Maria Mannone

Networks of Music and Images

Introduction

While hearing a complex orchestral piece, have you ever experienced "seeing" a fascinating landscape in your mind? Might this have something to do with synesthesia? Synesthesia is a sensory stimulation that evokes feelings in both the initial and at least one additional sensory channel. "Synesthesia" comes from ancient Greek,[1] and is used as a concept in poetry («L'urlo nero», the «black scream», for example).[2] This topic is also discussed in the fields of psychology, neurology, and, of course, studies about arts. Sonification experiments may benefit from studies about synesthesia, and more generally, psychology, to find which sonification technique may be most effective for listeners. There is a topic of study akin to synesthesia: cross-modal correspondences. While synesthesia is more or less an involuntary experience, cross-modal associations are thought to be more organized, structured, and statistically-based experiences.[3] Synesthesia is often considered as a specific neurological condition, while cross-modal correspondences may be more largely (and maybe culturally) shared. Research showed that also non-synesthetic people can experience cross-modal correspondences.[4] Here we will not deal with details about their similarities and differences. We will only focus on the broad concept of superposition between simultaneous and different sensory-channel experiences (i.e. the association between stimuli from different sensory fields).

Scholars of synesthesia and cross-modal correspondences develop the analysis of similar information from different fields – sounds, visuals, kinetics. Sometimes, they frame

1 It comes from σύν "together" and αἴσθησις "sensation".

2 «[...] All'urlo nero della madre / che andava incontro al figlio / crocifisso sul palo del telegrafo» from the poem *Alle fronde dei salici* within *Giorno dopo giorno* (1947) written by Salvatore Quasimodo, Nobel prize for the Literature in 1959.

3 Cf. Charles Spence, *Crossmodal correspondences: A tutorial review*, «Attention, Perception, & Psychophysics», LXXIII, 4 (2011), pp. 971-995; Ophelia Deroy - Charles Spence, *Why we are not all synesthete (not even weakly so)*, «Psychonomic Bulletin & Review», XX, 4 (2013), pp. 643-664.

4 Cf. Cesare Parise - Charles Spence, *Audiovisual crossmodal correspondences and sound symbolism: a study using the implicit association test*, «Experimental Brain Research», CCXX, 34 (2012).

ISSN: 2240-7944
http://www.ojs.unito.it/index.php/spazidellamusica

their studies in the context of Gestalt, especially while dealing with the perceptual grouping[5] and music.[6] Other studies deal with the perception of sound and the localization of points in space. A higher-frequency sound is more likely to be localized at a higher point in the space. In contrast, a low-frequency sound is more likely to be localized at a lower point in the space.[7] There are several studies in the field.[8] There are also several studies connecting the spectrum of speech and the sharpness/smoothness of the visuals' shape. An example of this is the association between (meaningless) words and lines, an object of experimental research in psychology. Words and lines can be associated depending on their degree of "angle-ness" or smoothness, as shown in a well-known experiment based on Gestalt principles (the "takete-maluma" experiment).[9] Recently, the results of this experiment have been analyzed in the light of psychophysics,[10] associating "angle-ness" in speech with explosive sounds, increased frequency, and shorter duration.[11] Analogies between images and sound ("angle-ness" and "explosivity") interpreted in terms of gestures is also a theme addressed by scholars,[12] and is the topic of iconicity[13] studies.[14] The binding relationship between visual shapes and gestures has been investigated in the formation of

[5] Cf. Luca Nobile, *Words in the mirror: analysing the sensorimotor interface between phonetics and semantics in Italian*, in *Iconicity in Language and Literature 10: Semblance and Signification*, ed. by Pascal Michelucci - Olga Fischer - Christina Ljungberg, Amsterdam – Philadelphia, John Benjamins, pp. 101-131; Suzanne Roffler - Robert Butler, *Factors that influence the localization of sound in the vertical plane*, «The Journal of the Acoustical Society of America», XLIII (1968), pp. 1255-1259; Michael Kubovy - Minhong Yu, *Multistability, cross-modal binding and the additivity of conjoined grouping principles*, «Philosophical Transactions of the Royal Society B», CCCLXVII (2012), pp. 954-964.

[6] Cf. Fred Lerdahl - Ray Jackendoff, *A Generative Theory of Tonal Music*, Cambridge (MS), MIT, 1983.

[7] Cf. S. Roffler - R. Butler, *Factors that influence the localization of sound in the vertical plane*, cit.

[8] Cf. Elena Rusconi [et al.], *Spatial representation of pitch height: the SMARC effect*, «Cognition», XCIX, 2 (2006), pp. 113-129.

[9] Cf. Wolfgang Köhler, *Gestalt psychology*, New York, Liveright, 1929; Dimitri Uznadze, *Ein experimenteller Beitrag zum Problem der psychologischen Grundlagen der Namengebung*, «Psychologische Forschung», V, 1-2 (1924), pp. 24-43; M. Kubovy - M. Yu, *Multistability, cross-modal binding and the additivity of conjoined grouping principles*, cit.

