Introduction

When we invoke "the electric age," we should understand this expression as actually referring to the electro*magnetic* age. By omitting "magnetic," we lose track of the discoveries that transformed daily life and the global economy. In 1820 Hans Christian Oersted noticed that a current-carrying wire deflected a nearby compass needle (fig. 1). The detection of a mysterious link between electricity and magnetism took the European scientific community by surprise. Most believed that these natural forces were unrelated. Oersted's discovery showed otherwise and led to the creation of a new field of research, electromagnetism, prompted by the need to study the two forces in tandem.

Electromagnetism quickly became the subject of an intense investigation that culminated in 1831, when Michael Faraday uncovered another striking effect known as "induction." He showed that he could generate an electric current in a conductor by simply moving a magnet near it. Electromagnetic induction made possible several world-changing technologies, such as the telegraph and the dynamo, and the latter was responsible for the advent of mass electrification during the second half of the nineteenth century.

The study of electromagnetism presented scientists with a new set of challenges that forced them not only to revise their conception of reality but also to think differently about how to investigate it. To illustrate the profound epistemological shift instigated by electromagnetism during the nineteenth century, Paul Valéry devised a thought experiment inspired by the phenomenon of induction at work in the dynamo. If we had access to the place where the great pre–nineteenth-century minds reside (Valéry jokingly calls this place "hell"), and were to give a dynamo to Archimedes, Galileo, Descartes, or Newton, they would not know what to do with it. They would spin the movable part, take the device apart, measure all its pieces, and never have a chance to penetrate its secret. The dynamo would confound them because, for Valéry, these luminaries could only think of "mechanical transformations."[1] Such thinking could

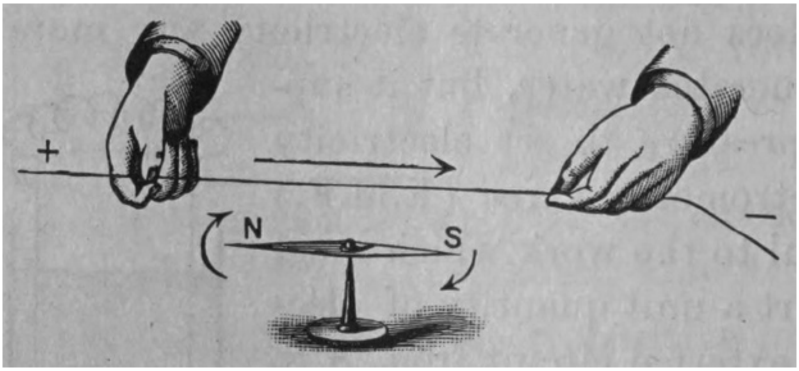

Fig. 1 Oersted's groundbreaking experiment, which revealed that an electric current deflects a nearby magnetic needle. Henry S. Carhart and Horatio N. Chute, *Practical Physics* (Boston: Allyn and Bacon, 1920), 366, figure 381. Library of Congress, Washington, DC.

grasp machines such as the classical clock, lever, or balance but could not have understood the dynamo.[2]

Electromagnetic induction manifests a transformation of energy that eludes mechanical interpretation. The great achievements accumulated by Newtonian physics since the eighteenth century legitimized this mechanical worldview associated with industrialization and the flowering of bourgeois society during the nineteenth century. However, a significant component of the world continued to elude the Newtonian conception of nature. The application of Newtonian physics to electromagnetism yielded only limited results. The classical laws of electromagnetism, what we now call "Maxwell's equations," took form in 1861 thanks to the elaboration of a new physical concept that originated in the patterns formed by iron filings around a magnet.

Faraday called these patterns "lines of force" and thought that they represented electric and magnetic forces better than the Newtonian law of universal gravitation, which states that gravitational attraction occurs between separate objects without delay or apparent mediation. Faraday thought that the instantaneous force at work in Newton's atomist universe seemed too magical to be true and saw in the curved lines of force extending beyond the magnet a more accurate way to represent a force acting in space. Whereas space is absolute and plays no part in gravitational attraction, lines of force show that a magnet reconfigures the surrounding space to move iron filings or to attract other magnets.

The concept of a magnetic field implies that objects are not really separate. They participate in the same continuum characterized by a malleable and active space that contains their potential for action. Now known as “field theory,” this new representation of the transmission of energy broke away from Newtonian atomism and prompted James Clerk Maxwell to develop a mathematical formalism compatible with a continuous physical reality. Besides the laws of electromagnetism, Faraday’s lines of force helped Maxwell formulate the electromagnetic wave theory from which he predicted the existence of the radio wave and identified light as an electromagnetic phenomenon. In 1905 Einstein published his special theory of relativity, which builds on field theory and an asymmetry in Maxwell’s interpretation of electromagnetic induction to show that time and space are indeed malleable. Einstein’s special theory of relativity completed Faraday’s critique of Newtonian physics and ended a theoretical system that had dominated the intellectual climate of the previous one hundred and fifty years.

In the dynamo thought experiment, Valéry contrasts mechanical with electromagnetic transformations to highlight a different kind of analytical thinking closely connected to this profound reconceptualization of nature. What made this alternative thinking so radically different was that it took root in electromagnetic phenomena. In the 1820s, alongside the mechanical thinking that characterized classical luminaries, a different way to explore and order our surroundings began to emerge that broadly could be called “electromagnetic thinking.”

This book examines some of the key elements in electromagnetic thinking that helped make the secret of the dynamo intelligible. These elements are inseparable from the apparatuses—what I call transformational motors and Romantic machines—that helped materialize and legitimize them. I therefore organize this study around three types of apparatuses powered by electromagnetism: chains, the lab experiment Faraday used to unveil the phenomenon of induction, and automata. My aim is not to provide an exhaustive historical account of these objects. Through reading strategies drawn from literary studies and the field of science and literature, I concentrate instead on how they bolstered the emergence of electromagnetic thinking.

