Working in the dark

Conference or Workshop Item

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Abstract *— Professional engineers work as experts who influence the work of others. They rarely have direct contact with the products of an enterprise. They work with analogues such as graphs, algorithms and simulations, and engage in discussions in specialized languages, which develop alongside the technological changes they promote or oppose. The engines of linguistic development are metaphors and analogies, however there is no system for creating them. Some metaphors and analogies become so familiar that they are treated as literal terms or literal explanations and become embedded in engineering language games. The field of electrical engineering offers hosts of examples. Students wishing to practice in engineering will need to become fluent in the language games of the profession. The haphazard evolution of language games offer students little help. As with acquisition of any language, repeated rehearsal is vital and practice in playing specialised language games is a primary part of engineering education.*

Index Terms *— Metaphor, Analogy, Language, Education*

INTRODUCTION

Arthur Miller, the playwright, recalled that his relations and neighbours often wanted to buy fruit with scarce cash, and 'since no one expected an unblemished apple or pear or cherry — a lot of feeling and calculating went on as to exactly how spoiled the innards would be'[1]. They wanted a way of predicting a future situation where they had bought some fruit and were sitting down to eat it. They hoped their scrutinising and calculating would tell them something about that future eating experience. Informed by their examination of the produce, the terms in their calculations became analogous to components of the situation where they had the fruit. Presumably, if their predictions forecast a satisfying experience, then they would make a purchase, but if calculations prophesised that their future eating experience would be unpleasant then they would not part with their money. And if they did not buy the fruit they would never know if their prediction was correct. Indeed it would not be a prediction but a speculation

Engineers are usually brought into contact with situations as experts rather than people who are directly and immediately involved. Rather than experiencing and coping with a situation the engineers work with descriptions and explanations, which are often speculations about what will befall others in the future. The situations that the engineers attempt to influence are commonly outside of their personal experience: the situation may be in the future; the engineers may not be members of the groups that will be affected by the engineers' proposals; the situation may be too extensive for anyone to experience (like the road system or the internet); it may be too small (like a nanotube or a transistor on a chip); it may last too long (like global warming); it may be invisible (like the radio spectrum). To position these abstract situations within the bounds of their own experience, engineers occasionally create analogues.

ANALOGUES

An advantage of many analogues is that they have properties that the analogous domain does not possess. For example, a scale model of a building is likely to be quicker, cheaper to construct and easier to move about than the building itself. And Vannevar Bush's electromechanical computer could quickly mimic the transients on extensive and costly electrical power networks even before they were built[2]. Numeric and algorithmic analogues clearly make predictions feasible since a numeric computation can often be carried out faster than the phenomena it reflects. On the other hand a software simulation of an electronic circuit can be run at speeds that a human designer can cope with, much slower than the operating speed of the proposed circuit. Traffic simulations can give the engineer a bird's eye view of a proposed traffic scheme, accelerated in time and without the expense of road modifications and potential chaos. Finite element analysis plots can masquerade as inaccessible electrical field patterns beneath the surface of silicon in microscopic electronic devices. Experiments can be carried out with prototypes before making a major investment in production machinery.

Graphs and diagrams form spatial analogues. A graph of temperature against time, for example, uses a displacement on paper or a screen as an analogue of temperature and a displacement across the page as an analogue of time. Although it would be impractical and nonsensical to attempt to store the temperature for twenty four hours, temperature over a twenty-four hour period could be displayed easily on a graph — a spatial analogue. The graph can be transferred to other locations and other times for examination in a way the temperature could not. Information, such as the area under the temperature graph, can be derived. An analogue is thus an artefact that can be manipulated and described but which finds a place in an atypical context. The graph of temperature, a picture on a piece of paper, might find a place in the maintenance of a power station boiler, for example, or an electronic amplifier might find a place in a discussion about a suspension system.

A crucial part of an engineer's work is in convincing other people in the engineering enterprise that the engineer's proposals are worthwhile and his or her explanations are sound. Analogues, as manipulable artefacts, can provide experiences, which cement speculations and buttress arguments that form a part of an engineer's case. If a model of an aeroplane flies, for example, it lends credence to the potential success of a full-scale version. If an arithmetic calculation of power dissipation in an integrated circuit generates results within a specific bound then the prospect of a future product overheating recedes.