[10] Correspondences between the perception of sounds and the perception of images are the object of recent experimental research: cf. C. Parise - C. Spence, *Audiovisual crossmodal correspondences and sound symbolism: a study using the implicit association test*, cit. Crossmodal correspondences are also studied in the field of neuroscience, cf. Maurizio Gentilucci - Paolo Bernardis, *Imitation during phoneme production*, «Neuropsychologia», VLV, 3 (2007), pp. 608-615.

[11] Cf. L. Nobile, *Words in the mirror: analysing the sensorimotor interface between phonetics and semantics in Italian*, cit.

[12] Cf. Lawrence Zbikowski, *Conceptualizing Music: Cognitive Structure, Theory, and Analysis*, Oxford, Oxford University Press, 2002.

[13] Iconicity is the relationship between the shape of a sign and its meaning.

[14] Cf. Willi Mayerthaler, *System-independent morphological naturalness*, in *Leitmotifs in Natural Morphology*, ed. by Wolfgang U. Dressler [et al.], Amsterdam – Philadelphia, John Benjamins Publishing, 1987, X, pp. 25-58.; cf. Adrien Merer [et al.], *Perceptual Characterization of Motion Evoked by Sounds for Synthesis Control Purposes*, «ACM Transactions on Applied Perception (TAP)», X, 1 (2013).

audio-visual objects.[15] Later, we will give more details about the connection between visual shapes and sounds via gestures.

Here, we will consider examples from the artistic practices of drawing and playing (acoustic) musical instruments. In particular, we discuss pitch in music and space in visuals, the two "indispensable attributes" for auditory and visual channels, respectively.[16] There is another concept from Greek thinking we can use: Plato's abstraction concept, the *idea*.[17] According to Plato, all that surrounds us is a copy of perfect things, the ideas. For example, all existing horses are copies of the "horse" idea. In this article, we need this concept to explain abstraction and universal forms, to be used as unifying elements of networks.

To connect sound and visuals, we refer to a specific technique of tridimensional mapping.[18] The coordinates (length, width, height) of a (finite) selection of points of a tridimensional object can be associated with musical parameters such as time, loudness, and pitch, see Figure 1.

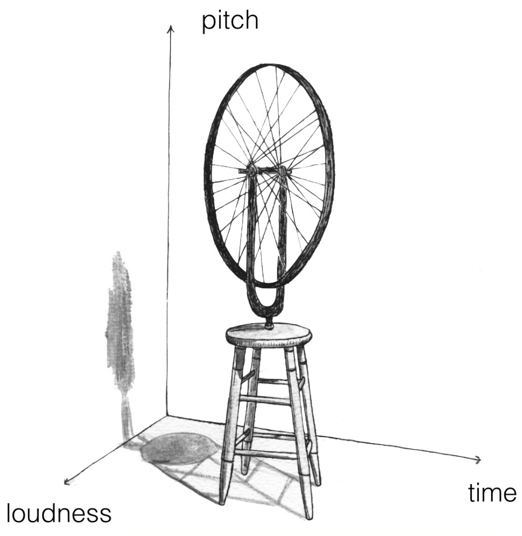

Fig. 1: Duchamp's *Bicycle Wheel* within the tridimensional space time-loudness-pitch. The representation is used to map the points of the image into sounds. It has been built to compose an orchestral score. Drawing by Maria Mannone.

[15] Cf. M. Kubovy - M. Schutz, *Audio-Visual Objects*, «Review of Philosophy and Psychology», 1 (2010), pp. 41-61.

[16] *Ibidem*.

[17] Plato, *The collected dialogues*, ed. by Edith Hamilton - Huntington Cairns, New York, Pantheon, 1961.

[18] Cf. Maria Mannone, *Dalla Musica all'Immagine, dall'Immagine alla Musica. Relazioni matematiche fra composizione musicale e arte figurativa*, Palermo, Edizioni Compostampa, 2011; Guerino Mazzola - Maria Mannone - Yan Pang, *Cool Math for Hot Music*, Heidelberg, Springer, 2016.

In this way, we can map visual shapes into sound. Timbre is a free parameter, but an additional mapping of parameters, for example from visual color to musical timbre,[19] can be defined and applied. Such a technique may be seen as the development of Xenakis' UPIC[20] and studies about the visual representation of scores.[21]

Our conjecture is the following: effective examples of such a technique can satisfy cross-modal correspondences. For example, we can musically re-create the shape of Gaudí's *Sagrada Família* with raising and lowering musical scales, or the *Concetto Spaziale* by Lucio Fontana via *acciaccature* and *staccato* articulations.[22] We can envisage the same gestural matrix for both: a "staccato" movement (i.e. one that is short and precise) may generate points (and even holes) on canvas just as it may create detached notes on musical instruments.[23]

As shown in literature,[24] the auditory channel is specialized in detecting "where" is the sound source, and the visual channel in getting information about "what" surfaces in space.

