Chapter 2

ANALOG AND DIGITAL: TWO COURSES OF ACTION

Authors from various fields of expertise recognize that the logic of the machine *S* depends on the product *w* produced by that machine; I began the present book declaring that I whished to share this special view and now this declaration is turning into a sort of challenge. Two different methods take care of processing signs. There are *digital* and *analog* devices, which should be discussed starting from the concepts of signifier and signified. The accurate examination of the semantic triad just ended and I have now to show how the stated plan should be put into practice.

1. ANALOG IS CLOSE TO NATURE

Modern glossaries define '*analogue*' as something having "*the property of being similar to something else, or bearing an analogy to something*". According to this statement, I am inclined to say that a technician applies the *analog paradigm* (or *method* or *mode*) when he/she communicates using a spontaneous signifier or a form resembling an object present in the reality. Otherwise an expert uses the *digital paradigm* which does not imitate occasional information but adheres to standards:

- Do these conclusions come true in the world?
- Is my reasoning correct?

The identity of the digital and analog methods remains a vexed conundrum, emphasized in (Allison et al 2005). I shall spend the next pages in scrutinizing how, when and why analog and digital machines operate in the real world.

I mean to start with easy cases.

An African tribal chief puts a huge leaf over his hut to mark his social status. Inhabitants of Oceania use shells to count. Many people identify the North by means of the Pole star. Dictionaries show us that a person applies the analog paradigm when he/she makes use of a generic object taken from the world to signify something. Thus the above mentioned agents who use leaves, shells and stars to signify something, may be deemed as analog experts from the viewpoint suggested by the dictionaries.

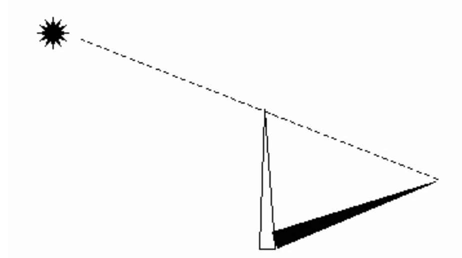

Figure 2.1. A sundial.

Technicians and engineers have a conduct not very different from that of the African tribal chief and the inhabitants of Oceania. Experience shows how several experts employ signifiers available in Nature. As an example I mention the Sun which rises in the morning, it reaches its peak and at sunset signals that the day is ending. The Sun is a natural source of information and ancient inventors created the *sundial*: an analog device which exploits the Sun's light, a resource ready for use. All the substances – solid, liquid and gas – expand under heat, and their volume is reduced when they are cooled. Some scientists – at different times – invented the *thermometer* that exploits those natural signifiers. The liquid that expands inside the thermometer bulb is a resource accessible in nature and is capable of marking the temperature

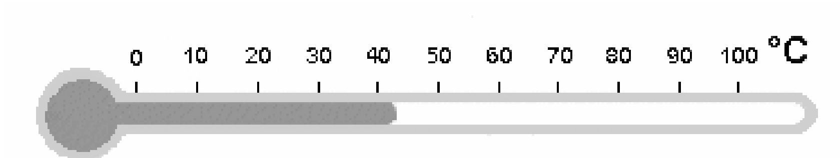

Figure 2.2. An analog thermometer.

Analog designers use signifiers extant in the world or otherwise copy signifiers from the world. Analog devices import or replicate natural information. Take the film of a movie that includes *shots* and the *sound strip*.

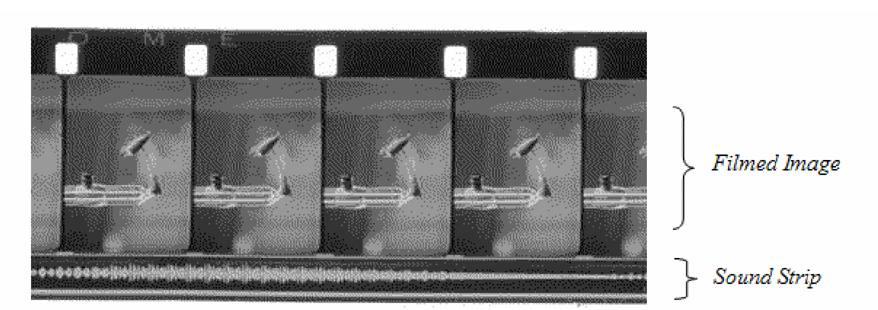

Figure 2.3. A film strip.

A frame exhibits an event which occurred in the world. The sound strip created by a photoelectric cell duplicates the sounds in a simple way. When the sound strip is dark, the original scene is silent; when the white trace is ample, there are many sound sources. In conclusion, both the sequence of frames and the sound strip provide true copies of the physical reality, and are analog signifiers.

By contrast, digital technicians build up signifiers unrelated to the objects of the world. They learn to use sets of electric pulses, of magnetic energy levels, of flashes of light and dark, and so forth. There is no intrinsic link between each digital signifier and the entity it represents. One cannot find a plausible connection between *E* and *NE* to the extent that people have to learn the meaning of each element. As an example take the voltage values E_1, E_2, E_3 and E_4 that provide the *alphabet* (or *base*) for a digital solution

$$E_1 = 1.3\text{ V};\quad E_2 = 4.7\text{ V};\quad E_3 = 8.1\text{ V};\quad E_4 = 11.5\text{ V}$$

There is no manifest relation between these signifiers and the entities in the world that they are called to represent which may be any. The contrast between the analog approach and the digital approach appears remarkable.

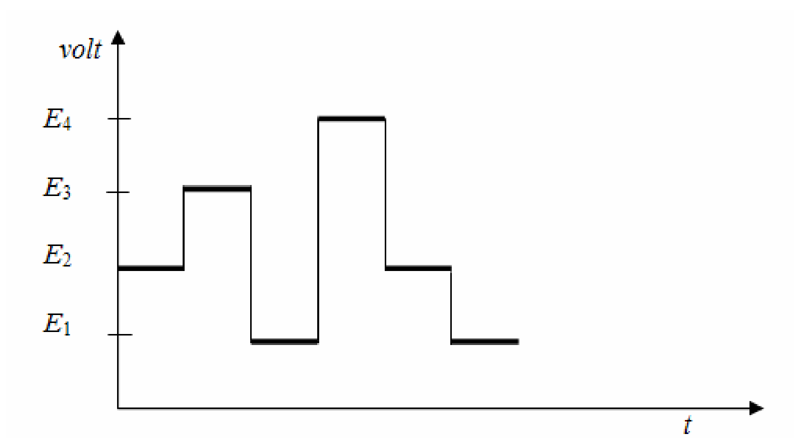

Figure 2.4.

A. Criticism on Naturalism

A circle of commentators agree that analog information appears somewhat close to nature. In his essay Antony Wilden (1972) states that the analog is defined by its always having a relation to things. The sign of an analog communication "has a necessary relation to what it represents". In contrast discretization produces representations “less real” or “less authentic” than analog forms. Other authors converge toward the same position (Watzlawick et al 1967), (Blachowicz 1998), (Dretske 1981) and the reader could be inclined to sanction the analog/digital paradigms on the basis of the natural/artificial criterion in a definitive way.

But this rigid conclusion raises some doubts.

Digital devices handle discrete signals rather alien to natural forms found in the world. Although this judgment is not absolute: there are digital solutions somewhat close to Nature. Take the sounds that are normally translated into discrete signals. A converter can transmute a continuous wave into a stream of discrete signals and ensures the realism of the digital sequence. Figure 2.5 demonstrates the parallel between the electric impulses and the intended sound, and this symmetry is regulated by the *sampling theorem* in a precise manner. This fundamental result has various labels since it was discovered independently by Harry Nyquist, C. Shannon, E. T. Whittaker, Vladimir Kotelnikov, and by others.

Suppose a signal is the continuous function $s(t)$ which consists of components at various frequencies. The sampling theorem holds that the sampling frequency should be at least twice the highest frequency contained in the signal (Aftab 2003), that is to say:

$$Fs \geq 2Fm$$

Where Fs is the sampling frequency – how often samples are taken per unit of time – and Fm is the highest frequency component of $s(t)$. The sampling theorem sanctions the symmetry extant between the analog and the digital, and states that the higher Fs and the more realistic is the discrete signifier. As a practical case, digital signals generated at 96 kHz with the resolution of 24 bits make a high-definition format which represents sounds much more accurately than a hi-fi vinyl record.

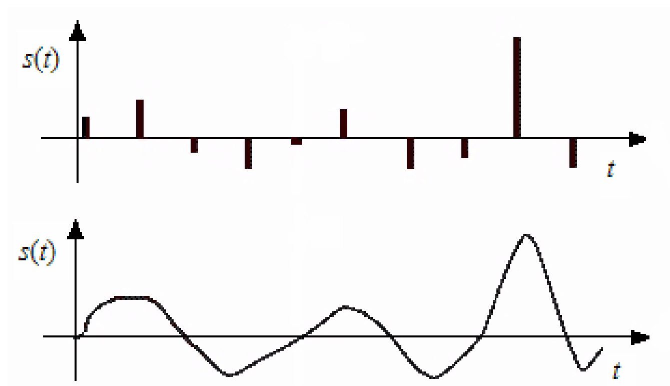

Figure 2.5. Equivalent digital and analog signals.