The legacy of electromagnetism in the history of science and technology has recently been the subject of important revisions and clarifications by, among others, David Gooding, Ryan D. Tweney, Christine Blondel, Friedrich Steinle, Kenneth Caneva, and Françoise Balibar. Yet beyond physics treatises and laboratories, lesser-known intellectual legacies also deserve attention. Electromagnetism supported ideas and practices based on an interpretation of reality more organic and interconnected than previous worldviews. Like many scientific theories, it soon captured the attention and imagination of humanists and social reformers. I argue that literature became a site of textual experimentation that engaged with early interpretations of electromagnetism and prompted significant changes in the understanding of language, social relations, and polarities such as subject and object, mind and nature, conscious and nonconscious, and life and death. I will show how these changes occurred as evidenced by analogies inspired by the newly found link connecting electricity and magnetism, and I will demonstrate how the images these analogies produced helped authors explore and redefine social, aesthetic, epistemological, and metaphysical domains. This overlooked dialogue between science and literature provides a new perspective on critical debates that shaped the nineteenth century.

In recent years electricity has been the subject of growing interest in literary studies.[3] Sam Halliday has followed the emergence of a kind of "electrical thinking" in works by Nathaniel Hawthorne, Herman Melville, Mark Twain, and Henry James, where electrical communication technologies such as the telegraph and the telephone provided key models to reimagine not only interpersonal connections but the nature of thinking itself. Paul Gilmore has examined the impact of electricity on modern definitions of aesthetics and has shown how, from British Romantics to the American Renaissance and from Edmund Burke to Frederick Douglass, it rearticulated and complicated the relationship between the aesthetic and political spheres. Jennifer Lieberman has demonstrated how Mark Twain, Charlotte Perkins Gilman, Jack London, Ralph Ellison, and Lewis Mumford relied on electrical technologies to undermine dominant modes of thinking associated with American industrialization and individualism and to promote alternative visions of social interconnectedness. Many contemporary discussions of networks and systems can be traced back to scientific and literary discourses addressing the nature of electricity.

My study contributes to this scholarship by shifting the focus from electricity to electromagnetism.[4] Authors have traditionally relied on either electricity *or* magnetism to convey the nature of human interactions such as power relations and romantic attraction. After the discovery of electromagnetism, these interactions could also be described through the link between electricity *and* magnetism. I will show that these remarkable electromagnetic analogies appeared as early as 1833 and examine how they impacted the works of three main authors. I trace their emergence in the writings of Honoré de Balzac and

Edgar Allan Poe and examine their legacies in Villiers de l'Isle-Adam. I employ a comparative approach to recognize patterns and structures that extend beyond individual, national, and genre specificities. Comparing examples across time helps clarify the origin and function of electromagnetic analogies and their profound cultural and epistemological impacts.

These analogies shed light not only on the history of literature but also on scientific thinking. One of the central aims of the humanistic field of science and literature, according to Devin Griffiths, "is to explain the role of imaginative language in science and to explore the impact of literary form on scientific practice."[5] Hans Christian Oersted's 1820 detection of a relation between the electric current and magnetism resulted in great part from a research program that took its cue from the "polarity" and "unity" of natural forces, heavily contested notions disseminated by Romantic literature and *Naturphilosophie*.[6] By unifying the domains of electricity and magnetism, his discovery provided empirical evidence for these notions. It also contributed, I argue, to the rehabilitation of the discourse of analogy.

Griffiths characterizes the nineteenth century as "the age of analogy." His study of the interactions between science and literature in the works of Erasmus and Charles Darwin shows that writers and scientists increasingly relied on various types of analogies involving comparisons, tropes, and "correspondences" to challenge boundaries and drive conceptual innovation. Such analogical approaches had fallen into disrepute due to their association with pre-Enlightenment theological, philosophical, and alchemical methods. Yet they continued to exist as alternative modes of analytical thinking in the margins of the intellectual establishment. I contend that the unexpected identification of a link between electricity and magnetism provided crucial empirical grounds to relegitimate and redefine the discourse of analogy. I examine the appearance of electromagnetic tropes in literature and show how they anticipated similar analogies in scientific and philosophical discourses.

My analysis demonstrates that electromagnetic analogies provided a more complex model of reality that called into question prevalent views concerning how things relate through space and time. Whereas electric imagery tended to emphasize metaphorical relations founded on resemblance, electromagnetic imagery underscored metonymic relations based on contiguity. In Poe's little-known tale "The Spectacles," which I discuss in chapter 1, the narrator describes how love "at first sight" invisibly links bodies across space not just through its similarity to an electric connection but also through a relation of contiguity between electricity and magnetism. Oersted's and Faraday's experiments with electromagnetic interaction proved that the two forces are contiguous phenomena that share an intimate link despite their spatial separation and different physical properties. In "The Spectacles," the representation of falling in love does not simply depend on an electric "fluid" *or* magnetic fluid anymore; it is an interaction between the two. The reality portrayed in such electromagnetic imagery manifests a shift from metaphoric to metonymic relations where spatial and temporal separation are not simply subsumed by the undifferentiated continuity of a single "fluid."

The metonymic shift that I trace in the complex models unveiled by nineteenth-century electromagnetic analogies prefigures the explosion of metonymic reasoning that marked the beginning of the twentieth century, which Ronald Schleifer has identified in influential notions such as Walter Benjamin's "constellation," Mikhail Bakhtin's "interfacings of 'borders,'" Bertrand Russell's "arrangement of order," Albert Einstein's "operational definition," and Werner Heisenberg's "alternation."[7] This earlier metonymic shift is therefore significant because it contributes to our understanding of not only the history of analogical thinking but also some of the less familiar origins of modern metonymic reasoning. Electromagnetic thinking also sheds light on a critical turning point that contributed to rediscovering modes of thought based on relations of contiguity.

Metonymic Contiguity and the Imagination

Building upon the ideas of Roman Jakobson, George Lakoff, and Mark Johnson, cognitive linguists have recently obtained greater empirical evidence that metonymy is not merely a figure of speech but a fundamental cognitive process that plays a central role in the way we produce and order meaning, interpretation, and knowledge.[8] Electromagnetism has greatly contributed to the revalorization of metonymic reasoning, often working as a model for its conceptualization. For instance, when Jakobson formulated his theory on the bipolar structure of language, he relied on a model informed by field theory.[9] According to Jakobson, metaphor and metonymy are the two fundamental "poles" that structure all linguistic systems. Despite their marked difference, they are inseparable. Linguistic formations always depend on a combination of the two that emphasizes one or the other.

