LOOK AT THAT SOUND!
VISUAL ASPECTS OF AUDITORY PERCEPTION

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Abstract: While it usually seems to be self-evident that perception of sound is a simple process, carried out within one sensory space, the existence of color hearing points at the fact that hearing includes visual aspects. In fact, not only during individual synesthetic processes, but even under common perceptual conditions sound refers to multi-sensory attributes. Thus, a multi-sensory design must be based on qualitative references between the senses. As an integral part, knowledge of the visual aspects of auditory perception is essential for creation of sounds which fit into a cross-modal environment.

Various mechanisms of processing of stimuli ensure coupling of auditory qualia to multi-sensory perceptual objects. In the reality of daily life, even simple events which are heard include several references to those objects. Speech usually contains semantic and associative attributes as well as various analogies, like cross-sensory features (e.g. brightness, sharpness, volume), spatial distribution and temporal behavior (e.g. motion). Knowledge on spatial alignment of auditory, visual and tactile senses was inspired by research on spatial hearing capabilities and applied to design the multi-sensory environment surrounding human being. In this manner, a *soundscape* is the auditory analogy to a *landscape*, stimulating and reflected by the subjective *emotionscape*. As another aspect, correlations of dynamic noise, music and prosody of speech to visual motion are essential for perception of temporal changes of auditory events.

Studies on the multi-sensory content of sound provide an in-sight into the complexity of auditory perception and illuminates the variety of tools available for multi-sensory approaches on sound design. Furthermore, genuine synesthetic experience offers a wide-ranging potential for advanced approaches.

Keywords: sound perception, synesthesia, color hearing, visualisation, soundscape, psycho-acoustics

1. INTRODUCTION

Genuine visual synesthesia leads to the most impressive phenomena of auditory perception. Beside auditory sensation, listening to sounds, music or spoken language thus induces visual sensation, which mainly consists of abstract shapes, colours, spatial and motional information. Within the elder literature those phenomena have been summarized as “colour hearing”. While strictly individual, various phenomena of synesthetic experience are reported. During the last two decades, when research on genuine synesthesia showed the idiosyncratic nature of this phenomenon, is became a common approach to strictly separate it from other perceptual processes of cross-modal linking. Descriptions of synesthetic experience, however, often show influence of cross-sensory correlations or associative input, which are common ways of multi-modal coupling. An interesting approach for demonstration of those perceptions is to sketch visual phenomena which are stimulated by sound. Although each drawing may only provide a rough indication of the images which are already perceived, and although it may in many cases not be comparable to elaborated art, this approach provides an insight into the specific and uncommon types of synesthetic perception. First drawings have been published during the last decade of the 19th century. Later on, during the 1920th and 1930th, a variety of colored pictures were exhibited and reproduced within books of “Farbe-Ton-Forschung” (Anschütz, 1927a, b, 1929, 1930, 1931, 1936a, b; Voss, 1936). Today, various book publications on synesthesia can not forgo the use of colored illustrations of those perceptional phenomena (e.g. Duffy, 2001; Cytowic, 2002; Emrich et al., 2001; Sidler, 2006; Dittmar, 2007). While sensations caused by processes of genuine synesthesia always show basic, abstract elements, an influence by common ways of cross-sensory coupling can be observed at many pictures (Haverkamp, 2003). Such influences are also reported by many synesthetes. Number forms show influence of semantic content on perceived shapes and colors. Abstract shapes of genuine synesthesia can cause iconic coupling (concrete associations) of objects known from daily life (Petersen, 1931). Color-graphemic phenomena can – even if exclusively related to the shape of characters – be influenced by pitch and timbre of spoken language. Therefore it can be stated that some difficulties exist to clearly distinguish phenomena of genuine synesthetic perception from other types of cross-sensory coupling. A closer view on common ways of modal interaction and on genuine synesthesia will clarify both: distinction between common and specific phenomena as well as influence of common processes on synesthesia. Clear understanding of common and individual experience also enables application of cross-sensory principles within synesthetic design (Riccò, 2008; Haverkamp, 2009).

