skilled technician who was rinsing the silicon wafers in a solution. "She is watching," I was told, "for a sign that not everyone can see, a certain iridescent sheen, which tells her the process is done." "The peacock's tail!" I thought, but didn't say.[36] It is also interesting that the raw material of most semiconductor devices is silica (silicon dioxide, quartz), that is, sand, one of the commonest substances on earth; for, as the alchemists say, "The prima materia has the quality of ubiquity: it can be found always and everywhere."[37] It "is found everywhere, being a stone, and also not a stone; common and precious; hidden and concealed, yet known by everyone."[38]

Of course, semiconductor manufacturing has other, less romantic similarities to alchemical practice, including the use of noxious, toxic, and corrosive chemicals, to which workers are exposed and which contaminate the environment. Both activities involve high temperatures, molten metals, poisonous gases, and toxic wastes.

Masculine Creation

It is significant that Wagner's accomplishment was a purely masculine affair, as was much of "good old-fashioned AI," in fact as well as spirit. Normally the alchemical Magnum Opus requires cooperation between the alchemist and his Soror Mystica, a woman who provides the required sexual polarity and gender balance, which symbolizes on the level of the operators the necessary coniunctio oppositorum necessary on the level of the operation.[39] Perhaps this is why Wagner has been hitherto unsuccessful in this operation, for I expect he is celibate in mind as well as body.[40] The necessity of synthesizing the masculine and feminine perspectives is an important psychological insight, not confined to alchemy.[41] Alice Raphael explains:

> According to legend, Pythagoras received the greater part of his ethical knowledge from a Delphic priestess. Historically, the relationships of Plutarch to Klea and of Socrates to Diotima illustrate that a serious exchange of thought and feeling existed between men and women of superior philosophic interests in antiquity. The Soror Mystica was manifest also in the alchemical tradition, for many an alchemist had as disciple either his wife or a Mystical Sister, who assisted him in his laboratory and represented the all-important feminine principle in the production of the philosophers' stone.[42]

More directly relevant to Faust, we may add the example of Simon Magus and his Helena, with all its "tantric" implications, for she was simultaneously courtesan, muse, and embodied divine Wisdom. Thus the Gnostic mage called himself Faustus (Lat. "Fortunate"), and Helena incarnated divine Thought or Sophia, the fallen World-Soul, whose ascent to the Godhead would redeem the world.[43] Simon also claimed to have created a homunculus nobler than God's creation, with a purer soul than ordinary people, because conjured from subtle air rather than molded from earth.[44] Faust's Homunculus, like traditional AI systems, is similarly subtle and ungrounded.

When Mephistopheles drops in on Wagner's alchemical laboratory and inquires what he is up to, Wagner announces that a man is being made. The devil playfully asks, "And what loving pair / Have you got hidden in the smoke-hole there?" ("Und welch verliebtes Paar / Habt ihr in's Rauchloch eingeschlossen?") (F, 6836–37), [45] but there is neither love nor sexual union in Wagner's machinations, who disdains such irrational messiness:

> No God forbid! That old style we declare
> A poor begetting in a foolish fashion.
> The tender core from which life used to surge,
> The gracious force that came from inward urge,
> Which took and gave, for self-delineation,
> Blending near traits with far in new mutation,
> To this we now deny its lordly height;
> What if beasts still find it their delight,
> In future man, as fits his lofty mind,
> Must have a source more noble and refined.
>
> (Behüte Gott! wie sonst das Zeugen Mode war
> Erklären wir für eitel Possen.
> Der zarte Punkt aus dem das Leben sprang,
> Die holde Kraft die aus dem Innern drang
> Und nahm und gab, bestimmt sich selbst zu zeichnen,
> Erst Nächstes, dann sich Fremdes anzueignen,
> Die ist von ihrer Würde nun entsetzt;
> Wenn sich das Tier noch weiter dran ergötzt,
> So muß der Mensch mit seinen großen Gaben
> Doch künftig höhern, höhern Ursprung haben.) (F, 6838–47) [46]

Wagner ridicules the delicate process, of which Goethe was so aware, of organic growth and development, by which the organism defines itself out of its own inner necessity, a self-organizing process that, as we now know, has evolved by random mutation and recombination of traits.[47] Similarly, in the past we tried to engineer AI and robotic systems, rather than to grow them, but despite Wagner's optimism (or arrogance), we often reach the limits of our ability to design complex systems and must resort to various forms of evolutionary computation, which use selective retention in combination with random mu-

tation and recombination, aping biology to achieve what rational design cannot. Nevertheless, Wagner predicts,

> What men as Nature's mysteries would hold,
> All that to test by reason we make bold
> And what she once was wont to organize,
> That we bid now to crystallize.
>
> (Was man an der Natur geheimnisvolles pries,
> Das wagen wir verständig zu probieren,
> Und was sie sonst organisieren ließ,
> Das lassen wir kristallisieren.) (F, 6857–60) [48]

Crystals are closely connected to computing. Of course semiconductor devices are made from silicon crystals, but crystals are also a good metaphor for computers and computation for, like crystals, computers are highly organized and regular in structure, and programs and data structures have the austere beauty of crystals.[49] We also find crystal-like structures in living nature, but as implied in the title of Donna Haraway's history of embryology, Crystals, Fabrics, and Fields,[50] other metaphors also apply, and self-organizing organic material, especially during embryological development, is better characterized as soft matter (or viscoelastic material).[51] Roughly, these are materials that stretch elastically when you pull on them weakly, but deform and flow when you pull on them strongly enough. These are the characteristics of most living tissues, and they are likely to be the characteristics of robots grown by artificial morphogenesis. (So far, however, the crystal metaphor has dominated research on self-reconfigurable robotics and programmable matter, which often is based on fixed "lattice architectures.") We will look further at the flexibility of living matter below.

The distinction between rigid crystals and soft matter also applies at a more metaphorical level, for symbolic AI viewed knowledge as rigid, formula-like structures constructed from atomic word-like units, that is, as formal, logical, abstract objects. Their inflexibility led to "brittle" behavior; that is, minor exceptions or unexpected circumstances could break the systems (cause them to behave unintelligently). Furthermore, the rigidity of these structures complicated learning and adaptation, since these processes could not be gradual. Dissatisfied with brittle, inflexible behavior, AI researchers have returned to organic intelligence and the brain (sometimes called "wetware" to distinguish it from hardware and software), and developed new connectionist techniques, which permit flexible, adaptable, deformable, and fluid ways of representing knowledge and cognition. Metaphorically, organic knowledge is soft.[52]

Moreover this organic knowledge is grounded in an organic body, and recent work in AI and cognitive science has shown the importance of the physical body and its physical environment in structuring and molding these knowledge structures.[53] It has become apparent that intelligence is as inseparable from its physical embodiment as the hole is from the doughnut.

But Wagner, the pedantic academic, has not learned this lesson, for he has created an artificial, idealized version of himself: an intellect without a body, a talking head.

Homunculus is not so much a "little man" as a little brain in a vat. As Charles Passage states, "he is without substance, the mere 'idea' of a man, though the chemicals in the retort have apparently assumed the crinkled half-a-walnut-meat appearance of an extracted brain." [54] This chemical brain comes stocked with universal knowledge, according to Goethe in his second Helena sketch,[55] nor does Homunculus have to learn language, for it is also preloaded in his artificial brain.[56] As will be discussed in more detail below, much AI research has been directed to the production of disembodied (or minimally embodied) "brains in vats," which, it was hoped, would be intellectually developed from the moment of their creation and could be preloaded with knowledge by their creators. (The Cyc project, which is attempting to encode all of common sense into a comprehensive AI knowledge-base, is an excellent example.[57]) Behind these projects is the widespread Western intellectualist assumption that the mind comprises facts and inferential processes and that the body is an unfortunate impediment to our swift soaring rational intellects.[58]

Is intellect all there is to being human? Some futurists interested in AGI talk of an eventual technological singularity, when artificial intelligence surpasses human intelligence.[59] The idea is that this achievement would mark "the end of the human era," since such an artificial intelligence would be better able to design AI systems than we are, and therefore a self-reinforcing acceleration of AI technology would leave us behind.[60] While some, such as Bill McKibben and Bill Joy, have seen the singularity as catastrophic for humankind, others, such as AI researchers Ray Kurzweil and Hans Moravec, have hailed it as humanity's destined self-transcendence.[61] They argue that we should not feel sad if humans are superseded, for by designing our successors we are fulfilling our role in the evolution of intelligent life on earth. Moravec writes,

> At the same time, by performing better and cheaper, the robots will displace humans from essential roles. If their capacities come to include self-replication (and why not?), they may displace us altogether . . . Personally, I am not alarmed at this; these future machines will be our progeny, our mind children, built in our image and likeness, ourselves less flawed, more potent.[62]

Homunculus is nothing if not a "mind child."

Wagner, the intellectualist technologist hiding in his laboratory, is of course in agreement. He sees the random processes of evolution being bettered by scientific technology:

> Insane, at first, appears a great intent;
> We yet shall laugh at chance in generation;
> A brain like this, for genuine thinking meant,
> Will henceforth be a thinker's sure creation.
>
> (Ein großer Vorsatz scheint im Anfang toll,
> Doch wollen wir des Zufalls künftig lachen,
> Und so ein Hirn, das trefflich denken soll,
> Wird künftig auch ein Denker machen.) (F, 6867–70) [63]

Likewise, "good old-fashioned AI" attempted the rational design of intelligent systems,

whereas now we depend more on biologically-inspired self-organization, which can result in systems that are effective but may not be intellectually comprehensible.