Some analogues seem to be self-evident. Scale models, for example, have visible resemblance to the full-scale counterpart. Other analogues though are familiar only to specialists and novices require training before they can appreciate the analogue. A graph, a circuit diagram or a plan of a building, for instance, may be inaccessible to the uninitiated. An early use of the word analogue treated the humming bird as being analogous to the butterfly[3]. The analogue would have guided people who knew about butterflies but were ignorant about humming birds towards seeing how the humming bird might sip nectar; but while there may be some similarities, it is clear that in many respects the resemblance is poor, inadequate or misleading. Equally with engineering analogues it is not always obvious what similarities are being highlighted in the presentation of an analogue. In general, an analogue stands in for the thing it parallels in customary ways, and the person using the analogue needs to be familiar with its customary uses. In any case, if the analogue is used to make a particular point the analogue may not be enough and an additional commentary, that qualifies the use of the analogue, may be needed. A plan of a building for example, might be prepared for predicting the amount of concrete needed for constructing the floor. The plans — the analogue of the building — would then be a stimulus for discussion and calculation leading to the preparation of a bill of materials but may be quite unsuitable for energizing a conversation about positioning light fittings.

An analogue is an artefact that can provoke conversations that could convincingly be about something else even something that does not exist or cannot be seen. Thus the graph on a screen might provoke a conversation about the wear in a bearing, a scale model of a ship in a tank might stir a conversation about the power required to push a full-sized hull through the water, or the plan of a factory might trigger a conversation about evacuation of the factory in the face of an emergency. A conversation about an analogue is a conversation about two different things and this encourages a mixing of vocabulary. Filter designers will use the spatial analogue of a circuit diagram in place of arrangements of components and then describe common topologies by referring to the analogous shapes of letters of the alphabet and writing about H sections, O sections, C sections, L sections, T sections and π sections[4] Graphs are pictorial objects and discussions about them borrow vocabulary from other fields thus we talk of the 'slope' of a graph or its 'peak' as though it were a geographical feature at the same time as talking about the voltage or temperature, time or frequency displayed on the graph.

ANALOGIES

Analogues are non-verbal forms of analogy; they transpose verbal or non-verbal phenomena into another nonverbal domain but in doing so encourage a shift in vocabulary. Analogues, like the situation they represent, inspire conversation and it is frequently these conversations that carry the greatest significance in speculations about the future or the past. It is difficult to know, for example, when Heaviside wrote

> 'There is in great measure, a formal resemblance between the problem of a telephone circuit along which electromagnetic disturbances are being propagated, and the mechanical problem of the transverse motions of a stretched flexible cord.' [5]

whether he was describing a mechanical analogue that he had seen or was just employing an analogy. Since he was concerned with the formal relationship and all that remains is the text, it is the textual analogy, rather than any particular analogue, that matters to the reader.

An analogy is an analogue constructed from language and like other analogues it is set in unusual surroundings and can be manipulated. An analogy may be inspired by a material analogue, but it does not have to be. An analogy intermingles the vocabulary from two linguistic contexts to create a hybrid. For example, in describing the operation of an amplifier an author alternately writes about sawing and amplifiers and begins 'To get a rough idea of how it works, think of two lumberjacks sawing a tree, one at either end of a long, old-fashioned saw.' The article continues 'In Class B push-pull, output current is delivered by only one transistor at a time … In the case of the lumberjacks, only one could be pushing on the saw at any given instant — and they would have to time their exertions very precisely to work efficiently' and later concludes in a thoroughly hybrid clause, 'Class AB operation frees them from the restriction that they may push only one at a time' [6].

