Metaphorical Uses of an Electric Power Network: Early Computations of Atomic Particles and Nuclear Reactors

Aristotle Tympas, Athens (tympas@phs.uoa.gr)

Dina Dalouka, Athens (kdalouka@phs.uoa.gr)

Abstract

To retrieve the constitutional importance of metaphors, analogies, and models in scientific computations of the immediate post-World War II period, we shall investigate the uses of an understudied artifact known as the 'network analyzer'. As an electrical model of an electric power network, it was introduced during the interwar period as the best option to compute the complex environment produced by lengthening and interconnecting electric power transmission lines. Now considered an exemplar of the devaluated analog computer, ostensibly limited by being a special purpose machine, the network analyzer was used for many purposes beyond electric power transmission computations, including that of science-related computations. We shall consider the suggestive case of its use in computing atomic particles and nuclear reactions, based on the metaphoric consideration of both as analogous to an electric power network.[1]

Um die Wichtigkeit von Metaphern, Analogien und Modellen bei der Konstitution wissenschaftlicher Berechnungen in der Phase nach dem Zweiten Weltkrieg rückblickend deutlich zu machen, untersucht dieser Beitrag den Gebrauch eines wenig untersuchten Artefakts, des ‚Network Analyzers'. Jenes elektrische Modell eines Elektrizitätsnetzwerks wurde in der Zwischenkriegszeit als beste Möglichkeit zur Berechnung der komplexen Umgebung eingeführt, die durch Verlängerung und Zuwachs von Zwischenverbindungen von Elektroleitungen entstanden war. Der Network Analyzer gilt heute als ein Exemplar des überholten analogen Computers. Doch nur scheinbar war er auf eine einzige Funktion eingeschränkt, wurde er doch nicht nur zur Berechnung von Elektrizitätsübertragung eingesetzt, sondern auch für zahlreiche andere Zwecke, einschließlich wissenschaftlicher Berechnungen. Dieser Artikel fokussiert seine Verwendung bei der Berechnung von atomaren Teilchen und Kernreaktionen. Dabei werden jene durch die verwendete Metaphorik als analog zu einem Elektrizitätsnetzwerk konzeptualisiert.

1. Introduction

A wealth of studies by philosophers of science, historians of science, Science and Technology Studies (STS) scholars, cognitive scientists, and linguists (es-

[1] Acknowledgments: This article is based on material that was located while Aristotle Tympas was conducting research supported by fellowships from the IEEE History Center, the National Museum of American History at the Smithsonian Institution, the Hagley Museum and Library, and the Dibner Library.

pecially specialist in cognitive linguistics) have shown that metaphors, analogies and models (immaterial and material) are both central and indispensable to science. Yet the precise contribution of each of the three (metaphor, analogy and model), not to say their interrelationship, remains an open issue, in immediate contact to the issue concerning the very definition of the scientific as such. In her recent review of the scholarship on metaphors, analogies and models, Daniela Bailer-Jones, suggested that any advance in our understanding of them seems to require the cautious involvement of many disciplines (Bailer-Jones 2002: 110). This article seeks to make a modest contribution to such understanding of by adding a perspective from the history of technology.

In a companion text, we focused on a case of a diachronic transition of the flow of computing metaphors, analogies and models, from established to emerging technical configurations (Tympas 2007). In the text that follows, we shall focus on a sample from the synchronic flow of computing metaphors, analogies and models from what is technically explored to what is scientifically unfamiliar. The very presence on a technical-to-scientific metaphor, i.e., the origins of important scientific metaphors in historically specific technical configurations, is the basic observation of our article.

