Communication, information and music

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In this brief article, we would like to take the reader on a journey through the fields of information, communication and music, as well as the places where these domains intersect. As it turns out, contemporary and seemingly abstract concepts related to information processing can be conveyed in an accessible form through music. To spice things up, the thoughts in this article are supplemented with pictures of postage stamps, which include all of the above-mentioned concepts.

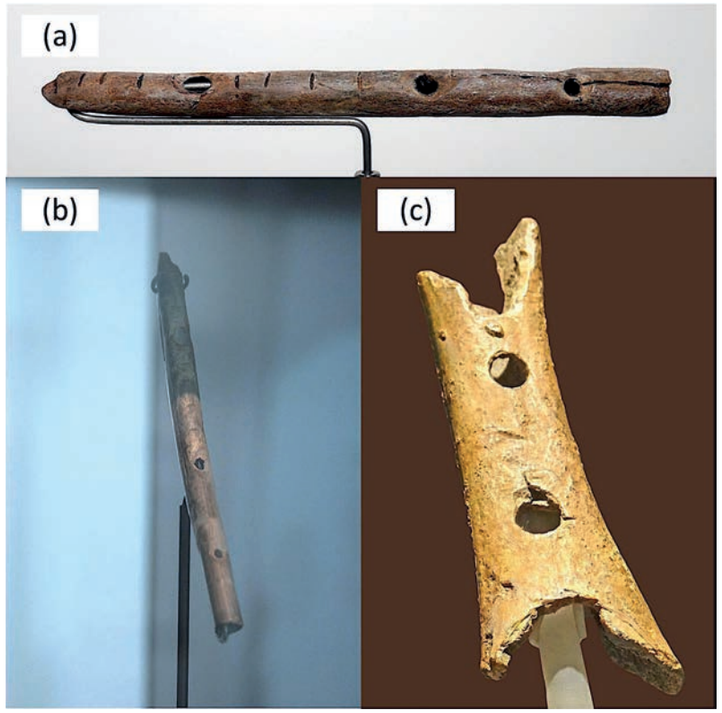

Fig. 1. Paleolithic musical instruments: upper Paleolithic from Geissenklösterle (a), middle Paleolithic flute, ca. 35000-40000 years, (b) and neandertalic flute from Divje Babe Cave (Slovenia, 55000 years ago, c).
Photos courtesy José-Manuel Benito (a), Marco Ciamella (b) and Jean-Pierre Dalbéra (c).

Communication between organisms is an ubiquitous phenomenon, both at intraspecies and interspecies level in all kingdoms: *Archaea*, *Bacteria*, *Protista*, *Fungi*, *Plantae* and *Animalia*. Surprisingly, primitive communication was detected even between individual virions. All these organisms possess both intracellular, intraorganismic and transorganismic communication protocols, however the most complex and interesting ones, from the point of view of information theory, are those between individual organisms. In most cases the intracellular and intraorganismic communication is based on signalling molecules, the same concerns most of the interorganismic and interspecies communication protocols. Communication in general can be described as a sign-mediated interaction between at least two living entities, which share the common repertoire of signs representing a form of natural language. These signs may be combined according to syntactic rules in various contexts (according to pragmatic rules) and used to transport biologically relevant information. Almost all kingdoms of life use molecules as the only available communication tool, whereas animals add vocal and visual communication tools to their repertoire of available signs.

In humans, these evolutionary novelties dominate, almost completely, over the molecular language, however "molecular senses" of olfaction and gustation are still significantly important. Most of animals use senses of vision and hearing for most of their communication purposes. Whereas our own (human) senses seem to be impaired (as compared with some predatory birds), their ability to process signals is still amazing. We have also developed unique ways of communication: music and language, manifested sonically as speech, and graphically as writing. These tools provide an unprecedented opportunity to communicate language and emotions using graphical symbols and aesthetic, religious and cultural feelings via organized sounds of different parameters like pitch, durations, and timbral qualities, arranged in melodic, rhythmic, and harmonic (tonal) patterns.

Music is the only form of natural communication, that is created and perceived only by humans (however studies on animals indicate some aspects of sensitivity to music). Music belongs to human universals, *i.e.* elements, patterns, features, or notions that are common to all human cultures worldwide, however, according to some opinions, it does not convey any biologically-relevant information. According to the mathematician and musicologist Guerino Mazzola "*music embodies meaningful communication and mediates physically between its emotional and symbolic layers*."[4] The importance of music is exemplified by the discovery of Paleolithic musical instruments. Whereas most probably music at early times had no direct effect on the economy or a reproductive success, it may have had provided medium of social integration (Fig. 1). As of today, the influence of *muzak* on our decisions in supermarkets and retail centres proves its impact on real profits from these businesses. Nowadays music is one of the most ubiquitous human activity, independently on any social and cultural attributes or intellectual abilities.