As a second case, consider the *classical camera* that creates the chemical image of a house on the film plate. The analog process ends with the faithful photo $\mathcal{A}$ printed on a sensitive paper.

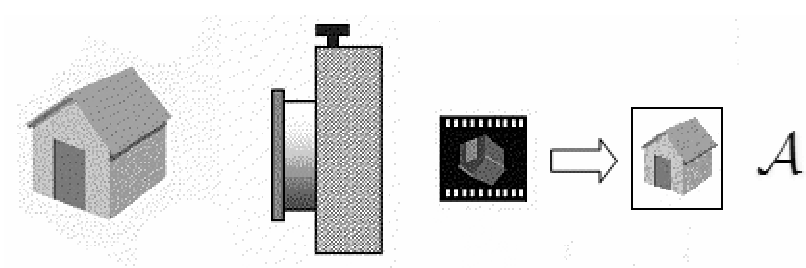

Figure 2.6. Analog camera.

The *digital camera* stores a sequence of bits in a tiny chip and then a computer printer provides the final result on the paper. The intermediate outcome does not show any evident connection with the original image, but the final image – consisting of discrete elements – appears identical to the portrayed original. A high-quality digital image – say an image including over 2000 dpi (= dots per inch) on paper – appears absolutely realistic and no one would be able to distinguish between the computer print $\mathcal{B}$ and the traditional print $\mathcal{A}$. Discretization proves to be in keeping with the natural reality in the most perfect way.

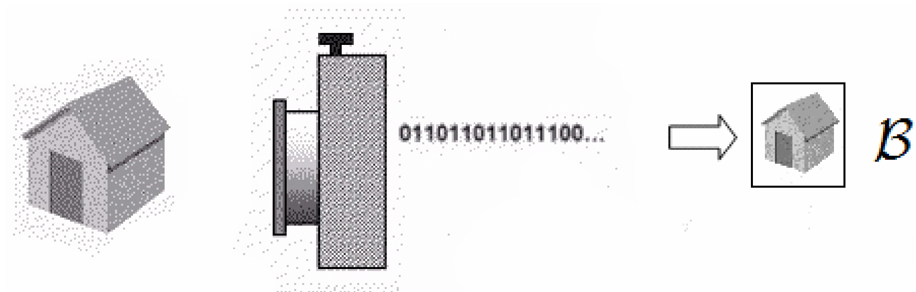

Figure 2.7. Digital camera.

This pair of examples shows how the digital paradigm can create signifiers very similar to the related objects extant in the world. The discrete elements are disposed in such a way as to recreate a realistic image or a natural sound. We find symbols in the digital domain and even icons such as the pictures captured by a digital camera. The popularity of icons and symbols inverts in the analog domain where the majority of signs is iconic.

	Are Icons	Are Symbols
Analog Signals	***Normally***	***Rarely***
Digital Signals	***Less Frequently***	***More Frequently***

Figure 2.8.

I overlook the statistical distributions, and can conclude that analog and digital signs are iconic and symbolic as well. The analog/digital distinction does not overlap with the distinction between realistic and abstract representations since there are digital elements in pure perception and analog elements in abstract thought. The scientific community agrees that the criterion *natural/artificial*, which I have examined, appears somewhat reasonable but does not provide the definitive answer for understanding what is analog and digital respectively.

B. Criticism on Continuous/Discrete

The relation between analog signifiers and Nature has manifest consequences in ICT since physical parameters – e.g. electric current, space, time, and energy – are continuous and constitute usual analog signifiers. David Lewis (1971) discusses the details of this aspect and holds that what counts is that the representation does its work via a quantity. Hence the analog representation of numbers is the representation by physical magnitudes. The analog describes any fluctuating, evolving, or continually changing process, while the digital uses pulses that are separated values to represent information and systematically use Discrete

Mathematics. Nelson Goodman (1968) claims the digital scheme is *differentiated* – that is to say any two points are distinct – whereas the analog scheme is *dense*, which means that there is always a point between any successive pair of points.

The vast majority of technical writers are inclined to take '*analog information'* as synonymous with a *continuously variable signal* and '*digital information'* as synonymous with a *discrete signal.* The criterion continuous/discrete has many fathers since this idea seems to be self-evident, and infiltrated the scientific community in a natural manner.

But some cases bring this criterion into question.

Modern systems handle electric square-waves, and continuous electric waves that – for example – faithfully reproduce a sound. It is obvious how the former signifiers are digital and the latter analog.

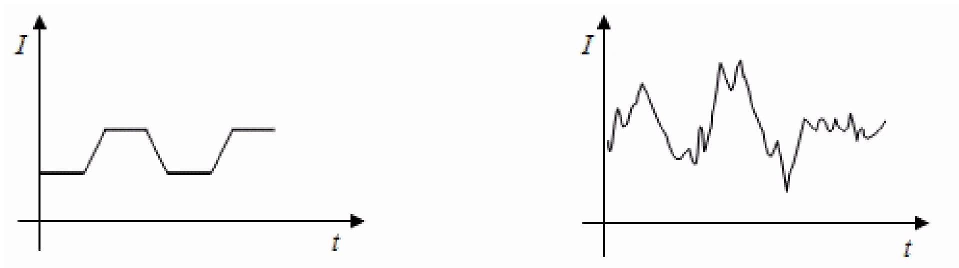

Figure 2.9. Square waves and continuous waves.

However there are waves that cannot be easily catalogued.

Take the Frequency-Shift Keying (FSK), a modulation pattern in which digital information is transmitted through frequency changes of a carrier wave. The signal consists of high-frequency wave-blocks and slow-frequency wave-blocks. All the wave-blocks have the same duration and the final outcome is a continuous wave that creates a bit stream. Thus the electromagnetic wave should be catalogued as a continuous signal and a discrete signal at the same time.

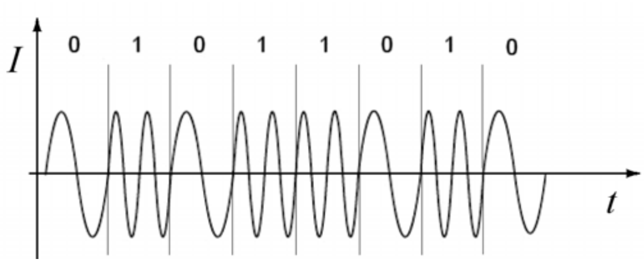

Figure 2.10. Frequency-Shift Keying (FSK).

As a further case, let us consider two mechanisms used as components of mechanical calculators and mechanical counters (e.g. the milometer and the oil-meter).

The *Maltese cross* is engaged with the wheel X equipped with the pin P (Figure 2.11 top). When X rotates, P enters between the branches of the cross Y and obliges Y to change position. The *single-tooth gear* Z engages its single tooth with the ten-tooth gear W once every time it revolves (Figure 2.11 bottom). It takes ten revolutions of Z to rotate the ten-tooth gear once. Both the mechanisms convert the continuous rotation of the input gear into the jerky movement of the output drive which assumes fixed positions. Each of these positions relates to a numerical value, e.g. the wheel W displays the decimal figures on the border.

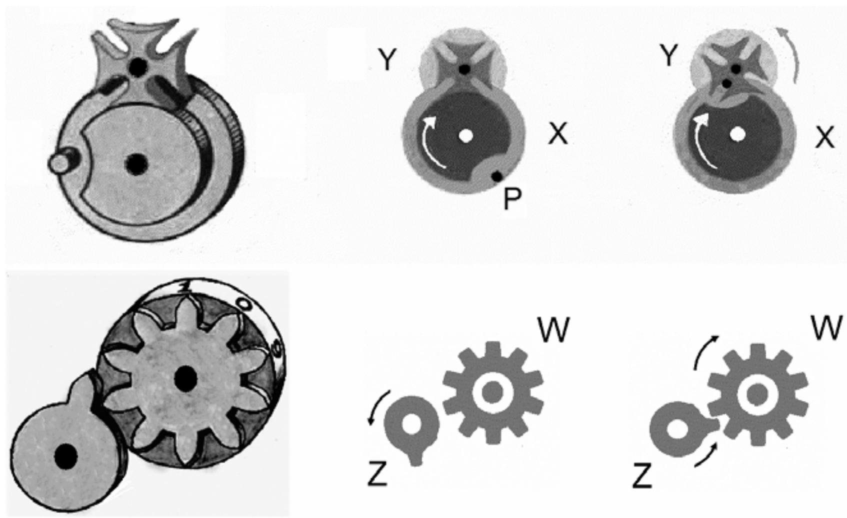

Figure 2.11. Maltese cross (top) and single-tooth gear (bottom).

Lastly, take the needle which rotates over the scale and is free from jolts. Speedometers, watches, thermometers and many other indicators exhibit mixed continuous/discrete bearings since the needle has a continuous movement and points to discrete values.

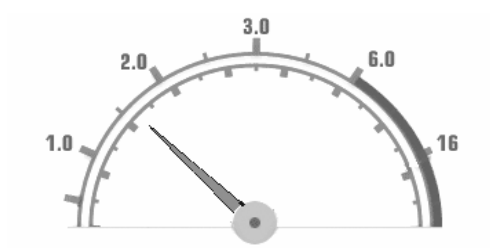

Figure 2.12. A speedometer.