In a classic 1974 study, W. H. Leatherdale collected the preliminary observations from scholarship's attention to metaphors, analogies and models, and deduced that the concept of metaphor and the concept of model include within their sense the concept of analogy. Analogies and metaphors are frequently coupled together as integrated topics, and, sometimes, are even used interchangeably. The same holds in respect to the model-analogy relationship. Leatherdale considered it implicit that analogy is a more fundamental and simple concept than metaphor or model, since, for example, one talks of metaphor 'expressing and analogy' or 'being 'grounded on analogy, while, similarly, one writes that a model works 'by analogy' or exhibits an analogy with what it is a model of, or for (Leatherdale 1974: 1-2). Technological analogies, finds Peter Kroes, range from (vague) metaphors to structural analogies, which are based on mathematical similarities (Kroes 1989) (see, also, Sarlemijn / Kroes 1987). Bailer-Jones clarifies, however, that a metaphor may prompt the recognition of an analogy (Bailer-Jones 2002: 14). In our case, the electric power network metaphor prompted certain analogies and invited the use of the electric power network model, the network analyzer.

Unlike the older mechanical models discussed in the available historiography of technology on modeling, the network analyzer was an electrical model, more typical of a more recent technological era. Moreover, the discussion of these models makes no reference to the model, analogy and metaphor relationship. For a convincing treatment of both a model, and, also, at the other end of the spectrum, even the metaphor as a "material intervention" (Keller 2000: 77), we would rather point to Evelyn Fox Keller's detection of a "dramatic narrowing of the gap between computers and cells" (Keller 2000: 84), due to the interactive development of the metaphorical consideration of the cell as a computer and the computer as a material model of the cell. That Keller discusses more recent models, and especially models explicitly relevant to computation, makes her study all the more useful to our purposes.

In their study of a mechanical model used in economics, Mary S. Morgan and Marcel Boumans suggest that the move from a metaphor to a model requires certain commitments, a reduction of degrees of freedom (Morgan / Boumans 2004). In our story, we find such a reduction in Gabriel Kron's mid-1940s series of articles on atomic particles computations, which attached the electric power network metaphor to a specific model, the network analyzer. On the other hand, Kron's deployment of the same metaphor in the mid-1950s, in the context of nuclear reactor computations that were detached from the use of a network analyzer, suggests that a metaphor, because it represents a less specific commitment, may outlive the model. We have here, perhaps, one more manifestation of what N. Katherine Hayles, in her study of the metaphor that induced the emergence of Nobert Wiener's cybernetics, aptly calls 'the play of the metaphor' (Hayles 1990).

Metaphors are historically specific. In the interwar decades, electric power networks represented an unprecedented technical complexity. The complex entities and processes that emerged as central to the science of the immediate post-World War II period, most notably those associated with atomic and nuclear phenomena, were computed on the grounds of their metaphorical consideration as versions of an electric power network. The story that we shall tell in the following pages involves metaphorical uses of an electric power network, analogies between an electric power network and atomic-nuclear phenomena, and a model of an electric power network, an artifact known as 'network analyzer.' This is to say that it covers all the range, from the materiality of writing (metaphor) to the materiality of modeling (network analyzer).

2. Revisiting the historiography of computing

As we suggest in this section, the importance of metaphors, analogies and models in the early use of computers in science has been obscured, first, by the reproduction of the uncritical assumption that there can be a technical demarcation between a digital and an analog computer, second, the associated devaluation of the analog computer as inappropriate for science and generally inferior, and, third, the *a posteriori* projection of the post-1940s digital-analog demarcation and the evaluation that accompanies it to the previous history of computing. To defend this suggestion, we offer here a historical and a historiographical overview of the uses of the network analyzer.

In the following illustrations, we see, first, a General Electric network analyzer as actually used by the electrical engineers of the Virginia Public Service Co. in 1941, and, second, a Westinghouse network analyzer as sketched in a *Westinghouse Engineer* July 1944 editorial. According to the sketch, the network analyzer replaced batteries of desktop mechanical calculator. In year 1944, in various electrification-related uses, the network analyzer was found to be superior to desktop mechanical calculators. Later, due to abstract *a posteriori* comparisons, the network analyzer was devaluated as a representative of the analog computer, which was assumed to be technically inferior to the digital computer, of which the desktop mechanical calculator was the pre-electronic exemplar.