Moravec advises that for our mind children, as for our biological children, "It behooves us to give them every advantage and, when we have passed evolution's torch, bow out."[64] With foresight, our twilight need not be unpleasant; he contends,

> As with biological children . . . we probably can bargain for some consideration in our retirement. Good children like to see their parents comfortable in their later years. 'Tame' super intelligences could be created and induced to protect and support us, at least for awhile. The relationship, however, requires advance planning and diligent maintenance. It is not too early to start paying attention.[65]

As superintelligent Homunculus abandons his creator, leaving him to dot his "i"s, Mephistopheles reminds us, "Upon the creatures we have made / We are, ourselves, at last, dependent" ("Am Ende hängen wir doch ab / Von Kreaturen die wir machten") (F, 7003–4).[66]

Since Mephistopheles has just acknowledged his dependence on Homunculus in their immanent journey to the classical world (F, 7001–2), these lines hint that he has had a hand in Homunculus' creation, which Goethe acknowledged in his December 16, 1829 conversation with Eckermann.[67] Wagner's learned experimentation had been impotent until the devil's well-timed arrival, as Homunculus recognized (F, 6885–88). Mephistopheles brought the needed shadow element, an urge to embodiment and physical activity, to Wagner's intellectual but inanimate creation, and at exactly the right psychological moment (the kairos or occasio). As Edward Edinger explains, "Psychologically, the homunculus signifies the birth of the conscious realization of the autonomous psyche."[68] That is, a new psychic center has been constellated that is independent from the conscious ego, represented by Faust. It represents "the ego's dawning awareness of the existence of a second psychic center, the [unconscious] Self."[69] Homunculus is enlightened consciousness, which has the wisdom to seek union in the depths of the unconscious. Thus his illumination leads Faust/Ego and Mephistopheles/Shadow into the archetypal world of the Aegean Festival, where the beauty at the heart of nature will revive Faust.

Mephistopheles and Homunculus are akin; they are both daemones (Dämonen), as Goethe told Eckermann.[70] In psychological terms, a daemon (Gk. daimôn) is a subconscious complex, which can behave as an autonomous personality.[71] The two share "clearness of intellect" ("geistiger Klarheit"), as Goethe said,[72] and a disposition to act. They are also akin in that, as Denton Snider observes,[73] Mephistopheles is "the spirit of negation" ("der Geist der stets verneint") (F, 1338) and Homunculus is defined by limitation, for he is confined to his little flask, at least until his final immolation. "Thus Homunculus is related to Mephisto by his limit."[74] Homunculus' strict determination is nothing other than Mephistopheles' negation, according to the Spinozan principle, "omnis determinatio est negatio" ("all determination is negation").[75]

Indeed, as Snider also points out, all three personalities present at Homunculus'

genesis contribute to his character.[76] We may call them Man, Devil, and Professor (or Scientist or Engineer). Professor Wagner contributes theory, technical skill, and raw materials, as well as the little man's intellectual endowments, the light that will guide the others, but also his tendency to trust authority over personal experience.[77] This benefactor is left behind, for Homunculus is also motivated by Mephistopheles' contribution of "negation, activity, and life," and by his own Faustian aspiration to transcend limitation and seek beauty and embodiment.[78] For Faust, though hailing from the Professor's environment, has escaped the academic cloister and contributes "aspiration [and] freedom from the narrow world of Wagner."[79] Nevertheless, Faust the Man, as conscious ego, remains unconscious while these archetypal forces mobilize.

These psychological considerations may seem far removed from AI, but they suggest the neglect of embodiment and the unconscious mind that characterized AI, cognitive science, and philosophy throughout so much of their history. They are relevant also to our disembodied, intellectualist relation with nature and to how we understand it. So Homunculus' quest for a body is also ours.

Fiery Spirit

It is worthwhile to dwell a little more on the nature of Homunculus and what it suggests about a disembodied artificial intelligence, for he is consistently described as a flame, fiery, brilliant, flashing, shining, etc.[80] This is certainly appropriate to his nature, for both fire and light are subtle and immaterial, and in alchemy fire is the element of transformation.[81] Thus we can get additional insight into Homunculus' nature by recalling that traditionally fire is characterized by two qualities or powers (Lat. potentiae, Gk. dynameis): it is hot and dry.[82] Heat is the power that decomposes mixtures into their constituents, for it causes unalike to separate and like to cling to like;[83] think of distillation. Thus heat is the power of discrimination; it makes distinctions, and so it symbolizes analysis. Therefore heat and light are appropriate to Homunculus as an active intellectual spirit. The traditionally masculine warm elements (fire and air) always strive upward, whereas the traditionally feminine cool elements (water and earth) sink into the depths.[84]

The other quality of fire is dryness, which, as Aristotle explains, gives form to things, and is opposed to the formlessness of fluids.[85] Thus dryness represents determination, but it is the fixed determination of a static form, as opposed to the active discrimination of heat. Thus the combined qualities of fire suggest active analysis leading to rigid systemization (as might be expected of Wagner's creation).

Symbolic AI systems are similarly fiery, acting through the fundamental discrimination of 1 and 0 (true and false) to operate on rigid symbolic structures, often representing logical propositions of one sort or another. Even machine learning systems, if they are symbolic (based on fixed, word-like symbols), are ultimately inflexible and brittle, for they can only rearrange the fixed parts of these knowledge structures. Therefore it is symbolically consistent that Homunculus' body is a rigid crystalline vessel, which confines and delimits him. Likewise, the electrical currents in our computers (which suggest fire and are physically akin to light) are confined within their silicon crystals.

Living things, in contrast, are characterized by moistness, which is the opposite

quality to dryness. Dry things are rigid, moist things are supple, and life requires such flexibility. Most organisms are either soft on the outside or soft on the inside (or both), and the physics of soft matter is especially appropriate to living things.[86] Likewise water is expansive, but conforms to its surroundings, adapting to its environment.[87] Therefore, it is appropriate that Homunculus' quest for an organic body ends in the Aegean Sea. This suggests that AI's quest for embodiment will end likewise in structures that are soft, both literally and figuratively.[88]

Minimal Embodiment

Of course AI systems are not literally disembodied — existing only in a mental realm — for computers are physical objects — but they are minimally embodied; that is, they have trivial bodies capable of only impoverished interaction with their environments, like brains in vats. In this they are very like Homunculus.

For example, Thales notices an embarrassing aspect of Homunculus' inadequate embodiment:

> Another aspect would seem critical —
> He is, I think, hermaphroditical.
>
> (Auch scheint es mir von andrer Seite kritisch,
> Er ist, mich dünkt, hermaphroditisch.) (F, 8255–56) [89]

This is to be expected from alchemical tradition, for the homunculus is a rebis ("two-thing") resulting from a coniunctio oppositorum, especially of male and female.[90] More to the point, Homunculus is a thinking machine. The rational mind is traditionally sexless, and while the issue is not closed, contemporary research supports the fact that there are no sex-linked differences in adult cognition.[91] Be that as it may, sexual dimorphism is more significant in the body and "lower" psychological faculties, including the nonrational and unconscious minds, where the drives reside, than it is in the idealized intellect represented by Homunculus.

Second, although Homunculus can apparently perceive his environment, we cannot conclude that he must have sense organs, for he may be clairvoyant, as mentioned in some alchemical sources.[92] Even if he does have sense organs, he does not have limbs with which he can interact with his environment. Limbs are important not only for locomotion and manipulating physical objects, but also as a prerequisite to active perception, which, in contrast to passive observation, is essential to embodied intelligence in humans and other animals. Physical interaction with the environment structures the information in our brains and creates knowledge. As Bergson said, "Intellectuality and materiality have been constituted, in detail, by reciprocal adaptation."[93]

Finally, Homunculus' means of locomotion is to float in the air in his crystalline vehicle; he is literally ungrounded, minimally connected with the physical world. Similarly, most AI systems have resided in immobile computers. Even most robots, at least until very recently, have been very limited in their ability to interact with their environ-

ment. Typically they roll around on wheels and have simple grippers for manipulating objects.

Thus Homunculus has much in common with traditional disembodied AI systems, which are like brains in vats in that they have little or no significant interaction with their environments. For example, since much AI research has focused on higher cognitive capacities, such as language understanding, abstract reasoning, playing board games, etc., the input-output medium was often textual, some formal artificial language or some formal approximation to a natural language. Even systems that did process sensory information, such as computer vision systems, did so in a remarkably passive and disembodied way. For example, such a system might take a digitized photographic image and attempt to segment the scene into discrete objects and to identify these objects (i.e., to attach words to them). In contrast, natural perception is usually a more active process in which perceptual structures are revealed by the organism's purposeful motion in and interaction with its environment.[94]

In part, this AI research strategy was a manifestation of an intellectualist bias in Western psychology, but it was also a consequence of incorrect assumptions about the relative difficulty of "pure thought" and interaction with the physical world. For example, it was supposed that it would easier to understand typed text than situated spoken language, and that it would be easier to parse a static scene than for a situated agent to extract relevant information from an environment with which it was purposefully interacting. In fact the opposite is the case, and it is often easier for a situated embodied agent to behave competently in its environment than for a disinterested observer to make sense of it. For example, an embodied agent does not need a complete mental model or description of its environment; it is sufficient to be able to identify affordances (perceivable potential actions) that enable its intended behavior. (Thus insects and other simple organisms behave very effectively, in spite of their tiny brains.) As the phenomenologist philosopher Hubert Dreyfus observed long ago, there are many things that we "know" simply by virtue of having a body, and therefore an embodied intelligence does not have to explicitly represent or process this "knowledge."[95]

Fortunately there has been a sea change in AI research, and a growing number of theoreticians and experimenters understand the importance of embodiment as a foundation for intelligence.[96] In particular, we now understand that genuine information is not simply a given (datum), but that it is created by agents' embodied purposeful interaction with an environment in which they are situated.[97]

Embodiment is becoming an important and indeed transformative concept in contemporary philosophy, psychology, cognitive science, and linguistics, as well as in AI. Although the significance of embodiment has roots in Kant, and more recently in the pragmatism of Dewey and James, and in phenomenology and existentialism (e.g., Merleau-Ponty, Heidegger, and Dreyfus), it has been increasing in importance since about 1990.[98]Among the recent contributors are Terry Winograd and Fernando Flores in AI, Rodney Brooks, Hans Morovec, and Rolf Pfeifer in robotics, and George Lakoff, Mark Johnson, and Raphael Núñez in cognitive science.

Fluid Morphogenesis

Homunculus' apotheosis is achieved in the Aegean Festival, the climax of Part II Act II, a "mythical festival of life and love, procreation and organic evolution."[99] Here Galatea appears as a goddess of nature, but also as a surrogate for sea-born Aphrodite.[100] Thus, she is surrounded by Erotes in Raphael's Triumph of Galatea, which Goethe knew. As a goddess of both nature and beauty, she is the goal of the striving of Homunculus, who is possessed by Eros; the two are desire and the object of desire. But why does Homunculus seek his consummation in the sea?

