

Chapter 1

Time

1.1 Sympathy for Clocks

Christiaan Huygens wrote about his first discovery of synchronization in a letter to his father Constantyn, dating back to 1665:

“While I was forced to stay in bed for a few days and made observations on my two clocks of the new workshop, I noticed a wonderful effect that nobody could have thought before. The two clocks, while hanging [on the wall] side by side with a distance of one or two feet between kept in paces relative to each other with a precision so high that the two pendulums always swung together, and never varied. While I admired it for some time, I finally found that this happened due to a sort of *sympathy*: when I made the pendulums swing at different paces, I found that half an hour later they always returned to synchronism and kept it constantly afterwards, as long as I let them go. Then I put them further away from one another hanging one on one side of the room and the other one fifteen feet away. I saw that after one day, there was a difference of five seconds between them, and consequently their earlier agreement was only due to some sympathy that, in my opinion, cannot be caused by anything other than the imperceptible stirring of the air due to the motion of the pendulums. [...] and the vibrations of the pendulums when they have reached synchronism are not such that one pendulum is parallel to the other, but on the contrary, they approach and recede by opposite motion.”

1.2 Music is Time

Steve Strogatz, in his brilliant book on synchronization, noted: “At the heart of the universe is a steady, insistent beat: the sound of cycles in sync. It pervades nature at every scale, from the nucleus to the cosmos”

(Strogatz, 2003). Even our bodies are participating at every scale to these rhythmic symphonies (Zerubavel, 1981).

In his recent book on *musicophilia*, Oliver Sacks stressed how our nervous system is exquisitely tuned for music. But, how much of this is due to the intrinsic physical characteristics of music itself and its complex sonic patterns woven in time? Its logic, momentum, sequences, rhythms, repetitions and the mysterious way in which it embodies emotion, all play an important role. Just how much depends on special mind/brain resonances, synchronizations, oscillations, mutual excitations, and/or feedback in the immensely complex, multi-level, neural circuitry that underlies musical perception and replay, is an intriguing matter for research (Sacks, 2007).

E. T. Hall (1983) has been an important figure in noticing that humans in all cultures are engaged in rhythmic dance. He documented the variety of rhythms by studying films of people interacting in a wide range of different situations, from laboratory to everyday life (Hall, 1983).

The role of music in the social technology of bonding is well known, having been explored by anthropologists in studies of tribal rites of passage, ordeals, and ceremonies, invariably accompanied by the use of music, drumming, dance, and other forms of predictable repetitive actions. Robert Jourdain (1997) explored the various possibilities in which music exploits our brain and body rhythms. He highlighted two different notions of rhythm: *meter* consists of a regular pattern of beats; while *phrasing* includes organic and seemingly irregular, but structured organizations of musical shapes. These different kinds of rhythm are usually superimposed but there may be prevalence to it (Jourdain, 1997).

In this complexity of biological and psychosocial interactions, we have a goal to understand how order arises. Order in space seems often to present architectures you can see but explaining order in time has proved to be more problematic and remarkably subtle. We call this kind of order synchrony. Until a few years ago, biologists, physicists, mathematicians, astronomers, sociologists and psychologists all developed the study of synchrony along parallel lines of inquiry. Synchrony, also known as sync, is an attempt to synthesize and integrate a vast body of knowledge on time orders produced in several different disciplines: a science of

synchrony has been coalescing as the study of coupled oscillators. Sync is strange and beautiful at the same time. It is strange because sometimes it seems to defy the laws of physics though it relies on them simultaneously. It is beautiful because it results in a sort of cosmic dance, or rather, a universal orchestra.

Synchrony, after studies on very simple oscillators, like pendulums, tides or transistors, is now dealing with the challenge presented by nonlinear dynamics arising in systems with many variables and a large number of oscillators. Even using super computers, the collective behavior of giant systems involving many oscillators of the same type (for example neurons) or of different type (for example speech, movement and the brain) is a *terra incognita* worth a thorough exploration.