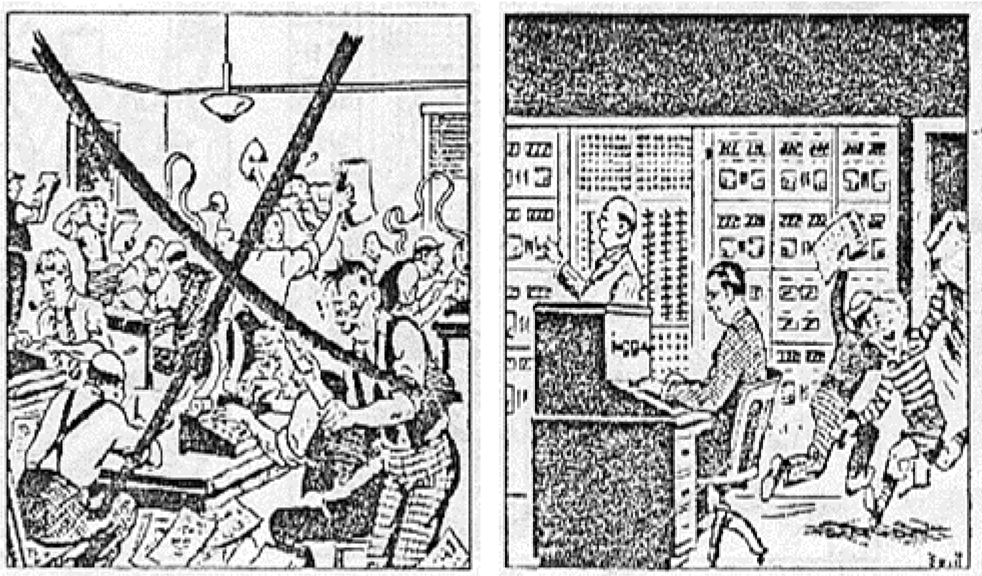

Plate 1: Network Calculator...Mathematician Par Excellence", Westinghouse Engineer Volume 4 (July 1944), front cover (editorial).

Plate 2: General Electric Archives, Schenectady, New York.

The lengthening and interconnecting of multiple electric power transmission lines during the interwar period resulted in networks that set a new standard of technical complexity. Computing the stability of these complex networks would have been impossible without the configuration of a whole new set of computing artifacts, including machines that could fill a big room, like the 'differential analyzer' and the network analyzer. As an electrical artifact, the network analyzer was designed especially for electric power network computations. By comparison, the differential analyzer, a mechanical artifact, appeared to be a machine that was less attached to a special use. Other historians have registered the use of the differential analyzer in scientific computations. In this article, we shall retrieve a sample from the use of the network analyzer in scientific computations. The celebrated Vannevar Bush, a professor of electrical engineering at the Massachusetts Institute of Technology (MIT) and top manager of the Manhattan project who became widely known by his influence in the formation of Science and Technology Policy as a distinct field, lead the effort to use the differential analyzer in scientific computations. The less well-known protagonist of the network analyzer in scientific computations was another electrical engineer, General Electric's Gabriel Kron (for details on the context of the emergence of analyzers, see Aspray 1993, Tympas 1996, Tympas 2001, Tympas 2003, Mindell 2004, Turkle 1984, Small 1993) (for how other engineers remembered Kron, see Alger 1969).

The network analyzer was initially a board (a table) with various resistances mounted upon it. To produce a computation these resistances were connected so as to form a miniature circuit, electrically equivalent to the large network under consideration. This is why it was called 'calculating board'. The network analyzer of the 1940s that we see in the above illustrations emerged from the interwar reconfiguration and reconceptualization of artifacts such as 'calculating boards' and 'artificial lines', which were used since the last decades of the nineteenth century. The artificial line was a laboratory miniature of a large electric line. For the same computing capital, one could choose between a calculating board, which could be flexibly used for computing more than one electric network, and an artificial line, which was less flexible but more accurate (Tympas 2001) (Tympas 2003).