Water is a common symbol of matter, the flux of material existence, and the realm of Becoming.[101] For example, in Porphyry's commentary On the Cave of the Nymphs, which allegorizes Odysseus' wanderings over the sea as the soul's sojourn in matter,[102] we read, "Again, according to Plato, the deep, the sea, and a tempest are images of material reality. And on this account, I think, the poet called the port by the name of Phorcys. For he says, 'It is the port of the ancient marine Phorcys.'"[103] Of Phorcys, to whom Plato attributes generation, Proclus remarks, "that as the Jupiter in this ennead causes the unapparent divisions and separation of forms made by Saturn to become apparent, and as Rhea calls them forth into motion and generation, so Phorcys inserts them into matter, produces sensible natures and adorns the visible essence . . . "[104] The daughters of Phorcys are the Phocyads, "sprung forth from Night" ("In Nacht geboren"), who "stem from Chaos by undoubted right" ("Des Chaos Töchter sind wir unbestritten") (F, 8010, 8028), whom Mephistopheles met on the Upper Peneios, and of whom he became an honorary member as Phorcyas (F, 8012–33). Rhea, the Great Mother, was connected with rheô ("to flow") and its derivatives, rhoê ("flux"), and rhythmos ("measured motion," "order"), and thus with the cycles and processes of nature.[105]

Porphyry also describes the descent of souls into fluid material reality, which is Homunculus' goal as well:

> Since, however, [matter] is continually flowing, and is of itself destitute of the supervening investments of form, through which it participates of morphe, and becomes visible, the flowing waters, darkness, or, as the poet says, obscurity of the cavern, were considered by the ancients as apt symbols of what the world contains, on account of the matter with which it is connected.[106]

He further observes that this is the cave of not just any Nymphs, but those whom Homer calls Naiads,[107] whose name comes from the verb naô ("to flow").[108] Porphyry continues,

> For we peculiarly call them Naiades, and the powers that preside over waters, Nymphs; and this term, also, is commonly applied to all souls descending into generation. For the ancients thought that these souls are incumbent on water which is inspired by divinity . . .[109]

Likewise, Homunculus descends into generation, an artificial being eager to be reborn through organic evolution and development.[110] Here, the bountiful sea is a symbol of fruitful matter, as Thales' paean (F, 8433–43) reminds us: "From the water has sprung all life! / All is sustained by its endeavor!" ("Alles ist aus dem Wasser entsprungen!! / Alles wird durch was Wasser erhalten!") (F, 8435–36).[111] Everyone sings, "Of life's renewal you are the fount" ("Du bists dem das frischeste Leben entquellt") (F, 8444).[112] Homunculus immerses his fiery spirit into Galatea's fluid depths, but the opposites do not cancel, for fire and water have been intensified in the persons of Eros and Galatea, and thus their union creates a new synthesis. As Goethe explains,

> Whatever appears in the world must divide if it is to appear at all. What has been divided seeks itself again, can return to itself and reunite. This happens in a lower sense when it merely intermingles with its opposite, combines with it; here the phenomenon is nullified or at least neutralized. However, the union may occur in a higher sense if what has been divided is first intensified; then in the union of the intensified halves it will produce a third thing, something new, higher, unexpected.
>
> (Was in die Erscheinung tritt, muß sich trennen, um nur zu erscheinen. Das Getrennte sucht sich wieder und es kann sich wieder finden und vereinigen; im niedern Sinne, indem es sich nur mit seinem Entgegengestellten vermischt, mit demselben zusammentritt, wobei die Erscheinung Null oder wenigstens gleichgültig wird. Die Vereinigung kann aber auch im höhern Sinne geschehen, indem das Getrennte sich zuerst steigert und durch die Verbindung der gesteigerten Seiten ein Drittes, Neues, Höheres, Unerwartetes hervorbringt.)[113]

Further, in their debate about the relative merits of fire and water as creative forces, Anaxagoras praises the rapidity with which fire can cause change, but Thales answers that the sea creates forms gently:

> Never was Nature and her fluid power
> Indentured yet to day and night and hour.
> She shapes each form to her controlling course
> And be the scale immense, eschews all force.
>
> (Nie war Natur und ihr lebendiges Fließen
> Auf Tag und Nacht und Stunden angewiesen;
> Sie bildet regelnd jegliche Gestalt,
> Und selbst im Großen ist es nicht Gewalt.) (F, 7861–64)[114]

Fire is an active agent of change and discrimination, and so it leads to sudden transforma-

tion and phase changes, as when water boils or ice melts; it is ultimately violent, as we witness on the Upper Peneios, which recalls the hellish technology ("Flämmchen" [F, 11125]; "Feuergluten" [F, 11129]) of Faust's project to drive the ocean from his land.[115] Water, in contrast, is a more passive catalyst of union, mixture, and adaptation. Thales says that, while fire can create inanimate objects, life came to be through moisture (F, 7856), which Homunculus realizes is precisely his objective (F, 7858). In practice, both fiery and watery processes are required for the self-organization of complex, organic forms, an insight we can apply in AI, alife, and artificial morphogenesis.

Before his hieros gamos, Homunculus' embodiment had been minimal (just enough to contain his form); it was transparent, thin, and fragile (easily broken by contact with matter)—rather like a sperm, which must break itself on the egg in the womb; only the nucleic acid, encoding the genotype, penetrates through the egg's membrane. The fusion of the information-bearing sperm with the egg, which provides substance as well as information, triggers the developmental process (Bildung) by which cells divide, proliferate, and rearrange flexibly and fluidly to create the embodied organism. Morphogenesis is watery, because water is synthetic, cooperative, and coordinating, as opposed to fire, which is analytic, competitive, and isolating.

The zygote (fertilized egg) polarizes, into animal and vegetable poles (above and below), which then interpenetrate, leading to successive stages of polarization and spiraling differentiation governed by mutually interacting cooperation and competition.[116] The process is characterized by circular causation, a fundamental law of self-organization by which local interactions among the cells create global patterns and fields, which in turn govern the behavior of the cells.[117] We find analogous processes in Goethe's theory of morphology and in his alchemical inspirations, which are, however, outside the scope of this chapter. We are applying these insights in artificial self-organizing systems.

Embryological morphogenesis, and many other natural processes of formation, transformation, and re-creation,[118] are fundamentally fluidic.[119] Cells proliferate and move according to the laws of viscous fluids; they coordinate their activity and create physical form by processes such as chemical reactions, growth, diffusion, and chemotaxis (following differences in chemical concentration). Embryology is best understood in terms of soft matter,[120] and this understanding can be applied to artificial morphogenesis.[121]

Homunculus' self-immolation unites his fiery spirit with Galatea's watery nature. In addition to tempering his discriminative heat with integrative coolness, it allows him to dissolve his crystalline limitations and boundaries because formless moisture opposes rigid dryness. Conversely, Homunculus is the agent of transformation:

> this is Eros, Love, the first of the Gods, according to Plato (Symposium 178, 6), who came out of Chaos, hence the primitive form and maker of forms. Love is, then, really the ultimate shape, the little demiurge at work in Nature and in Man, transforming them both, breaking the hard limits of all that is fixed and throwing them into his flame for a new creation.[122]

This process is an alchemical "blending and fusion of opposites—of fire and water, of spirit and substance, of the masculine and the feminine—through which life is created in the sea."[123] An alchemical text in which Goethe "found particular pleasure,"[124] the Aurea Catena Homeri (Golden Chain of Homer), states:

> God has ordained it so that the Universal spirit by means of Humidity should work all things, because Humidity mixes easily with everything, by means of which the spirit can soften, penetrate, generate, destroy and regenerate all things. Thus Humidity or water is the Body, the Vehicle and Tool, but the spirit or fire is the Operator, the Universal Agent and fabricator of all Natural Things.[125]
>
> Whosoever wishes to arrive at the Fountain of Secret Wisdom, let him mind this well; and let him go with this Central Point of Truth to the circumference, and forever imprint in his memory: that from fire and water, or spirit enclosed in Humidity all things in the World are generated, preserved, destroyed and regenerated.[126]

In summary, fire is hot and dry, but water is cool and moist. Coolness reflects a lack of discrimination (hot), and so a mixture of diverse qualities, integration, blending, even chaos.[127] Moistness reflects a lack of rigidity or fixed form (dryness), and so conformability and adaptability to surroundings.[128] Organisms are characterized by integration, coordination, cooperation, and adaptability; thus the qualities of water are especially characteristic of life, and should be a basis for alife as well, but fire cannot be omitted. For Homunculus and Galatea effect a coniunctio oppositorum, an alchemical union of all the opposites (fire+water = hot+dry + cold+moist), which provides the foundation of life: activity (hot = discrimination) + structure (dry = rigidity) + integration (cold) + adaptability (moist). In this way the quintessence is created from the union of all four elements (fire, water, air, earth), which the Sirens and then the chorus hymn:

> Let Eros who wrought it be honored and crowned!
> Hail to the Ocean! Hail the wave,
> The flood with holy fire to lave!
> Waters hail! All hail the fire!
> The strange event hail we in choir!
>
> ALL VOICES IN CONCERT:
> Hail light airs now floating free!
> Hail earth's caves of mystery!
> Held in honor evermore
> Be the elemental four!

(So herrsche denn Eros, der alles begonnen!
Heil dem Meere! Heil den Wogen!
Von dem heilgen Feuer umzogen;
Heil dem Wasser! Heil dem Feuer!
Heil dem seltnen Abenteuer!

ALL-ALLE!
Heil den mildgewogenen Lüften!
Heil geheimnisreichen Grüften!
Hochgefeiert seid allhier
Element' ihr alle vier!) (F, 8479–87)[129]

New approaches to computing, called natural computation, are more suggestive of organic fluidity and embodied action than of fiery words and pure spirit. These include new forms of analog computing (which admits a continuum between 0 and 1), soft computing, DNA and molecular computing and self-assembly (which actually take place in solutions), swarm intelligence, fluid computation, field computation, evolutionary computing, and artificial morphogenesis, as well as algorithms such as simulated annealing and particle swarm optimization, which is inspired by the fluid motions of flocks of birds and schools of fish.[130] Polarity and intensification play an important role in these self-organizing and form-creating systems. Like Homunculus, AI and computing have taken the plunge.