Sebastian Matzner recently reevaluated Jakobson's theory of the bipolar structure of language from a tropological perspective and produced more support for the claim that metaphor and metonymy are the two fundamental tropes from which all the others can be derived.[10] He also pointed out that definitions of metonymy as the trope of "association," "proximity," "propinquity," or, in the general modern usage, "contiguity" have been particularly vague concerning the actual relation they supposedly describe. According to philosophy and psychology, contiguity implies "a relation based solely on frequently experienced togetherness, without the necessary involvement of *any* logical principal as such." Yet this more contingent aspect of contiguity has been downplayed by rhetoricians who, since antiquity, have attempted to define metonymy through ever-expanding categories of relations that have usually foregrounded the substitutive logic of synecdoche: "place and inhabitant, individual and group, producer and product, container and contained, cause and effect, and so forth."[11] This emphasis has caused problems of classification, often leading to theories considering synecdoche as distinct from metonymy.[12] The lack of clarity concerning the exact nature of its operation also translated into a neglect of metonymy, which, compared with metaphor, has received less critical attention.

Matzner contends that metonymy, as the trope of contiguity, should represent logical and nonlogical relations. Its general principle should account for synecdoche and more contingent links based on "frequently experienced togetherness" such as "heart" and "courage." Like Jakobson, he turns to a type of field theory—the linguistic concept of "semantic fields"—to reformulate this principle on more all-encompassing grounds.

Before field theory, earlier scientific interpretations of (electro-)magnetic phenomena had already made important contributions to the understanding of the elusive concept of metonymic contiguity. Jakobson's use of metaphor and metonymy is particularly indebted to associationist theories,[13] which elevated resemblance and contiguity to central operations of the mind and which have been linked to electricity and magnetism since David Hume. The philosopher claims that his greatest contribution to the "science of man" was to recast its foundation in the operations of "the imagination." According to Hume, the function of the imagination is to order the mass of impressions and ideas crowding the mind through association. This ability to make connections is the primary engine of the imagination, which produces "chains of thought" that can lead to both "reverie" and scientific insight.[14]

For Hume, the principles of association come down to three basic types of connections that occur through resemblance, contiguity in time and space, and cause and effect. He describes this fundamental ability to make associations as "a kind of ATTRACTION, which in the mental world will be found to have as extraordinary effects as in the natural, and to show itself in as many and as various forms."[15] Hume compares his scientific approach to that of Newton by transposing the latter's use of the term *attraction* to the domain of the mind. Although Newton is famous for his work on gravity, his use of the term refers to all natural forces, including electricity and magnetism.[16] Hume's influential elevation of the imagination and its associative processes based on resemblance and contiguity (or what Jakobson and cognitive linguists call metaphor and metonymy) already depended on an analogy informed by electric and magnetic attractions to materialize how the imagination—and more broadly, thought—works.

As the understanding of these two forces changed during the first half of the nineteenth century, so did thought. As electromagnetic phenomena contributed to the rehabilitation of the discourse of analogy, cognitive association based on contiguity received fresh empirical backing and new conceptual options for representing its mode of operation. In the same movement, these new options redefined the nature of relation and difference, providing critical tools to rethink the interconnection of things in more metonymic terms.

The way this redefinition shaped nineteenth-century literature and science has been obscured due to the rise to prominence of Einstein's theory of relativity and its reconceptualization of electromagnetism. Throughout her works, Linda Dalrymple Henderson has reminded us that, up until 1919, cultural productions were not impacted by Einstein's physics and were instead informed by previous interpretations of electromagnetism. This book traces the legacies of these lesser-known models of electromagnetism dating back to the 1830s.

Imaging (Electro-)Magnetic Contiguity

To clarify how electromagnetic phenomena have expressed and shaped relations of contiguity, I will turn to their visual representation as a kind of chain in Faraday's and Maxwell's diagrams. These images participate in an older and influential tradition that, since Plato's *Ion*, relied on the magnetic chain to visualize metonymic as well as metaphoric relations. A brief discussion of this tradition will reveal an overlooked yet crucial cultural context informing these scientific diagrams and their significance for the concept of contiguity.

In *Ion*, Socrates relies on an analogy inspired by a magnetic chain to convince the rhapsodist Ion that his famed poetic declamation depends on an art devoid of technical or rational skill. The strong influence his performance has on spectators derives instead from its participation in a larger series of connections emanating from a divine source:

> The gift which you possess of speaking excellently about Homer is not a technique, but, as I was just saying, an inspiration; there is a divinity moving you, like that contained in the stone which Euripides calls a magnet, but which is commonly known as the stone of Heraclea. This stone not only attracts iron rings, but also imparts to them a similar power of attracting other rings; and sometimes you may see a number of pieces of iron and rings suspended from one another so as to form quite a long chain: and all of them derive their power of suspension from the original stone. In like manner the Muse first of all inspires men herself; and from these inspired persons a chain of other persons is suspended, who take the enthusiasm.[17]

This passage anticipates Plato's more pronounced opposition between the ideal forms and their lowly copies in the *Republic*. Although rhapsodic interpretation constitutes an embodiment of the divine, it is only the result of a chain of duplications. Such interpretation happens in the enthusiastic state provoked by divine inspiration or possession (*éntheon*). The poet is out of his mind, and as if in a Bacchic trance, he becomes the medium of the Muse who invested him.