One may wonder:

Are the above mentioned solutions to be classified as digital since they deliver numbers? Or are they analog solutions due to the continuous movements?

Several systems operate in continuous and discrete modes at the same time and show hybrid characters. One could define three classes of products: continuous, discrete and hybrid in order to prepare a brochure for marketing purposes.

But this is not the case.

We are oriented to search for a serious, exhaustive definition of the analog/digital paradigms, and we can but concur with the majority of thinkers who believe that the criterion *natural/artificial* and the criterion *discrete/continuous* do not provide satisfactory answers to our needs. Those criteria illuminate our knowledge of the digital and the analog domains although they do not clarify the inner substance of the technologies over which we are discussing.

B. Poorly and Strongly Theory-Based

The tenets *natural/artificial* and *discrete/continuous* appear convincing but are not sufficient for fixing all the differences between the analog and the digital. I guess that the contents of Chapter 1 can aid me to address the problem; in particular I go back to the complete catalogue [1.12]. Signifiers fall into two principal classes and these classes suggest that engineers either can exploit natural pieces of information or otherwise activate special processes to build up artificial signals.

But what is exactly the conduct of engineers?

Which methods do they use?

I mean to explain myself using a parallel with civil engineering.

From immemorial times, people constructed their houses using the material at their disposal in the environment. For instance, the communities who lived close to a forest used to build up log cabins. Humans employed stones and mud, iron and straw, clay, leaves and other material in various parts of the world in order to take shelter from rains, the sultry weather and cold.

In the middle of the 19th century experts discovered that the high tensile strength of steel and the compressional strength of concrete could be combined together. Civil engineers inaugurated the technology of reinforced concrete which is hard, durable, and provides excellent corrosion protection for the steel reinforcement. Reinforced concrete makes the buildings stronger and better able to withstand the ravages of time and the weather; furthermore it is flexible to construct an endless variety of buildings; actually concrete can easily be molded into any shape. In conclusion the ancient methods of constructions were rather improvised and *poorly theory-based*. Modern engineers follow general and exact rules to design a structure and we say that reinforced concrete is a *strongly theory-based* technology.

I introduce my idea using a second case.

Nature provides medicaments by means of a variety of plants, herbs, lucernes and mineral substances. These medicines have been in use for centuries but fall short of curing complicated ailments and pharmaceutical firms create medicines through industrial processes. We find two lines of products in pharmacology nowadays: on the one hand there are drugs derived from natural sources, on the other hand, drugs are built up after methodical researches. An individual can make use of a medicine of the first category or otherwise of the second category to cure a disease. If you have a sore throat you are able to cure yourself using *propolis*, a natural antibiotic prepared by bees, or a normal antibiotic. In short, herbal remedies have their origin in empirical and also occasional discoveries; whereas modern pharmacology is grounded upon rational and systematic studies.

I find it reasonable to deduce that two far differing approaches embody the information and communication technology. Engineers are capable of taking advantage of spontaneous information or otherwise creating artificial signs through dedicated procedures. The first paradigm should employ natural or nature-like pieces of information; the second paradigm should devise signs independently from Nature. Whether the parallel with civil engineering and pharmacology is right, *the first paradigm should exhibit a somewhat empirical profile whilst the second paradigm should be methodical and grounded upon principles*. The next pages will serve to verify whether the digital – corresponding to reinforced concrete and industrial pharmacology – is *strongly theory-based* and whether the analog is *poorly theory-based*.

2. SHARPNESS FIRST

Let us begin with digital elementary signifiers which show separation as an evident property. Suppose the initial example (Figure 2.4) exhibits the impulses E_1=1.3 V; E_2=4.7 V; E_3=8.1 V and E_4=11.5 V which lie 3.4 volts away

$$s = (11.5 - 8.1) = (8.1 - 4.7) = (4.7 - 1.3) = 3.4 \text{ V}$$

This means that the points E_j and E_k – where j and k are any two of the integers 1, 2, 3 and 4 – take place at a certain distance in the continuous metric space $\mathcal{E}_{\mathrm{m}}$, and *conform perfectly to the principle of sharpness*

$$s = \left| E_j - E_k \right| > 0 \quad j,k = 1,2,3,4 \tag{2.1}$$

The separation shows how digital engineers look after the distinctness of signifiers. The pairs *yes/no, true/false*, and even *all/none* often explain the form of digital signifiers, and emphasize their superiority. In fact there is nothing more contrasting than *yes* and *no*, *all* and *none*.

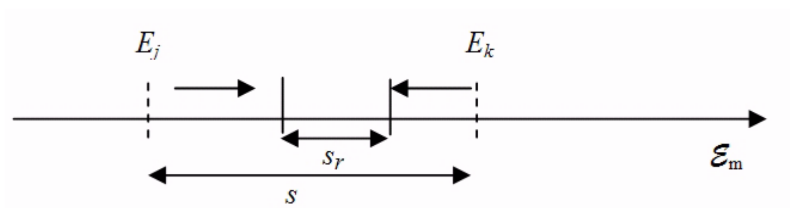

Figure 2.13.

Engineers want that digital signals do not overlap under normal conditions and even under external attacks (Boylestad et al 2005). They apply the rule (2.1) in a rigorous manner and guarantee the high quality of their results. Attenuation or other disturbances bring E_j and E_k nearer and experts ensure that signals continue to work under the worst situations. They determine the initial separation s so adequately that the digital signifiers remain distinguishable due to a residual distance s_r

$$s >> s_r > 0 \tag{2.2}$$

Obviously the larger is the separation and the higher are the energies spent for capturing, recording, processing, storing, and transmitting signals; so experts tune up (2.2) with respect to cost-effectiveness of appliances. They balance s and s_r against insulation, power supply and other involved electrical parameters. Engineers ensure that [1.3] is true within the normal and the critical contexts as well, that is to say eqn. (2.1) and (2.2) calculate the distinction of signs along with the reliability of signs.

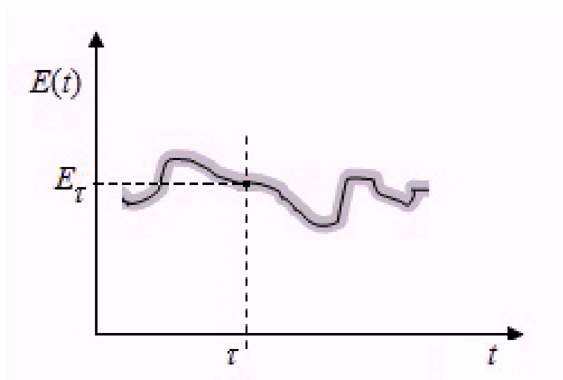

Figure 2.14.

Distance involves gaps between discrete elements and the digital paradigm is systematically grounded on Discrete Mathematics. In this way one proves how *discretization is the special quality of digital signs but is not their essential quality* because *discretization is a consequence* and not the foundational criterion of the digital paradigm. In this subtle remark, I intend to demonstrate that the criterion continuous/discrete is correct but not exhaustive.

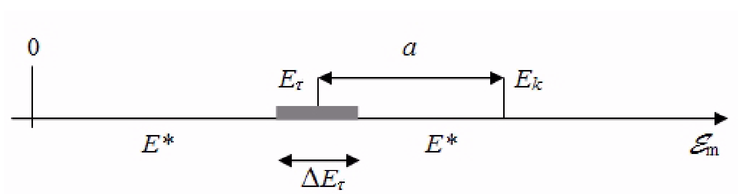

Figure 2.15.

In conclusion, digital experts shape elementary signifiers according to the principle of sharpness and in this way they give a first testimony to their inclination toward a strongly theory-based paradigm. They adopt a methodical conduct right from the first stage and do not improvise.

Distinctness preoccupies digital designers since the first stage, whereas analog designers import or copy spontaneous pieces of information from the environment in the initial step. The analog take signifiers from Nature and do not base the form of signs on any principle. They use the signifiers at their disposal in the context and those signifiers may be more or less confused. The distinctiveness and reliability of signs are features that analog designers endeavor to improve in a second stage.

Usually the analog E belongs to the continuous metric space $\mathcal{E}_m$ and makes a continuous function of the time

$$E = f(t) = E(t) \tag{2.3}$$

Unfortunately signifiers – no matter whether digital or analog – are affected by disturbance of various kinds coming from the environment and depending on the technology of the device, e.g. *noise, echo* and *attenuation* act upon electrical transmission. Moreover, the response of an electronic device is influenced by the *frequency response shift*, and the *parasitic effects* within semiconductor. Analog experts are obliged to apply themselves systematically to the reduction of the fuzziness of $E(t)$ which they examine at different levels of granularity.