Let us suppose that the "where" is changing, and the sound source is moving in space. We can decide to freely use the concept of sound localization and surface description, as well as another concept, the figure-ground segregation applied to sound, to describe a surface via a moving sound source. We can apply these ideas to musically render a visual shape such as a water lily. We can use two simultaneous melodies, one raising and the other lowering, for each petal. To represent the conic shape of the water lily, we can imagine ourselves "walking along" the petals, hearing a couple of melodies for each petal, and a petal after the other. To make the feeling of "movement" more evident, we can use a different timbre for each petal, and slightly change the pitch and the loudness, mimicking the Doppler effect in physics. The Doppler effect describes the frequency change that is perceived by the listener when he or she is moving with respect to the sound source (the

---

19 We are comparing color and timbre not as two ends of a spectrum, but as a semi-expansive list of possible applications.

20 Cf. Iannis Xenakis, *Formalized Music*, Stuyvesant (NY), Pendragon Edition, 1971.

21 Cf. Salvatore Sciarrino, *Le figure della musica: da Beethoven a oggi*, Milano, Ricordi, 1998.

22 Cf. M. Mannone, *Dalla Musica all'Immagine, dall'Immagine alla Musica. Relazioni matematiche fra composizione musicale e arte figurativa*, cit.

23 The basic mapping is: length-width-height into time-loudness-pitch, and we add the condition of gestural similarity (see Section 1). This is a creative choice. There is not explicitly evidence that such a mapping alone fulfills embodied cognition requirements. Further research will involve cognitive experiments to test our conjecture.

24 Cf. M. Kubovy - M. Schutz, *Audio-Visual Objects*, cit.

frequency shift is not *produced* by the sound source). Thus, we can musically reproduce the illusion of movement through the perception of frequency change. For example, we may hear higher and louder sounds when we move toward a petal, and lower and softer sounds when we move away from a petal. Such a compositional experiment is described in a recent dissertation, which includes an orchestral score and its reading.[25] The connection between music, motion, and the perception of motion as an "image" created in the mind of listeners, is also a topic of experimental research.[26]

Conveniently, a branch of math known as category theory is particularly suitable in describing objects and transformations between them.[27] An object, represented by a point, can be transformed into another object (represented by another point). The transformation (morphism) is represented by an arrow. Arrows can be mathematically composed, and their associativity can be studied. A category is given by a set of objects connected by arrows, satisfying associative and identity properties. In category theory we can build complex, nested structures starting with these simple ideas. In our frame, we can see a musical sequence as an object, and the variation process as an arrow. The same can be applied to visual arts. From a more broad perspective, we can argue that, due to the developments of modern mathematics, a convergence of disciplines may be envisaged. This fact is reminiscent of the interdisciplinary approach to knowledge in Renaissance culture.

In summary, we can transform musical objects into other musical objects, visual shapes into musical shapes, and we can map sounds into images and vice versa.

Let us take this one step further. Once we define a sequence of transformations of images, we can map each one onto music, creating a parallel sequence of different images. In principle, if we have a *network* of images, we can also have an associated network of musical sequences, connected through mappings, such as length-width-height to time-loudness-pitch. The images in the network will have in common a similar structure (something we might compare with the Platonic "idea"), as well as the network of musical sequences. An example of a visual network, based upon the idea of "triangle" and investigated through computer sciences within the frame of category theory, is given in litera-

[25] Cf. Maria Mannone, *Musical Gestures between Scores and Acoustics: A Creative Application to Orchestra*, Ph.D. dissertation, University of Minnesota, 2017. Recording: https://soundcloud.com/maria-mannone/mannone-genesis-of-music-from-gestures-second-part-fugue, from 5'05'' to 6'20''.

[26] Cf. Zohar Eitan - Roni Granot, *How Music Moves: Musical Parameters and Listeners' Images of Motion*, «Music Perception», XXIII, 3 (2006), pp. 221-247.

[27] Cf. Saunders Mac Lane, *Categories for the Working Mathematician*, Heidelberg, Springer, 1971.

ture.[28] Where it is also stated that "the network is the abstraction". The network is given by a collection of images with a common characteristic (that in literature[29] is the triangular shape), connected by arrows. The arrows represent the transformation that brings an image into another. The final arrow leads to an image reminding to "perfect triangle" (that is a pure idea, and cannot even be drawn as a specific triangle), the *colimit* of the entire collection of triangles. In building the network of visuals, the authors used concepts and terminology from category theory.[30] In our article, we extend these ideas to music, and to image-music interactions. In this way, we may ideally connect concepts from ancient philosophy and abstract mathematics to contemporary artistic and computer applications. The structure of the article is the following. In Section 1, we describe networks of music and images using the concept of gestural analogy and the frame of category theory. In Section 2, we describe some examples of networks, using the example of music derived from the shape of cathedrals. Finally, we comment on the results and discuss further research in the Conclusion Section.