1.3 Concert for Hormones

There are invisible and inaudible concerts. Because of different kinds of forces, the tendency to synchronize is one of the most pervasive causes of order in the universe, from atoms, to animals, from people to planets. An example of how synchrony might involve different intermingled domains is provided by biorhythms. We might refer to the frequency among female friends or coworkers who spend a great deal of time together that tend to synchronize their menstrual cycle. In another book (Orsucci, 2002b), we mentioned an interesting experience on this matter, reported by one of our students. She went to stay in an apartment where two other female students already lived. They were single, friends and already synchronized in their menstrual cycle. They remained synchronized after her arrival but she didn't join them. She explained that she was emotionally distant from their close friendship, probably because she had a boyfriend, while they were single. She also didn't share a lot of time with them. Some months later, she and her boyfriend spent a great deal of time apart due to a new job he had started: she then started feeling alone and became emotionally closer to her apartment mates. They began sharing many activities, spending more time together and with time grew to be close friends. At this point, she was surprised

that her menstruation cycle had become synchronized with theirs. The rhythm of periods for these three female apartment mates remained steady and in sync for months until the girl's boyfriend came back into town: then, suddenly, she became desynchronized. In this example there is a mix of different factors which could have influenced sync and de-sync: spatial proximity, living together sharing a similar schedule and a variation of emotional proximity.

A slightly different story has been reported by another woman, living very far from her sister with whom she still has a strong emotional bond. She and her sister live in two different continents. When they were living together, in their parent's house, they used to synchronize their periods, sometimes even sharing the same rhythm with their mother. Now that she lives so far away, she keeps in touch with her sister via video-chat over the Internet, and she has been noticing that when their video calls become more frequent, their periods become synchronized again. This doesn't happen when video calls are rare.

In this case, sync seems to happen due to different factors: there is no sharing space, no physical proximity, but there is a form of communication which is still carrying visual and voice signals of emotional expression.

The menstrual cycle, in biophysical terms, can be regarded as a noisy coordinated oscillation of several different hormones. The regulation of these hormones occurs via positive and negative feedback loops, as the presence of feedback is a typical feature of self-sustained oscillators. The period of oscillation, as we know it, occurs about every 28 days but can fluctuate considerably. Martha K. McClintock and her research group performed several studies which seem to support the idea of a hidden chemical communication between women (Stern & McClintock, 1998; Jacob & McClintock, 2000; McClintock et al., 2005). For example, she took swabs from the armpits of women at different points of their menstrual cycle and dabbed them on the upper lips of other women. Swabs taken from women at the beginning of their cycles tended to shorten the cycles of women who received them. In contrast, swabs taken from women at the ovulation phase prolonged the cycles of the receivers. This study might support the idea of a 'silent conversation' mediated by chemical messages, probably even pheromones.

McClintock performed another study of the menstrual cycle of 135 females from ages 17 to 25, all of whom resided at the same dormitory in a female college. The findings showed an increase of synchrony during the academic year. This confirmed that social grouping influences the balance of the endocrine system. Particularly, sub-groups of close friends defined by a self-rating scale, showed a reduction of dispersion of their frequencies. Research also showed that physiological, emotional and psychosocial factors can influence hormonal cycles. Whether this might be due to pheromones, and/or psychosocial interactions is still a matter of debate.

All mammals show forms of hormone synchronization and this is usually explained with an attempt to ovulate and conceive in step, in order to share rearing, feeding and the protection of offspring. Reproductive sync has benefits for all, if the group is cooperative. The role of pheromones in this sync process is clear for most mammals as the function of the vomeronasal organ (the part of the inner nose receptive to these chemical signals of pheromones) and its pathways to the hypophysis are proven. This is controversial for humans were this 'nose organ' is considered atrophic, and other psychosocial factors seem to influence menstrual synchronization (Orsucci, 2000).

Self-organization has been called to explain these phenomena. We know that classical science has been following, since the scientific revolution of the 17th century, the adagio "*simplex sigillum veri*": simplicity is the seal of truth. Albert Einstein posed a *caveat* using to say that "everything should be made as simple as possible, but not simpler".

1.4 Resonances

It is puzzling that in mind science statistics are still more important than dynamics, but this might be due to the difficult management of complex data and variables produced by the bio-psychosocial mind *milieu*. Psychophysical variability, for example, is usually treated as an error rather than temporal distributed information about cognitive processes. For example, seemingly random fluctuations can convey

valuable information on human behavior if considered from the dynamic viewpoint.

In a beautiful book, Scott Kelso (1995) described brain activity as being based on rhythms in a “pattern forming, self-organized, dynamical system poised on the brink of instability”. For example, he presented a clever finger-twiddling experiment, in which he explained using his famous model of coordination developed in collaboration with Hermann Haken and W. Bunz: the Haken-Kelso-Bunz (HKB) Model. The HKB model is a basic structure built in order to explain how the brain organizes itself to create the rhythmic flow of behavior, including perception and learning. Although the Haken–Kelso–Bunz (HKB) model was originally formulated to account for phase transitions in bimanual movements, it evolved, through experimentation and conceptual elaboration, into a formal construct for the experimental study of rhythmically coordinated movements in general. The model consists of two levels of formalization: a *potential* defining the stability properties of relative phase and a *system* of coupled limit cycle oscillators defining the individual limb movements and their interactions.