- Small electrical effects create the subset ΔE_τ which contains points common to E_τ and to the surrounding subset E^* (Figure 2.15). Experts strive to ensure that at any given moment τ, the *absolute error* ΔE_τ be negligibly small

  $$\Delta E_\tau = |E_\tau \cap E^*| > 0 \tag{2.4}$$

  Sometimes practitioners relate the absolute error to the value of the signal in order to see the real impact of interference. For example the analog signifier E_A is four volts and fluctuates to the extent of more or less 0.1 V, namely $|\Delta E_A|$ is 0.2 V. The ensuing quantity is called the *relative error* of E_A

  $$\partial_A = \frac{|\Delta E_A|}{|E_A|} = \frac{0.2}{4} = 0.050$$

  The relative error explains the overall variation of a signifier. By way of illustration E_B is of better quality than E_A – even if the absolute error $|\Delta E_B|$ is larger than $|\Delta E_A|$ – in that ∂_B is smaller than ∂_A

  $$\partial_B = \frac{|\Delta E_B|}{|E_B|} = \frac{0.4}{12} = 0.033 < 0.050$$

- When the disturbance is high, the curve $E(t)$ changes its shape. For example the random signifier $E_{n\tau}$ is the noise which is superimposed on the original signifier E_τ at the given time τ and cannot be separated from it (Figure 2.16). *Signal-to-noise ratio* (SNR) or *noise margin* is the most common measure of noise

  $$\text{SNR} = E_\tau / E_{n\tau} \tag{2.5}$$

  Where E_τ and $E_{n\tau}$ are measured in volt, or watt etc. at the same point of the system. Because signals have a very wide dynamic range, SNRs are often expressed using the logarithmic decibel scale. The decibel is defined in such a way that the SNR can be applied to any unit of measure

  $$\text{SNR} = 10 \log_{10} (E_\tau / E_{n\tau}) \text{ dB} \tag{2.6}$$

A high perturbation regime causes a single signifier to shift to the left side or right side instead of assuming the true value E_k. The *accuracy* is defined as the distance a between the reference value E_k and the actual value E_τ (Figure 2.15). This range should be zero, but an analog signifier moves apart from the value which it should take

$$a = | E_\tau - E_k | > 0 \quad (2.7)$$

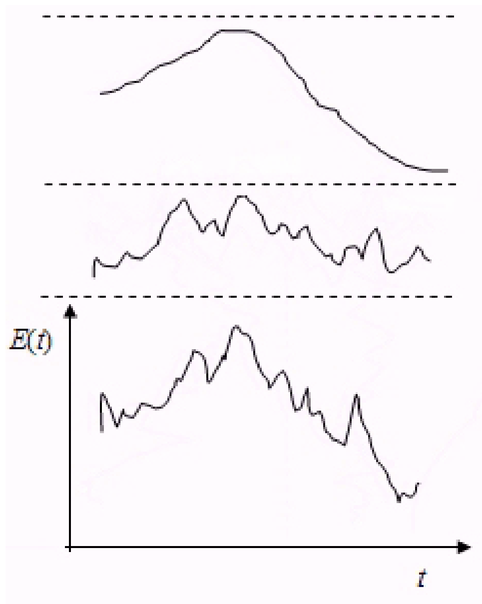

Figure 2.16. Original signal (top), noise (middle), and disturbed signal (bottom).

The assignment of significance is independent of the setting up of the digital signifiers; by contrast a continuous signal is rarely symbolic. In the previous chapter we have seen how each natural signifier represents itself (see [1.10]); analog signals are imported from the Nature and keep their own significance. Normally analog experts do not use the principle of arbitrariness; that is to say the signifier E_k represents the physical value NE_k, E_h stands for NE_h and so forth

$$E_k \equiv NE_k \quad (2.8)$$

As a consequence, when (2.7) is true, one obtains wrong information. E.g. E_τ stands for NE_k instead of NE_τ. The inaccuracy can provoke semantic misunderstanding, and in practice one cannot recognize the voice of a friend on the phone or views a ‘snowy’ pattern on the TV screen.

Analog signifiers do not reach the high standard of digital signifiers even if engineers strive to ameliorate the distinctness and accuracy of $E(t)$. Analog signals exhibit a certain blurring from the physical and semantic viewpoint which increases in a hazardous environment. Conversely digital signs can resist external interferences and are able to work under the worst conditions as we shall see next.

I derived the use of discrete signals from the principle of sharpness (1.1). Hence from the present perspective, it appears that digital experts reveal a strong orientation toward methodical behavior. They follow rigorous criteria to build up artificial signifiers since the inception of a digital project. In contrast analog designers tend to improvise and afterward attempt to improve the quality of the imported signals. Both groups of experts are involved in neat signals but exhibit far diverging conducts and obtain products with different degrees of quality. I could conclude that *digital experts act in accordance with a methodology which is rational and strongly based on theory.*

Pharmacists follow two methods: herbalism and synthetic pharmacology. The former prepare remedies using molecules made-up by nature, while the latter build up molecules non-existent in nature through chemical processes. The comparison of drug-molecules with continuous and discrete signals seems apparent to me.

However the reader can find this closing sentence somewhat questionable since I have myself defined the principle of sharpness and hold that digital technicians are intelligent because they adhere to my regulation. In this case the French usually quip: “Toujours dans la même boutique (All along in the same shop)!”

Justification of the rational approach followed by digital experts should be proved in a more extensive and complete manner. Hence I now delve deep into this argument.

3. After the First Stage

Let us pay attention to how digital designers proceed after the first step.

A. Stability

The famous *Ockham razor* may be summed up in the following terms:

> "All other things being equal, the simplest solution is the best".

This principle – introduced by William of Ockham, a medieval philosopher – is valid everywhere and engineers aim at simplifying artifacts of whatsoever gender. Designers search for straightforward processes to formulate reliable solutions in each sector. They avoid any surplus and any non-essential component to build up efficient products. This rational tendency toward simplification governs all the engineering areas since the larger is the number of parts the higher is the possibility of errors and failures beyond the abilities of manufacturers.

Digital experts build up messages by means of elementary signifiers which make an alphabet. Ockham’s lesson teaches us to reduce the size of that alphabet and technicians aim at being the first in their class. They cut the alphabet back and reduce the set of symbols to two elements. This is the minimum theoretical size in that the paradox [1.5] holds that a sole elementary element cannot work

The minimal alphabet includes two elementary signifiers. [2.1]

Various disturbances adversely affect communications in reality. Noise, perturbations, echoes and a variety of failures are capable of changing the value of signals as we have seen in the previous section. By definition an elementary signal must occupy a fixed place, hence the size of the alphabet increases when a signal shifts. For instance suppose perturbations move the bit E_1 ahead and back. There are four signals in all instead of two in consequence of those disturbances.

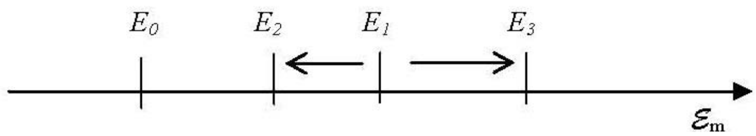

Figure 2.17.

The minimization rule [2.1] goes belly up when the signals shift and it is evident how the binary base must not vary. Digital experts are concerned with this problem and ensure that the alphabet remains binary notwithstanding the restless attacks from the context. For this purpose they introduce a principle which perfects [2.1] and may be expressed in the following terms

The minimal alphabet includes ***two and only two*** *elementary signifiers.* [2.2]

The current literature agrees that digital paradigm is grounded upon the *law of the excluded middle* [2.2] expressed in formal terms in classical logic (Anapolitanos et al 1998). This historical precedent induces people to consider the law of the excluded middle as a purely abstract tenet. Frequently one mistakes practical solutions for ethereal ideas and I immediately examine the engineering ploy that puts [2.2] in material form.

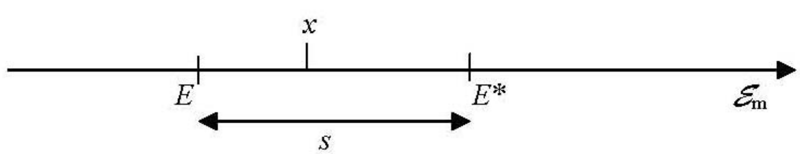

Figure 2.18.

Digital experts take the separation *s* large enough to keep the bits clear when interference brings them closer to one another. In addition, experts fix the generic point *x* inside the range *s*, and establish that any extra impulse at the right of *x* is rounded to the *E**. Any extra value at the left of *x* is approximated to *E.* When disturbance deforms a signal, this electrical effect does not create a new elementary item in that the altered signal is associated to the bit *E* or to the bit E^*. Any corrupted signifier is a bit and this stratagem guarantees the stability of the binary alphabet. A disturbance factor does not result in errors unless the shift is so large as to result in the bit inversion. In the worst situation bits swap – namely 1 becomes 0 or vice versa – and anyhow the receiver detects a bit. A new piece of elementary information never comes into existence and the law of the excluded middle [2.2] comes true. Noise, distortion and other electrical effects cause errors far less heavy than the damages created in the analog domain. These details furnish further evidence on how the digital designers adopt general criteria and are not inspired by suggestions occasionally found in the natural context. The technical advantages are evident: the *robustness* and the *stability of the binary data* resist full-power trails.