Musical Gestures, Diagrams, and Networks

In this Section, we join concepts of synesthesia (in a broad sense), (musical) gesture, category, diagrams, and visuals to start building networks of music and image, giving instruction for a creative technique. We can combine *synesthesia* and *networks* via a simple syllogism: 1. music can be described by category theory;[31] 2. category theory can be successfully applied to visuals;[32] thus, 3. also interactions and translations between music and images can be framed within category theory.[33] Because networks in literature[34] use cate-

[28] Cf. Leonidas Guibas, *Networks of Shapes and Images*, Lecture ICVSS, 2014, http://www.slideshare.net/milkers/lecture-07-leonidas-guibas-networks-of-shapes-and-images (slides 122-123), and Shubham Tulsiani [et al.], *Learning Shape Abstractions by Assembling Volumetric Primitives*, ArXiv, 2016, https://arxiv.org/pdf/1612.00404v1.pdf.

[29] Cf. L. Guibas, *Networks of Shapes and Images*, cit.

[30] The concept of categorization, in a more broad sense than strictly mathematical, as well as classification, is also present in other works about perception: cf. for example John Paul Minda - David Smith, *Prototypes in category learning: the effects of category size, category structure, and stimulus complexity*, «Journal of Experimental Psychology: Learning, Memory, and Cognition», XXVII, 3 (2001), pp. 775-799, and Robert Nosofsky, *Tests of an Exemplar Model for Relating Perceptual Classification and Recognition Memory*, «Journal of Experimental Psychology», XVII, 1 (1991), pp. 3-27. Experiments about similarity in perception may profit from mathematical framing, especially regarding a predictive model to test, and the analysis of results to improve the theoretical model.

[31] Cf. S. Mac Lane, *Categories for the Working Mathematician*, cit; David Spivak, *Category Theory for the Sciences*, Cambridge (MS), MIT, 2014; G. Mazzola - M. Mannone - Y. Pang, *Cool Math for Hot Music*, cit.

[32] Cf. L. Guibas, *Networks of Shapes and Images*, cit.

[33] Cf. Maria Mannone, *Introduction to Gestural Similarity in Music. An application of Category Theory to the Orchestra*, «Journal of Mathematics and Music», submitted 2017.

[34] Cf. L. Guibas, *Networks of Shapes and Images*, cit.

gories, we propose here a joint use of networks and categories for sounds and visuals. Such a syllogism is coherent according to category theory. We may conjecture that, if each step of the process verifies cross-modal correspondences, also the entire networks verify them, and if we move from a network to another, we can be able to listen to shapes and to see sounds.

We need one more concept, the concept of musical *gestures*. There is an extended research on musical gestures.[35] The perspective on music and embodied cognition integrate the mathematical definition of gesture, that is meant as a formalization of such an embodiment. In the mathematical theory of music, a gesture is defined as a mapping of an abstract structure of points and arrows, onto a system of continuous curves in space and time (trajectory in a generalized space),[36] see Figure 2 for a simple example. Such a basic and abstract definition can be applied to a variety of cases, from piano movements to violin, conducting, and even to voice (if we consider the inner movements made by a singer).[37] Focusing on this system of continuous curves, we can compare gestures on the same musical instrument, and between different musical instruments. Because the comparisons between gestures are reduced in this way to a comparison between curves, we can use mathematical tools of homotopy theory to classify musical gestures. Such a tool should be joined with the analysis of the musical spectra obtained as results of musical gestures for a more complete description.

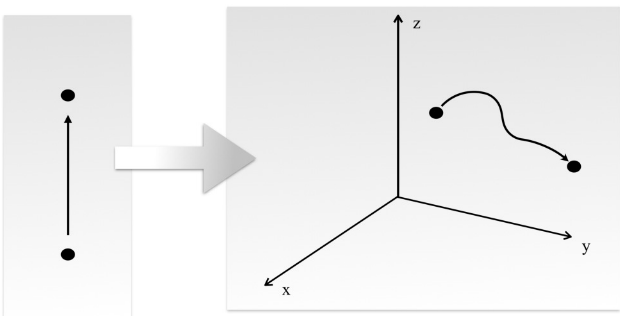

Fig. 2: Mathematical definition of a gesture as a mapping from a skeleton (on the left: an abstract structure with points and arrows connecting them) to a body (on the right: a system of continuous curves in a space, that can be, for example, x = time, y = vertical position of the hand, and z = horizontal position of the hand).

35 Cf. *Musical Gestures: Sound, Movement, and Meaning*, ed. by Rolf Inge Godøy - Marc Leman, New York – Abingdon, Routledge, 2010.

36 Cf. Guerino Mazzola - Moreno Andreatta, *Diagrams, Gestures, and Formulae in Music*, «Journal of Mathematics and Music», I, 1 (2007), pp. 23-46.

37 Cf. M. Mannone, *Introduction to Gestural Similarity in Music. An Application of Category Theory to the Orchestra*, cit.; G. Mazzola - M. Mannone - Y. Pang, *Cool Math for Hot Music*, cit.