When an analogy is drawn between the processes of designing and Darwinian evolution, a series of phrases are equated: 'the design description (structure) maps on to the phenotype', 'the processes of designing map on to the evolutionary processes of crossover and mutation' and 'performances (behaviours) of designs map on to fitnesses' [7]. The two vocabularies are kept distinct, however the analogy encourages the reader to accept relationships between terms in one domain as templates for relationships between terms in the other. Thus the valid logic of one field provides a potential new framework for presenting arguments in the analogous domain. In another instance of an analogy Heaviside suggests

> 'For the reservoir of water substitute a conductor of electricity of the same size and shape, and for the pipe a conducting wire similarly terminated carrying a current of electricity, and the analogy is quite complete'[8]

Later in deference to the analogy he wrote 'for the purposes of analogy, we may regard the earth and a wire joining two points as being always filled with electricity' [8] He slips into use of the idiom 'filled with electricity' and as a result he gives the verb 'to fill' a new use, and generates a novel relationship between the word 'electricity' and the verb 'to fill'.

Grammar reflects the customary positional relationships between words and as the examples show, use of an analogy can include the importation of grammar into an alien domain. After seeing, in an encyclopedia, an analogy between electricity and heat identified in the sentence:

> 'It is evident, therefore, that electricity is capable of being transferred, in the same sense as caloric, of which we speak as being communicable' [9]

it comes as no surprise that terms like 'insulator' and 'conductor' occur both in texts on electricity and the analogous domain of thermodynamics. And where Partington wrote of the materials becoming 'over saturated with the electric fluid'[10] we are not surprised at the use of 'saturated' alongside mention of a 'fluid' albeit a metaphorical fluid. So an analogy encourages the adoption of both vocabulary and grammar from the analogous context and alters what can be said. And warnings about the scope of an analogy such as

> 'The analogy must not, however, be carried too far, for the starting or stopping of a material current in one pipe does not cause any current in a neighbouring pipe, as the starting of an electric current does in a neighbouring wire' [11]

can be read as a reminder that the imported fragment of grammar is itself invisibly constrained and there are unseen bounds on what new combinations of words are acceptable as part of the analogy.

LANGUAGE GAMES

The philosopher Ludwig Wittgenstein introduced the term ‘language game’. He saw in the family of games ‘a complicated network of similarities overlapping and criss-crossing: sometimes overall similarities, sometimes similarities of detail’ [12]. He treated language games as phenomena that ‘have no one thing in common’ but, he conceded, ‘they are *related* to one another in many different ways. And it is because of … these, relationships, that we call them all “language”’ [13].

According to Richard Rorty, a metaphor is a word taken from one language game and inserted into another. Metaphors do not have a place in the language game into which they are pitched yet they create an effect. A metaphor can, for instance, make ‘us attend to some likeness, often a novel or surprising likeness, between two or more things’ [14]. For example, a thyristor is a semiconductor device that can crudely control an electric current. The prefix ‘thyr’ is a metaphor acquired in the semiconductor lexicon from thyratron, which refers to an electronic device made from a gas filled glass envelope that has similar properties to the thyristor. But Thyratron itself originated as a trademark of the BTH Company and encapsulates a metaphor obscured, in English, by the use of a classical language. ‘Thyra’ is Greek for a door. [15] Obscuring the metaphor in this way reduces its resonance for those not familiar with Greek. Nevertheless, thyratron and then thyristor became common and familiar terms to electronics engineers.

People are liable to copy the metaphorical use of a word, if they find it helpful, moving or striking. Repeated metaphorical use will breed familiarity, usage will become routine, and the newly generated custom will become absorbed into the language game and alter the game it entered. Once commonplace the word ceases to be a metaphor; it becomes literal and allows things to be said or written that could not be said or written before. As the metaphor becomes ingrained in our practices its use becomes increasingly predictable and can be described as purposeful and thus a part of a statement of belief. After it has become ‘stale, familiar, unparadoxical and platitudinous’, the tired metaphor can become an element in our reasons for beliefs, but while a word remains alien to a language game and its future use uncertain then it is only a potential cause for a belief. Metaphors, therefore, offer prospects for the modification or refinement of descriptions, explanations and justifications, and thus they act as ‘*causes* of changing beliefs’ and ‘causes of our ability to know more about the world’ [16]. The influential metaphors will generate ‘new types of language, new language games, as we may say, come into existence, and others become obsolete and get forgotten’[17] .