While most observations are focusing on perception of music, sounds of daily life are not less interesting. They define the *background* of daily experience a synesthete has to face – a multi-sensory data stream that cannot easily be ignored.

It therefore is reasonable to focus on sound-perception and visual-synesthetic experience caused by sounds which occur during daily life.

2. SYNESTHESIA AND CROSS-SENSORY COUPLING

It is not yet clear whether genuine synesthesia depends on common processes of cross-sensory coupling, which are modified in a very specific manner, or if additional processes occur which are not applied in the perceptual systems of the majority. Genuine synesthesia provides a variety of phenomena, which are strictly individual, but seem to cover all possibilities of primary and secondary modalities. Statistically, the visual sensation occurs most frequently as primary and secondary sensation (Day, 2007). The statistic, however, is strongly influenced by inclusion of the relative frequent color-graphemic type of synesthesia. If this is excluded, the most frequent primary modality is given by auditory perception. Genuine synesthesia is characterised by perception of simple, abstract shapes and correlations which in general can not be explained by associations taken from experience with perception of everydays life. Genuine synesthesia therefore shows various features which are clearly different to common ways of cross-modal connections.

In contrary, the perceptual system of each human being tends to provide multi-sensory models of physical objects. These models are needed by the individual to interpret its environment and to coordinate his actions, while it is surrounded with objects which physical nature cannot be accessed directly. As a result of perception and cross-sensory integration, an image occurs in consciousness. This image can show aspects of vision, audition or of any other sensory channel. In contrary to the *physical object*, these subjective representations are here named *perceptual objects*. A sensory channel will further on be described as *modality*.

A subjective representation of a physical object is based on a sensory hypothesis, generating a perceptual object that in some ways – but not perfectly - correlates to its physical source. While physical objects always provide various stimuli, perceptual objects usually appear to be multi-sensory, i.e. they contain auditory, visual, tactile and other data (Fig. 1). Only if stimuli of a single sensory channel are presented which are unknown to the individual, a first approach is made by generating perceptual objects of this single modality, e.g. auditory or visual. **In case of known stimuli, perceived sounds are always related to multi-sensory perceptual objects.** Unknown signals, however, are meaningless and not attributed to a known source, which otherwise would provide multi-sensory stimuli.

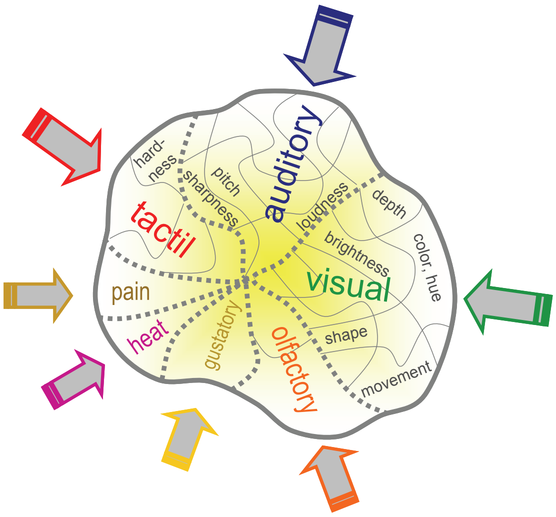

Figure 1. Model of a multi-sensory perceptual object

A multi-sensory perceptual object can be understood as a cluster of perceptual objects of single modalities. The data of different modalities can be coupled by a set of neuronal processes, which in the following are denoted as *cross-sensory strategies* (Haverkamp, 2004).