The Platonic opposition between divine ideal forms and their mundane copies has been an ongoing influence on the critical discourse on art. It often privileges philosophy and science at the expense of art, since mimesis can only aspire to resemble a model that will always remain out of reach or more truthful. Yet as Jean-Luc Nancy's deconstructive reading of *Ion* has demonstrated, the magnetic chain analogy also manifests a metonymic relation that undermines this emphasis on the metaphorical relation linking art to its model and, consequently, the hierarchical separation of scientific and artistic disciplines.[18] When the poet is in a state of "enthusiasm," gods do the talking. Nancy translates this transmission of the divine voice (*theîa moîra*) as "*le partage divin*" (divine sharing) and "*le partage des voix*" (sharing voices). In French, the word *partage* means both participating, as in sharing, and dividing, as in cutting. This double logic expresses something paradoxical about Ion's art that magnetism also renders apparent.

The divine *partage* is like magnetization. The iron rings participate in the overflowing power of the lodestone while remaining separate from the source of their attraction. Correspondingly, the chain of "inspired persons" comes together not because they share a resemblance with the divine but due to an elusive connection made apparent by their proximity. In Plato, divine magnetization depends on a link marked by difference that relates seemingly unrelated domains through metonymic contiguity. This concatenation occurs through a process of *partage*, which involves a combination of metonymic as well as metaphoric relations and which does not necessarily degrade art to mere imitation. The initial model of the Platonic chain in *Ion* depends on an analogy with magnetic power that is instrumental in making its complex vision of the interconnection of things cling together.

Ion marks the beginning of a long and influential tradition that has represented and explored the inner workings of the cosmos through notions of magnetism. As Koen Vermeir demonstrates, analogies with the magnetic chain and, more broadly, the lodestone's ability to attract and magnetize iron are found in early philosophical and theological texts to support various conceptions of the order and continuity of things. This magnetic imagery appears in works as wide-ranging as the *Corpus Hermeticum* (second century C.E. and later) and the writings of the church fathers. Augustine directly refers to the magnetic chain as an object of fascination: "Who would not be amazed at this virtue of the stone, subsisting as it does not only in itself, but transmitted through so many suspended rings, and binding them together by invisible links?"[19] Through the Middle Ages and the modern era, magnetism remained a popular model to render manifest divine attraction and the "invisible links" connecting God and "His" creation.

Such magnetic "invisible links" inspired a striking iconography that proliferated in the seventeenth century. In 1600 William Gilbert's discovery of geomagnetism provided a scientific foundation for visions of the cosmos as inherently magnetic. Supporters of this "magnetic philosophy" included luminaries such as Johannes Kepler and Robert Boyle. Magnetic philosophy was an important contributor to the scientific, theological, and artistic productions of this era. Its most famous proponent was the Jesuit polymath Athanasius Kircher.

He published several books on magnetic philosophy, two of which contained remarkable frontispieces depicting magnetic chains. They show the hand of God holding the end of magnetic chains that descend from the heavens to Earth and that, along the way, connect with various objects and bigger rings with images inside of them. In Kircher's *Magnes sive de arte magnetica opus tripartitum* (1641), the chains pass through symbols of the Holy Roman Empire, highlighting the political ramifications of Kircher's magnetic vision of the cosmos (fig. 2). The rings also frame images representing various disciplines, which are part of a greater interacting whole connecting the mundane and divine worlds and which range from theology, philosophy, poesis, rhetoric, and music to cosmography, mechanics, astronomy, arithmetic, natural magic, and medicine.[20] In *Magneticum Naturae Regnum* (1667), the images depict various symbols of "sympathies" associated with magnetism at the time (fig. 3). Both frontispieces have banners proclaiming that everything is linked by "arcane knots" (*arcanis nodis*).

Contiguous rings bonded together by magnetic force give form to these "arcane knots."[21] Evoking the description in *Ion*, the magnetic chain offers a remarkable empirical model to make sense of difference and relation within a vision of the cosmos where everything is not only metaphorically but also metonymically interconnected. God is a divine lodestone from whom a transformative power emanates. Just as the lodestone turns iron into a magnet, this power transforms everything it passes through. The magnetic chain brings support to a conception of God as absolutely different, yet everything can partake in "His" power. The contiguity of the rings conveys this "invisible link" or "arcane knot" between the divine and the mundane by representing a relation marked by difference. God's concatenation stays whole thanks to a metonymic power associated with magnetism.

The Platonic tradition of the magnetic chain helped pave the way for the metonymic shift that occurred in the wake of electromagnetism during the nineteenth century. To support this claim, I will turn to Faraday's and Maxwell's use of diagrams. These diagrams were visual cognitive tools that, along with experiments and mathematical reasoning, played a crucial role in their elaboration of the classic laws of electromagnetism. Faraday and Maxwell explored electromagnetic phenomena through images that allowed them to visualize and synthesize particular aspects of the puzzling interaction of electricity and magnetism. David Gooding has shown how Faraday's diagrams built on each other to generate new insights and guide his line of inquiry as he