From the perspective we are following it is clear that bits are electric impulses, spots of light and dark, holes in punched cards etc. Bits are elementary signifiers and are absolutely physical as such, whereas bits – usually represented by the digits *1* and *0* – are considered to be abstract elements in the theoretical studies on Computing. The term '*bit*', which is a contraction of 'binary digit', reinforces the immaterial interpretation of bits as numbers. I shall go back on this interpretation next, for the moment I note how the noteworthy qualities of the digital paradigm such as sharpness, robustness and stability of the binary base do not emerge at all from present-day abstract studies. The rationality and efficiency of the digital paradigm inevitably vanishes when one creates an airy image of binary information.

B. Unified Calculation

The excluded middle rule ensures that the binary basis is stable. A binary device processes bits in any circumstance and consequently digital engineers can work out circuits using a sole mathematical subject: *the Boole algebra.*

Boole's algebra may be defined as a method of calculus in which the variable has only two values (Goodstein, 2007). It has a pair of *binary* operations (the adjective '*binary'* means a 'two-inputs' operation) detailed in the following tables:

$$\begin{array}{ll} 0 \text{ AND } 0 = 0 & 0 \text{ OR } 0 = 0 \\ 0 \text{ AND } 1 = 1 & 0 \text{ OR } 1 = 0 \\ 1 \text{ AND } 0 = 1 & 1 \text{ OR } 0 = 0 \\ 1 \text{ AND } 1 = 1 & 1 \text{ OR } 1 = 1 \end{array} \tag{2.9}$$

And a *unary* operation ('*unary'* means a 'one-input' operation):

$$\begin{array}{l} \text{NOT } 0 = 1 \\ \text{NOT } 1 = 0 \end{array} \tag{2.10}$$

Five properties define the Boolean algebra: *associativity, commutativity, absorption, distributivity,* and *complements* that yield all the statements necessary to calculate a circuit. By way of illustration I quote the famous De Morgan laws devised by Aristotle and discussed by medieval thinkers too

$$\begin{array}{l} \text{NOT}(a \text{ OR } b) = (\text{NOT } a) \text{ AND } (\text{NOT } b) \\ \text{NOT}(a \text{ AND } b) = (\text{NOT } a) \text{ OR } (\text{NOT } b) \end{array} \tag{2.11}$$

I deliberately recall historical quotations because philosophical and logical topics are worthy of comment.

1. Terminology and Chaos

Classical algebra applies to a wide group of fields: Economics, Physics, Chemistry and many others. To exemplify, people execute the arithmetic sum and add up dollars or miles, tons or cars. In a similar way the *Boolean algebra* turns out to be a powerful mathematical tool available in different fields and has different applications (Brown, 2003). Hardware and software specialists use the Boole algebra; in addition experts in the set theory and in the bivalent logic adopt the Boolean calculus. Two significant areas in Computer Science – the *hardware* and the *software* – and two abstract disciplines – *set theory* and *bivalent logic* – that is to say *classical logic* – resort to the binary algebra. Each group of experts is concerned with special quantities used in the four domains and adopts its own terminology.

Electronic engineers call *gates* the operations (2.9) and (2.10) which scramble the bits passing through. Technicians often write plus (+) for OR and a product sign (·) for AND when they design circuits. NOT is represented by a line drawn above the expression being negated ($\overline{a}$). Actually this notation makes it very easy to write complex expressions:

1	Binary *E,*
0	Binary *E*,*
$\cdot$	Gate AND,
$+$	Gate OR,
$\overline{}$	Gate NOT.

Experts in *set theory* specify that *0* denotes the *empty set*, and *1* the *universe set*. They customize significance for each operation and use the ensuing notation:

1	Universe set,
0	Empty set,
$\cap$	Set intersection as AND,
$\cup$	Set union as OR,
$\sim$	Set complement as NOT.

In *bivalent logic* the symbol *0* denotes the value *false*, and *1* the value *true*. The operations are marked by the following symbols:

1	True,
0	False,
$\wedge$	Logical AND,
$\vee$	Logical OR,
$\neg$	Logical NOT.

The Boolean terminology flexes in the four areas in order to highlight the special significance of the operations and the distinguished results obtained in each territory. There is evident separation amongst the domains mentioned above, and the outcomes pertaining to each domain are not transferable from one to the other. Rigid separation is valid even in the arithmetic calculus:

Does an oilman perhaps multiply 'meters' instead of 'gallons'?
Or does a tycoon divide 'volts' in the place of 'dollars'?
Or have you ever added 'miles' instead of 'bottles of beer'?

Certainly not. Each individual adopts the terminology pertaining to his job, however one discovers that computer professionals like to import the idiom from unrelated domains into their own sector (Everest, 2007). Besides the terminology appropriate to the hardware and the software techniques, computer experts often call tables (2.9) and (2.10) as '*truth tables'* and use the adjective '*logical*' for the Boole operations even if the gates do not achieve any logic calculation but mix up bits that are signifiers. The hardware operations (2.9), (2.10) are used for the purpose of creating original bit-strings and do not explicate '*logical statements*' exclusive to the logic domain. Circuits swap the bits around. Electronic chips do not execute immaterial actions but physical operations because signifiers are concrete entities.

I find this behavior extremely bizarre and somewhat absurd. I am incapable of finding a reason for such a linguistic enterprise which conceals the rational profile of the digital techniques and worsen the job situation of ICT practitioners.

C. Progressive Standard Assembly

Boole's algebra begins with a precise set of objects and operations:

1. Signifiers = the *bits*,
2. Operations = the *gates AND, OR, NOT*.

This theoretical premise entails that *hardware systems are equipped with standard parts* of necessity (Tocci et al 2006), whatsoever message and whatsoever circuit are built up using exclusively components 1 and 2. Digital creators sketch any solution by means of well defined groups of initial elements. In practice they join together the listed parts in various ways and obtain an astonishing variety of products.

Of course the fabrication process follows a progressive pathway: the tiniest parts are joined in the first step; the outcomes of previous steps are connected later.

The progressive standard assembly is the fundamental protocol in the digital domain.
[2.3]

The progressive standard assembly is the regulation allowed by the Boole algebra that casts further light on the rational profile of the digital paradigm. This technical domain appears to be well governed by theoretical concepts.

I shall concisely discuss the major stages necessary to assemble complex messages and intricate circuits. Technical manuals illustrate details which we do not have space here to explore further.

Stages			*Actors*
5 th	**Hypermedia**	*Rich in Contents Imagination*	*Users*
4 th	**Texts, Pictures, Sounds etc.**		*Users/ Software experts*
3 rd	**Common Words, Frames etc.**		*Users/ Software experts*
2 nd	**Binary Words**		*Hardware experts*
1 st	**Bits**	*Poor in Contents Calculus*	*Hardware experts*

Figure 2.19. Progressive standard construction of digital information.

1. Assembly of Signifiers

The first stage consists in the design of elementary signifiers – the *bits* – in the intended technology e.g. electrical, optical, mechanical. Then a *binary word* stands for a character, or a figure, a symbol, a sound, a color etc. Thirdly authors prepare a common *word*, a decimal *number* or other compounds by joining binary words. At the fourth stage authors prepare a *text*, a *document*, a *picture*, a *piece of music* etc. by joining together the previous components. Lastly authors assemble various forms previously prepared and obtain a *hypermedia*. A web-page that offers texts, pieces of music, maps, diagrams, films and interactive tools makes a fine example of multimedia communication.

Electronic engineers work around the first two stages; they construct bits and binary words using the formulas just seen and even other measures. Mathematicians have defined a considerable number of binary codes for the benefit of practitioners.

The items at 3rd level are established through calculus or otherwise may be created by means of imagination. The items at 4th and 5th levels lie under the domain of creative thinking, artistic imagination or personal sentiment. People set up complex messages according to communicative feeling and it is evident how the outcomes of the upper stages are rich in contents and figment. The present scheme spells out how hardware experts are little concerned in the symbolism of signifiers as we have seen in the previous chapter.

Bits are reliable and work in a manner similar to the regular bricks that guarantee that a house built with them is solid. Technicians take care of the initial phases likewise brickworks produce standard bricks. By contrast the interior of a house is designed under the influence of human tastes so levels 4th and 5th rely on peoples' feeling and emotion. At the bottom technicians are responsible for the rigid assembly steps; at the top drawers, creative, users, secretaries, employees etc. contrive the upper pieces of information. The orderly and intelligent organization of the work is evident.

2. Assembly of Circuits

Any message consists of bits, hence a binary circuit gets a string of bits and carries on a new sequence of bits. Circuits basically make combinatory tasks and execute very intricate actions.

Boole's algebra defines the most straightforward operations for scrambling bits. The gates AND, OR bring forth four actions, the gate NOT does two actions. They never step out of the lines listed in (2.9) and (2.10) even in case of errors since the excluded middle rule prevents non-bit signals from being generated. Gates have a defined conduct and it is easy for a designer to connect the outputs of one gate to the inputs of another gate. Engineers create any digital circuit from the AND, OR and NOT, using them as a sort of building blocks. They bring together the gates following regular assembly.

Stages		***Actors***
5 th	**Operations** (e.g. Addition, Division)	*Hardware experts*
4 th	**Sequential Circuits** (e.g. Counter, Register)	"
3 rd	**Combinatorial Circuits** (e.g. Coder)	"
2 nd	**Complex Gates** (e.g. Nand, Nor)	"
1 st	**Gates** (And, Or, Not)	"

Figure 2.20. Progressive standard construction of digital circuits.