Eros and the Orphic Egg

Deeper insights into the "spiritualization of matter and the materialization of spirit" and the basis for a true artificial mind come from further penetration into the symbolism of the sea. Goethe says that he had especially great sympathy for Hesiod, the Orphic poems, and Stoic philosophy:

> With the most ancient men and schools I was best pleased, because poetry, religion, and philosophy were completely combined into one; and I only maintained that first opinion of mine with the more animation, when . . . the lays of Orpheus and Hesiod, seemed to bear valid witness in its favor . . . For the Stoics, on the contrary, I had already conceived some affection, and even procured Epictetus, whom I studied with much interest.
>
> (An den ältesten Männern und Schulen gefiel mir am besten, daß Poesie, Religion und Philosophie ganz in Eins zusammenfielen, und ich behauptete jene meine erste Meinung nur um desto lebhafter, als . . . die Orphischen und Hesiodischen Gesänge dafür ein gültiges Zeugniß abzulegen schienen . . . Zu den Stoikern hingegen hatte ich schon früher einige Neigung gefaßt, und schaffte nun den Epiktet herbei, den ich mit vieler Theilnahme studirte.)[131]

Therefore, unlike the Herald, we are not surprised when the Orphic Egg makes an unscheduled appearance in the masque for the Emperor ("Spacious Hall" ["Weitläufiger Saal"]).

Although the Orphic poems differ among themselves, in most Orphic cosmologies either Night or Water (but sometimes Matter, Gk. hulê) is the ultimate origin.[132] From this first principle an Egg is produced, often by means of Aithêr or Chaos as an intermediary. The Egg splits, its halves becoming Heaven and Earth, and from it emerges an incorporeal (Gk. asômatos) god described as "winged, bisexual and self-fertilizing, bright and aitherial."[133] He is most often called Phanês ("the one who appears") and Eros, but also Protogonos ("first-born"), and Mêtis ("practical wisdom").[134]

In the Emperor's masque there was a premature, aborted, or false birth from the cosmic egg, perhaps because it was a diabolical affair engineered by Mephistopheles, who, with a stroke from the Herald's wand, transforms himself into dark and chaotic prima materia. The Herald describes the events:

> Lo, how this double-dwarf, this ape,
> Curls in a ball, a loathsome shape!
> The shape turns egg-like! Wondrous view!
> Puffs itself out, and breaks in two!
> And strange twin-progeny appear;
> A bat, an adder have we here:
> The one in dust-tracks slides and curls,
> The dark thing round the ceiling whirls,
> Now out to join her mate she's whirred,
> I would not care to make a third.
>
> (Wie sich die Doppelzwerggestalt
> So schnell zum eklen Klumpen ballt!—
> —Doch Wunder!—Klumpen wird zum Ei,
> Das bläht sich auf und platzt entzwei.
> Nun fällt ein Zwillingspaar heraus,
> Die Otter und die Fledermaus.
> Die eine fort im Staube kriecht,
> Die andre schwarz zur Decke fliegt.
> Sie eilen draußen zum Verein,
> Da möcht' ich nicht der Dritte sein.) (F, 5474 – 83) [135]

The Herald, sensing the shadiness of the operation, does not want to be the Third to effect reunification of this polarity, opposed creatures of earth and air. As Raphael says on this passage, "Goethe has inducted us gently into Orphic theology."[136]

Perhaps the Boy Charioteer, who unexpectedly appears at this point, was born like Phanes from the egg. His character suggests the alchemical quintessence, since he is driving a levitating chariot pulled by four dragons, which could correspond to the elements, which he has mastered. The Herald thinks he looks effeminate (F, 5548–51), and so sym-

bolically he is hermaphroditical, an alchemical rebis uniting the opposites, as do Homunculus and Euphorion, who are his later manifestations; the three are spirits of inspiration.[137] Faust calls him "spirit of my spirit" ("Geist von meinem Geiste") (F, 5623), suggesting the highest essence of the mind. Raphael explains that this "soul-daemon came as a stranger-guest from the distant land of the gods, entering into man in order to give him a soul"; it is "active in the higher mode of knowledge, in ecstatic inspiration."[138] In Jung's terms, he is the unconscious self, the innermost archetypal core, unification with which is the goal of the lifelong process that he called "individuation" ("becoming undivided," Lat. individuus). But apropos artificial minds, Jung stresses that "our consciousness does not create itself—it wells up from the unknown depths . . . out of the primordial womb of the unconscious."[139] Is this possible in an artificial intelligence?

The Depths of the Embodied Mind

Artificial intelligence, like cognitive science, has focused primarily on the conscious mind, but it is discovering the mind's necessary material embodiment. Even here, however, it has focused on the faculties of the conscious mind, such as discursive reason, rather than on conscious experience itself. Fortunately, after a long period of neglect, neuroscience and allied disciplines are taking consciousness seriously, but a coherent theory of the relation between conscious experience and physical processes, which Chalmers calls the Hard Problem,[140] eludes us. The issue is salient in AI, and the problem of artificial consciousness provides a useful test case for natural consciousness.[141] The problem is not restricted to rational cognition, and the importance of emotions in autonomous robotics has been recognized,[142] but whether it is possible for robots to feel their emotions, and under what conditions they might do so, is an open question.[143]

What can we learn from Homunculus' quest? The sea is a traditional symbol of material existence, but it is also a potent symbol of the unconscious mind. Anthony Stevens, a Jungian analyst, writes, "As the source of life, the sea is equated with the mother and the unconscious psyche . . . This association stresses the life-generating potential of the unconscious."[144] The unconscious mind (both personal and collective) is the Third between the polarities of the conscious mind and materiality, for as Jung says,

> The deeper "layers" of the psyche lose their individual uniqueness as they retreat further and further into darkness. "Lower down," that is to say as they approach the autonomous functional systems, they become increasingly collective until they are universalized and extinguished in the body's materiality, i.e., in chemical substances. The body's carbon is simply carbon. Hence "at bottom" the psyche is simply "world."[145]

Thus Homunculus' immersion of his brilliant light into dark watery depths is also a reunification of the conscious and unconscious minds, which is essential to individuation.[146] Therefore Mephistopheles is correct when he explains that he (as Shadow, part of the un-

conscious mind, grounded in matter) is prior to the light of consciousness, which thus depends on matter:

> I am a part of the part that once was everything,
> Part of the darkness which gave birth to light,
> That haughty light which envies mother night
> Her ancient rank and place and would be king—
> Yet it does not succeed: however it contend,
> It sticks to bodies in the end.
> It streams from bodies, it lends bodies beauty,
> A body won't let it progress;
> So it will not take long, I guess,
> And with the bodies it will perish, too.
>
> (Ich bin ein Teil des Teils, der Anfangs alles war,
> Ein Teil der Finsternis, die sich das Licht gebar,
> Das stolze Licht, das nun der Mutter Nacht
> Den alten Rang, den Raum ihr streitig macht,
> Und doch gelingt's ihm nicht, da es, so viel es strebt,
> Verhaftet an den Körpern klebt.
> Von Körpern strömt's, die Körper macht es schön,
> Ein Körper hemmt's auf seinem Gange;
> So, hoff' ich, dauert es nicht lange
> Und mit den Körpern wird's zu Grunde gehn.) (F, 1349–58)[147]

Spirit and matter are a polarity (included in Goethe's list in "Polarity"),[148] and their higher reunion requires a Third, with a necessary connection to each of the poles. This Third is the unconscious mind. On the one hand, it is psychical, like consciousness. On the other, like material reality, it is never completely illuminated by consciousness; it is the inner darkness corresponding to the outer darkness of the unperceived physical world.[149] Although the Herald declined to be the Third in Mephistopheles' attempted coniunctio oppositorum, he is perhaps the alchemist who can do the job. As master of ceremonies of the masque, a phantasmagoria of often archetypal figures, he stands in for Goethe,[150] but we cannot fail to see him also as Hermes, herald of the gods and interpreter (hermêneus) of their signs, the psychopomp who with his sleep-inducing wand leads souls into the archetypal realms.

IV Conclusions

The challenge of modern embodied philosophy, theory of the mind, and artificial intelligence is to understand the necessary interrelation of mind and matter (a polarity, connected by the unconscious as a Third), without a simplistic reduction of one to the other. For this, traditional science, which looks outward, must be supplemented with phenomenology, which looks inward. But phenomenology can look only as deep as the light of consciousness can penetrate, and so it too must be supplemented, by depth psychology. By thus filling in the gap between conscious mind and unconscious matter we will see better how to create an artificial mind.

Traditional symbolic AI was akin to Wagner's scholasticism and to Homunculus' inadequate embodiment. The focus was on words devoid of content and on intellect divorced from action. Contemporary developments of embodied AI and cognitive science have shadowed Faust's progression from dry intellectualism to embodied striving, and Homunculus' union of his subtle thought with the oceanic depths of the unconscious mind and the material body. In both cases the agent of change was Mephistopheles, the archetypal Shadow and Spirit of Negation, creating an antithesis to the word and catalyzing the synthesis.

Because of his deep insights into nature, the mind, and biological form and development, Goethe was able to see beyond some of the problems that AI and alife would encounter and to anticipate solutions that we are still learning to apply. These insights informed Faust, his life's work, his alchemical magnum opus, which explores our relations with nature, both seen and unseen, and the conscious ego's relation with the unconscious self, which is continuous with nature. Therefore it continues to be a fount of inspiration for those of us frequenting the shoreline where mind meets matter.

Notes

1. Marvin Minsky, ed., Semantic Information Processing (Cambridge: MIT Press, 1968), v.
2. See, for example, Ben Goertzel and Cassio Pennachin, eds., Artificial General Intelligence (Berlin: Springer, 2007).
3. See, for example, Bruce J. MacLennan, "Consciousness: Natural and Artificial," Synthesis Philosophica 22.2 (2008): 401; Bruce J. MacLennan, "Robots React but Can They Feel? A Protophenomenological Analysis," in Handbook of Research on Synthetic Emotions and Sociable Robotics: New Applications in Affective Computing and Artificial Intelligence, ed. Jordi Vallverdú and David Casacuberta (Hershey: IGI Global, 2009), 133.
4. See, for example, the Oxford English Dictionary.
5. George A. Bekey, Autonomous Robots: From Biological Inspiration to Implementation and Control (Cambridge: MIT Press, 2005), 1.
6. Bruce J. MacLennan, "Editorial Preface: Computation and Nanotechnology," International Journal of Nanotechnology and Molecular Computation 1, no.1 (2009): i.
7. Bruce J. MacLennan, "Models and Mechanisms for Artificial Morphogenesis," in International Workshop on Natural Computing, ed. Ferdinand Peper and Hiroshi Umeo (Berlin: Springer, 2010), 25.
8. The "sociable robotics" project at MIT is a good example; see Cynthia L. Breazeal, Designing Sociable Robots (Cambridge: MIT Press, 2002). There is already an International Journal of Social Robotics.
9. Johann Wolfgang Goethe, Faust, ed. Albrecht Schöne, vol. 7, pt. 1, Sämtliche Werke. Briefe, Tagebücher und Gespräche (Frankfort a.M.: Deutscher Klassiker Verlag, 1995); all subsequent citations are to this edition, henceforth cited as F. This chapter draws on a number of English translations of Goethe's Faust. Here, l. 11585 is translated by Walter Arndt, Faust: A Tragedy, ed. Cyrus Hamlin (New York: Norton, 2001) and l. 1700 by Walter Kaufmann, Goethe's Faust: Part One and Sections from Part Two (New York: Doubleday, 1961).