Fig. 2. Prominent musical personalities : Sayed Darwish, Jim Morrison and Frederic Chopin portrayed on postage stamps of United Arab Republic, Germany and Soviet Union.

Fig. 3. Important political changes depicted on postage stamps : socialistic revolution in Bavaria (1918), Upper Silesia plebiscite (1921), Jordanian annexation of the West Bank (1948), the fall of the Nazi Germany (1945), formation of the Soviet Occupation Zone (1948), and the independence of Ukraine (1991).

The importance of music in modern society is unquestionable – composers, performers and musical instruments are leading motifs of numerous postage stamps (Fig. 2), along with monarchs, dictators, religion, nature and sport. Interestingly, in the past postage stamps (first introduced in 1840 by the United Kingdom) were considered as a very effective medium of communication. Therefore, each political or territorial change was (and still is) immediately reflected in postage stamps (Fig. 3). Year 1985 was announced European Year of Music (this fact was commemorated by a numerous series of stamps issued by European countries), and 2019 was announced the Smithsonian Year of Music.

Fig. 4. Examples of musical scores: Die Meistersinger von Nürnberg (R. Wagner) and 2nd Brandenburg Concerto (J.S. Bach) as depicted on German postage stamps.

Music and language are created and processed in distinctly different neural structures but have some common features: they are specific forms of communication, they have specific syntax and vocabulary – *i.e.* they have a set of elements (words or notes) and a set of rules (grammar or harmony and counterpoint) that govern the appropriate combination of these elements. Some kinds of music, like European tonal music, have strict syntax, some others (like dodecaphonic music) may be strictly

Fig. 5. Tjlempung, totobuang, gangsa and kalintang: traditional musical instruments used in gamelan music.

organized while at the same time lacking of audible regularities. Finally, there also exist genres, avant-garde, experimental music, and anti-music movements, which aim at breaking traditional regularities. Such exceptions and declared negation of musical syntax also confirms the existence of one. Music is a domain of human artistic and entertaining activity, but also a field of vigorous studies. Information alike, music is a very difficult notion to define in precise terms; dislike speech, it is not meant for direct communication purposes, especially of biological importance.[5] Conversely, it is meant to trigger various emotional responses in recipients due to aesthetical feelings. On the other hand, music is a very well-organized structure. Even the denial of the existence of such structure, conceptually declared by the author, proves the existence of specific "musical language" with appropriate grammar, syntax and vocabulary – the harmony, rhythmical patterns, timbres and their mutual relations. Therefore, not every combination of sounds should be considered as music. This indicates that music (like hardcore pornography) may be considered as a kind of an emotional communication of the « *I know it when I see it* » type.[6] Despite that, specific fractal signatures derived from compositions can be assigned to

Fig. 6. Sultan's tughra on old Saudi (1934) and Ottoman (1898) postage stamps.

specific genres. The simplest musical message, melody, can be defined as an appropriate time sequence of quantized frequencies, usually noted as a musical score (Fig. 4).

These frequencies, called steps, are strictly defined by tuning systems. Most of musical systems are founded on a concept of the octave: an interval between frequencies of *f* and 2*f*. Octave is an interval between the first and second harmonics of the harmonic series. Therefore, octave is considered as a natural phenomenon that has been referred to as the "*basic miracle of music*", the use of which is "*common in most musical systems*."[7] There exist many different tuning systems,[8] and octave divisions (like Balinese and Javanese *gamelan* systems, Fig. 5). Other musical systems, both traditional (*e.g.* the Middle East, India and Far East), as well as modern experimental musical genres, use different intervals, including division of octave into 4, 5, 7, 34 (to name only a few possibilities), or even 96 equal steps, leading to the whole musical tuning continuum.[9]

These very strict structural rules and mathematical relations are naturally embedded in musical structures.[10] Current progress in computer

Fig. 7. Circulation of goods and information as a decorative motif of postage stamps of Germany and Greece.

sciences, machine learning and artificial neural networks significantly influences musical creativity.[11] Unconventional computing is a natural consequence of research towards new computational paradigms and application of new materials and systems as computational platforms.[12] Therefore, some time ago, the composer Eduardo Miranda has initiated the multidisciplinary research and creative activity in the field at the border of music and unconventional computing.[13] Among the newest computational paradigms, *reservoir computing* is one of the latest discoveries.

Reservoir computing is a computational paradigm that explores the internal dynamics of physical systems for information processing. In principle, any physical system with internal dynamics can serve as a foundation for reservoir computing.[14] Dynamics at the edge of chaos renders a perfect medium for computation as it is the most sensitive for any perturbation of external signals (input data). Graphical representation of such dynamic behaviour usually resembles *tughra*, a calligraphic signature of a sultan, frequently found on postage stamps of Ottoman Empire and Saudi Arabia (Fig. 6).