At the second step we find the *complex gates* NAND, NOR, and XOR where the basic gates are wired in series or parallel. To exemplify, NAND is obtained by joining AND and NOT. At steps 3 and 4 we find *combinatorial circuit*s using all the previous gates, and *sequential circuits* that are to be synchronized such as *memories*. *Digital operations* – at the fifth step – include the components created in advance.

Integration processes, optimization techniques, special calculations and other measures run through the assembly procedure. Anyway, electronic engineers draw a broad variety of equipment following a unique rule from the first stage up to the fifth stage. They design the logic of mobile phones, digital TV, satellite navigators, computers and so forth through the progressive standard assembly of parts. Standard components are used in many different areas of application and users enjoy multiple advantages.

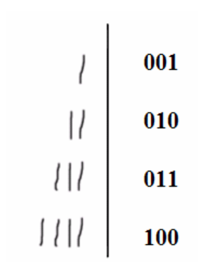

Figure 2.21. Analog and digital numbering.

Concluding, the digital paradigm is strongly grounded on theory not only because bits comply with the sharpness principle which I have introduced, but also because the digital paradigm is governed by the law of the excluded middle; digital designers use the Boole algebra and adopt linear and standard methods of work.

4. ENCODING

The digital paradigm shows an elegant style from the formal viewpoint because of the theoretical support received in literature, but the reader may perhaps wonder whether the digital mode is powerful enough to comply with the requirements of users. In particular one may question if the progressive assembly is capable of conveying all the messages necessary for human communication.

Encoding is the technique that covers three steps out of five in Figure 2.19 and I have now to go deep into this argument.

A. The Exponential Law

Encoding consists in building compound signifiers – usually called *words* or *codewords* – by means of *elements* – also named *modules* – of a prearranged set – the *alphabet* – and later assigning a precise meaning to each word. For the sake of simplicity I shall usually refer to written words, and the modules shall be intended as letters, digits, characters, punctuation marks etc.

Coders – namely the persons who prepare a code and assign meanings to each codeword – arrange the elements of the assigned alphabet in a line and scramble the elements to ensure differentiated signifiers in accordance with the principle of sharpness. Combinatorics – a branch of pure Mathematics concerning the study of discrete elements – certifies that each codeword differs from any of the remnants. For instance, *00*, *01*, *10* and *11* are obtained by swapping the bits *1* and *0,* and the four codewords verify six inequalities

$$00 \neq 01; \quad 00 \neq 10; \quad 00 \neq 11; \quad 01 \neq 10; \quad 01 \neq 11; \quad 10 \neq 11$$

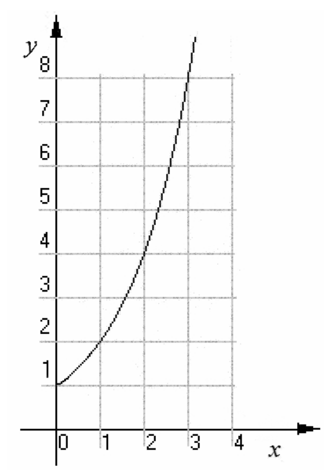

Figure 2.22. Exponential curve (a = 2).

Coders do not portray or imitate the objects of the reality as analog creators do. Scrambling is a mechanical and cool operation far different from the creative activities of analog inventors. The iconic reproduction of numbers exhibits – for example – a stroke or another stylized image for each unit to be represented (see left side of Figure 2.21). The analog author adds a new stroke to the previous ones when the objects rise in number and he tends to create a realistic image. The writer alludes to the physical objects by direct way and does not resort to Combinatorics.

Combinatorial analysis provides the grand total N of the codewords attainable by a coder when the words have the fixed length L and the alphabet has a symbols

$$N = a^{L} \qquad L \geq 1;\ a \geq 2 \tag{2.12}$$

For example, the total amount of codewords from *00* to *99* is squared ten

$$N = 10^2 = 100$$

Equation (2.12) is an exponential function of the kind

$$y(x) = a^{x} \qquad a \geq 2 \tag{2.13}$$

Where x is the variable that potentially ranges from zero to infinity.

Equation (2.13) grows faster than any polynomial function. This feature goes beyond common imagination. I mean to introduce this astonishing mathematical property through a pair of cases which should be useful for readers even if they are unfamiliar with Mathematics.

Nuclear fission consists of a chain reaction that exponentially expands (Giancoli 1984). The reaction starts with one neutron injected by an external device – this is a first generation neutron – and a uranium-235 atom absorbs this initial neutron and splits into two new atoms releasing an amount of energy and 2 or 3 more neutrons depending on the way in which the uranium nucleus splits. Those 2/3 neutrons are second generation neutrons. They, in turn, prompt the fission of 2/3 uranium atoms and produce third generation neutrons. Nuclear fission chain reaction produces neutrons 2/3 times greater at any generation. Each nuclear reaction generation will produce 2/3 times as many neutrons as went into it. The exponential function depicts how the number of neutrons U bursts on

$$U(t) = e^{\frac{\alpha}{\tau}t}$$

Where α is a constant; τ is the average lifetime of each neutron before it either escapes from the core or is absorbed by a nucleus and e is the Neper constant approximately equal to 2.718. The energy released by a single atom is extremely modest but the fast progression depicted by the exponential law causes the bursting power of the nuclear bomb well-known to mankind after the Hiroshima and Nagasaki bombings.

A man and a woman procreate and generate n_1 babies; these in turn give birth to n_2 little ones and so on with geometrical progression over time. The number of people after a certain time t is obtained by the exponential equation

$$N(t) = N_0\, e^{rt}$$

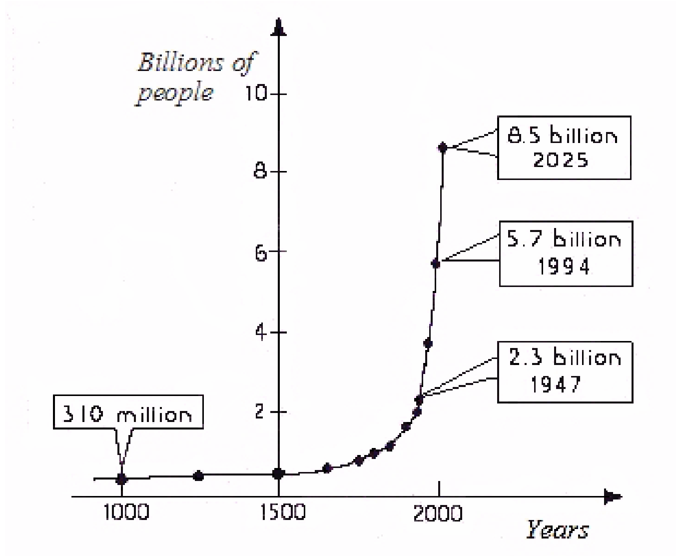

Figure 2.23. Growth of world population (Source UN Fund 1994).

Where N_0 is the starting population at $t = 0$ and r is a constant depending on the values n_1, n_2, n_3, n_4… In the past millennia substantial infant mortality, plagues and exterminations smoothed this theoretical calculation. In the modern era – say from 1500 AD onward – authentic data furnish evidence of the exponential growth of population which constitutes an enormous social problem due to its irresistible rate of increase. The expansion of the human race resists the massive loss of lives occurring in various parts of the globe. Earthquakes, wars, famines, tribal carnages, tsunamis, terrorist attacks and other lethal occurrences do not flatten the population growth curve. Even the First and Second World Wars – two horrendous massacres which caused millions of deaths – did not slacken off the bursting rise of the masses which provide evidence of the extraordinary force of the exponential law.

Sometimes we find it difficult to perceive the astonishing growth of the exponential function because the slow initial progress of the function deceives us. I would like to comment on the deceptive beginning of the exponential function by narrating an interesting story.

A legend says that a young man invented the game of chess and brought his invention to his king. The king was enthusiastic about the chess game and offered the inventor any reward he wanted. "All I want is for you to cover this chessboard with corn as follows: one grain for the first square; two grain for the second; four grain for the third square... and so on for all squares". The request amazed the king who suspected the request was much too modest and the young man added: "Your majesty, you have to double that grain of wheat until the chessboard is full". The king ordered baskets of grain to be brought in and the counting began. For the first row of the chessboard (eight squares), the payment was 1, and 2, and then 4, and then 8, and then 16, and then 32, and then 64, and then 128 grains of corn. Far less than a bushel and the king was smiling. For the next row, the payment was 256, and then 512 and at the end of the row 32,768, almost a bushel. For the third row, the final square totaled 8,388,608 grains. The king was flabbergasted, and the operations stopped since the king could not provide enough grains to give the inventor a chessboard's worth of grains. Why?

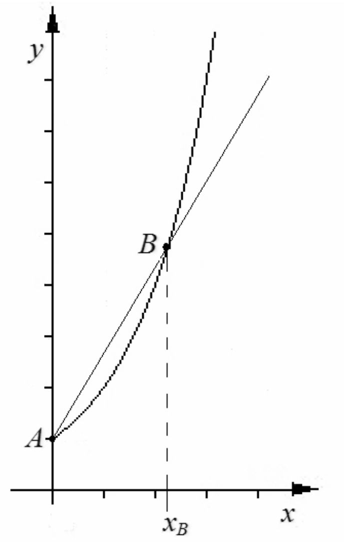

Figure 2.24. Initial profile of the exponential curve.