This is how Kron and one of his colleagues, G. K. Carter, described the network analyzer in a 1946 article:

> "The alternating current network analyzer consists of a set of adjustable resistance, inductance, and capacitance units, each connected to a pair of flexible cords and plugs. Connections between units to form any desired network are made by inserting the plugs in adjacent jacks in a jack panel. As many units as desired can be connected to a common point. Alternating-current network electric power is supplied by a motor-generator set to individual generators so that several different voltages, independently adjustable, can be inserted into different parts of the network. A centrally located set of measuring instruments can be connected to any unit by means of a set of key switches" (Kron / Carter 1946: 32).

The network analyzer was used in innumerable contexts, in several engineering disciplines beyond electrical engineering, and in scientific disciplines that ranged from the most theoretical to the most concrete. Entities and processes, real and fictional, ranging from a water distribution network to a sub-atomic event, have been computed as being analogous to an electric power network. A review of network analyzer uses was offered in 1945 in the *General Electric Review* by H. A. Peterson and C. Concordia, both at the Central Station Engineering Division of the General Electric Company, who entitled their article "Analyzers…For Use in Engineering and Scientific Problems." They gave a sample of 62 relevant references and listed many uses under the four class of analyzers reviewed: the 'direct current network analyzer', the 'alternating current network analyzer', the 'transient network analyzer', and the 'differential analyzer' (Peterson / Concordia 1945).

From a history of science perspective, the history of computing with a network analyzer can be studied from an angle that involves not only the history of uses of the network analyzer in scientific computations, beyond its initial use for the computation of an electric power network, but also, the history of the science involved in computing an electric power network with a network analyzer[2]. For example, the history of what turned out to be called 'computer science' owes much more than usually assumed to the tradition of computing with calculating boards, artificial lines, and network analyzers, by advancing certain versions of mathematical science in general and of the calculus in particular (Tympas 2001).

The differential analyzer, another kind of analyzer, was also developed during the interwar period to compute initially the electric transmission of power. Among analyzers, it is the best researched historiographically (Owens 1986) (Owens 1996). From a synchronic comparison, the differential analyzer appeared to be more explicitly mathematical than the network analyzer. When a differential analyzer was used, the analogy employed was, relatively speaking, more mathematical than physical (for an interwar classification of analyzers, see Fry 1941). The engineering community had proposed the use of the differential analyzer for something as important as the solution of the Thomas-Fermi equation, from as early as in 1931 (Bush / Cardwell 1931).

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[2] For a historiographical update on the history of computer science that mentions some electrical engineering contributions to computer science, see Mahoney 2002.

If the use of the differential analyzer in scientific computations is understudied, the use of the network analyzer in scientific computations is practically absent from the available historiography of scientific computations.[3] Yet, the network analyzer too was used in important scientific computations. Before we turn our attention to details of this use, we want to clarify that it would be incorrect to reproduce the canonical emphasis on impressive state-of-the art machinery (at the expense of all other computing artifacts) in the study of the analog computer use in scientific computations. The artifacts actually employed in such computations varied greatly, ranging from something simplistic as a humble graph, which was based on a low constant to variable capital computing ratio, to something as impressive as the network analyzer, which exemplified computing by the highest constant to variable computing capital ratio. In between those two categories stood various other classes of computing artifacts. Moreover, there was a hierarchy of sub-classes within the same class of computing artifacts (Tympas 2001) (Tympas 2004) (Tympas 2005).