In literature,[38] two musical gestures are called "similar" if their curves in space and time can be homotopically transformed one into the other, and if their sound spectra show consistent analogies (e.g. they both correspond to *vibrato* or *non vibrato*).[39] If we consider drawing as the result of a specific gesture, or, in general, a visual artwork as the result of a painting/sculpting gesture, we can easily generalize the concept of gestural similarity beyond music. Comparisons between music and visuals are easy in this way. The same detached gesture can generate a *staccato* musical fragment, as well as a collection of points on the canvas. The same happens with a more continuous movement, and so on. In the same article[40] orchestral conductors' movements, using the terminology of category theory, are described as the *colimit* of all the orchestral musicians' gestures, and the listeners' projections as the *limit* of all sounds. In the case of feedback (e.g. the orchestra influencing the conductor's gestures, or the public influencing the musicians' performance) the arrows can just be reversed.

Now, let us revisit topic of mappings and networks. We can define networks of gestures with progressive ramifications and transformations. Because, as said in the Introduction, the same gesture can generate either an image or a sound on acoustic instruments, we can see networks of gestures as the connection between networks of visuals and networks of (mapping-related) sounds. In fact, we can see an image as the result of a *drawing gesture*.[41] See Figure 3 for a simple example of gesture, image, and sound networks and diagrams. In Figure 3, we have arrows from Image to Sound, and from Gesture to Sound. The inverse arrows, i.e., from Gesture to Sound and from Sound to Image, can represent the inverse transformations. Figure 3, in fact, is only an example of how a network may be built, from Gesture 1, Image 1, Sound 1, to Gesture 2, Image 2, Sound 2 and so on. The diagram does not represent the most general case. The path Sound 1 to Sound 2 to Sound 3 is a fragment of an audio network. The more general path is Image to/from Gesture to/from Sound. The choice of a specific direction allows us to study precise commutative diagrams[42] one after the other.

[38] Cf. M. MANNONE, *Introduction to Gestural Similarity in Music. An application of Category Theory to the Orchestra*, cit.

[39] The measure of similarity is continuous: e.g., we can use a decimal within the interval [0, 1] (0 for minimal similarity and 1 for maximal similarity).

[40] Cf. M. MANNONE, *Introduction to Gestural Similarity in Music. An application of Category Theory to the Orchestra*, cit.

[41] Cf. A. MERER [et al.], *Perceptual Characterization of Motion Evoked by Sounds for Synthesis Control Purposes*, cit.; M. MANNONE, *Introduction to Gestural Similarity in Music. An application of Category Theory to the Orchestra*, cit.

[42] In category theory, a commutative diagram is a diagram where arrows (representing paths) can be composed, and the composition of different arrows with the same start and end points lead to the same result.

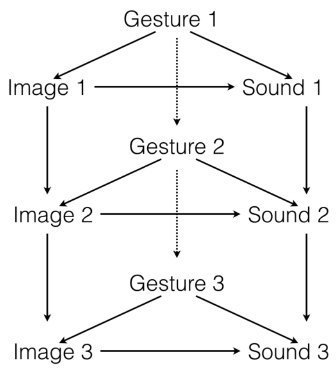

Fig. 3: An example of a Gesture - Image - Sound network.

In Guibas' work[43] the concept of the Platonic idea for "cow" is seen as the final element of a collection of cows, and a simplification of the cow's skeleton structure as its *colimit*. If we see such a structure as the result of a drawing *gesture* in the tridimensional space, we have successfully linked gestures to the Platonic idea.

We now propose a method to build networks of sounds and visuals. This can be used merely as a compositional technique, but it can also be a tool for programming, as well as a tool to analyze and compare artworks, and (hopefully) to deepen our knowledge of synesthetic processes.

Given an image or a collection of images, we can:

- modify the images, then convert each of them into music, and finally, listen to the different sounds;
- modify a musical fragment by changing its articulation, timbre, pitch, or other parameters, then convert the result into a visual shape;
- compare the new image with the one derived from the initial musical fragment;
- create a separate network for each image and sound, and compare the results at each separate step for both networks.

All that we have heretofore covered, may be applied on a computer software for educational, research, and creative purposes. As implied by Guibas,[44] visual arts can profit from diagrammatic techniques of visual rendering and shaping (techniques described by Guibas[45] do not deal with sound-to-image conversion, but with the definition of visual

[43] Cf. L. Guibas, *Networks of Shapes and Images*, cit.

[44] *Ibidem*.

[45] *Ibidem*.

networks and categorical concepts). We can say that even interactions between music and visual arts[46] can be improved via diagrammatic thinking.[47] We already use software and programming languages to transform music, such as Max/MSP, Open Music (based on Lisp), and Rubato Composer, with the application of gestural interaction. Technology such as 3d-image manipulation[48] can be applied to create musical material via the tridimensional mapping described above.[49] The resulting sounds represent a starting point for the sound art, for musical informatics purposes, and they can be transcribed and played on acoustical instruments. Examples of networks of music and images are given in Section 2. In fact, we can design and develop software that automatically composes music from the gestural and visual analysis. Programming applications may help cognitive experiments, as asking the research question: Is this musical rendition effective?