The chessboard problem involves adding up 64 exponential terms that make the ensuing geometric progression

$$2^0, 2^1, 2^2, 2^3, \dots , 2^{63}$$

The grand total of grains is a number of twenty digits, exactly 18,446,744,073,709,551,615 grains. There are not enough grains in the whole world to give the young man the sum. H.J.R. Murray (1985) estimates that the required quantity of grain is sufficient to cover England to a depth of 12 meters: an incredible amount respect to the modest quantity covering the first two rows of the chessboard.

One normally believes that the exponential growth should start suddenly, and the steep slope should begin immediately. But this idea is somewhat misleading and one falls into a trap. I take the following straight line as a good comparison term for (2.13)

$$y = mx + 1 \qquad\qquad m > a \geq 2 \qquad\qquad (2.14)$$

Suppose m=(a+1) for the sake of simplicity (Figure 2.24). The line climbs immediately behind the point A; whereas the incline of the curve $y=a^x$ is lower in the initial range and carries on with high values only beyond the point B where the exponential function surpasses the straight line (2.14). The exponential curve produces modest outcomes in the initial range but shortly thereafter climbs in an irresistible manner. It may be said that $y=a^x$ has a 'cool start'. The size of the 'warming period' – say the interval (0, x_B) – depends on the base. The smaller is a, the more the warming range turns out to be deceptive. The minimum base of (2.13) has so long a 'knock-up' as to fool the king of the story narrated above.

The 'warming range' results in a special effect on coding. A small alphabet comes up to user's expectations when the user has a dozen items to codify, but as soon as the user needs a larger amount of codewords the words' length reaches critical values. E.g. binary words which are 10 bits in length codify a little over 1,000 objects. A natural language handles a number of topics that go far beyond 1,000 and people should exchange monster-binary-words when they adopt the binary alphabet.

It is evident how humans labor to handle words containing dozens and dozen of symbols and prefer short words. This tendency is apparent in English. The *Short Word Rule* observes that several English *grammatical words* have one or two letters such as *I, we, in, at, if, of*, etc. and some *content words* sound similar to short grammatical words and have a few redundant characters in the written version such as *in/inn; of/off; be/bee* (Carney, 1997).

Appliances handle voluminous signifiers without much effort, whilst people prefer to use large alphabets that generate words far smaller than binary words. The throughput of a modern written alphabet brings forth a lot of short words. For example the numbers of words compiled with the Latin alphabet are the following ones

$26^1, 26^2, 26^3, 26^4, 26^5, 26^6 \ldots$

The first term spells out that there are 26 monograms; next there are 676 bigrams which are words made up of two letters; 17,576 trigrams; 456,976 words of four letters, 11,881,376 words of five letters; 308,915,776 words of six letters. It is enough to stop here, and to see how words with six letters in length are capable of signifying billions of objects, events and ideas.

The human preference for large alphabets is a universal tendency. There are 26 letters in the Latin alphabet, 28 basic letters in the Arabic alphabet, 29 in the Cyrillic alphabet, and the Hebrew alphabet consists of 22 letters. The "*Guinness Book of World Records* (1995 edition)" lists the Khmer or Cambodian alphabet as the largest alphabet in the world which consists of 33 consonants, 23 vowels and 12 independent vowels. The Khmer language is the official language of Cambodia and approximately 12 million people use it in Cambodia, Vietnam, Laos, Thailand, and China. The Thai language with 44 consonants, 15 vowel symbols and 4 tone marks is the second largest alphabet in the world. On the other hand we learn that the Rotokas alphabet, used by some 4,000 people in Bougainville, an island to the east of New Guinea, contains only 12 letters and is considered to be the smallest written alphabet.

Thus the smallest alphabet has a dozen letters and the largest about sixty, so that roughly speaking, the alphabets familiar to humans are from five to thirty times greater than the binary alphabet.

Large alphabets provide a further benefit. Six-letter in the Latin alphabet generate 308,915,776 words, an incomparable quantity with respect to about 3,000-10,000 words sufficient for a layman to make himself understood in common speech. The enormous surplus of words generated by any human alphabet clarifies why a sole written alphabet can serve dozens of languages with modest overlapping. The Latin letters are used by nine languages out of the 30 most spoken languages such as English, Spanish, Portuguese, French, Indonesian and German (in order of popularity). The grand total of the Latin-alphabet users reaches about 1,713 million people. Lastly the abundant amount of available words makes the verbal communication very articulate and easy to be controlled as we shall see in Chapter 7.

B. A Monster Number

The function $y=a^x$ ensures the massive production of signs which go beyond the needs of any community. A population adopting any written alphabet does not use all the words available in that alphabet. The used words make a small fraction of the writable words which constitute an enormous set. The exponential law surpasses the writing needs of people at an unimaginable level.

“The Library of Babel", a lovely allegory written by Jorge Luis Borges (1994) seems to me very efficacious in demonstrating the force of digital encoding. This story deals with the surrealistic library containing every possible combination of a book which is 410 pages in length; each page containing 40 lines; each line 80 letters. “In the vast Library there are no two identical books” and there are treasures beyond measure. Borges writes:

> On the shelves somewhere are "the minutely detailed history of the future, the archangels' autobiographies, (…) the Gnostic gospel of Basilides, the commentary on that gospel, the commentary on the commentary on that gospel, the true story of your death, the translation of every book in all languages, the interpolations of every book in all books, the treatise the Bede could have written (but did not) on the mythology of the Saxon people, the lost books of Tacitus".
>
> How is it possible to make a search inside that library?
>
> The faithful catalog of the library is supplemented with "thousands and thousands of false catalogs, the proof of the falsity of those false catalogs, a proof of the falsity of the true catalog".

Borges’ suggestive tale holds a great amount of meanings. The title referring to the biblical tower of Babylon intends to highlight the confusion generated by a wealth of information. In addition it may be said that the imaginary book collection foreshadows the impressive amount of data gathered in the World Wide Web. The author also draws a parallel between the Universe and the Library of Babel that “exists ab aeterno” and whose books are all placed in hexagonal bookshelves in order to occupy all the available space in the Universe

> “The universe (which others call the Library) is composed of an indefinite and perhaps infinite number of hexagonal galleries, with vast air shafts between, surrounded by very low railings. From any of the hexagons one can see, interminably, the upper and lower floors. The distribution of the galleries is invariable. Twenty shelves, five long shelves per side, cover all the sides except two; their height, which is the distance from floor to ceiling, scarcely exceeds that of a normal bookcase. One of the free sides leads to a narrow hallway which opens onto another gallery, identical to the first and to all the rest. (…) In the hallway there is a mirror which faithfully duplicates all appearances. Men usually infer from this mirror that the Library is not infinite (if it were, why this illusory duplication?)“

The dimension of the Babel library cannot be fully described in words. Even a great writer such as Luis Borges has no suitable terms to accomplish this task. Solely Mathematics can describe the fantastic honeycomb structure of the Babel universe. A book with the dimensions mentioned above contains 1,312,000 characters

$$410 \times 40 \times 80 = 1{,}312{,}000$$

Borges adds that the orthographical symbols are twenty-five in number. Using the exponential function we obtain the number of books in the Library of Babel

$$25^{1,312,000} \approx 2\times10^{1,834,097}$$

One can put this quantity down on the paper in an easy way but this quantity is literally unimaginable. I allude to the astronomical extension of the Universe in an attempt to explain this number.

The most remote object we observe in the interstellar space is quasar ULAS J1120+0641 discovered in the year 2011. It took 12.9 billion years for its light to reach us and thus all that we see in the Universe is included in a sphere of nearly 25.8 billion light-years in diameter. A light-year approximately corresponds to 9.4×10^{15} meters therefore the diameter of the visible Universe is

$$(25.8\times10^{9})\times(9.4\times10^{15}) \approx 2.4\times10^{26}\ \text{m}$$

William G. Bloch in his recent book (2008) claims that if each book of the Library were the size of a proton – about 1.7×10^{-15} m – our universe would still not be big enough to hold anywhere near all the books. Not even two or three universes are enough. We should have billions and billions of Universes to host the Babel Library when each book is as tiny as an invisible particle.

Borges' tale starts with a normal book with 410 pages and leads to a monster quantity. Borges's nice metaphor offers an aid to grasping the unimaginable properties of the exponential law and in turn the power of the digital paradigm which is capable of preparing endless pieces of news.

C. Measures of Distance

Encoding conforms to the inequality $E \neq E^*$ since a generic codeword belonging to a code differs from any other word of the same code. Technicians should like to measure how much any two words differ, but this measurement is unachievable at large.

One finds a nice exception with the binary alphabet.