Fig. 1. Christiaan Huygens (1629–695).

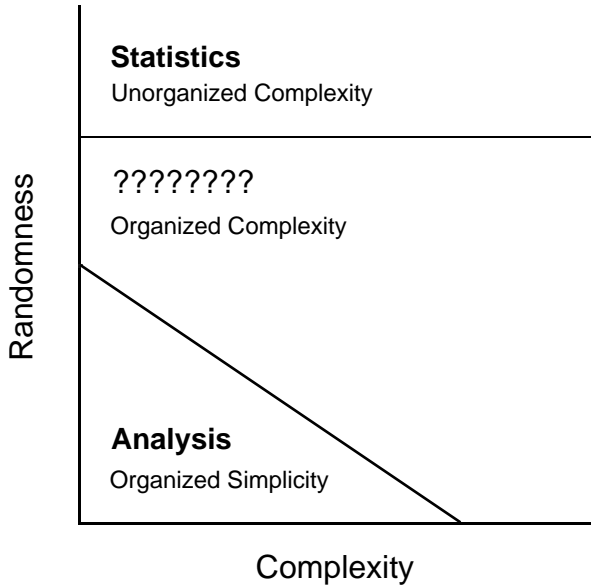


Fig. 2. Complexity, randomness and order.

1.5 Time Dimensions

The time dimension considered in most discussions on dynamical systems is the *absolute* space-time of Newtonian, or classical, physics. In contrast, with this absolute way to look at time-space, Leibniz (1996), who co-discovered differential calculus, had already proposed a *relational* space-time where space is generated by difference and discrimination and time by duration and periodicity.

Rather than thinking of changes as occurring within an independent time flow, we should think of them as *creating time*. We can do this by considering system states as boundaries of time and recurrence patterns as the matter of time (Ward, 2002).

Lorenzana and Ward (1987) argued, in the same line, that systems should be placed in an evolutionary context in which those with increasing complexity emerge from an environment following two principles: *combinatorial expansion* — a linear process whereby the system develops an unrealized potential; and *generative condensation* —

a nonlinear process whereby complexes recombine to create new possible functions. Both processes operate through system-environmental interactions.

Considering all the layers and bindings, waves and cascades of sync phenomena in humans is a great theoretical challenge. This is quite challenging as some of these rhythms are generated at the cellular level as demonstrated by the fact that unicellular organisms express circadian rhythms similar to mammals (Mittag and Volker, 2003). In the individual Central Nervous System (CNS) cells, the expression of so-called clock proteins cycle in double auto-regulatory feedback loops in order to adjust their own transcription in a circadian manner. A circadian rhythm of action potential firing frequency can even be measured in many individual CNS cells when dispersed in cell culture (Welsh, 1995). How then do these individual oscillators communicate with each other in order to construct the resulting *master rhythms*? In the mammalian CNS, the average sum of these individual oscillations can be measured in numerous ways. Studies demonstrate that the circadian rhythmicity of the individual oscillators as well as of the ensemble CNS is maintained even in a brain slice *in vitro* preparation. Given that dispersed cells vary more than cells in organotypic culture, it was deduced that intra-CNS cell coupling is responsible for keeping CNS cells synchronized, even though each autonomous cellular period is determined by its own molecular clock. A model was proposed in which the circadian phases of core oscillators in the CNS are weakly coupled to one another and this syncore then recruits outlying cells to oscillate under the same period. Eventually, the majority of cells in the CNS oscillate with a period close to the average period expressed by the whole organism (Reppert & Weaver, 2002).

More recently, a study examining brain slice cultures described the CNS as a network of at least three separate groups of oscillators, the phases of which distribute around the average phase of the entire network (Quintero et al., 2003). This phase heterogeneity was hypothesized and could probably arise from intercellular coupling. What sorts of intercellular coupling mechanisms are available to CNS cells? Some coupling, which leads to the expression of some circadian rhythms, may

be achieved by also by synapse-independent mechanisms, though direct synapses are responsible for quick and effective interactions. Several alternative coupling pathways have been proposed, such as gap-junctions and diffusible factors.