A case study: Music of Cathedrals

We present a simple case study to show the proposed methodology. We will give some examples of what music-image networks are, and how to build them. This is a simple compositional example to give an idea, but the applicability of such a method goes far beyond this, including, in principle, sets of experiments about perception. The networks can also be defined depending on the analogies experimentally found between sequences of images, sequences of sounds, and their connections. Here, the chosen idea is the shape of some cathedrals. The profile of each cathedral is indicated in red in Figures 4, 5, and 7.

Figure 4 shows an example of point (a) in Section 1: the modifications in the image are converted into music. We have three different cathedrals, and we envisaged a little network where the three images are ideally transformed, one into the other, through a progressive addition of spires. We composed the three short musical sequences starting from the highlighted shape of each cathedral. In a nutshell, vertical lines are associated to chords and clusters of notes, and oblique lines as ascending and descending scales. We rendered the horizontal lines with the repetition of the same note. We constructed each musical sequence separately from each visual shape, but the three sequences can be seen as part of another little network, with three elements, transformed one into the other, increasing the musical variety. In this way, we built two parallel networks: one for visual

[46] Cf. M. Mannone, *Introduction to Gestural Similarity in Music. An application of Category Theory to the Orchestra*, cit.

[47] Cf. Charles Alunni, *Diagrammes et Catégories comme prolégomènes à la question: Qu'est-ce que s'orienter diagrammatiquement dans la pensée?*, «Théorie Littérature Epistémologie», XXII (2004), pp. 83-93.

[48] Cf. L. Guibas, *Networks of Shapes and Images*, cit.

[49] Cf. M. Mannone, *Introduction to Gestural Similarity in Music. An application of Category Theory to the Orchestra*, cit.

shape, the other for music, both with increasing complexity. We may show people the three images and the three musical sequences, without their established order, asking to "re-order" them. We expect that people would choose the order of increasing complexity, or decreasing complexity. Such an experiment may validate the construction of parallel networks proposed here, and similar experiments may constitute the development of our work.

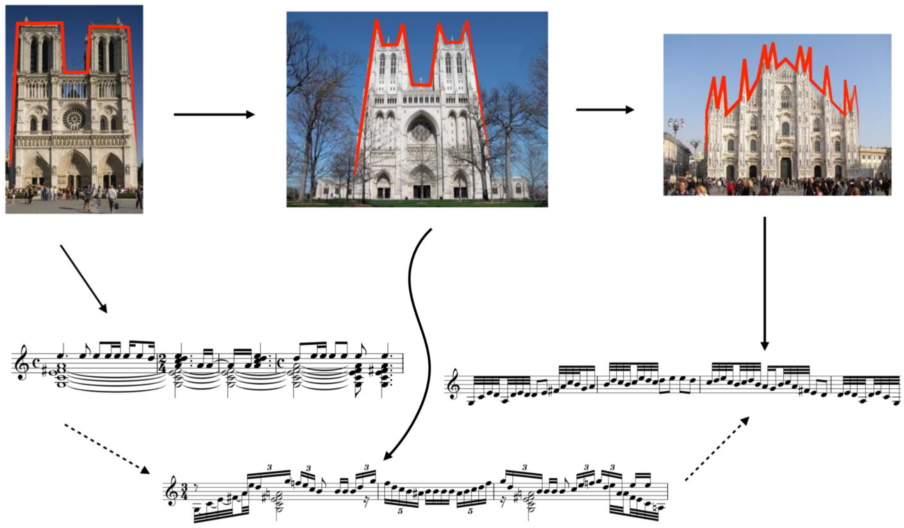

Fig. 4: The profile of a cathedral is ideally transformed into another (red lines indicate the cathedral profiles), constituting a simple visual network. Each profile is mapped into an original short musical fragment, and the sequence of the three musical sequences constitute a simple sound network connected with the visual one.

In Figure 5, a musical sequence composed from a visual shape is progressively modified (point b). The final musical fragment is converted into an image and compared with the initial one (point c). Here, we start the musical network from a single visual shape. After several purely musical variations, the melodic contour is transformed back into a visual shape, and it is compared with the initial one. In this way, we can construct visual variations through (hidden) musical variations.