In order to find correlations between the different sensory spaces, the various strategies of cross-sensory coupling occur *in-parallel*. A model of cross-sensory coupling clarifies this fact (Fig. 2). It includes genuine synesthesia and consciously, conceptual constructions beside three *intuitive strategies*. Additionally, not shown in figure 2, basic coupling of sensory data of various channels is established. In example, those processes enable coupling of proprioceptive and visual data for control of eye movement, bearing of sound sources with intuitive head rotation to improve spatial hearing and many other tasks of sensory and motional coordination. Those elementary processes

are not discussed here, while they usually are not represented in conscious.
The main *intuitive strategies* (*coupling features*) are:

- cross-sensory analogies = correlations of single features/attributes,
- iconic coupling (concrete association) = identification of sources of stimuli
- symbolic connections = semantic correlations by analysis of meaning

Each main intuitive strategy splits into a variety of mechanisms, e.g. analogies can be made up in-between basic attributes, like brightness or roughness, or can consider movement, shape, emotion and many other aspects.

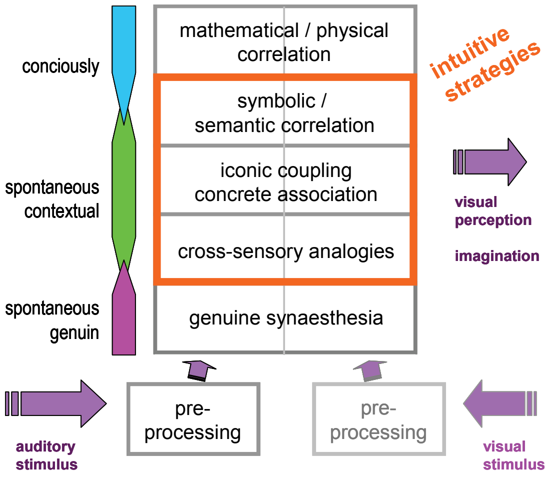

Figure 2. Model of cross-sensory coupling

During the process of perception, the listed main strategies of interaction are interpreted intuitively and do not need conscious analysis. Other correlations can be constructed with reference to known physical properties, e.g. the frequency of color light can be related to pitch frequency of a given pure tone by means of appropriate calculations. A "perfect match" of pitch and color scales has been searched for throughout the centuries, but without discovery of an optimum solution (Jewanski, 1996). Common ways to provide constructions can easily be found by programming specific algorithms, as used by audio-visual media players and automated light-shows. If the perceiving subject, however, cannot find any correlations by use of the abovementioned intuitive strategies, it will not be able to find any match of data provided by different senses.
There is strong evidence that the listed main strategies of interaction are acting in-parallel, showing mechanisms that initially are independently from each other. Therefore, for the first step of perception the analysis can separately refer to those strategies. The next step then must compare the coupling of each strategy and integrate the results to provide a map of correlations which is consistent, not including any contradictions. Assumptions regarding this process of integration are discussed below.

Shaping of perceptual objects from a variety of data requires integration of all perceived elements. This includes various mechanisms of grouping and segregation. First approaches which are also valid today have been provided by Gestalt-psychology (Werner, 1966). Recently, theories of scene analysis have added essential insight into integration processes (Bregman, 1999).
The quality of a perceptual object is only experienced by the perceiving subject itself. The various qualitative aspects inherent to a specific perceptual object are named *qualia*. Perceptual objects are not only sensed while stimuli are present. They are also recalled from memory. The stored mnemonic information is used to completely remind a known object or to complete it in case that stimuli are only partly available.
The aim of the perceptual system is to identify physical objects by generating those multi-sensory perceptual objects. If such an object is known and represented in memory, its cross-sensory features can be recalled by stimulation of only one single modality. Learning to handle physical objects of daily life requires testing of all sensory properties, like vision, audition, smell, taste, surface structure, hardness and many others.
Parallel processing is a basic feature of the brain. It can be found on all levels of neuronal activity, from the interaction of single neurons with its inhibitions and amplifications up to the binding activity of complete cortical domains.
Each of the described three intuitive strategies of cross-sensory coupling implies processing of contextual information. In contrary to genuine synesthesia and constructed mathematical/physical correlations, the assignment of sensory attributes is not fixed, but to some degree influenced by the context of perception.