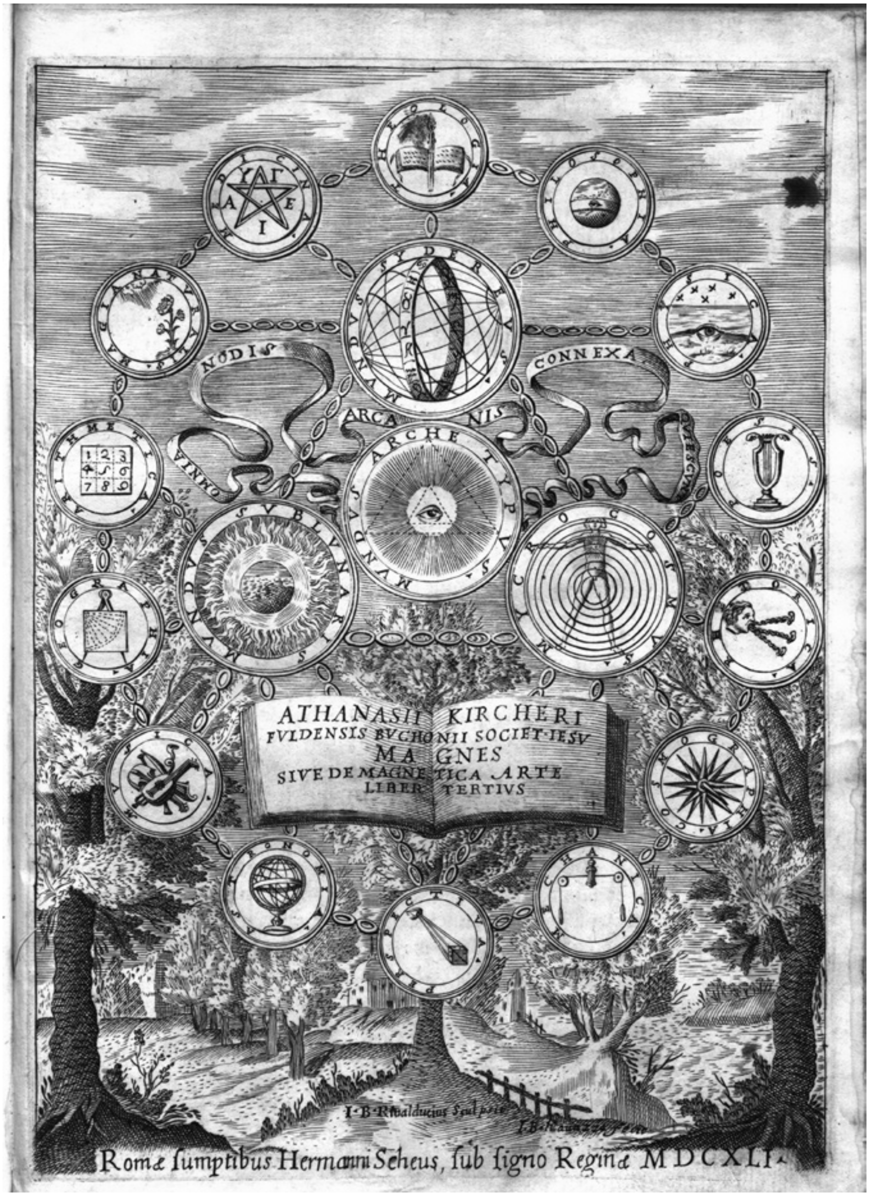

Fig. 2 Frontispiece from Athanasius Kircher's *Magnes sive de arte magnetica opus tripartitum* (1641). Courtesy of the Department of Special Collections, Stanford University Libraries, RBC QC751 K58 1641.

Fig. 3 Frontispiece from Athanasius Kircher's *Magneticum Naturae Regnum* (1667). Courtesy of the Department of Special Collections, Stanford University Libraries, RBC Q155 K58 1667 t.

developed the theory of magnetic lines of force and established the foundation of field theory.[22] According to Thomas K. Simpson, the diagrams accompanying Maxwell's theoretical work on electromagnetism were "figures of thought," which provided effective mathematical and physical analogies for the elusive nature of the field.[23]

Gooding and Simpson have examined these diagrams as they appear within the confines of Faraday's and Maxwell's works. Their close readings do not attend to their relation to the wider visual and cultural context that informed them. Beyond its caption, the meaning of a diagram depends on older and more familiar iconography that shapes the context of its perception, providing a recognizable background on which its author can highlight the contribution he is making. The visual trope of the magnetic chain offers such familiar background and helps clarify the conceptual innovations expressed by some of Faraday's and Maxwell's diagrams. Before turning to these visual representations of electromagnetism and metonymic contiguity, I will describe in more detail the groundbreaking line of thought that they helped formalize.

In the 1850s, following years of meticulous experimentation, Faraday became confident that "magnetic curves," or what he renamed "lines of force," provided an effective physical model to measure and conceptualize the nature of electromagnetic phenomena. He observed that magnetic force exerts its power along curved lines of force that could be rendered visible through the patterns produced by iron filings near a magnet (fig. 4).

The lines of force clearly extend beyond the actual magnet, providing a way to visualize the medium responsible for the propagation of action through space. Faraday thought them mathematically useful because the trajectory they followed between magnetic poles represented the direction of the force at any given point in space. They also provide an effective way to calculate the magnitude of the force. As the patterns of iron filings show, lines of force are closer together near a magnetic pole, where the force is stronger, than further away from it. The different concentration of lines of force allows the measurement of the force's magnitude anywhere in the magnetic sphere of action.[24]

Faraday thought that his idea of lines of force could provide an alternative to Newtonian action at a distance. Although Newton himself did not believe that gravity could operate in a vacuum, his law of gravitational attraction ($F = Gm1m2/r^2$) implied that its action took place between two masses (m1 and m2) instantaneously through space as if without mediation.[25] Space remains unaltered or absolute in Newtonian action at a distance. Faraday believed lines of force around magnetic bodies modified the configuration of space around them and that such modifications are responsible for attraction, thereby laying the foundation of field theory.

The shift from action at a distance to magnetic lines of force provided a radically new theoretical framework that played a crucial role in uncovering the general principles of puzzling phenomena such as the induction of an electrical current by a magnet in motion. In 1852 Faraday synthesized most of his findings concerning such electromagnetic interaction in a diagram that became one of the starting points of Maxwell's mathematical theory of electromagnetism (fig. 5).[26] This image represents the interconnection of electric and magnetic action. Faraday schematizes this quantitative relation in terms

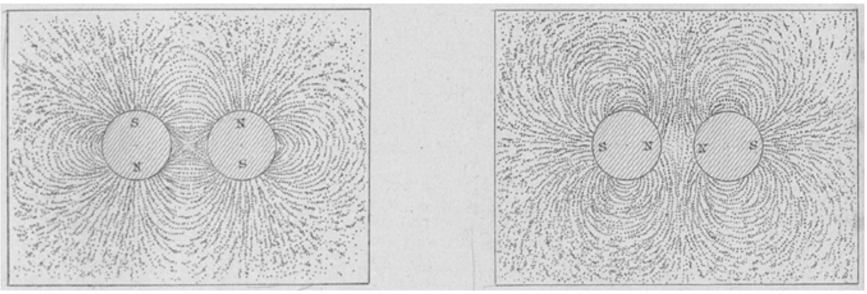

Fig. 4 Lines of magnetic force diagrams from Faraday's *Experimental Researches in Electricity, Volume 3* (London: R. and J. E. Taylor, 1855), plate IV (detail). Library of Congress, Washington, DC.

of two rings representing electricity (E) and magnetism (M), respectively. The invisible link responsible for this equivalence takes the form of a traditional chain of two interlocking rings. Yet the rings are not phenomenologically the same thing, and their interaction does not derive from a simple mechanical exertion of one ring against the other. It derives from a relation of contiguity. Like the Platonic magnetic chain, their invisible link is represented by a gap, which recalls Kircher's contiguous rings but in this case is much wider. This larger degree of separation visually accentuates the metonymic nature of electromagnetic interaction.

