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THE COGNITIVE MECHANISM OF MUSIC

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SUMMARY. Music clearly has a mathematical structure. From the ancient Pythagoreans we know that harmony is the mathematical ratio between the notes (the frequencies as has been discovered by physics). This operation can be performed by the brain which has been seen as a kind of computer by the philosophy of mind of the last decades. And it is an unconscious operation. The conscious presentation of music contains the intervals as phenomenal components, yet not in a mathematical form, obviously, but in a sensorial form, alongside the notes themselves. The experience of music must contain the intervals as cognitions (in the sense that they have phenomenal form), otherwise no music would be possible at all. The phenomenological structure of harmony shows us the notes themselves in the foreground but the intervals in the background that we can still hear and experience it fused with the notes. The experience of the intervals are also not the emotions that music evokes in us - though they are definitely connected in some ways by the neural circuits of the brain and compose further phenomenological structures.

Keywords: Music, Mathematics, Intervals, Cognition, Computation, Phenomenology

Music is a complex phenomenon that includes a multitude of dimensions such as cultural, psychological/cognitive/emotional, physiological, physical, mathematical, philosophical; both as pragmatic and theoretical manifestations. Underlying the complexity of the phenomenon, however, is a relatively simple structure related to the way in which the mind/the cognitive system perceives sounds and conceives/creates the musical experience. The form of this mechanism is mathematical and easily deducible once certain facts are established.

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Already from antiquity, Pythagoras (or his school) discovered that there is an arithmetical relationship between the sounds we perceive as harmonic, (2:1 for the octave, 3:2 for the fifth, 4:3 for the third, etc.), even though it seems that they did not know that it is about the vibration of the air at certain frequencies. It was only in the 19th century that a physical theory of sound was conceived by Heinrich Hertz, whose name is used for the unit of measurement of the frequency of the sound wave 1 Hz=1/s. This constitutes the understanding of the mechanics of sound, of its physical form. Music theory, on the other hand, works at the level of subjectivity, it is interested in intervals, in the relationships between sounds. These do not exist as such in the physical world. In the ontology of the physical world there are instruments, there are acoustic vibrations of certain frequencies, but nowhere do we find anything substantial and/or natural in the form of the mathematical relationship between frequencies, unless we consider the brain and the cognitive system that can perform these operations.

The Pythagorean school seems to have discovered not a purely physical theory, but the cognitive mechanism by which we conceive and understand harmony, an essential element of music (along with rhythm and melody - which also have mathematical structures). To describe this mechanism, we need two theories of the mind: 1. the theory of mental representation and intentionality; and 2. the theory of computational functionalism.

The representational theory of the mind has a long and often inconsistent or contradictory history. The origin of the term intentionality for example comes from medieval philosophy which was interested in the logical structure of concepts; “The term ‘intentio’ was employed as a technical term for a concept or notion.”[2] notes Tim Crane; which seems to derive in turn from the Aristotelian term noema. For simplicity I will use a generic formula for perception: mental states such as perceptions possess intentionality in the sense that they are representations of objects/things, just as a photograph of an apple is a representation of the physical apple.

In the case of auditory perception, the auditory sensation can be said to be a mental representation of physical sound. I have in mind a non-reductive representational theory, the physical properties of sound and the phenomenal properties of representations are different (because physical sound and mental representation are two different things), but there are causal connections and quantitative correlations between the two. A sound perceived as high in pitch represents a higher physical frequency compared

[2] Crane, Tim. *Elements of Mind. An Introduction to the Philosophy of Mind*. Oxford University Press, 2001, p. 9.

to a sound perceived as low. There is a correlation between the physical frequency of the vibration of the air and the pitch of the perceived sound in the mind.

Quantitative correlations can also be explained by the computational theory of mind which holds that the brain is a type of computer and mental processes are based on computations. Jerry Fodor notes: “Specifically, a computation is a transformation of representations which respects these sorts of semantic relations.”[3] To the extent the theory is correct (around which philosophical and scientific arguments have been carried for at least 60 years), we can easily regard the brain as a computational organ that can represent and memorize quantities in the form of information and perform operations on them.

The two theories are compatible; thus, we obtain a model with three levels of description: the physical level, the computational level, and the phenomenal level (Ray Jackendoff distinguishes between two problems of consciousness, the computational mind-brain problem, and the mind-mind problem)[4]. The cognitive mechanism involved in music can be understood in the relationships between these levels.

The general schematic would be as follows. On the physical and computational side, the mechanical waves of frequency f and g enter the ear, electrical impulses are sent to the part of the brain that processes sound which (while retaining f and g by themselves) computes f/g or g/f. Then, on the phenomenal side through a process still incompletely understood by contemporary science or philosophy (known as “the hard problem of consciousness”) the structure composed of the representations of f, g and f/g is manifested as the experience of a chord.