3. DIMENSIONS OF SOUND PERCEPTION

The physical phenomenon of sound and also its perception can be described as entities with three main dimensions. Both firstly show temporal behavior as changes in time and secondly spectral properties, defining specific instantaneous qualities. Sound waves are thirdly propagating within space, causing sound sources to be perceived as spatial arrangements of objects.

Temporal dimension

Changes of sound features in time are perceived when a minimum threshold is exceeded (*just noticeable difference*). Slow changes provide sensation of fluctuating signals. When temporal changes appear to be shorter than a time frame of approximately 50ms, no fluctuation is perceived, but a static signal is apparent. Periodic changes like modulations are then transformed into static sensations with modified spectral properties. Thus, with shorter duration of changes, perception quality *fluctuation* changes to *roughness*. Whereas we state existence of an objective, monotonously proceeding time, the subjective sensation of time is uneven. Thus, the perceived length of sound events can differ widely. It is influenced by mental and contextual conditions as well as by causal classification (Schaeffer, 1967). If auditory and visual events are perceived in-between a close time frame, sensations will be assigned to a specific cross-sensory object (for delay values see Kohlrausch, 2005). A typical example can be observed during a performance by a ventriloquist, during which the voice of the performer is attributed to his puppet (Vroomen, 2004).

Spectral dimension

Every sound is physically composed of sinusoidal signals. Combination of those signals leads to specific sensations of pitch and timbre. Moreover, it determines whether a sound is perceived as pure tone (one sinusoidal signal), complex tone (various harmonic signals) or as noise without distinguished pitch (various non-harmonic signals). Figure 3 gives an example of temporal and spectral features of speech, which have been extracted by a sound analysis system. Spectra and magnitudes are changing with time. In case of language, those changes mediate information of the sound source (a specific person) as well as of semantic content (the meaning of the speech).

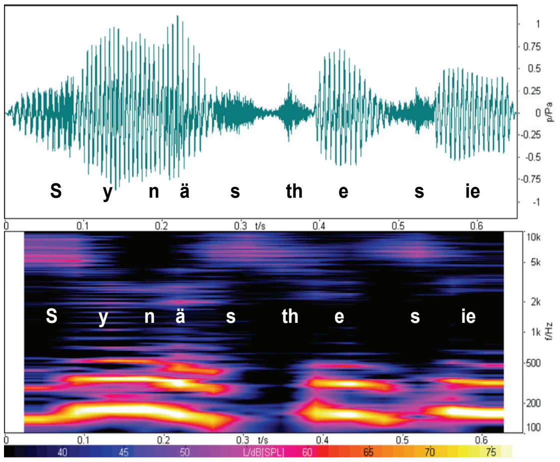

Figure 3. Temporal and spectral representation of sound. The drawing shows analysis results of the spoken word "Synästhesie" (German for "Synesthesia").
upper diagram: sound-pressure versus time
lower diagram: spectra of frequency [Hz] versus time
color scale: sound-pressure level [dB]

For description of an auditory stimulus, a physical description of sound is required. Scientific analysis of sensory perception is based on the assumption that a specific relation exists between physical or chemical stimuli and resulting perceived qualia. The paradigm of causality is basis of psycho-physical investigations. With view of synesthetic images it appears to be of specific interest to compare introspective visualisations with those from analysis of physical data.