3. Atomic particles and nuclear reactors as electric power networks

In the mid-1940s, Kron published an important series of articles on the use of the network analyzer in key scientific contexts. Given that the network analyzer was, explicitly, an analog of an electric power network, Kron based this article series on the metaphorical consideration of atomic particles and other scientific entities as versions of an electric power network. His 1945 article on the network analyzer solution of the Schrödinger equation (Kron 1945a) was followed by an article entitled “A.C. network analyzer study of the Schrödinger equation,” the co-author of which was G. K. Carter (Kron / Carter 1945). This two-article set was the crown piece of a cluster of mid-1940s articles that caught up with reporting late interwar and war-period work on scientific computations at General Electric.

[3] For pioneering studies of the history of science-related computations, see: (Seidel 1986) (Medwick 1988) (Aspray 1989) (Wolfe 1989) (Curtiss 1989) (Nash 1990) (Kidwell 1990) (McKenzie 1991) (Croarken 1990) (Cortada 1993) (Bolcher 1994) (Nebeker 1995) (Akera 1996) (Brenner 1996) (Seidel 1996a) (Seidel 1996b)(Grier 1997) (Grier 1998) (Seidel 1998) (Grier 2000) (Croarken 2000) (Yost 2002).

Over a period of few months, several of Kron's articles were accepted for publication in a whole spectrum of scientific and engineering journals.[4] It appears that the network analyzer that Kron had used was the most advanced version of an interwar one. It was described in a 1938 *AIEE Transactions* article by H. P. Kuehni and R. G. Lorraine, which was also the only article that Kron referred to in his mid-1940s articles for a detailed description of the machine that he was talking about (Kuehni / Lorraine, 1938).

The emergence of the digital-analog technical demarcation in the following decade, and the associated establishment of the digital computer as technically superior to the analog one, came along the assumption that computing analogies ought to become unnecessary. Reading Kron clarifies that this was not the case. As accumulation of knowledge about the science of atomic particles allowed for a developed interest in the science of nuclear reactions, Kron moved on to discuss metaphorically the nuclear reactor as one more version of an electric power network. "No one can deny," he wrote in a July 1954 article in the *AIEE* Transactions "that the sciences of waves and electronics both profited by concepts of the electric power engineer, namely, by the concepts of impedance, of equivalent circuit etc., after suitable generalizations, of course" (Kron 1954a: 259). In a section entitled "Nuclear Reactor as a Transmission System", Kron introduced to the metaphor and the analogy that he sought to promote by his article:

> "The electric circuit model of a reactor is analogous to an electric power transmission network and it gives a visual picture of several of the processes (greatly simplified) that take place in a reactor. Each generator (impressed junction current) represents a generation of neutrons by fission. The loads (impedance to ground) stand for the

[4] The following list of titles of Kron's publications is indicative: "Equivalent Circuits to represent the electro-magnetic field equations" (Kron 1943a), "Equivalent circuits for Oscillating Systems and the Rieman-Christoffel Curvature Tensor" (Kron 1943b), "Equivalent Circuit of the Magnetic Field Equations of Maxwell-I" (Kron 1944a), "Tensorial analysis and equivalent circuits of elastic structures" (Kron 1944b), "Network analyzer solution of the equivalent circuits for elastic structures" (Kron / Carter 1944), "Numerical and Network Analyzer Solutions of the Equivalent Circuit for the Elastic Field" (Kron 1944c), "Numerical Solution of Ordinary and Differential Equations by Means of Equivalent Circuits" (Kron 1945b), "Equivalent Circuits of Compressible and Incompressible Flow Fields" (Kron 1945c), "Numerical and Network-Analyzer Tests of an Equivalent Circuit for Compressible Fluid Flow" (Kron 1945d), "Electric Circuit Models for the Vibration Spectrum of Polyatomic Molecules" (Kron 1946), and "Network Analyzer Tests of Equivalent Circuits of Vibrating Polyatomic Molecules" (Kron / Karter 1946).

> absorption of neutrons by the material in the reactor, while the flow of electric current along the transmission network itself represents the diffusion of neutrons (the neutron current) from point to point within the reactor. The absolute potential at every junction is equal to the neutrons of some particular energy appearing at that point of space" (Kron 1954a: 259-260).