Fortunately, the physiological details (how the inner ear and the auditory cortex work) are not necessary for the present analysis, we can deduce the functions that the “black box” must perform to obtain the form that we experience as music. In other words, we are only interested in the formal or syntactic properties that the cognitive system uses for music. This way of theorizing is generally called functionalism, proposed among others by Stephen Stich who writes “...I have urged the adoption of the Syntactic Theory of Mind, which constructs cognitive mental states as relations to purely

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[3] Fodor, Jerry. *The Modularity of Mind. The MIT Press*, Cambridge, 1983, p. 5.

[4] Jackendoff, Ray. *Consciousness and the computational mind*. The MIT Press, Cambridge, 1994, p. 18.

formal or syntactic mental sentences."[5] By mental sentences is usually understood anything that has a logical or computable structure.

To simplify, we can use the term information in a ubiquitous sense. Thus, we have physical information (the frequency of the mechanical wave), phenomenal information (found in experience), and computational information (which is the actual mechanism/algorithm). In the case of a single sound, the information is preserved from the physical to the phenomenal level (approximately, since the mechanism of perception has certain limits). But the relationships between sounds have a special phenomenology. They are undoubtedly to be found in the musical experience, because otherwise we would not be able to distinguish between different intervals and consequently, we would not have a musical experience (in contrast we can consider the case of a tone-deaf person who hears the sounds but not the relationships between them). The intervals, however, seem to occupy an obscure phenomenal position, secondary to the clearer phenomenality of the sounds themselves that come to the fore.

However, we can understand the fraction as a cognition that has a phenomenology[6] of its own. David Pitt holds that there is such a phenomenology for cognition in general, "there is something it is to think that P"[7] independently of the actual language in which P is expressed. Similarly we can believe that there is something it is like to think or rather feel a ratio (a third, a fifth, etc.) independently of the sounds evoke it, even though it has an obscure presentation and in experience the two types of cognitions, the physical sounds and the ratios are almost completely fused, we hear them together – just as we hear a word and its meaning together – yet we can separate them as having their own phenomenologies. This is all the more plausible because the identity of an interval depends on the *relative ratio* of the frequencies of the sounds, rather than the absolute values if the notes. For example, we hear the same octave relationship between both the frequencies 200 Hz and 400 Hz, and between 500 Hz and 1000 Hz, and a trained ear can easily identify them as octaves.

If we accept computational theory, the operation of the fraction is carried out by the brain, and is an automatic process, it does not involve any decision making. Indeed, when we listen to music, we do not make a conscious mental effort to hear the relationships between sounds, but the

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[5] Stich, Stephen. *From Folk Psychology to Cognitive Science.* The MIT Press, Cambridge, 1983, p. 209.

[6] Here phenomenology and phenomenality are understood as synonymous terms.

[7] Pitt, David. "The Phenomenology of Cognition or What Is It like to Think That P". Philosophy and Phenomenological Research, Vol. LXIX, No. 1, July 2004, p. 2.

experience of music is spontaneously constructed by the unconscious mind (computational level). At the phenomenological level we hear the relations between sounds not as a mathematical ratio but as something closer to a sensation or an abstract feeling that accompanies the sounds, but a feeling that is, without our knowledge (at least not directly), the phenomenal manifestation of the mathematical ratio.

An experienced listener can additionally identify the values of different musical structures (for example, the transition from G major to D# minor) which can enrich his experience of musical understanding, but this knowledge comes in addition to the basic experience. The underlying mechanism of musical cognition is mathematical (not in a formal symbolic sense, but in a raw computational sense) and remains unconscious even when we are familiar with how it works. It is not necessary to know any math at all to experience music or even to understand music theory, but it can help.

Music theory does understand that intervals play as important a role as the notes themselves, if not more so, but it also tends to forget that the nature of intervals and harmonies and rhythm is mathematical. This is probably because music theory does not need formal mathematical language, its descriptive and heuristic language is sufficient. The idea applies more to the school of classical theory and less to modern musicology that has interdisciplinary accents, as an example the study of Lerdahl and Jackendoff that applies an empirical-linguistic methodology to music: "We conceive of a rule of musical grammar as an empirically verifiable or falsifiable description of some aspect of musical organization, potentially to be tested against all available evidence from contrived examples, from the existing literature of tonal music, or from laboratory experiments."[8]

Modern mathematics approaches music by applying various mathematical devices (such as set theory) to the composition or proposing computational structures to explain the origin of tonalities. The Journal of Mathematics and Music specialized in this type of approach. As an example, Christina Anagnostopoulou asks "Can computational music analysis be both musical and computational?"[9] Her answer is affirmative, but with the caveat that a completely automatic intelligent system that does not consider the human factor cannot be created.