10. This is already occurring; see Peter Warren Singer, Wired for War: The Robotics Revolution and Conflict in the Twenty-first Century (New York: Penguin, 2009).
11. Bruce J. MacLennan, From Pythagoras to the Digital Computer: The Intellectual Roots of Symbolic Artificial Intelligence (forthcoming).
12. Ludwig Wittgenstein, Tractatus Logico-Philosophicus, trans. David F. Pears and Brian F. McGuinness (London: Routledge and Kegan Paul, 1974), ¶5.43. German text: http://www.tractatus.hochholzer.info/ (accessed February 12, 2010).

13. These developments, culminating in the computational theory of mind, are explained well in Howard Gardner, The Mind's New Science: A History of the Cognitive Revolution (New York: Basic Books, 1985).
14. John Haugeland, Artificial Intelligence: The Very Idea (Cambridge: MIT Press, 1985), 106.
15. Trans. Kaufmann.

16. Johann Wolfgang von Goethe, Zur Farbenlehre, ed. Manfred Wenzel, vol. 23, pt. 1, Sämtliche Werke. Briefe, Tagebücher und Gespräche (Frankfort a.M.: Deutscher Klassiker Verlag, 1991), §754, 245; "Color," Scientific Studies, trans. and ed. Douglas Miller, vol. 12, Collected Works (Princeton: Princeton University Press, 1988), §754, 277.
17. For example, Mephistopheles' interviews with the Student (F, 1868–2048) and with the Famulus (F, 6620–84), Wagner on delivery (F, 524–27, 546–47), Homunculus to Wagner (F, 6987–98). Other examples of "empty noise" presenting the illusion of meaning are discussed by Alan Corkhill, "'Why all this noise?': Reading Sound in Goethe's Faust I and II," in International Faust Studies: Adaptation, Reception, Translation, ed. Lorna Fitzsimmons (London and New York: Continuum, 2008), 60–61.
18. F, 534–37.
19. F, Part II, Act I, "Pleasance" ("Lustgarten") and Act IV, 10242–60; Act IV, "In the Foothills" ("Auf dem Vorgebirg").
20. F, 1910–17, trans. Kaufmann.
21. Trans. Arndt.
22. Trans. Kaufmann.
23. Bruce J. MacLennan, "Field Computation in Natural and Artificial Intelligence," in Encyclopedia of Complexity and System Science, ed. Robert A. Meyers et al. (Berlin: Springer, 2009), 72-77.
24. Charles Scott Sherrington, Man on His Nature (Cambridge: Cambridge University Press, 1955), 178. For the roots of this metaphor, see Henry McIlwain, "Neurochemistry and Sherrington's Enchanted Loom," Journal of the Royal Society of Medicine 77 (5) (1984): 417. He traces the metaphor and Sherrington's title, "Man on His Nature," to the seventeenth-century alchemical philosophers Henry and Thomas Vaughan. No doubt Sherrington also knew Faust well.
25. Harold Jantz, Goethe's Faust as a Renaissance Man: Parallels and Prototypes (Princeton: Princeton University Press, 1951), 114.
26. Jantz, Goethe's Faust, 115, 116.
27. Goethe, who was very aware of contemporary linguistics, toys throughout Faust with the connection, and often disconnection, between the surface structure of language (including its sound) and its meaning; see Corkhill, "'Why all this noise?'" 60–61.
28. Daniel C. Dennett, The Intentional Stance (Cambridge: MIT Press, 1987).
29. On the inadequacy of formal syntax and semantics for even disembodied intelligence, see Hubert Dreyfus, What Computers Can't Do: The Limits of Artificial Intelligence, rev. ed. (New York: Harper & Row, 1979).
30. Dreyfus, What Computers Can't Do, chs. 7–9.
31. Hans Christoph Binswanger, Money and Magic: A Critique of the Modern Economy in the Light of Goethe's Faust, trans. J. E. Harrison (Chicago: University of Chicago Press, 1994), 56.
32. Marie-Louise von Franz, Alchemy: An Introduction to the Symbolism and the Psychology (Toronto: Inner City, 1980), 258–60.
33. There is an extensive, half-century-long literature pro and con strong AI, which continues to be debated; I cannot hope to summarize it or representatively cite it. For the Turing Test, see Alan M. Turing, "Computing Machinery and Intelligence," Mind 59 (1950): 433. This paper has been reprinted in many anthologies, such as John Haugeland,

ed., Mind Design II: Philosophy, Psychology, Artificial Intelligence (Cambridge: MIT Press, 1997), ch. 2.

34. Jennifer Couzin, "Virology. Active Poliovirus Baked from Scratch," Science 297 (2002): 174; Hamilton O. Smith, Clyde A. Hutchison III, Cynthia Pfannkoch, and J. Craig Venter, "Generating a Synthetic Genome by Whole Genome Assembly: φX174 Bacteriophage from Synthetic Oligonucleotides," Proceedings of the National Academy of Science USA 100 (2003): 15440.

35. "Phiole" (F, 6824, 6865, 6871, 6879, 6902, 6904), "Kolben" (F, 6852), "Glas" (F, 6871, 6881, 7069, 7832, 8093, 8236, 8251).

36. The stages in the alchemical process were associated with colors and corresponding birds; see Alice Raphael, Goethe and the Philosopher's Stone: Symbolical Patterns in 'The Parable' and the Second Part of 'Faust' (New York: Garrett Publications, 1965), 56. "The 'peacock's feathers' were a widespread symbol in all alchemical literature, representing either the Philosopher's Stone itself or the stage in the Magnum Opus immediately preceding it." Ronald D. Gray, Goethe the Alchemist: A Study of Alchemical Symbolism in Goethe's Literary and Scientific Works (Cambridge: Cambridge University Press, 1952; Mansfield Centre: Mantino Publishing, 2002), 65. It is "regarded as a favourable portent in the Great Work" (Raphael, Goethe, 56). Paracelsus writes, "When you have seen the different colours, it is necessary that you persevere in the work . . . until the peacock's tail is quite consumed . . . and the vessel attains its degree of perfection." Paracelsus, The Hermetic and Alchemical Writings of "Paracelsus," the Great, ed. Arthur Edward Waite (London, 1894; Chicago: de Laurence, Scott and Co., 1910; Kila: Kessinger, 1991), 1:87.

37. Carl Gustav Jung, Psychology and Alchemy, 2nd ed., trans. Richard Francis Carrington Hull, vol. 12, Collected Works (Princeton: Princeton University Press, 1968), par. 433.

38. Arthur Edward Waite, ed. and trans., Turba Philosophorum: or, Assembly of the Sages (1895; Kila: Kessinger, 2007), 42–43.

39. Jung's own magnum opus on this topic, including the symbolism of the hieros gamos ("sacred marriage") in alchemy, was inspired by Kerényi's essay on the Aegean Festival in Faust. Carl Gustav Jung, Mysterium Coniunctionis: An Inquiry into the Separation and Synthesis of Psychic Opposites in Alchemy, 2nd ed., trans. Richard Francis Carrington Hull, vol. 14, Collected Works (Princeton: Princeton University Press, 1970), xiii. "Mysterium Coniunctionis can thus be considered an exhaustive commentary on Goethe's Faust, especially as it concerns its central image, the coniunctio." Edward F. Edinger, Goethe's Faust: Notes for a Jungian Commentary (Toronto: Inner City, 1990), 67.

40. F, 6829. He soon expresses his abhorrence of begetting in the traditional way (F, 6838).

41. June Singer, Androgeny: The Opposites Within, 2nd ed. (Boston: Sigo, 1989).

42. Raphael, Goethe, 162.

43. Hans Jonas, The Gnostic Religion: The Message of the Alien God and the Beginnings of Christianity, 2nd ed. (Boston: Beacon, 1963), 111. For more on the Gnostic background of Faust, see Michael Mitchell, Hidden Mutualities: Faustian Themes from Gnostic Origins to the Postcolonial (Amsterdam: Rodopi, 2006), ch. 1. Simon and Helena are

associated with the Sun and Moon, and their alchemical union brings about the salvation of humankind "by making straight the true human within" (Mitchell, 25).

44. Elizabeth M. Butler, The Myth of the Magus (Cambridge: Cambridge University Press, 1948), 81–83. See also Philip Mason Palmer and Robert Patterson More, The Sources of the Faust Tradition from Simon Magus to Lessing (New York: Oxford University Press, 1936).

45. Johann Wolfgang von Goethe, Faust, Part One and Part Two, trans. and ed. Charles E. Passage (Indianapolis: Bobbs-Merrill, 1965).

46. Johann Wolfgang von Goethe, Faust, trans. Philip Wayne (Baltimore: Penguin, 1959).

47. In On the Origin of Species Darwin acknowledged Goethe as a predecessor in evolutionary thinking. John Gearey, Goethe's Other Faust: The Drama, Part II (Toronto: University of Toronto Press, 1992), 14–15.

48. Johann Wolfgang von Goethe, Faust: Parts One and Two, trans. George Madison Priest (New York: Covici Friede, 1932).

49. Bruce J. MacLennan, "Aesthetics in Software Engineering," in Encyclopedia of Information Science and Technology, 2nd ed., ed. Mehdi Khosrow-Pour (Hershey: IGI International, 2008), 1: 72-77.