It can be hard looking back and trying to imagine the absence of certain words from our technical vocabulary and how that would constrain our explanations. When Volta wrote about electricity, for example, the term ‘Voltage’ was not in use. The volt was not instituted until the International Electrical Congress in Paris in 1881[18] and Volta’s translators wrote instead about the ‘intensity of electricity’[19] and not, of course, voltage. Once terms such as volts and voltage were coined phrases like ‘the intensity of electricity’ were displaced. Units such as Volts and Herz are derived from people’s names. Clearly people’s names have a place in different language games to quantities, so the use of a personal name to indicate a quantity is a metaphorical use and the particular names are often chosen because, at the time of minting, specific biographical details of a person with the name resonated with the quantity being identified.

A metaphor involves the displacement of a word from its customary lexical setting whereas the elements of an analogy are relationships between words and it is the relationships that are shifted from one context to another. Thus an analogy involves the export of grammatical scheme from one language game to another, possibly accompanied by the export of odd items of vocabulary. In a scheme for regulating data traffic, where tokens for the right to send packets of data are issued regularly and can be accumulated in a metaphorical 'bucket', the maximum amount that can be hoarded is described by the grammar and vocabulary of the bucket analogy as '[t]he bucket depth'. But the grammar of discourse about buckets does not fully penetrate the realm of data communications since in the text on data communications bucket depth is 'measured in bytes' rather than centimetres. This hybrid of language games is starkly exposed by the vernacular phrase describing a parameter as 'the fluid delay of a flow obeying a token bucket'[21] which seems to be introducing the abnormal requirement of obedience to a bucket!

Repeatedly observed and reported similarities in the world strengthen the fabric of language games. For instance 'Whatever may happen in the future, however water may behave in the future, — we know that up to now it has behaved thus in innumerable instances. This fact is fused into the foundations of our language game'[22]. To be able to absorb a new empirical result into our beliefs requires the augmentation or modification of such sturdily institutionalised games. Resonant metaphor and compelling analogies are the tools for bringing about change to the language games that exhibit our theories. But simply citing a new metaphor or coining a new analogy is not enough since

> 'among professed physical philosophers, the great abuse of theories and hypotheses, is, that their promulgators soon regard them, not as aids to science, to be changed if occasion should require, but as absolute natural truths; they look to that as an end, which is in fact but a means; their theories become part of their mental constitution, idiosyncracies; and they themselves become partisans of a faction'[23]

In the face of the tenacity of language games, an analogy or metaphor does not always gain acceptance and may fail to become popular, or may be displaced by the increasing popularity of another. For example Oliver Heaviside, who published several notes on nomenclature, proposed the use of the term impedance as a linguistic analogy to resistance. He proposed

> 'Let us call the ratio of the impressed force to the current in a line when electrostatic induction is ignorable the Impedance, from the verb impede. It seems as good a term as Resistance from resist.'[24]

W H Preece, an influential figure, rejected the use of the term impedance. This was not surprising since Heaviside and Preece squabbled publicly and vehemently over theories of the behaviour of telegraph cables[25]. Preece may well have subscribed to the view that 'in nomenclature there is a strong tendency to promiscuous coining'[23] since he declared,

> 'As practical men in the telegraph world they had been familiar with self-induction for the past twenty years — they knew it, they called it electromagnetic inertia, and its effects upon wires were always spoken of as retardation ... Practical men spoke of it ... as throttling. Some people called it choking but why it should be called impedance, why it should be called

> hindrance, and why it should be called other names applied to it at the present moment, they could not possibly understand'[26]

In commenting, Preece hints at competing analogies through the accompanying metaphors including 'retardation', 'throttling', 'hindrance' and 'choking' which still has an influence on present-day terminology when people talk about inductors, known as chokes, specifically designed to limit high frequency signals. Preece also revealed in the quotation the use of the term 'inertia' taken from mechanics, a term that has fallen out of use in electrical engineering. Currently the word 'impedance' is in common use and Preece's preferences have been displaced. In spite of Preece's objections, in this instance Heaviside's preference gained support. Heaviside though was not always successful in promulgating new terms and he himself acknowledged that new terms, even if derived from analogies, might not be immediately acceptable. He conceded

> 'The use of the words decalescence, reluctancy, elastance, elastivity, permittivity, might well be deferred till they are more generally adopted'[27].