Reservoirs must be also equipped with input and output ports. Any physical stimulus altering the internal dynamics can be considered as a carrier of information. The output in turn monitors the internal state of a part of the reservoir and is the only trainable (in the sense of machine learning) element of the whole device. Whereas the construction of a reservoir computer following the description given

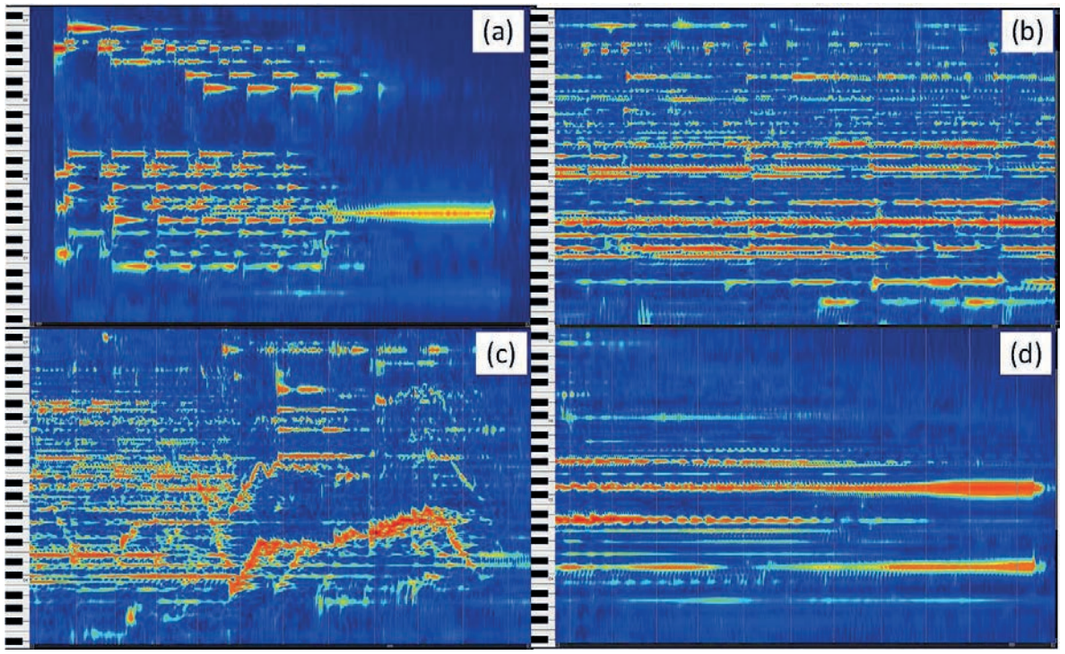

Fig. 8. Spectrograms calculated from the audio path of the Resevoir Study No. 1 world premiere recording.

above may pose significant difficulties, a simplified scheme based on a single nonlinear node equipped with a delayed feedback loop may be equally efficient from computational point of view, however much easier to build and operate. In such systems, the input signal (stream of data) circulates in a feedback loop and undergoes gradual changes (Fig. 7). The evolution of this signal serves as the reservoir state and is used for the generation of the output. This computational scheme has inspired us to compose and perform a piece of music inspired by the concept of reservoir computer.

The *Reservoir Study No. 1* (Marcin Strzelecki, 2019) scored for two electric guitars, cello, piano four hands and electronics is a composition in repetitive minimalism style. It is based on 555 ms delay feedback loop, which repeats and transforms music being played by a consort of musicians. These repetitions and transformations result in harmonic and timbral fluctuations of particular aesthetic quality. Numerous repetitions (both in the score and also added by the feedback) reflect dynamic changes inside the reservoir computer.

The Reservoir Study opens with a short improvisation of keyboard (Fig. 8a), that can be understood as an input for computation. These improvisations are followed by a slowly evolving tune, each bar is repeated four times and subsequently bars introduce subtle harmonic and timbral changes, as a very suggestive illustration of a revolution of signal in a feedback loop (Fig. 8b). In the middle part, this regular pace is suddenly broken and followed by another improvisation loaded with glissandi and irregular rhythmic patterns. Then the reservoir has reached the chaotic state (Fig. 8c)! Musical chaos slowly calms down and the regular pattern is reborn – the reservoir has reached the final state, which is the end of computation (Fig. 8d). Final chords represent the output layer generating the result of computation. World premiere performance of this piece was given by The Nano Consort (Konrad Szaciłowski – cello, Dawid Przyczyna, Kacper Pilarczyk – guitars, Marcin Strzelecki – keyboard, Dominika Peszko, Piotr Zieliński – piano) in Krakow Opera House, September 16th, 2019. Original recording is available as a supplementary material to our recent paper.[15]

This example illustrates the close relationship of contemporary music with unconventional computing, especially with the novel computational paradigms. It also shows how areas seemingly unrelated to art can become an inspiration for it and can be better understood thanks to it.

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