The dissimilarity of the generic binary words E_j and E_k is given by the number of positions at which the corresponding symbols are different. For instance, all the corresponding bits mismatch between $E_j=0101$ and $E_k=1010$. They are absolutely different and the distance between E_j and E_k reaches the maximum that equals the length of each word

$$d_{jk} = L_{jk} = 4$$

Given a code, experts calculate the distances between any two pair, and the minimum value of these distances – named *Hamming distance* – specifies the overall quality of that code (Russell 1989). Technicians appreciate the reliability of a code through insecure media using d_H. The higher is d_H, the more that code is reliable. For example $d_H = 1$ in the ensuing code {*00,01,10,11*}. When the last bit inverts in the string *00*, this string becomes identical to *01* and one cannot distinguish the first word of the code from the second. The code {*0000,0011,1100,1111*} is more reliable in the face of risks than the previous code, in fact d_H = 2. At least two bits should invert to make a codeword equivocal.

D. Assignment of Meaning

A written codeword does not resemble anything in the world and coders assign the significance to words without preliminary restrictions. Coders employ of the principle of arbitrariness with full degree of freedom because of the independence of codewords from the signified. In the computer sector coders adopt an algorithm or otherwise the *semantic table,* a two-entry table that mirrors the scheme $E \rightarrow NE$ directly. Coders are rarely guided by imagination. They pursue scientific objectives for example they handle meanings in order to speed up the circuit operations, to reduce the store size etc.

Coders apply some intelligent expedients to enhance the quality of a code. For example gaps amongst the words make the *discrete code*. New codewords will be inserted in the discrete code which can include random updates. Natural languages inspire *mnemonic* codewords which are easy to remember. For instance, the *country code* consists of two letters copied from the country name, so that each word can be effortlessly recalled to the mind.

DE	*Deutchland*
FR	*France*
IT	*Italia*
ES	*España*
PE	*Peru*
AR	*Argentina*

Figure 2.25. Semantic table.

Coders adopt variable-length coding to reduce the size of storage and the time of transmission. For example, instead of occupying 20 bits (= 4×5) using the following fixed-length words

0000 0001 0010 0011 0100

The following variable-length solution occupies 9 bits (= 1+1+2+2+3) that implies 55% of memory reduction and transmission time

0 1 10 11 100

Coders assign the meanings to the words according to the *occurrences* (or *frequencies*) of the words and this trick further reduces the elapsed shifting time due to transmission and the amount of store occupied by variable-length codewords.

Shortest codeword	*Most frequent subject*
…	↓
…	
…	
Longest codeword	*Less frequent subject*

Figure 2.26. Ordered semantic table.

In practice a coder orders the codewords according to their lengths in the semantic table and places the subject contents to be represented according to the frequencies of use which follow the inverse order. That is to say, a coder assigns the shortest word to the most frequently used message; and couples the most cumbersome codewords to rare subject matters. S.E. Morse applied this criterion when he wrote his famous code. One dot symbolizes the letter *E*, the most frequently employed in English; the letter *Q* far less used consists of two dots and a dash. Communication systems adopted the Morse code for one century – longer than any other electronic encoding system – and made minor changes due to Morse's efficient design.

CONCLUSION

The present chapter starts with the discussion of the essential differences emerging between the analog and the digital paradigms.

A. Basic Guidelines

Once we verified that the criteria natural/artificial and continuous/discrete are reasonable but not exhaustive, we plunged into the argument and ascertained how the digital paradigm is grounded upon statements that can be formally expressed. In particular we have examined:

1. The *sharpness principle* that ensures neat elementary signifiers.
2. The *law of the excluded middle* that fixes the binary alphabet.
3. The *Boolean calculus* that offers the exhaustive mathematical basis.
4. The *standard assembly rule* that implements solutions using standard components and methods.
5. The *exponential law* that ensures immense amount of signifiers.
6. The *principle of arbitrariness* that enables accurate, flexible assignment of meanings.

Rule 2 derives from 1 in point of logic; calculus 3 has 2 as prerequisite; standard elements 4 are warranted by 3 and the exponential law 5 is a part of 4. This just to say that the rules from 2 to 5 are consistent; and have their roots on the principles of sharpness and arbitrariness. Points 1 and 6 govern all the procedures followed by digital practitioners in the professional practice and prove how the digital paradigm has a theoretical solid basis whose roots stem from Semiotics.

Computers and other digital appliances lie under the umbrella of consistent conceptualization whose tenets and equations we have examined step by step. These formal expressions demonstrate the similarity between the digital sector and pharmacology intended as the systematic study of drugs.

The current literature does not pay much attention to all the details which have been discussed in these pages, and consequently the boundaries between analog and digital appear as an uncertain frontier. Thinkers do not have much evidence of the rational conduct of digital due to the incomplete illustration of the six rules that give orientational support to scientists and practitioners.

B. Objections

The reader may object that electronic engineers calculate the Boolean circuits but, for example, are unaware of the sharpness principle. They are rather unfamiliar with the terms '*signifier'* and '*signified'* and with other topics introduced in the previous pages.

I put forward the following answer.

Some concepts discussed heretofore sound rather apparent. The concepts of signifier and signified are consistent with common sense. It appears as a somewhat natural fact that a piece of information has a physical basis and stands for something. Even layman's experience shows how signs must be sharp and distinguishable. The principle of arbitrariness merely claims that people can assign meanings without restrictions. Hence the lack of official statements may be considered rather inconsequential in the working environment. Experts are capable of grasping fundamental rules in the digital sector even if they are not well acquainted with the formalization discussed in the previous pages.

This mode of operation is not new in the history of sciences.

Primitive men invented the wheel while they were absolutely unaware of the principles of Mechanics. Mankind proceeded by trial and error for millennia. Practitioners built up astonishing mechanisms, buildings, military equipment and discovered other outstanding solutions of mechanical problems by virtue of the natural perspicacity of their minds; they had no formal statements in hand, which were formulated far later.

The reader may even object that the semiotic principles of sharpness and arbitrariness sound somewhat linear.

This is absolutely true. Dictionaries tell us that a '*principle is a basic truth'*, and usually a straightforward issues expresses a general rule. For instance the second law of Mechanics expresses the proportionality of acceleration and mass to force

$$f = m \times a$$

An essential cornerstone of Mechanics is no more than a multiplication. Also Chemistry, Optics, Electronics and other disciplines are grounded upon rather simple theoretical statements. A basic law usually exhibits a simple form, and does not require much effort to be understood by a reader.

By contrast it took long to arrive at this law. The scientific method is based on gathering observable, empirical and measurable evidences, and the formulation of a conclusion must match with tests and practical verification. General issues require strenuous labor to be defined as authors dissect a lot of documents and facts, and have to ponder all of them. The earlier ideas on the signifier and signified date back to Greek philosophy. Thinkers digressed into examination of dubious analogies and engaged in debates over conflicting theories. After prolonged discussion the thought matured and advanced to the modern semiotic notions. As a gold-digger sifts out gold from tons of sand, so a theorist filters large amount of experimental evidence to obtain a sole simple principle that covers a wide area of interest. Therefore, it is natural that the present book bases the discussion on a large number of down-to-earth cases, examples and counterexamples.

BIBLIOGRAPHY

Aftab A. (2003) - *Data Communication Principles for Fixed and Wireless Networks* - Springer.

Allison A., Currall J.E.P., Moss M., Stuart S. (2005) - Digital Identity Matters - *J. of the American Society for Information Science and Technology,* 56 (4), pp. 364-372.

Anapolitanos D., Baltas A., Tsinorema S., Athenon P. (eds) (1998) - *Philosophy and the Many Faces of Science* - Rowman & Littlefield.

Blachowicz J. (1998) - *Of Two Minds: the Nature of Inquiry* - Suny Press.

Bloch W. L. (2008) - *The Unimaginable Mathematics of Borges' "Library of Babel"* - Oxford University Press.

Borges J.L. (1994) - *Ficciones* - Grove Press.

Boylestad R.L., Nashelsky L. (2005) - *Electronic Devices and Circuit Theory* - Prentice Hall.

Brown F.M. (2003) - *Boolean Reasoning: The Logic of Boolean Equations* - Dover Publications.

Carney E. (1997) - *English Spelling* - Routledge.

Dretske F. (1981) - *Knowledge and the flow of information* - MIT Press.

Everest B.M. (2007) - *Philosophy and Fun of Algebra* - Chapman Press.

Giancoli D.G. (1984) - *General Physics* - Prentice Hall.

Goodman N. (1968) - *Languages of Art* - Hackett Publishing.

Goodstein R. L. (2007) - *Boolean Algebra* - Dover Publications.

Lewis D. (1971) - Analog and Digital - *Nous*, 5, pp. 321-327.

Murray H.J. (1985) - *History of Chess* - Benjamin Press.

Russell D. (1989) - *The Principles of Computer Networking* - Cambridge University Press.

Tocci R., Widmer N., Moss G. (2006) - *Digital Systems: Principles and Applications* - Prentice Hall.

Watzlawick P., Beavin J. H., Jackson D. D. (1967) - Some Tentative Axioms of Communication - In *Pragmatics of Human Communication: A Study of Interactional Patterns, Pathologies, and Paradoxes*, W.W. Norton & Company, pp. 48-71.

Wilden A. (1972) - Analog and Digital Communication: On Negation, Signification and the Emergence of Discrete Elements - *Semiotica,* 6(1), pp. 50-82.