In this paper, Kron described a project conducted for the Knoll Atomic Power Laboratory, which General Electric operated for the U.S. Atomic Power Commission, Contract No. *W-31-109, Eng. 52*. The project was part of a general program that was contracted by the Nuclear Engineering Unit of the Laboratory (Kron 1954a: 259). "As the first large-scale industrial application of nuclear energy appears to be at present the generation of electric power," explained Kron, "the electric power engineer is again being pressed by circumstances outside his control to get acquainted with a new physical science, namely, nucleonics and quantum mechanics."

An excellent engineer of technical analogies, Kron was, spontaneously, an engineer of historical analogies. "Three decades ago," he elaborated, "a similar situation confronted the electric power engineer when the arrival of radio forced him to study electronics and electromagnetic wave theory" (Kron 1954a: 259). Going from the past to the future, Kron concluded his introductory sub-section on "Electric Power Engineers and Electronics" by stating that "[t]here is every reason to believe that in the coming coalition between the electric power engineer and nuclear engineer the latter will also profit by his contact with the power engineer and his basic concepts" (Kron 1954a: 259).

4. Computing analogy, accuracy and visualization

From a historiographical viewpoint, there is much more at stake than simply adding the history of scientific computations based on the network analyzer to the histories of scientific computations based on the digital computer. We may try to indicate why by focusing on the writings of Kron and other electrical engineers. Reading Kron's 1945 article on the computation of the Schrödinger equation leaves no doubt about his opinion concerning the accuracy of using a network analyzer in scientific calculations:

> "Equivalent circuits are developed to represent the Schrödinger amplitude equation for one, two and three independent variables in orthogonal

curvilinear systems. The networks allow the assumption of any arbitrary potential energy and may be solved, within any degree of accuracy, either by an a.c. network analyzer, or by numerical and analytical circuit methods. It is shown that by varying the impressed frequency on a network of inductors and capacitors (or by keeping the frequency constant and varying the capacitors), it is possible to find by measurements the eigenvalues, eigenfunctions, and the statistical mean of various operators belonging to the system represented. The electrical model may, of course, be replaced by an analogous mechanical model containing moving masses and springs. At first the network for the one-dimensional wave equation for a single particle in Cartesian coordinates is developed in detail, then the general case. A companion paper contains results of a study made on an a.c. network analyzer for one-dimensional problems: a potential well, a double barrier, the harmonic oscillator, and the rigid rotator. The curves show good agreement, within the accuracy of the instruments, with the known eigenvalues, eigenfunctions, and 'tunnel' effects" (Kron 1945a: 39).

In the articles that he published in The *Journal of Chemical Physics* a decade earlier (1946), on computing vibrating circuits of polyatomic molecules, Kron devoted a section to details on why the network analyzer could provide with a better model and analogy than the older mechanical models and analogies. He concluded this section by stating that "[i]n the absence of a network analyzer, the electric circuits may be solved numerically by hand or by punch-card methods" (Kron 1946: 20), thereby implying that the network analyzer method was generally preferable but, given the small number of network analyzers around (next to punched-card installations), not as available. In the abstract of the one of the two papers, he had introduced to the analyzer measurements as agreeing "satisfactorily" with the "normal characteristics" (Kron / Carter 1946: 32).

The 'numerical' did not (as late as) in 1945 correspond to what would turned out to be called 'digital.' In the articles that he published in The *Journal for the Aeronautical Sciences* in 1945, Kron had also reported satisfactory results based on tests comparing the use of the alternating current network analyzer to that of the differential analyzer. In his "Numerical and Network-Analyzer Tests of an Equivalent Circuit for Compressible Fluid Flow", he explained that "[t]his procedure having shown the validity of the equivalent circuit, the network was set up on the a.c. network analyzer and was used to solve a whole field from given boundary conditions; the solution so obtained matches the differential analyzer solution of the same field and thus shows the feasibility of solving such field problems with network-analyzer equipment" (Kron 1945d:

232). In the absence of the analog-digital demarcation as late as in the early 1940s, the numerical was still just a class of what would subsequently be differentiated as the analog, it was not the opposite to the analog. To put it differently, the punched card methods (currently an exemplar of the digital during this period) were numerical and so was the differential analyzer (currently an exemplar of the analog during the same period).