50. Donna Jeanne Haraway, Crystals, Fabrics, and Fields: Metaphors That Shape Embryos (Berkeley: North Atlantic, 2004).

51. P. G. de Gennes, "Soft Matter," Science 256 (1992): 495; Gabor Forgacs and Stuart A. Newman, Biological Physics of the Developing Embryo (Cambridge: Cambridge University Press, 2005), 2, 21–2, 133.

52. Bergson also remarked that, in contrast to the discrete separated spatiality of formal knowledge, "the essence of the psychical is to enfold a confused plurality of interpenetrating terms," "the mutual interpenetration and continuity that I find at the base of my own self." Henri Bergson, Creative Evolution, trans. Arthur Mitchell (New York: Modern Library, 1944), 280, 281.

53. Fumiya Iida, Rolf Pfeifer, Luc Steels, and Yasuo Kuniyoshi, eds., Embodied Artificial Intelligence (Berlin: Springer, 2004); Rolf Pfeifer and Josh C. Bongard, How the Body Shapes the Way We Think—A New View of Intelligence (Cambridge: MIT Press, 2007); Rolf Pfeifer, Max Lungarella, and Fumiya Iida, "Self-organization, Embodiment, and Biologically Inspired Robotics," Science 318 (2007): 1088; Rolf Pfeifer and Christian Scheier, Understanding Intelligence (Cambridge: MIT Press, 1999).

54. Passage, Faust, Part One and Part Two, lxvi.

55. Faust: A Tragedy, trans. Walter Arndt, ed. Cyrus Hamlin, 525.

56. Alan Corkhill, "Language Discourses in Goethe's Faust II," in Unravelling the Labyrinth: Decoding Text and Language, Festschrift for Eric Lowson Marson, ed. Kerry Dunne and Ian R. Campbell (Bern: Peter Lang, 1997), 69–72.

57. Douglas Lenat and R. V. Guha, Building Large Knowledge-based Systems: Representation and Inference in the Cyc Project (Reading: Addison-Wesley, 1990).

58. Dreyfus, What Computers Can't Do, ch. 7.

59. Apparently I. J. Good was the first to suggest (in 1965) that a non-human "intelligence explosion" would occur after the first superhuman intelligence was created. Irving John Good, "Speculations Concerning the First Ultraintelligent Machine," in Advances in Computers 6, ed. Franz L. Alt and Morris Rubinoff (New York: Academic Press, 1965), 31–88. In 1983 V. Vinge called this event "The Singularity." Vernor Vinge, "The Coming Technological Singularity," Vision-21: Interdisciplinary Science and Engineering in the Era of CyberSpace, proceedings of symposium at NASA Lewis Research Center, 30–31 March 1993 (NASA Conference Publication CP-10129).

60. Vinge, "Coming Technological Singularity."
61. Bill McKibben, Enough: Staying Human in an Engineered Age (New York: Henry Holt, 2003); Bill Joy, "Why the Future Doesn't Need Us," Wired Magazine, April 2000, http://www.wired.com/wired/archive/8.04/joy.html (accessed January 5, 2010); Ray Kurzweil, The Singularity Is Near: When Humans Transcend Biology (New York: Viking, 2005); Hans Moravec, "Robots: Re-evolving Mind at 10^7 Times Nature's Speed," Cerebrum 3.2 (Spring 2001): 34–49, http://www.dana.org/news/cerebrum/detail.aspx?id=3010 (accessed June 18, 2010).

62. Moravec, "Robots: Re-evolving Mind."
63. Johann Wolfgang von Goethe, Faust: A Tragedy, trans. Bayard Taylor (New York: Modern Library, 1950).

64. Moravec, "Robots: Re-evolving Mind."
65. Ibid.
66. Trans. Taylor.
67. Johann Peter Eckermann, Gespräche mit Goethe in den letzten Jahren seines Lebens, ed. Christoph Michel, vol. 12, Johann Wolfgang Goethe, Sämtliche Werke. Briefe, Tagebücher und Gespräche (Frankfurt a.M.: Deutscher Klassiker Verlag, 1999), 365–66; translated as Words of Goethe: Being the Conversations of Johann Wolfgang von Goethe [tr. John Oxenford] (New York: Tudor, 1949), 310–11.
68. Edinger, Goethe's Faust, 62.
69. Ibid.
70. Eckermann, Gespräche, 365; Words of Goethe, 310.
71. Carl Gustav Jung, The Structure and Dynamics of the Psyche, trans. Richard Francis Carrington Hull, vol. 8, Collected Works (Princeton: Princeton University Press, 1969), par. 253.
72. Eckermann, Gespräche, 365; Words of Goethe, 310.
73. Denton J. Snider, Goethe's Faust: Second Part (St. Louis: Sigma, [1886]), 110.
74. Snider, Goethe's Faust, 110.
75. Ibid. In fact it seems that this is Hegel's extension of Spinoza's statement and intent. Simon Duffy, The Logic of Expression: Quality, Quantity and Intensity in Spinoza, Hegel and Deleuze (New York: Ashgate, 2006), 18.
76. Snider, Goethe's Faust, 111–12.
77. F, 7836–41, 7849.
78. Snider, Goethe's Faust, 111–12.
79. Ibid., 112.
80. For example, F, 7067, 7068, 7826, 8093, 8104, 8231–36, 8245, 8459, 8466–67.

81. John Read, Prelude to Chemistry: An Outline of Alchemy (Cambridge: MIT Press, 1966), 143–45.
82. Aristotle, On Sophistical Refutations; On Coming-to-be and Passing Away; On the Cosmos, trans. E. S. Forster and D. J. Furley (Cambridge: Harvard University Press, 1978), bk. 2, ch. 2, 330b4; all subsequent references to On Coming-to-be and Passing Away are cited as Gen. corr. According to Aristotelian physics, each of the four elements has two qualities: warm or cool, moist or dry (330b4–6).
83. Aristotle, Gen. corr., bk. 1, ch. 8, 325b25–29.
84. Ibid., bk. 2, ch. 3, 330b31–34.
85. Ibid., bk. 2, ch. 2, 329b31–33.
86. de Gennes, "Soft Matter"; Forgacs and Newman, Biological Physics.
87. Aristotle, Gen. corr., bk. 2, ch. 2, 329b31–33.
88. MacLennan, "Models and Mechanisms."
89. Trans. Passage.
90. Jung, Mysterium Coniunctionis.
91. See, for example, Lise Eliot, Pink Brain, Blue Brain: How Small Differences Grow into Troublesome Gaps — and What We Can Do About It (Boston: Houghton Mifflin, 2009). The title does not accurately reflect the conclusions; see A. Scott Henderson, "Unsexing the Brain," Science 327 (2010): 414.
92. Franz Hartmann, The Life and Doctrines of Philippus Theophrastus, Bombast of Hohenheim, Known by the Name of Paracelsus (New York: John W. Lovell, 1891), 303–6n2.
93. Bergson, Creative Evolution, 205.
94. See, for example, James Jerome Gibson, The Ecological Approach to Visual Perception (Boston: Houghton Mifflin, 1979); Robert Shaw and John Bransford, eds., Perceiving, Acting, and Knowing: Toward an Ecological Psychology (Hillsdale: Lawrence Erlbaum, 1977).
95. Dreyfus, What Computers Can't Do, 248–50, 253.
96. See, for example, Iida, et al., Embodied AI; Pfeifer and Bongard, How the Body Shapes the Way We Think.
97. See, for example, Pfeifer, Lungarella, and Iida, "Self-organization"; Pfeifer and Scheier, Understanding Intelligence.
98. See, for example, Andy Clark, Being There: Putting Brain, Body and World Together Again (Cambridge: MIT Press, 1997); Horst Hendriks-Jansen, Catching Ourselves in the Act: Situated Activity, Interactive Emergence, Evolution, and Human Thought (Cambridge: MIT Press, 1996).
99. Goethe, Faust, trans. Arndt, ed. Hamlin, 433.
100. William Page Andrews, Goethe's Key to Faust: A Scientific Basis for Religion and Morality and for a Solution of the Enigma of Evil (Port Washington: Kennikat, 1968), 66.
101. Jean Campbell Cooper, An Illustrated Encyclopedia of Traditional Symbols (London: Thames and Hudson, 1978), 188-89.
102. Porphyry's work is a commentary on the Odyssey bk. 13, ll. 96–112. For this metaphor, cf. Plato, Statesman, 273d–e.
103. Porphyry, On the Cave of the Nymphs, trans. Thomas Taylor (Grand Rapids: Phanes, 1991), 55.

104. Quoted by the translator in Porphyry, Cave, 70n22.
105. Henry George Liddell, Robert Scott, and Henry Stuart Jones, A Greek-English Lexicon, 9th. ed. (Oxford: Oxford University Press), s.vv.; Lucas Siorvanes, Proclus: Neo-Platonic Philosophy and Science (Edinburgh: Edinburgh University Press, 1996), 151.
106. Porphyry, Cave, 30.
107. Homer, Odyssey, bk. 13, l. 104.
108. Note, however, that Galatea and her sisters are Nereids, not Naiads.
109. Porphyry, Cave, 34.
110. F, 8324–26. See also Corkhill, "Language Discourses," 71–72.
111. Trans. Arndt.
112. Ibid.
113. Goethe, "Polarity," in Scientific Studies, 156. Goethe, "Physikalische Vorträge schematisiert," in Schriften zur allgemeinen Naturlehre, Geologie und Mineralogie, ed. Wolf von Engelhardt and Manfred Wenzel, vol. 25, Sämtliche Werke. Briefe, Tagebücher und Gespräche (Frankfort a.M.: Deutscher Klassiker Verlag, 1989), 143.
114. Trans. Arndt.
115. Goethe, Faust, trans. Arndt.
116. Scott F. Gilbert, Developmental Biology, 6th ed. (Sunderland: Sinauer, 2000), 20–22, 223–61.
117. Ricard Solé and Brian Goodwin, Signs of Life: How Complexity Pervades Biology (New York: Basic Books, 2000), 150.
118. "Gestaltung," "Umgestaltung," "Unterhaltung," the generative activities of the Mothers (F, 6287–88).
119. D. A. Beysens, Gabor Forgacs, and J. A. Glazier, "Cell Sorting is Analogous to Phase Ordering in Fluids," Proceedings of the National Academy of Science USA 97 (2000): 9467.
120. de Gennes, "Soft Matter"; Forgacs and Newman, Biological Physics.
121. MacLennan, "Models and Mechanisms."
122. Snider, Goethe's Faust, 196.
123. Goethe, Faust, trans. Arndt, ed. Hamlin, 239n7.
124. Gray, Goethe the Alchemist, 5, citing Goethes Werke (Weimar: Böhlau, 1893), I, 27, 203–4.
125. Aurea Catena Homeri: The Golden Chain of Homer, trans. Sigismond Bacstrom (San Francisco: Sapere Aude, 1983), 4 (ch. 2).
126. Aur. Cat. Hom., 5–6 (ch. 2).
127. Aristotle, Gen. corr., bk. 2, ch. 2, 329b29–31.
128. Ibid., bk. 2, ch.2, 329b31–32, bk. 2, ch.3, 330a5–11.
129. Trans. Wayne.
130. For example, Leandro Nunes de Castro, Fundamentals of Natural Computing: Basic Concepts, Algorithms, and Applications (Boca Raton: Chapman and Hall/CRC, 2006).
131. Goethe, The Autobiography of Goethe. Truth and Poetry: From My Own Life, new ed., rev., trans. John Oxenford (London: George Bell, 1881), 185; Goethes Werke, I, 27, 11–12.
132. Geoffrey Stephen Kirk, John Earle Raven, and Malcolm Schofield, The Presocratic Philosophers, 2nd ed. (Cambridge: Cambridge University Press, 1983), 21–29.