In the 1860s, Faraday's idea of lines of force led Maxwell to synthesize and cast into a set of related equations everything known at the time about electromagnetism.[27] Today the laws of electromagnetism are referred to as "Maxwell's equations," a slightly modified version of his original work.[28] Beyond grand synthesis, Maxwell also predicted from his equations the existence of radio waves. He showed that covarying and mutually inducing electric and magnetic fields exhibited over time a wavelike pattern that could self-propagate in free space. In 1888 Heinrich Hertz announced that he had detected the existence of radio waves, thereby validating Maxwell's self-propagating electromagnetic wave theory. The discovery of self-propagating electromagnetic waves ushered in the age of wireless telecommunication and the revolutionary impact that radio, television, and cell phone would have on the twentieth century.

Maxwell's electromagnetic laws also led to the unification of optics and electromagnetism. He calculated the speed of his theoretical self-propagating electromagnetic wave and found that it was nearly the same as the speed of light. At the time, physicists envisioned light as a wavelike disturbance or vibration

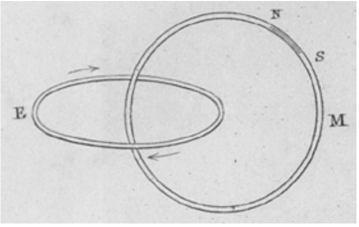

Fig. 5 Diagram from Faraday's *Experimental Researches in Electricity, Volume 3* (London: R. and J. E. Taylor, 1855), plate IV (detail). Library of Congress, Washington, DC.

transmitted through its own ubiquitous medium called the "luminiferous ether." From these striking similarities, and a known link between light and magnetism uncovered by Faraday ("magneto-optic rotation," or the "Faraday effect"), Maxwell inferred that the luminiferous ether was in fact the electromagnetic medium and that light was a type of electromagnetic wave.[29] Phenomena associated with light such as infrared (heat) and ultraviolet radiation also turned out to be electromagnetic waves. Furthermore, detection of radio waves by Hertz foreshadowed the discovery of other types of electromagnetic radiation such as X-rays in 1895 and uranium's radioactivity in 1896. By the end of the nineteenth century, Maxwell's electromagnetic theory of light had become widely accepted, and scientists agreed that wide-ranging phenomena such as radio waves, heat, visible light, ultraviolet, X-rays, and radioactivity shared the same electromagnetic fabric. Their distinct behavior derives from their different wavelengths.

In one of the most groundbreaking and influential diagrams of nineteenth-century theoretical physics (fig. 6), Maxwell conveys the wavelike pattern of mutually inducing electric and magnetic fields and its similarity to light.[30] He depicts this pattern through related electric and magnetic fluctuations occurring on separate perpendicular planes. The planes are contiguous, coming into contact along an axis that marks their separation as well as connection. The vertical orientation of the diagram and the ringlike shapes of electric and magnetic parabolas recall Kircher's magnetic chains descending from the heavens. Electromagnetism is now a self-propagating chain, where the metonymic power holding it together does not come from a divine source anymore. It derives from Maxwell's sophisticated equations and the way they establish links between the electric and magnetic domains through quantitative relation.

In Faraday's and Maxwell's diagrams the Platonic model of the magnetic chain has become an electromagnetic motor. Instead of a divine lodestone, concatenation and metonymic connection result from a physical interaction between electricity and magnetism. This interaction hinges on a newly found

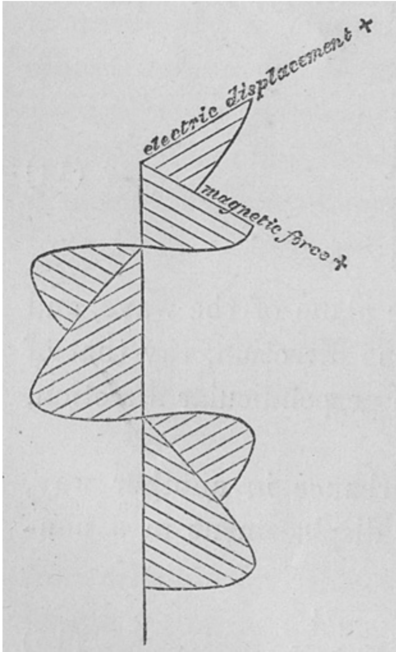

Fig. 6 Diagram from Maxwell's *A Treatise on Electricity and Magnetism*, vol. 2 (Oxford: Clarendon Press, 1873), 390. Library of Congress, Washington, DC.

electromagnetic difference and relation that helped nineteenth-century scientific thinking move beyond divine and Newtonian frameworks.

(Electro-)Magnetism

The depiction of electromagnetism as a chain shows not only the emergence of a new way to express metonymic contiguity but also its close association with previous magnetic models and their visual representation. Yet the legacy of magnetism in the rise of electromagnetic thinking has been overshadowed by many recent critical studies of electricity. Throughout this book, I shift the focus from electricity to electromagnetism by paying closer attention to the less familiar pole of the "electric age"—magnetism.