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[8] Lerdahl, Fred. Jackendoff, Ray. *A Generative Theory of Tonal Music*. MIT Press, Cambridge, 1996, p. x

[9] Anagnostopoulou, Christina. Buteau, Chantal. ''Can computational music analysis be both musical and computational?'', Journal of Music and mathematics, Vol.4, 2010, p. 75

Conversely musicians like Leonard Berstein tend to move away from the mathematical dimension, because they sense something mystical, magical, or metaphysical in music. “We try to be scientific about it, in our bumbling way - to employ principles of physics, acoustics, mathematics and formal logic. We employ philosophical devices like empiricism and teleological methods. But what does it accomplish for us? The “magic” questions are still unanswered.”[10] He does not, however, completely reject the mathematical dimension: “The most rational minds in history have always yielded to a slight mystic haze when the subject of music has been broached, recognizing the beautiful and utterly satisfying combination of mathematics and magic that music is.”[11]

In the present analysis what might be recognized as magical or mystical in music is how a mere neurological-computational mechanism can produce the experiences, emotions or feelings music elicits in us. A metaphysical vision like that of Sergiu Celibidache “ The fact that man has not yet learned this, namely that the physical world is supported by another superior one (if you wish we can call it “astral”)..*”*[12] (*tr.)* is too Platonic for modern scientific taste, despite the fact that some weak form of Platonism is prevalent or at least discussed in both the philosophy of mathematics; as well as in the ontology of music which poses the question: In what sense does a particular musical work exist? Carl Matheson and Ben Caplan answer: “The dominant view in the ontology of music is the *type of theory*, according to which the *Hammerklavier*[13] is a type [...] whose tokens are sound events that sound exactly like note-perfect performances of the *Hammerklavier.”*[14] Music thus pertains to the logic of the ontology of information, for which a paradigmatic example is the type/token distinction.

Music is indeed mysterious, but no more or less mysterious than consciousness itself. Theories of consciousness attribute qualities, or qualia, to mental phenomena. Qualia have an ineffable character in the sense that they cannot be described directly but can be subjected to a structural or phenomenological analysis.

One of the definitions of consciousness, offered by David Chalmers, is formulated in a way in which the sensible character is highlighted: “...we

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[10] Bernstein, Leonard. *The Joy of Music*. ed. Simon & Schuster, New York, 1959, page 12
[11] Ibid.
[12] Celibidache, Sergiu. *Despre fenomenologia muzicii (About the phenomenology of music).* Spandugino Publishing House, Bucharest, 2012, p. 22
[13] Refers to Sonata No.29 in B flat Major, Op.108, “*Große Sonate für das Hammerklavier”* by Ludwig van Beethoven, completed in 1818.
[14] Matheson, Carl. Caplan, Ben. ‘‘Ontology’’. The Routhledge Companion to Philosophy and Music, New York, 2011, p. 39

can say that a mental state is conscious if it has a qualitative *feel* – an associated quality of experience."[15] (the emphasis does not appear in the original). The terms "feel" and "feeling" apply especially to the experience of music because music is, at a phenomenal level, primarily felt and only secondarily thought (if by thinking music we understand the analysis of tonal structures of a melody and not the computational mechanism whose effects is also felt rather than thought.) But we must not confuse this meaning of the term feeling with the psychological meaning (the distinction between "phenomenal concepts" and "psychological concepts" made by Chalmers)[16]. The psychological meaning is understood the behavioral character "what the mind does", and by the phenomenal meaning the qualitative character "what it feels like" or "what it is like". The two are related but the question is in what way?

Musical intervals, as indicated above, are the result of the computational mechanism active in music and can be identified in experience. The question that remains is related to the qualitative and expressive character. The explanation of Pythagorean origin indicates the correlation between the degree of harmony and the degree of simplicity of the mathematical ratio, an explanation that has some virtues. Indeed, there is a correlation between the degree of "positivity" of the musical feeling and the simplicity of the mathematical ratio represented by tonal intervals. For example, the distance of six semitones - in physical terms a mathematical ratio of about 99/70, that is numerically complex - is perceived as strange, negative, or dissonant, while the distance of seven semitones - a mathematical ratio of 3:2, is numerically simple – and it is perceived as positive/harmonic. It is interesting that these correlations are universal, they are a kind of psychophysical laws that do not depend on the cultural-historical context. It may depend however to some degree to the musical context.