133. Kirk, Raven, and Schofield, Presocratics, 24n3.
134. See the definitive work, Martin L. West, The Orphic Poems (Oxford: Clarendon Press, 1983).
135. Trans. Wayne.
136. Alice Raphael, Goethe and the Philosopher's Stone: Symbolical Patterns in "The Parable" and the Second Part of "Faust" (New York: Garrett Publications, 1965), 130.
137. Euphorion and the Boy Charioteer are so identified in Goethe's December 20, 1829 conversation with Eckermann. Eckermann, Gespräche, 369–70; Words of Goethe, 314.
138. Raphael, Goethe and the Philosopher's Stone, 132.
139. Carl Gustav Jung, The Structure and Dynamics of the Psyche, trans. Richard Francis Carrington Hull, vol. 8, Collected Works (Princeton: Princeton University Press, 1969), par. 935.
140. David J. Chalmers, The Conscious Mind: In Search of a Fundamental Theory (New York: Oxford University Press, 1996).
141. B. J. MacLennan, "Consciousness: Natural and Artificial," Synthesis Philosophica 22.2 (2008): 401–33.
142. See, for example, Jordi Vallverdú, and David Casacuberta, eds., Handbook of Research on Synthetic Emotions and Sociable Robotics: New Applications in Affective Computing and Artificial Intelligence (Hershey: IGI Global, 2009).
143. MacLennan, "Robots React but Can They Feel?"
144. Anthony Stevens, Ariadne's Clue: A Guide to the Symbols of Humankind (Princeton: Princeton University Press, 1998), 113.
145. Carl Gustav Jung, The Archetypes and the Collective Unconscious, 2nd ed., trans. Richard Francis Carrington Hull, vol. 9, pt. 1, Collected Works (Princeton: Princeton University Press, 1968), par. 291.
146. Jung, Structure and Dynamics of the Psyche, par. 432.
147. Trans. Kaufmann.
148. Goethe, Goethe, "Physikalische Vorträge schematisiert," 142; Goethes "Polarity," Scientific Studies, 156.
149. Carl Gustav Jung, Aion: Researches into the Phenomenology of the Self, 2nd ed., trans. Richard Francis Carrington Hull, vol. 9, pt. 2, Collected Works (Princeton: Princeton University Press, 1978), par. 2.
150. Raphael, Goethe and the Philosopher's Stone, 123.

Bibliography

Andrews, William Page. Goethe's Key to Faust: A Scientific Basis for Religion and Morality and for a Solution of the Enigma of Evil. Port Washington: Kennikat, 1968.

Aristotle. On Sophistical Refutations; On Coming-to-be and Passing Away; On the Cosmos. Translated by E. S. Forster and D. J. Furley. Cambridge: Harvard University Press, 1978.

Aurea Catena Homeri: The Golden Chain of Homer. Leipzig und Winterthur, 1775. Translated by Sigismond Bacstrom. San Francisco: Sapere Aude, 1983.

Bekey, George A. Autonomous Robots: From Biological Inspiration to Implementation and Control. Cambridge: MIT Press, 2005.

Bergson, Henri. Creative Evolution. Translated by Arthur Mitchell. New York: Modern Library, 1944.

Beysens, D. A., Gabor Forgacs, and J. A. Glazier. "Cell Sorting is Analogous to Phase Ordering in Fluids." Proceedings of the National Academy of Sciences USA 97 (2000): 9467–71.

Binswanger, Hans Christoph. Money and Magic: A Critique of the Modern Economy in the Light of Goethe's Faust. Translated by J. E. Harrison. Chicago: University of Chicago Press, 1994.

Breazeal, Cynthia L. Designing Sociable Robots. Cambridge: MIT Press, 2002.

Butler, Elizabeth M. The Myth of the Magus. Cambridge: Cambridge University Press, 1948.

Chalmers, David J. The Conscious Mind: In Search of a Fundamental Theory. New York: Oxford University Press, 1996.

Clark, Andy. Being There: Putting Brain, Body and World Together Again. Cambridge: MIT Press, 1997.

Cooper, Jean Campbell. An Illustrated Encyclopedia of Traditional Symbols. London: Thames and Hudson, 1978.

Corkhill, Alan. "Language Discourses in Goethe's Faust II." In Unravelling the Labyrinth: Decoding Text and Language, Festschrift for Eric Lowson Marson, edited by Kerry Dunne and Ian R. Campbell, 57–73. Bern: Peter Lang, 1997.

---. "'Why all this noise?': Reading Sound in Goethe's Faust I and II." In International Faust Studies: Adaptation, Reception, Translation, edited by Lorna Fitzsimmons, 55–69. London and New York: Continuum, 2008.

Couzin, Jennifer. "Virology. Active Poliovirus Baked from Scratch." Science 297 (2002): 174–75.

de Castro, Leandro Nunes. Fundamentals of Natural Computing: Basic Concepts, Algorithms, and Applications. Boca Raton: Chapman and Hall / CRC, 2006.

de Gennes, P. G. "Soft Matter." Science 256 (1992): 495–97.

Dennett, Daniel C. The Intentional Stance. Cambridge: MIT Press, 1987.

Dreyfus, Hubert. What Computers Can't Do: The Limits of Artificial Intelligence. Rev. ed. New York: Harper & Row, 1979.

Duffy, Simon. The Logic of Expression: Quality, Quantity and Intensity in Spinoza, Hegel and Deleuze. New York: Ashgate, 2006.

Eckermann, Johann Peter. Words of Goethe: Being the Conversations of Johann Wolfgang von Goethe. [Translated by John Oxenford.] New York: Tudor, 1949. Originally published as Gespräche mit Goethe in den letzten Jahren seines Lebens. Edited by Christoph Michel. Vol. 12, Johann Wolfgang von Goethe, Sämtliche Werke. Briefe, Tagebücher und Gespräche (Frankfort a.M.: Deutscher Klassiker Verlag, 1999).

Edinger, Edward F. Goethe's Faust: Notes for a Jungian Commentary. Toronto: Inner City, 1990.

Eliot, Lise. Pink Brain, Blue Brain: How Small Differences Grow into Troublesome Gaps — and What We Can Do About It. Boston: Houghton Mifflin, 2009.

Forgacs, Gabor, and Stuart A. Newman. Biological Physics of the Developing Embryo. Cambridge: Cambridge University Press, 2005.

Gardner, Howard. The Mind's New Science: A History of the Cognitive Revolution. New York: Basic Books, 1985.

Gearey, John. Goethe's Other Faust: The Drama, Part II. Toronto: University of Toronto Press, 1992.

Gibson, James Jerome. The Ecological Approach to Visual Perception. Boston: Houghton Mifflin, 1979.

Gilbert, Scott F. Developmental Biology. 6th ed. Sunderland: Sinauer, 2000.

Goertzel, Ben, and Cassio Pennachin, eds. Artificial General Intelligence. Berlin: Springer, 2007.

Goethe, Johann Wolfgang von. The Autobiography of Goethe. Truth and Poetry: From My Own Life. New ed., rev. Translated by John Oxenford. London: George Bell, 1881.

---. Faust. Edited by Albrecht Schöne. Vol. 7, pt. 1., Sämtliche Werke. Briefe, Tagebücher und Gespräche. Frankfort a.M.: Deutscher Klassiker Verlag, 1995.

---. Faust. Translated by Philip Wayne. Baltimore: Penguin, 1959.

---. Faust: A Tragedy. Translated by Bayard Taylor. New York: Modern Library, 1950.

---. Faust: A Tragedy. 2nd ed. Translated by Walter Arndt. Edited by Cyrus Hamlin.

New York: Norton, 2001.

---. Faust, Part One and Part Two. Translated and edited by Charles E. Passage. Indianapolis: Bobbs-Merrill, 1965.

---. Faust: Parts One and Two. Translated by George Madison Priest. New York: Covici Friede, 1932.

---. Goethe's Faust: Part One and Sections from Part Two. Translated by Walter Kaufmann. New York: Doubleday, 1961.

---. Goethes Werke. Hrsg. im Auftrag der Großherzogin Sophie von Sachsen. Weimarer or Sophienausgabe. 4 pts., 143 vols. Weimar: Böhlau, 1887-1919.

---. "Physikalische Vorträge schematisiert." In Schriften zur allgemeinen Naturlehre, Geologie und Mineralogie, edited by Wolf von Engelhardt and Manfred Wenzel, 142-75. Vol. 25, Sämtliche Werke. Briefe, Tagebücher und Gespräche. Frankfort a.M.: Deutscher Klassiker Verlag, 1989.

---. Scientific Studies. Edited and translated by Douglas Miller. Vol. 12, Goethe's Collected Works. Princeton: Princeton University Press, 1988.

---. Zur Farbenlehre. Edited by Manfred Wenzel. Vol. 23, pt. 1. Sämtliche Werke. Briefe, Tagebücher und Gespräche. Frankfort a.M.: Deutscher Klassiker Verlag, 1991.