Graeme Gooday situates the turning point in the omission of magnetism at the influential 1881 International Exposition of Electricity in Paris. Publicists adopted the more convenient but less precise term "electrical" to describe the electromagnetic technologies that were transforming the world.[31] Compared to magnetism, electricity was a relative newcomer to science. It became prominent during the eighteenth century due to Benjamin Franklin's lightning experiment and the inventions of the Leyden jar and voltaic pile.[32] Magnetic properties have been well known since antiquity. Furthermore, the arrival of the magnetic compass in Europe during the Middle Ages had a profound impact on history.[33] By 1620, Francis Bacon famously listed it along with the printing press and gunpowder as the three main discoveries responsible for the making of the modern world.[34]

Magnets have been popular models for exploring and representing various types of motors or unmoved movers of divine or human origin. Before Plato described poetic "enthusiasm" and mimesis as magnetic, the pre-Socratic philosopher Thales of Miletus had already relied on the lodestone to describe the nature of the soul. Another fundamental property of magnetism known since the thirteenth century, bipolarity, provided the impetus to make sense of puzzling polarities such as attraction and repulsion, love and hate, and mind and matter. Faraday saw in magnetic "lines of force" a radical new model to rethink the nature of gravitational as well as electrical interactions, paving the way for Maxwell's and Einstein's elaboration of field theory. As a tool for conceptual exploration and innovation, magnetic analogies illuminate the cultural and epistemological origins of the electromagnetic age.

Consequently, I attend closely to the transition from magnetic to electromagnetic models. Early electromagnetic analogies often represented various metonymic relations traditionally described through categories of magnetization and magnetic bipolarity. For many writers and philosophers, magnetic phenomena helped explore other transformative powers and explained how opposites could attract or be intimately related. Examining the transition from magnetic to electromagnetic concepts and tropes provides an effective way to contextualize what was at stake when Oersted's and Faraday's discoveries began to reorder the world in the lab and beyond.

Transformational Motors and Romantic Machines

Faraday's and Maxwell's diagrams represent a metonymic power generating motion that derives not from a divine source but from an electromagnetic interaction. Through their mutual induction, electricity and magnetism move things. In a dynamo, the transformation of motion into an electric current is reversible. This current can activate magnetic objects, such as the engine of a streetcar. This new way to produce motion participates in the rise of what Michel Serres calls "transformational motors" and associates with the invention of the steam engine. This new type of machine changed not only the world but also how we understand it.[35]

Along with transformational motors came a redefinition of the origin of motion that played a fundamental role in the epistemological shift characterizing nineteenth-century cultural and scientific production. From Aristotle's "unmoved mover" to the neoclassic period, the ultimate cause of all motion in the universe remained purely metaphysical. Ancient motors such as a spring or a water mill relayed the motive force provided by human, animal, or natural actions, which themselves worked as relays of the primordial motor. The steam engine did not simply transport and transmit movement; it appeared to generate its own motive force by transforming heat into mechanical work. This remarkable motor turned age-old metaphysical inquiries concerning the origin of movement into a physical problem. In 1824 the founder of thermodynamics, Sadi Carnot, began to provide a scientific explanation to this problem when he demonstrated that the motive force of the steam engine depended on a temperature difference between hot and cold sources—namely, between the furnace and the condenser.[36] Carnot claimed a temperature difference displaces the metaphysical motor as the source of movement.

Beyond mines, factories, and locomotives, the steam engine embodied a shift from the metaphysical to the secular production of motion transpiring concurrently in the sciences, arts, and humanities. Serres has traced how influential figures such as Hegel, Turner, Darwin, Marx, Zola, Nietzsche, and Freud attempt to seize the means of production of their respective subject matters by displacing metaphysical intervention with the generative power of difference. Their wide-ranging works not only rely on analogies inspired by the steam engine; they themselves function as transformational motors.

Literary scholars such as Bruce Clarke, Barri Gold, and Sydney Lévy have also relied on the steam engine and thermodynamics as their main guide to examine the relation between artistic and scientific changes that occurred during the early period of industrialization.[37] Yet the attention commanded by the steam engine has overshadowed the importance and impact of other transformational motors, such as electromagnetism. This book argues that the electromagnetic motor powered the next and insufficiently understood cycle of the industrial revolution and much of its significant cultural production.[38]

It unveiled a new kind of difference—rendered manifest by the metonymic relation between electricity and magnetism—that became, like the temperature difference in the steam engine, another key source of engineered movement. By the mid-nineteenth century, electromagnetic difference was transforming the world through its implementation in the telegraph and, by the end of the century, through dynamos and power plants that brought forth the first wave of mass electrification.

One of the main challenges in better understanding the transformational power of electromagnetic difference consists in recovering the points of intersection among wide-ranging disciplines and practices where its influence initially spread and thrived. Situated at the interstices of literature and science, these points of convergence generate a fresh perspective on how electromagnetic difference became one of the main transformational motors that changed the world as it empowered analogical methods based on relations of contiguity.

Electromagnetism can be understood as one of the transformational motors that John Tresch has recently called "Romantic machines."[39] The steam engine and the electromagnetic motor are Romantic machines because they could symbolize Romantic as well as mechanical interpretations of the world. Although the two perspectives have traditionally been depicted as incompatible, they shared essential characteristics. As motors of industrialization, they advanced the mechanization of society and the power of clockwork rationalism. As volatile and seemingly self-propelled machines based on striking conversion processes, they also embodied prominent ideas of Romanticism: organicism, metamorphosis, and the unity of natural forces, reason and imagination, and mind and nature.

Romantic machines provided a common ground for mechanical and Romantic aspirations where new conceptions of knowledge production that Tresch broadly labels "mechanical Romanticism" flourished. The hybrid epistemologies of mechanical Romanticism contrasted with the enlightenment ideal of detached objectivity by emphasizing the interdependence of the perceiving subject and the perceived object in the establishment of facts and truths. Influential mechanical Romantics such as Saint-Simon, François Arago, and Auguste Comte produced theories of knowledge that unified scientific, artistic, and spiritual domains in concerted efforts to achieve social and political transformations.

Tresch traces the rise and fall of mechanical Romanticism during the first half of the nineteenth century in Paris. Unlike the exponential specialization and fragmentation of knowledge production that followed in its wake, mechanical Romanticism thrived on interactions among artists, scientists, philosophers, and social and political reformers. The development of realist and fantastic literature, thermodynamics, electromagnetism, socialism, and ecology are some of the wide-ranging yet related outcomes that resulted from such interactions.