And of these five words only one, 'permittivity' is currently in common use in the electrical sciences.

ELECTRICITY

A major feature of the development of the electrical sciences over nearly three hundred years has been an evolution in language — the unfolding of a blend of metaphor inspiring analogies and analogy inspiring metaphors. An account of electrical experiments, published in 1745, introduced 'an electric force', a 'quantity of electric matter' and a 'current of the electric matter'[28] thus associating the metaphors of a 'force', a 'quantity of matter' and a 'current' with the electrical phenomena it reported. Clearly each of these metaphors evokes a grammar and hence an analogy. For example, it would be quite normal to associate a weight with 'a quantity of matter' and later Cavendish, who supposed that electricity was a fluid, did exactly that and imagined that 'the weight of the electric fluid in any body bears but a small proportion to the weight of the matter'[29] .

The pioneers of electrical science struggled to find consistent explanations for phenomena that they came to believe were linked. Stirred by the effects of electrical sparks the Gentleman's Magazine reported that electricity 'is a kind of fluid lambent fire'. This linguistic coupling of electricity with fire and fluidity was common. It became so unexceptional to explain electrical phenomena using the fluid analogy that it gained the status of a belief for people like Henley who professed

> 'I ever considered electricity as a fluid *sui generis*, and properly characterised by the term electricity, electric fluid, or electric matter'[30]

The analogy of electricity as a fluid encouraged the nascent electrical sciences to adopt terms that describe fluids, states of fluids and devices that handle fluids. Cavendish was an adherent to the notion of an electric fluid composed of particles that pervaded material bodies. He exploited the fluid analogy and in doing so introduced some candidates for expanding the vocabulary of electrical science; for example, he wrote that when a 'body is overcharged … some fluid will run out of that body; but if the body is undercharged … fluid will run into the body'[29] . The verbal phrases 'run in' and 'run out' did not gain acceptance but their use does domesticate electricity in a way that the phrase 'fiery particles'[31] does not. Cavendish pressed home the analogy by writing about 'when …

two bodies communicate with each other by a canal'. The canal had, of course, become a significant mode of transport in Cavendish's England but Cavendish was using the word metaphorically to refer to 'a slender thread of matter of such a kind that the electric fluid shall be able to move readily along it'[29] . 'Canal' failed as a metaphor. Similarly Volta's phrase 'conducting communication'[19] did not gain acceptance, but a phrase, written about twenty years earlier, in 1747, about 'a wire to conduct the electric fire from the machine' has a more contemporary sound though the application appears to be decidedly cruel since the wire was to be applied in egg production to 'communicate [the electric fire] to the latter half of the fowls'[32].

In veterinary and medical applications of electricity it was proposed that beneficial results would accrue when 'the stream of the ethereal fire is convey'd by a pipe into the lungs', the 'electric vapour [is] convey'd … to the stomach' or a 'current of electrical fire … exert[s] its force' on regions of the body[32]. Thus, playing on the fluid analogy for electricity, 'stream', 'pipe', 'vapour' and 'current' found metaphorical uses in the electrical science but later, apart from the word 'current', became obsolete. 'Pipe' resurfaced recently as a metaphor in a related field, in specifications and descriptions of communication services, alongside terms such as 'hose' and 'funnel' [33]. The notion of a 'vapour' though prompted the question

> '[I]s it not therefore possible with a proper apparatus to collect, condense, and accumulate this elementary fire as to acquire a power capable of surmounting any resistance, and producing any effects of force, such as raising water, Etc?' [32]

which, in particular, suggests that electricity can be condensed. At one time, the electronic component, the capacitor was commonly called a condenser. The term was introduced into English in a translation of work by Alessandro Volta. In the paper Volta's translator wrote about a device consisting of metal plates separated by a thin resinous coating and explained

> 'I had rather call it a condenser of electricity, for the sake of using a word which expresses at once the reason and the cause of the phenomena'