Good, Irving John. "Speculations Concerning the First Ultraintelligent Machine." In Advances in Computers 6, edited by Franz L. Alt and Morris Rubinoff, 31–88. New York: Academic Press, 1965.

Gray, Ronald D. Goethe the Alchemist: A Study of Alchemical Symbolism in Goethe's Literary and Scientific Works. Cambridge: Cambridge University Press, 1951. Mansfield Centre: Martino Publishing, 2002.

Haraway, Donna Jeanne. Crystals, Fabrics, and Fields: Metaphors That Shape Embryos. Berkeley: North Atlantic, 2004.

Harnad, Stevan. "The Symbol Grounding Problem." Physica D 42 (1990): 335–46. http://cogprints.org/3106/ (accessed January 5, 2010).

Hartmann, Franz. The Life and Doctrines of Philippus Theophrastus, Bombast of Hohenheim, Known by the Name of Paracelsus. New York: John W. Lovell, 1891.

Haugeland, John. Artificial Intelligence: The Very Idea. Cambridge: MIT Press, 1985.

---, ed. Mind Design II: Philosophy, Psychology, Artificial Intelligence. Cambridge: MIT Press, 1997.

Henderson, A. Scott. "Unsexing the Brain." Science 327 (2010): 414.

Hendriks-Jansen, Horst. Catching Ourselves in the Act: Situated Activity, Interactive Emergence, Evolution, and Human Thought. Cambridge: MIT Press, 1996.

Iida, Fumiya, Rolf Pfeifer, Luc Steels, and Yasuo Kuniyoshi, eds. Embodied Artificial Intelligence. Berlin: Springer, 2004.

Jantz, Harold. Goethe's Faust as a Renaissance Man: Parallels and Prototypes. Princeton: Princeton University Press, 1951.

Jonas, Hans. The Gnostic Religion: The Message of the Alien God and the Beginnings of Christianity. 2nd ed. Boston: Beacon, 1963.

Joy, Bill. "Why the Future Doesn't Need Us." Wired Magazine April 2000, http://www.wired.com/wired/archive/8.04/joy.html (accessed January 5, 2010).

Jung, Carl Gustav. Aion: Researches into the Phenomenology of the Self. 2nd ed. Translated by Richard Francis Carrington Hull. Vol. 9, pt. 2, Collected Works. Princeton: Princeton University Press, 1978.

---. The Archetypes and the Collective Unconscious. 2nd ed. Translated by Richard Francis Carrington Hull. Vol. 9, pt. 1, Collected Works. Princeton: Princeton University Press, 1968.

---. Mysterium Coniunctionis: An Inquiry into the Separation and Synthesis of Psychic Opposites in Alchemy. 2nd ed. Translated by Richard Francis Carrington Hull. Vol. 14, Collected Works. Princeton: Princeton University Press, 1970.

---. Psychology and Alchemy. 2nd ed. Translated by Richard Francis Carrington Hull. Vol. 12, Collected Works. Princeton: Princeton University Press, 1968.

---. Psychology and Religion: West and East. 2nd ed. Translated by Richard Francis Carrington Hull. Vol. 11, Collected Works. Princeton: Princeton University Press, 1969.

---. The Structure and Dynamics of the Psyche. Translated by Richard Francis Carrington Hull. Vol. 8, Collected Works. Princeton: Princeton University Press, 1969.

Kirk, Geoffrey Stephen, John Earle Raven, and Malcolm Schofield. The Presocratic Philosophers. 2nd ed. Cambridge: Cambridge University Press, 1983.

Kurzweil, Ray. The Singularity Is Near: When Humans Transcend Biology. New York: Viking, 2005.

Lenat, Douglas, and R. V. Guha. Building Large Knowledge-based Systems: Representation and Inference in the Cyc Project. Reading: Addison-Wesley, 1990.

Liddell, Henry George, Robert Scott, and Henry Stuart Jones. A Greek-English Lexicon. 9th ed. Oxford: Oxford University Press.

MacLennan, Bruce J. "Aesthetics in Software Engineering." In Encyclopedia of Information Science and Technology. Vol. 1, 2nd ed. Edited by Mehdi Khosrow-Pour, 72-77. Hershey: IGI International, 2008.

---. "Consciousness: Natural and Artificial." Synthesis Philosophica 22. 2 (2008): 401–33.

---. "Editorial Preface: Computation and Nanotechnology." International Journal of Nanotechnology and Molecular Computation 1.1 (2009): i–ix.

---. "Field Computation in Natural and Artificial Intelligence." In Encyclopedia of Complexity and System Science, edited by Robert A. Meyers et al., 3334-60. Berlin: Springer, 2009.

---. From Pythagoras to the Digital Computer: The Intellectual Roots of Symbolic Artificial Intelligence. Forthcoming.

---. "Models and Mechanisms for Artificial Morphogenesis." In International Workshop on Natural Computing, edited by Ferdinand Peper and Hiroshi Umeo, 23–33. Springer series, Proceedings in Information and Communications Technology (PICT) 2. Berlin: Springer, 2010.

---. "Robots React but Can They Feel? A Protophenomenological Analysis." In Handbook of Research on Synthetic Emotions and Sociable Robotics: New Applications in Affective Computing and Artificial Intelligence, edited by Jordi Vallverdú and David Casacuberta, 133-53. Hershey: IGI Global, 2009.

McDermott, Drew. "Artificial Intelligence Meets Natural Stupidity." ACM SIGART Bulletin 57 (April 1976): 4–9.

McIlwain, Henry. "Neurochemistry and Sherrington's Enchanted Loom." Journal of the Royal Society of Medicine 77, no. 5 (May 1984): 417–25.

McKibben, Bill. Enough: Staying Human in an Engineered Age. New York: Henry Holt, 2003.

Minsky, Marvin, ed. Semantic Information Processing. Cambridge: MIT Press, 1968.

Mitchell, Michael. Hidden Mutualities: Faustian Themes from Gnostic Origins to the Postcolonial. Amsterdam: Rodopi, 2006.

Moravec, Hans. "Robots: Re-evolving Mind at 10^7 Times Nature's Speed." Cerebrum 3, no. 2 (Spring 2001): 34–49. http://www.dana.org/news/cerebrum/detail.aspx?id=3010 (accessed June 18, 2010).

Morris, Charles W. Signification and Significance: A Study of the Relations of Signs and Values. Cambridge: MIT Press, 1964.

Palmer, Philip Mason and Robert Patterson More. The Sources of the Faust Tradition from Simon Magus to Lessing. New York: Oxford University Press, 1936.

Paracelsus. The Hermetic and Alchemical Writings of "Paracelsus," the Great. 2 vols. Edited by Arthur Edward Waite. London, 1894. Chicago: de Laurence, Scott and Co., 1910. 2 vols. in 1. Kila: Kessinger, 1991.

Pfeifer, Rolf, and Josh C. Bongard. How the Body Shapes the Way We Think — A New View of Intelligence. Cambridge: MIT Press, 2007.

Pfeifer, Rolf, Max Lungarella, and Fumiya Iida. "Self-organization, Embodiment, and Biologically Inspired Robotics." Science 318 (2007): 1088–93.

Pfeifer, Rolf, and Christian Scheier. Understanding Intelligence. Cambridge: MIT Press, 1999.

Porphyry. On the Cave of the Nymphs. Translated by Thomas Taylor. Grand Rapids: Phanes, 1991.

Raphael, Alice. Goethe and the Philosopher's Stone: Symbolical Patterns in "The Parable" and the Second Part of "Faust". New York: Garrett Publications, 1965.

Read, John. Prelude to Chemistry: An Outline of Alchemy. Cambridge: MIT Press, 1966.

Shaw, Robert, and John Bransford, eds. Perceiving, Acting, and Knowing: Toward an Ecological Psychology. Hillsdale: Lawrence Erlbaum, 1977.

Sherrington, Charles Scott. Man on His Nature. Cambridge: Cambridge University Press, 1955.

Singer, June. Androgeny: The Opposites Within. 2nd ed. Boston: Sigo, 1989.

Singer, Peter Warren. Wired for War: The Robotics Revolution and Conflict in the Twenty-first Century. New York: Penguin, 2009.

Siorvanes, Lucas. Proclus: Neo-Platonic Philosophy and Science. Edinburgh: Edinburgh University Press, 1996.

Smith, Hamilton O., Clyde A. Hutchison III, Cynthia Pfannkoch, and J. Craig Venter. "Generating a Synthetic Genome by Whole Genome Assembly: φX174 Bacteriophage from Synthetic Oligonucleotides." Proceedings of the National Academy of Sciences USA 100 (2003): 15440–45.

Snider, Denton J. Goethe's Faust: Second Part. St. Louis: Sigma, [1886].

Solé, Ricard, and Brian Goodwin. Signs of Life: How Complexity Pervades Biology. New York: Basic Books, 2000.

Stevens, Anthony. Ariadne's Clue: A Guide to the Symbols of Humankind. Princeton: Princeton University Press, 1998.

Turing, Alan M. "Computing Machinery and Intelligence." Mind 59 (1950): 433–60.

Vallverdú, Jordi, and David Casacuberta, eds. Handbook of Research on Synthetic Emotions and Sociable Robotics: New Applications in Affective Computing and Artificial Intelligence. Hershey: IGI Global, 2009.

Vinge, Vernor. "The Coming Technological Singularity." In Vision-21: Interdisciplinary Science and Engineering in the Era of CyberSpace, proceedings of symposium at NASA Lewis Research Center, March 30–31, 1993 (NASA Conference Publication CP-10129). http://rohan.sdsu.edu/faculty/vinge/misc/singularity.html (accessed January 5, 2010).

von Franz, Marie-Louise. Alchemy: An Introduction to the Symbolism and the Psychology. Toronto: Inner City, 1980.

Waite, Arthur Edward, ed. and trans. Turba Philosophorum: or, Assembly of the Sages. 1895. Kila: Kessinger, 2007.

West, Martin L. The Orphic Poems. Oxford: Clarendon Press, 1983.

Winograd, Terry, and Fernando Flores. Understanding Computers and Cognition. Reading: Addison-Wesley, 1986.

Wittgenstein, Ludwig. Tractatus Logico-Philosophicus. Translated by D. F. Pears and B. F. McGuinness. London: Routledge and Kegan Paul, 1974. German text: http://www.tractatus.hochholzer.info/ (accessed February 12, 2010).