Whereas the steam engine has all but disappeared from contemporary life, electromagnetic machines remain ubiquitous and will continue to shape our behavior and the environment for a long time to come. Tresch concentrates on only one case study involving electromagnetism, the work and life of André-Marie Ampère, the other great pioneer of electromagnetic science. Ampère built electromagnetic machines that, soon after Oersted's discovery, helped mathematically prove the equivalence of the electric current and magnetism and establish the principles of electrodynamics. Ampère's achievements were an important influence on Faraday and Maxwell, and the latter famously characterized his French predecessor as the "Newton of electricity."[40] As Tresch shows, Ampère was not simply a mechanical thinker. His breakthrough investigation of electromagnetism was integral to his larger Romantic interests, which included open-ended scientific methods, how the mind interacts with the material world, the unity of natural forces and knowledge, and "animal magnetism."

The present book is entirely dedicated to electromagnetism. It focuses on how its discovery contributed to the development of Romantic machines and helped materialize and legitimize metonymic reasoning. It is structured around three types of apparatuses powered by electromagnetism: chains, the lab experiment Faraday used to unveil the phenomenon of induction, and automata. In the first part, I trace the emergence of a metonymic shift in early nineteenth-century conceptions of interconnection through the apparition of electromagnetic chains in Poe's oeuvre. From his mesmeric to detective tales, Poe relies on the relation of contiguity these chains rendered manifest to undermine traditional interpretations of the great chain of being and its ordering of things based on metaphoric gradation.

These electromagnetic chains provide empirical support for his nonlinear and ironic vision of physical and metaphysical interconnections by drawing extensively on popular theories concerning animal magnetism. These theories attempted to make sense of "magnetic" somnambulists and their strange states of dissociation. Their split-selves unveiled relations of contiguity within the mind that, many believed, were linked to death, haunting, and mourning. I show that Poe accentuates the contiguous nature of these phenomena by not simply relying on the older mesmeric idea of a magnetic fluid that connects bodies through space and time. Instead, he drew inspiration from newer views that had incorporated some of the metonymic implications of Oersted, Ampère, and Faraday's discoveries and that I call "animal electromagnetism."

In the second part, I contend that Balzac pioneered the literary exploration of animal electromagnetism and its metonymic thinking. Anticipating Valéry's dynamo thought experiment, he found in Faraday's induction apparatus a new model to represent relations of contiguity, which he initially invoked to cast inductive reasoning under a new light. His reinterpretation of the method most closely associated with scientific thinking sharply contrasted with the myth of the detached scientist. His rapprochement of electromagnetic and scientific inductions conveys a process of discovery where metonymic reasoning and the body play integral roles.

I also show how his references to electromagnetism inform the realist framework of his novel and enable him to conceive an alternative understanding of space and time intimately related to Einstein's later redefinition of the spatiotemporal fabric of the universe. Although these two luminaries produced completely different works, their respective theories were the products of a similar engagement with the relation of contiguity unveiled by Faraday's induction experiment. Faraday's new, transformational motor rendered manifest a puzzling relation and difference between electricity and magnetism that both Balzac and Einstein mobilized as an engine of conceptual exploration and innovation that, I argue, has been subsequently overshadowed by the rise to prominence of field theory.

The groundbreaking model of electromagnetic contiguity that emerges in Balzac's and Poe's writings is less known because other analogies inspired by the telegraph, telephone, and dynamo quickly became more popular during the time separating their works from Einstein's. Yet during the second half of the nineteenth century, this model continued to be influential through hybrid analogies where electromagnetic interaction and the new technologies it made possible appeared together. In chapter 3, I examine some of the legacies of these hybrid analogies through the remarkable account of an electromagnetic automaton in Villiers de L'Isle-Adam's *L'Ève future* (*Tomorrow's Eve*, 1878–86). This complex novel has been considered by critics and historians to be an important contribution to the philosophical tradition of conceptualizing the nature of life and cognition in terms of self-moving machines. To reach a better grasp of how Villiers's automaton signals epistemological changes concerning these perennial notions, I argue that it needs to be resituated within its (electro-) magnetic context.

The way this automaton derives its power from electromagnetic induction instead of a spring or steam engine is significant. It participates in an older and influential line of thought that culminated in *Naturphilosophie* and that had relied on self-moving machines propelled by magnetic bipolarity (such as the compass) to identify what made the universe move. For Schelling and Goethe, "Nature" was a mysterious, Romantic machine where conflicting elements such as life and death or mind and matter shared a relation of contiguity, which became intelligible through analogy with the opposite yet related poles of a magnet. In Villiers's automaton, the poles now establishing this relation of contiguity were electricity and magnetism. Through their interaction, they provided the conceptual motor that allowed the novel to explore the metonymic nature of life and cognition and that anticipated the invention of the unconscious.

I conclude with an extended discussion where I connect Balzac's and Poe's trailblazing use of electromagnetic contiguity with the broader explosion of metonymic reasoning that marked the first half of the twentieth century. I focus on the theoretical writings of philosopher Gaston Bachelard and writer Julien Gracq. Bachelard knew about the instrumental role Faraday's induction experiment played in Einstein's discovery, and he employed its metonymic dimension to elaborate his seminal idea of "epistemological break" and its nonlinear conception of the history of science. Although his philosophical and literary works have often been criticized for their lack of correspondence, the role of electromagnetic induction in Bachelard's oeuvre shows that it was a unifying concept that helped him represent the rise of a "new spirit" in literature as well as science.

Building upon Bachelard's literary theory, Julien Gracq wrote an important yet understudied essay on André Breton where he inaugurated the critical exploration of the *electromagnetic* imagination. For Gracq, electromagnetic induction lent its coherence to the avant-garde aesthetics of surrealism because it sprung from practices like automatic writing, where chance encounter through association based on contiguity played a defining role. I provide translations and close readings of key passages in the essay to show how, much like Poe and Balzac before him, Gracq mobilized electromagnetic induction to conceive of a mode of metonymic communication that, unlike the mere duplication of experience found in mimetic poetry, could overcome the constraints of linguistic mediation.