Are harmonic intervals therefore inherently "good" and disharmonic intervals inherently "bad"? Of course not. Music does not have the sole purpose of expressing or transmitting "positive" feelings. The aesthetic quality of the musical experience depends on the syntax composed not only of positive harmonies but can explore the entire harmonic spectrum. In fact, disharmonies play an essential role in many types of compositions, introducing a tension that needs to be resolved by returning to the tonic, which can be achieved

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[15] Chalmers, David. *The Conscious Mind. In Search of a Fundamental Theory*. Oxford University Press, 1996, p. 4

[16] Ibid. p. 10

through several musical modalities (major, minor, chromatic, or other). The musical mode is responsible for the overall feel, the atmosphere that a piece creates, and often contains specific disharmonies, for example the Persian scale that creates a certain type of atmosphere immediately recognizable in Middle Eastern music. (As a separate note music was considered a branch of mathematics in the Arab Middle Ages).

Music can express negative emotions such as sadness, mourning, tragedy, melancholy, etc. Theorists of musical emotions such as Stephen Davies suggest that music points beyond itself: "If music never referred us beyond itself, so that all that was involved in understanding music was an appreciation of its structure, its texture, the thematic relationships, and so on, then the nature of musical understanding (and, thus, of musical 'meaning') would raise few philosophical difficulties. But music does refer beyond itself, in that it is expressive of emotions, and there are considerable philosophical difficulties faced in attempting to account for this."[17] Stephen Davies theorizes that music expresses emotion by it resembles in some ways natural expressions of emotion (e.g. posture or tone of voice). He holds that even when something does not actually express emotion we project/anthropomorphize emotions onto it, for example the weeping willow, or a basset-hound (which although not necessarily sad, its appearance seems to express sadness, Davis's example). Davis believes that this is also the case with music, that music is inert, not alive, just a lot of sounds, onto which we project emotions by virtue of structural similarities.

A criticism that can be directed at the similarity theory is that music is not inert but is an experience in which different mental and cerebral mechanisms are active. The sound dimension and the actual emotional dimension are expressed in different parts of the brain (auditory cortex and amygdala). They are also not completely modular but can independently express several secondary aspects. The sound dimension contains an "emotional" aspect of its own, the immediate aesthetic feelings of the music we discussed are directly related to the physical character of the sounds and to the "simple" computational operations on the quantitative dimensions. The qualitative aspect can be explained locally. This is a possibility, considering the criticism addressed to the classic idea of modularity, for example by Peter Carruthers: "Understood in this weak way, the thesis of massive mental modularity would claim that the mind consists entirely of distinct components, each of which has some specific job to do in the functioning of

[17] Davies, Stephen. *Themes in the Philosophy of Music*. Oxford University Press, New York, 2003, p. 122

the whole. It would predict that the properties of many of these components could vary independently of the properties of the others."[18]

But music is also a global cerebral phenomenon, it extends to all parts of the brain [19] among which it may be mentioned: 1. the Auditory Cortex (the first stage of auditory perception and analysis of tones) and 2. the Amygdala and Nucleus Accumbens responsible for emotional reactions to music [20]. It is through this kind of extensive interconnectivity that it can explain why music evokes emotions in the listener and why these emotions are more relative than the music itself. They are a form of "interpretation" by the emotional part of the brain of the musical material processed around the auditory cortex where the main work of music processing occurs (or so we interpret the brain mappings).

The degree of relativity of the emotional response can depend on taste but also on the degree of understanding. The understanding of music depends on both the formal dimension and the expressive dimension, as Davis himself says: "...the expressive and the formal are not intrinsically opposed, and in many cases cooperate in propelling and shaping the course of the work. This is not to say that accounts of mood, color, and expressiveness can be easily reduced to technical descriptions, or vice versa. The two kinds of description are not perfectly inter-translatable. They are complementary, though, not opposed."[21]

The technical and metaphorical descriptions represent the two aspects of the musical phenomenon that were discussed the algorithmic/ phenomenal and the psychological/emotional. They are complementary because the two regions of the brain responsible for them are connected in a way that resonates. However, the causal direction seems to be from the former to the ladder. Our mood cannot change the structure of a composition, but a composition can change our mood.

However, the more metaphysically baffling is the relationship between the algorithmic and the phenomenal, that even if deterministic, is related to the fundamental nature of consciousness and its relationship to

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[18] Carruthers, Peter. *The Architecture of the Mind. Massive Modularity and the Flexibility of the Mind*. Clarendon Press, Oxford, 2006, p. 2

[19] The influence of the musical phenomenon extends to: motor cortex, sensory cortex, prefrontal cortex, cerebellum, visual cortex, corpus collosum, hippocampus and cerebellum.

[20] Levitin, Daniel, J., Tirovolas, Anna, K. "Current Advances in the Cognitive Neuroscience of Music". The Year in Cognitive Neuroscience, New York, 2009, p. 212

[21] Davies, Stephen. *Themes in the Philosophy of Music*. Oxford University Press, New York, 2003, p. 261

the physical world. Music is an interesting case in this sense because we have a formal theory (even if not always expressed in mathematical formalism) that describes a subjective dimension thus providing at least one way in which the chiasm between the subjective and the objective may be bridged.

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