A further sign that Volta was using an analogy comes from his description of the accumulation of a quantity of electricity as 'a condensation of the electric fluid'. Volta's paper explores, at length, the characteristics of his condenser and how it might be constructed and he introduced several well-known results by referring to the effect various constructional features had on the 'capacity for holding electricity'[19]. Later Oliver Heaviside would rail against the use of the term 'capacity' and sought a mechanical analogy and preferred to refer to 'the reciprocal of elastance' — a phrase that did not catch on. He wrote,

> 'capacity … may mean anything; it is too general; we should have a word suggestive of elastic yielding; capacity seems to suggest the power of holding electricity, a notion which is thoroughly antagonistic to Maxwell's notion of the functions of a dielectric'[34]

In spite of Heaviside's protest, condensers were commonly characterized by their capacity. And now condensers are mainly referred to as capacitors.

Some metaphors or analogies do not catch on, but others can be misleading. Heaviside, for example, warned of some of the dangers of treating electricity literally as a fluid. He identifies ‘the category of ‘men of science who are not natural philosophers’ … who seized upon the word Fluid as something intelligible, and forthwith endowed electricity, along with fluidity, with mass, inertia, etc.’[35]. He thought the analogy was only useful to ‘hang facts together’ and his objection was that

> ‘A fluid has mass, and when in motion, momentum and kinetic energy. But the facts of electromagnetism decidedly negative the idea that the electric current *per se* has momentum or energy … these really belong to the magnetic field’[36].

Simply, the fluid analogy could no longer be stretched to cover the full range of theoretical developments and empirical observations that had taken place in the one hundred or so years of development after the analogy found its first use. Metaphors and analogies become literal and also become redundant. New concerns arise and the changing language games provide new opportunities for exploiting metaphors and analogies: ‘Old metaphors are constantly dying off into literalness, and then serving as a foil for new metaphors’[37]. Long lived metaphors that have become literal include the word ‘tension’ which in 1785 Adams thought was the ‘the force with which [the electricity] endeavours to fly off from the electrified body’[38] and in spite of the comment that ‘the consecrated term ‘tension’, so often misused as a synonym for potential’[39] the term is still used today. The whole environment of electrical engineering is littered with old metaphors such as antenna, protocol, flip-flop, gate, push-pull, band and peak, software engineers use analogies such as the dining philosophers and security specialists write about the dining cryptographers[40]. In 1994 US Vice President Al Gore chose the analogy of the road to talk about how the Information Superhighway would replace the information networks like the ‘little two-lane highway [which at critical times] was completely clogged’[41]. In an article on integrated circuits the authors use a number of commonly employed terms which have clear metaphorical links to describe the functional parts of a transistor; terms such as ‘channel’, ‘drain’, ‘source’ and ‘gate’; they use the terms ‘body’ ‘trench’, ‘sidewall’ to describe the structural features of transistors; they refer to ‘trap’, ‘halo’, ‘well’ and ‘parasitic’ components to describe secondary features; and within the integrated circuits they mention effects such as ‘punchthrough’, ‘tunneling’ and ‘leakage’; voltages are confronted by ‘barriers’ and ‘thresholds’; and the circuits can enter a ‘sleep’ mode[42]. In semiconductor theory ‘holes’ can be ‘carriers’ they ‘climb’ or ‘slide down’ potential ‘hills’, electrons can ‘avalanche’, transistors ‘saturate’ and ‘cut-off’[43]. In networks transmission can be ‘hop-by-hop’, data is sent in ‘packets’ and a ‘firewall’ gives a degree of security[44]. ‘[P]ackets’ are ‘policed’[33].

Analogies like metaphors also become naturalised. Familiarity causes an author to write ‘the velocity-voltage analogy could be called the natural analogy between mechanical and electrical systems’ and suggests ‘the natural analogy is useful in analysis of the different phases of movement in walking machines’[46]. And more far-reaching analogies continue to emerge. Such as the analogy proposed between the ‘dynamic circulation network of atmospheric flows’ and the ‘neural network of the human brain’ which leads to the speculative claim that ‘It may therefore be more appropriate to design memory storage in analog form in a network of continuum fluid circulation patterns in artificial intelligence machines.’[47]

ENGINEERING STUDENTS

The heavy investment required in engineering limits access to facilities and encourages the development of skills to ensure that the plant is used effectively. These characteristics of engineering practice have led to the establishment of a cadre of professional specialists. Commonly a professional engineer gains the skills of a subject expert during the course of a specialised education at a University often remote from expensive engineering plant. In an academic environment therefore students primarily acquire linguistic skills and familiarity with the language games that will identify them as members of the profession. Because of their isolated and narrowly focused customary practices, professionals occupy linguistic enclaves where, on the margins, students will encounter language games that were inaccessible to them in their youth and childhood.