But accuracy was not the only parameter that Kron took into account in recommending the use of the network analyzer as a scientific computer. Given a satisfactorily accurate computation, other parameters could come into play, most notably flexibility. "In comparison with either analytic or differential analyzer methods," he concluded in his 1945 article on computing compressible circuit flow, "the equivalent circuit gives the possibility of a much greater variety of solutions. This is a result of offering a field solution directly for any special boundary conditions, instead of having to resort to separation of variables, or series solutions, or other analytic devices" (Kron 1945d: 234).

Another advantage had to do with "visualization", to be achieved by choosing an analogy that was pertinent to the problem. "It is suggested that for visualization," he wrote in his companion article on the computations of compressible and incompressible fluid flow fields, "the equivalent circuits of an ordinary or partial differential equation should not be assumed to represent the conditions at selected discrete points of the field. Instead, the network quantities should be considered to represent line, surface, and volume integrals of field quantities related to infinitesimal blocks into which space is divided" (Kron 1945c: 221).

5. The persistence of a computing metaphor

In his 1954 paper, Kron offered his own balance sheet of the preceding decade. Between the mid-1940s and the mid-1950s, some of the methods relevant to nuclear computations became declassified. Kron explained that the methods presented in his mid-1940s articles were also of relevance to nuclear reactor computations, but that he had not been explicit about it because of initial classification restrictions. Kron moved on to clarify that the computing artifacts of the mid-1940s were not adequate for the computing needs of the mid-1950s.

As we saw above, in the mid-1940s he was pleased by the accuracy of the network analyzers. By the mid-1950s, "the inadequacy and inexactness of all existing d-c and a-c network analyzers" was a problem (Kron 1954a: 260).

For Kron, the mid-1940s network analyzers were dispensable by the mid-1950s but not the need for computing metaphor and analogy as the prerequisite of all computation. An analogy was for Kron the central process of 'coding'--as programming was then called, without which a digital computer would have been useless. He became explicit about this in another 1954 article entitled "A Method for Solving Very Large Physical Systems" published in the *IRE Proceedings*. In the article's summary, Kron compared the prestigious and new digital computer with something as unimpressive and old as the 'slide rule', a humble artifact that has been used massively for centuries, before it was reconceptualized as an exemplar of the analog computer (one could compute with a slide rule by sliding its scales so as to move from known to unknown values):

> "Physical systems with a very large number of variables (say with tens of thousands) may be solved with available digital computers by tearing the system apart into a large number of small subdivisions. After solving each subdivision separately, the partial solutions are interconnected by a set of transformations so as to obtain the exact solution of the original system. Among the many advantages of the tearing method is the reduction of the amount of original calculations to a small fraction of about 2 / n(square), where n is the number of subdivisions. Another advantage is the reduction of the number of nonzero elements in inverse matrices to a fraction smaller that 1 / (square root)n. The same labor savings appears also in smaller systems using slide rule calculations. This paper illustrates the solution of Maxwell two-dimensional field-equations by tearing their electric-circuit models apart into a convenient number of subdivisions" (Kron 1954b: 680).

Promoters of the digital computer won the war against their analog adversaries only to find out that the pressing need for proper computing analogy was perpetuated, to stand at the heart of the 'software crisis' (coding and programming became part of what we now call 'software'). The voluminous literature on 'analog computation', 'equivalents circuits' and 'simulation' that was produced from the 1940s to the 1970s offers a testimony to the under laboring needed before any digital computer would run (Karplus 1958) (Karplus / Soroka 1959). Interestingly, the engineering literature of this period even contains direct comparisons of the analog computer and the digital computer as they could be used in scientific computations (see, for example, Symon 1953). This, however, is a story that deserves its own paper.