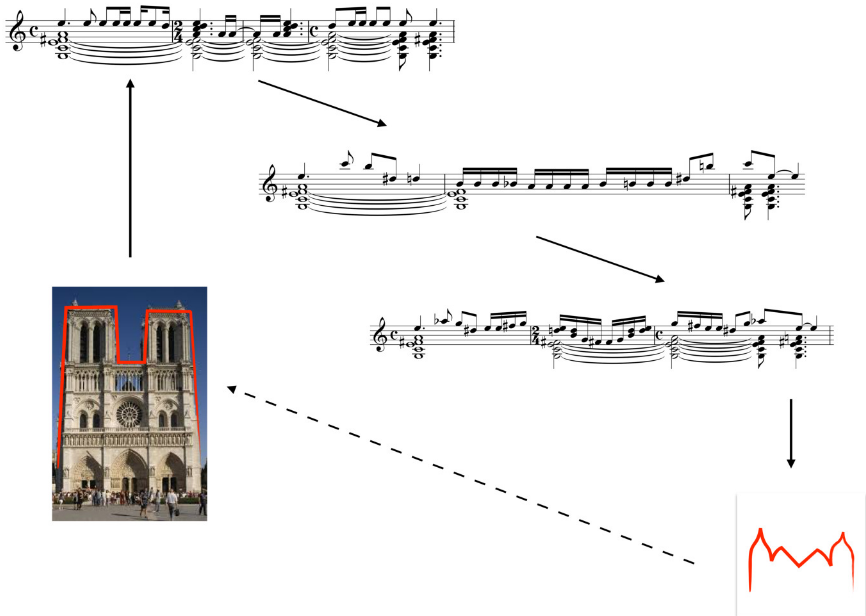

Fig. 5: A short musical fragment is derived from the profile of a cathedral. Then, the fragment is progressively variated, and finally re-transformed into a visual shape. The final visual shape can be compared with the initial one.

Finally, Figure 6 demonstrates a network for musical fragments. The "abstract idea" is here a very simple structure with a cluster, a melodic cell, and again another cluster. In Figure 7, we have a network of visual shapes of cathedrals in different styles and places. Also here, the "abstract idea" is a simple vertical-horizontal-vertical line, that is the visual analogous of the cluster-melody-cluster of Figure 6. The networks of Figure 6 and 7 are independent; they only have in common this simple "abstract idea", derived from the essential shape vertical line—horizontal line—vertical line.

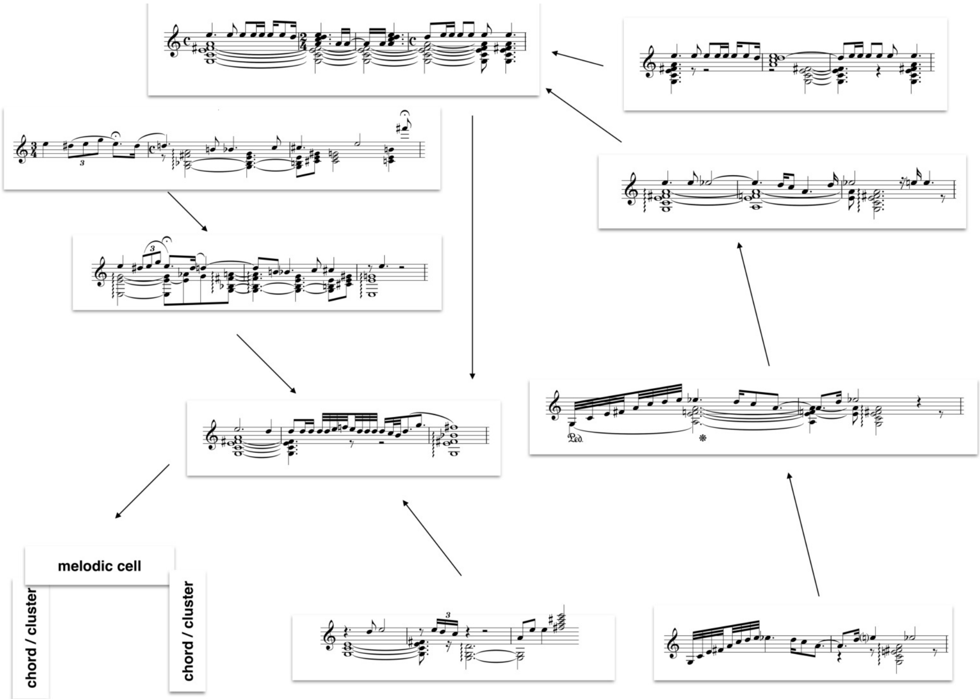

Fig. 6: An example of musical network, with the "abstract idea" given by a simple sequence chord/cluster—melodic cell—chord/cluster. This is the visual equivalent of the network of Figure 7.

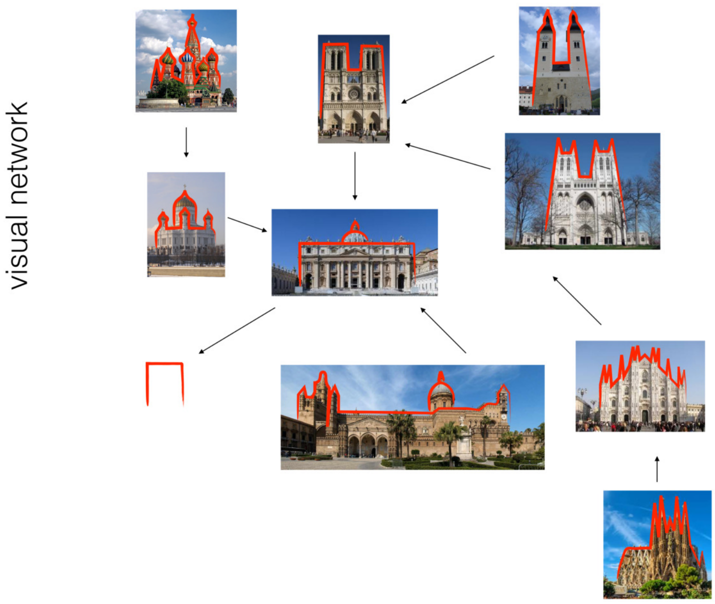

Fig. 7: An example of visual network, with the "abstract idea" given by a simple profile "vertical line—horizontal line—vertical line. This is the visual equivalent of the network of Figure 6.