The discovery that diffusible factors influence circadian rhythms however, does not indicate that diffusible factors are the primary coupling mechanism of circadian rhythms. Diffusible factors and synaptic communication both play a role in coordinating and shaping circadian rhythms. Numerous projections from the CNS to target areas involved in neuroendocrine and autonomic control, are believed to underlie organismic control of circadian rhythmicity (Reppert & Weaver, 2002). Similarly in the CNS itself, diffusible humoral signals, or regularly released peptides, may serve to consolidate the broad circadian rhythms, even in the absence of synaptic neurotransmission. But, the network itself is a circuit of inhibitory synaptic connections that presumably functions as a more immediate cell-to-cell communication mechanism. This may influence other processes as, for example, action potential firing patterns are critical for the coordination between CNS neurons and the projection of a cohesive output pattern to target areas.

1.6 Molecular Oscillators

Independent transcriptional-translational oscillators with relatively short (ultradian) periods can be coupled to generate a circadian oscillator using conventional mechanisms of molecular genetics and reasonable values of parameters describing these mechanisms. The resulting circadian oscillator can be entrained by 24-hour light-dark cycles. The model suggests that evolution of such a circadian oscillator would occur under selective pressure without significantly perturbing the underlying components (Paetkau et al., 2006).

This is a model of a 5-gene circadian oscillator. The components of the first of the primary oscillators are illustrated in the top half of the figure.

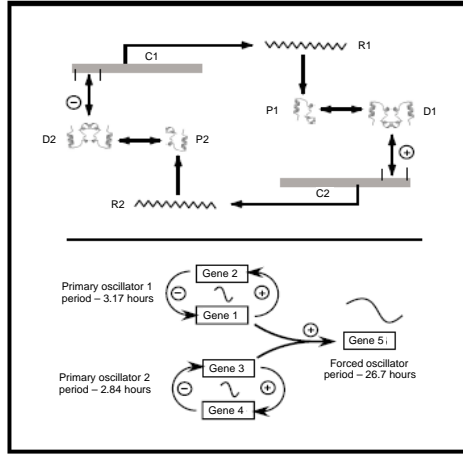


Fig. 3. Model of a gene/protein oscillator (Paetkau et al., 2006).

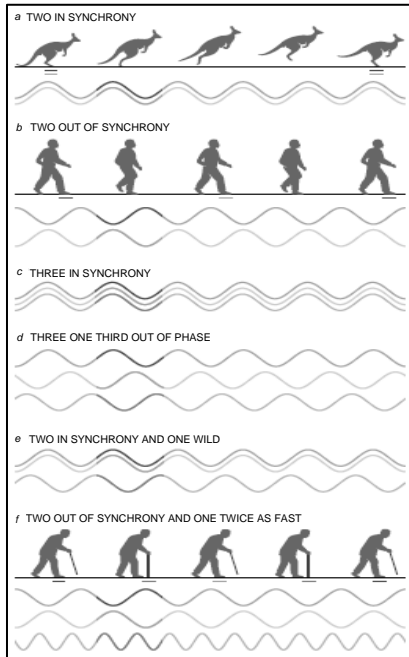


Fig. 4. Motor synchronies.

The overall model is shown in the lower half of the figure. It comprises two independent, ultradian, primary oscillators (genes 1+2 and 3+4, respectively), in which the homodimeric protein product of gene 1 positively regulates the transcription of gene 2, and a homodimer of protein 2 inhibits transcription of gene 1. Genes 3 and 4 are similarly related. The two primary oscillators differ slightly in their respective periods. The protein products of genes 1 and 3 form heterodimers that regulate the transcription of the fifth gene: the forced oscillator. In the present model, and using the parameters given the periods of the primary oscillators are around three hours, while the period of the fifth gene in the absence of light-dark coupling is just over 26 hours.

1.7 Basic Principles

We will now try to summarize some basic notions on synchronization dynamics in order to prepare our further steps for our exploration on Mind Force. First, we might define *synchronization* as *an adjustment of rhythms of oscillating objects due to their weak interaction*. An *oscillating object*, though this definition might recall pendulums and the origins of sync studies, is *an object displaying a periodic behavior*. The *oscillator* can be *self-sustained*, as an active and autonomous system with an internal source of energy. Alternatively, it may also be referred to as a *forced oscillator*, when the source of energy is external, and it is semi-autonomous. The main dynamical feature of the oscillator is *rhythm*, characterized by *period* (the time spent for each single oscillation) and *frequency* (the number of oscillations per time unit). As we have already seen, if there is more than one oscillator, it is possible for some form of interaction, or *coupling*. The interaction can be mediated by many different media, and is usually weak nor is it easy to recognize or measure. The result of coupling is an adjustment of rhythms, often described in terms of coordination of frequencies; also defined as *entrainment* or *locking* (they are synonyms in sync theory). The *coupling strength* describes how weak or strong the interaction is. Another important feature we might mention is the *tuning* or *detuning* (mismatch): this shows how different two or more oscillators are. If the