6. Metaphor, analogy and model: The Order of the Imaginary

The flow of the metaphor in Kron's articles was from engineering to what was then called 'field problems'. In his 1958 textbook on analog computation and simulation, one of the many similar engineering treatises of this period, Walter Karplus, an electrical engineering professor at the University of California, Los Angeles (UCLA), included Kron's 1954 article in a list of five others that he selected for a sample of literature on "Nuclear Reactor" field problems (Karplus 1958: 426). Field problems could be scientific; they could not be "purely scientific". Noticeably, even though Karplus presented a selected sample of hundreds of references on "the application of analog-simulation systems to field problems arising in important areas of engineering," he employed a classification scheme that organized the papers "according to the scientific field to which they pertain" (Karplus 1958: 405). In the introduction to his book, he had touched on a similar concept, by introducing to the important distinction between scientific and engineering analysis while carefully restricting the distinction only in respect to the pure scientist and the engineer. Noticeably, Karplus assumed that the scientist too was engaged in field problems, only from a different starting point:

> "The pure scientist is impelled to find complete descriptions of physical phenomena. In the case of a field problem, he considers the problem solved only if he has determined the exact system behavior at all points in the field for all time. When an engineer attacks the problem, on the other hand, he always has a specific objective in mind (which can probably be translated into dollars and cents). The engineer may ask, in the case of a heat-transfer problem: 'Where in the thermal conductor is the temperature a maximum? Where is the thermal gradient the largest? What is the temperature along a certain boundary? How long does it take for the conductor to cool to a certain temperature? etc.' He does not ask: 'What is the temperature in the conductor at all points and at all times?' It is, rather, to obtain specific answers within a specified accuracy at a minimum cost in time, labor, and equipment" (Karplus 1958: 405).

In our view, the engineer, who starts from what the French analyst Jacques Lacan has called the order of the 'Real', meets the scientist, who starts from the 'Symbolic', in the order of the 'Imaginary', the order of the computing metaphor, analogy and modeling. In the vocabulary of scholars from the field known as Science and Technology Studies (STS), this is the order of the 'cyborg' (Haraway 1991), the 'trading zone' (Galison 1997), the 'heterogeneous engineering' (Hughes 1987), etc. (for an elaboration on the correspondence between STS and psychoanalytic concepts, see Tympas 2001). The reference to Lacan (one could alternatively refer to Wittgenstein's conception of computing as a normative action) helps to point to computation as a normative process of production-transformation of nature by a certain division of labor between the scientist, who seeks an objective description of nature as it ought to be transformed, and the engineer, who takes this description into account in order to produce such transformation[5]. Their indispensable contact place in this division of labor is computation. Historians of scientific computations like Peter Galison have retrieved the normative nature of computation by starting from the scientific (see Galison and Stump 1996, and Galison 1997). In this paper, we wanted to advance this argument by a history that takes into account, also, a start from engineering.

Starting from science, the order of the Symbolic, have left us with a picture of post-World War II scientific computing as a self-referential exercise that was reinforced by the availability of a digital computer. This picture assumes that which needs to be questioned, namely the very demarcation between a computer that was 'analog' and a computer that could be non-analog, that is digital. As we understand it, the striking variants of self-referentiality that Peter Galison and other historians of science find in Monte Carlo and other scientific computations of the immediate post-World War II period was due to the prevalence of the shocking claim that there was finally a computer–the so called digital one-that eliminated the need for a computing analogy (Galison 1997). With this article, we wanted to suggest that things look different when we take into account the perspective of members of the engineering community who were explicit about the persistent need for computing metaphors, analogies and models.

[5] Sherry Turkle has successfully tried a Lacanian understanding of computation; Andrew Warwick a Wittgensteinian, see Turkle 1984, and Warwick 1994.

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