Translations from visual shapes into music can use algorithms and they can involve other musical parameters such as the change of timbre and articulation. For sake of simplicity, the proposed examples only involve pitch and onset, due to the easiness of the perception of raising/lowering pitch as ascending/descending movement in the tridimensional space.[50]

There is not only one way to transform visuals into music and vice versa. The chosen example was meant to explain the structure of visual, musical, and music-visual networks. As previously described, examples of Figure 1 to 4 can be themselves objects of experimental analysis in the frame of perception.

Summarizing, in this Section we analyzed some examples of visual and musical networks. We described the technique to make them, not only as a compositional tool, but also as a method that can be applied in programming and can be used for (and improved through) perception experiments.

Conclusions

In this article, we joined several ideas: 1. the concept of a network of visuals with elements of category theory; 2. the structure of category theory applied to music; 3. mappings image-music.

We ideally connected to music the concepts of synesthesia and Platonic abstraction, extensively treated in the literature about image networks, and we made reference to contemporary mathematics to describe and connect music and visual arts. In fact, the technology developed for visuals can be extended to music exploiting cross-modal correspondences. While connecting the elements 1, 2, and 3, we hypothesized the existence of networks of musical sequences, and networks of visuals plus music with mutual interaction and exchanges.

At this stage of the research, our contribution is mainly bound to music composition, general artistic creativity, and education. However, after a collection of enough data, we may think of broadening the field of research including possible applications to machine learning. In fact, the definition of visual and musical networks can enhance the collaboration between scholars of different fields, included artificial intelligence, where algorithms to compare and classify images are developed.[51] For example, machine learning applied to music may profit from these new concepts by incorporating visual comparisons. Perception experiments proposed to musicians, visual artists, as well as to non-musicians and non-

[50] Cf. S. Roffler - R. Butler, *Factors that influence the localization of sound in the vertical plane*, cit.

[51] Cf. Kevin Kirby, *On Memory, Neurons, and Rank-One Connections*, «The College Mathematics Journal», XXVII (1997), pp. 2-19.

artists, can help in refining the technique to develop networks, and give a stronger, experimental base to our hypothesis of connections. There are several studies about the perception of sound evoking motion, drawing-motion-gestures,[52] and the perception of music depending on gestures;[53] we may compare our proposed methodology with their work. Experiments may also confirm which mappings are more effective than others, approaching cross-modal correspondence studies, with Gestalt-inspired theory such as audio-visual object studies,[54] to musicology and analysis of visual arts.

All this knowledge may find new applications in the design of human-computer interfaces, helping to achieve the goal of making them more intuitive and user-friendly. Software to modify images may include sounds, or vice versa. This may be helpful to develop specific software for visually-impaired people, or other programs to help hearing-impaired people. This work may also enhance artistic creativity as well as deepen its theoretical understanding of arts. Finally, both visual and auditory network studies can help to develop new strategies for making more intuitive and accessible abstract concepts from mathematics, such as category theory and network theory. Further developments should also include cognitive experiments, starting from a simple listening test, where subjects are asked to listen/see shapes and draw/sing them ("Sing this Draw" and "Draw this Song"). Such a test could be run by using the cathedrals profile and the corresponding musical sequence we composed.

Summarizing, future developments of research about music and visual networks may involve computer science, human-computer interfaces, theoretical thinking on art and science interactions, as well as creative applications of scientific ideas. An interdisciplinary cooperation between artists and scientists can help non-scientists to draw abstract concepts from mathematics as well as non-artists to approach the complexity and richness of art.

NOTE

About the examples, according to the editorials guidelines the author has verified, under his own responsibility, that the reproductions are not covered by copyright: otherwise, he obtained from the copyrights holders consent to the publication.

[52] Cf. Adrien Merer [et al.], *Perceptual Characterization of Motion Evoked by Sounds for Synthesis Control Purposes*, cit.

[53] Cf. Michael Schutz - Scott Lipscomb, *Influence of visual information on auditory perception of marimba stroke types*, in *Proceedings of the 8th International Conference on Music Perception & Cognition*, ed. by Scott Lipscomb [et al.], Evanston (IL), Causal Productions, 2004, pp. 76-80; cf. Michael Schutz - Scott Lipscomb, *Hearing Gestures, Seeing Music: Vision Influenced Perceived Tone Duration*, «Perception», XXXVI, 6 (2007), pp. 888-897.

[54] Cf. M. Kubovy - M. Schutz, *Audio-Visual Objects*, cit.