mismatch is not so...much, there is a higher possibility of entrainment and synchronization. Once sync is nearly in place and we have the possibility that it might be in *phase* or in *antiphase*, like two pendulums that oscillate in the same or opposite directions.

The onset of a certain relationship of two self sustained oscillators will be called *phase-locking*.

There is no synchronization, for example if one system is passive and the other controls it via *resonance*. Another way to exclude synchronization is realizing that the coupling is so strong that there is a *unified system*. In order to categorize a phenomenon as synchronization, we need that all the following criteria are satisfied:

- we analyze the behavior of at least two self sustained oscillators, capable of generating their own rhythms;
- they adjust their rhythms via a weak interaction;
- adjustment of rhythms happens within a certain mismatch.

The conclusion is that synchronization is a complex dynamical process and not a state. Many systems exhibit an alternation of “silence” and rapid activity. These kinds of systems are important in biology as the spiking of neurons, contraction of muscles and macroscopic human behavior can follow this pattern. These kinds of oscillators are called *relaxation oscillators*.

In the 1930s, only periodic self oscillators were known. Nowadays, however, irregular or chaotic self-sustained oscillators are well studied.

We can describe the behavior of the system, as a vector moving by the time evolution of a pair of coordinates. This theater that represents the evolution of the system is called *state* (or *phase*) *space* and the resulting plot can be called *phase portrait*. A periodic oscillation is represented by a closed curve, which can be simple as in the limit cycle or complex as in chaos. The curve, representing all the dynamical behaviors is called an *attractor* and it can be either simple or *strange*, as in the complex quasi-periodicity of chaos (Lorenz, 1993).

The study of synchronization dynamics allows a deeper and clear understanding of how living systems are bounded and connected in the continuous and meandering flow of interactions and resonances we came to call Mind Force.

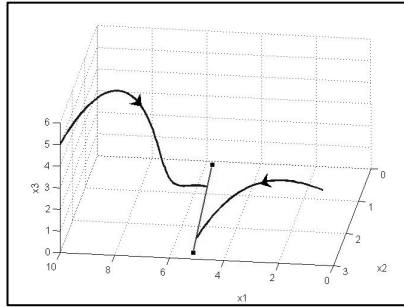


Fig. 5. Line attractor.

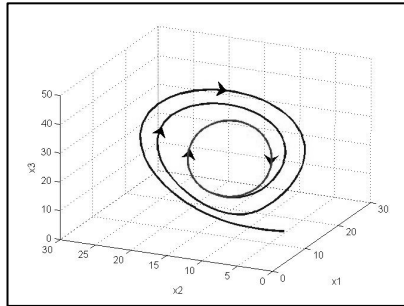


Fig. 6. Circle attractor.

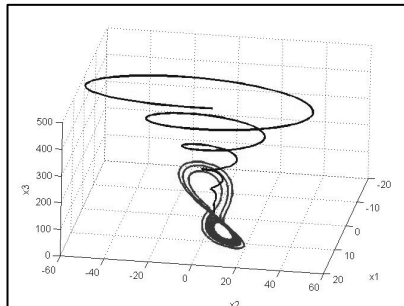


Fig. 7. Strange attractor.

Table 1. Examples of Normal Developmental Coupling of Ultradian Rhythms.

Rhythm	Period, Frequency, Amplitude	Coupling	Comments
heart rate	3 hrs newborn	sleep cycle during development	human
heart rate	3 hrs newborn	circadian 15-30 days of age	human
sleep architecture	newborn, old age	REM 80% REM 20%	human
luteinizing hormone	puberty	sleep + GNRH/LH burst	human: L HR increases 39 fold
<i>nasal cycle</i>	1-5 hrs	autonomic tone and cerebral dominance	decreases with age
blood glucose insulin	6 hrs blood Glucose 24 hrs circadian	mealttime dependent endogenous	healthy adults
Insulin in elderly	irregular release	pulsatile release lost	pulsatile release is lost in elderly