The professional influencing change in an industry lives within the developing language games and should be able to distinguish the mature analogies and metaphors from tentative experiments. For the student though, most metaphors, old or new, will be unfamiliar, will not be taken literally and will create dissonant effects and hence confusion as analogies pile in on top of one another in phrases such as ‘tying the gate and body together’[42], or ‘the second floating point value is the bucket size’[21], or in the account of how ‘data mining’ is used to extract patterns from ‘a flood of bits’[49] or in the text that reveals that ‘floating gates’ can ‘leak’[50].

In some cases, because of its obsolescence outside of the specialised field, a metaphor will be, for the student, an unconnected, unfamiliar word, a jumble of letters with no hint as to its proper use — like the word ‘thyristor’.

The novice can be confused by the absence of explicit rules for setting the bounds on an analogy or establishing the reach of a metaphor, for example, in Heaviside’s opinion

> ‘students are sometimes led, or rather misled, by the name and by certain ideas they may possess as to frictional resistance to imbibe the idea that *R* [the electrical resistance] is really analogous to the frictional resistance of the flow of water through a pipe, when the current of water is compared to the electric current’

Heaviside puts us on what he believed was the right path by providing a technical explanation by asserting ‘the real analogue to frictional resistance of water flowing in a pipe is not *R* , but *RC* in the electrical case.’ [35]

Competing analogies can add to the bewilderment. For example, newcomers to radar remote sensing often have ‘conceptual difficulties that can lead to lasting misconceptions about the nature of radar imaging’. In one author’s opinion the difficulties arise from the use of ‘visual metaphors’. The visual analogy may be inadequate because it carries with it a vocabulary that is alien to its target domain, for example, people working on optical systems commonly refer to ‘wavelengths’ but radar specialists use ‘frequencies’. On the other hand terms used by radar specialists such as ‘chirp’, ‘echo’, ‘amplification’, and measurements in decibels are more common in the audio field than in optics and this may make it easier to adopt an audio analogy. However the auditory analogy ‘cannot … be used to explain polarisation effects, since sound waves are pressure waves’. The ears nonetheless use the two auditory channels to infer the direction of sound and this is closely analogous to radar interferometry whereas the eyes exploit the stereoscopic effect to estimate distances.[48]

The toolkit of the engineer consists of a collection of intermingled language games. Knowing the subject is about being able to play such games with such fluency that they cease to weave their metaphorical magic and become routine. But, the evolution of language through analogies and metaphors makes it impossible to formulate universal rules, and the consequent arbitrariness of vocabulary and grammar makes the task of learning to become an engineer one of acquiring linguistic habits through regular practice as a participant in engineering language games.

IN THE DARK

Engineering enterprises are engaged in modifying their environment. Often they operate in a competitive field and must strive to offer improvements, rectify errors, and adapt to new circumstances. They will be continually creating new components, new products, new diagnoses and new techniques and a renewed vocabulary will accompany not only the innovations but prospective innovations which may never be materialised but only ever glimpsed at in text and analogues. This constant demand for innovation makes the engineering language games highly volatile. Metaphors, analogies or analogues can offer transformations to language games that refine descriptions and explanations and open up technological possibilities. However, selecting and using an analogy or a metaphor is beyond rational consideration. For example, exploiting the language surrounding flowing water in the description of electrical phenomena is not rational but poetic. Like poetry, the utility or popularity of an analogy or metaphor cannot be judged in advance of its use. And this makes it impossible to judge which descriptions of the future will be accepted, which technologies will be adopted or which language games will prove to be vital for the aspiring engineer.

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