Due to the complexity of sound, visualisations are also used to represent measured physical data. The sound pressure is picked-up by a microphone and thus transformed into an electrical signal. Discrete values are sampled with a specific periodicity (e.g. 48,000 values per second), stored and plotted versus time, as shown in the upper diagram of figure 3. The lower diagram provides spectra for each point in time. Frequency is plotted in vertical direction, while the magnitude at each frequency is coded by a color scale. Sound-pressure values are here used in a logarithmic expression with unit [dB]. The colours for scaling are subjectively chosen, while colour is not a physical parameter, but a sensory quality. Within the objective reality, colours do not exist. Yellow bars of the spectral plot indicate the main frequency components, which define sensory features like pitch and timbre, enabling identification of vowels and finally the understanding of speech.
Thus, spectral analysis of physical data provides visualisations via a *mathematical/physical correlation* as denoted in figure 2. Fixed algorithms are used for data transformation from the field of acoustics to optics. The visualisations, however, can be modified by specific parameters like colours, spectral or temporal resolution and others.

Spatial dimension

Sound sources are distributed within a specific space surrounding the subject. Some sound sources can even appear within the body. Handling and analysis of objects by the human being can only be done if perception projects sensory qualia to an estimated location of the source. Otherwise it would not be possible to assign sound to any object causing it – in that case we would not hear a bell chime, but would see a bell and separately hear a sound.

Figure 4. Synesthetic perception of a blind subject, stimulated by bird songs. Sketched according to descriptions of the blind musician Paul Dörken (Anschütz, 1936).

It is an important feature of audition that a projection of auditory sensation happens when signals of two ears are processed (binaural hearing). Therefore perception of sound includes spatial information, enabling arrangement of auditory qualia within a virtual space. The spatial distribution of perceived sounds can be described as an analogy of a landscape, with some parts integrated to a more diffuse background, while other elements are prominent and may show specific meaning. As proposed by the composer Murray Schafer, this configuration is named a *Soundscape* (Schafer 1977).

Synesthetic perception induced by sound can also show spatial distribution, which sometimes correlates with the perceived distribution of auditory sources, but often shows deviations. Many synesthetes report visual sensation occurring inside the head, often projected on an area described as *inner screen*.

A principle challenge of drawing visualisations related to sound perception is the transformation of temporal features into features of a static picture. If no moving image (e.g. an animation) is used, all temporal properties of the sound event will appear as spectral and spatial qualities of the visualisation (see fig. 4 as an example). One method to bypass this hurdle is to lead the observers sight via specific pathways, and thus embed a temporal dimension into the static image.

4. CROSS-SENSORY CORRELATIONS

Cross-sensory analogies refer to the capability of the perceptual system to detect correlations of specific attributes and to analyze them for identification of physical objects and atmospheric features (Haverkamp, 2004, 2007). The analysis of analogies can include:

- generic attibutes (intensity, sharpness, brightness ...)
- motion (*straight*, *rotational*, *irregular*, *expanding* ...)
- body perception (*tense*, *relaxed*, *floating* ...)
- emotion (*calm*, *troubled*, *angry* ...)

Correlations of generic attributes have been comprehensively discussed by Stevens and Werner (Stevens, 1961; Werner, 1966). Those basic features are well suitable to create animations of sound and music (see e.g. Abbado, 1988). Psycho-physics provides tools to quantify the relation between different sensations. A common analogy is the subjective assignment of musical pitch and/or timbre to spatial features. Especially the correlation of pitch and visual height is an important basis of classical (European) systems of musical notation (Wellek, 1963).

Motion is also an auditory feature that is clearly perceived within music and everyday sounds. Very few approaches, however, have been tried to objectively estimate the motional quality from musical signals (Shove, Repp, 1995). The perceptual system tends to cumulate sensory information for a holistic representation of the real world. In fact, the resulting perceptual objects only include rough estimations of physical or chemical elements of reality. In contrary to its holistic strategy, perception can also be focused on single qualities (sensations). In case of auditory perception, Chion calls this a process of *reduced listening* (Chion, 1994).

An objective analysis provides transformation of physical parameters into graphical elements as a mathematical transformation, using specified algorithms. In this case, some similarities to cross-sensory perception are obvious as well as some differences.

The sound of a hard-disk drive is characterized by a variety of pulses, caused by the positioning activity of the magnetic reading heads. The elementary property of a spread of short, relatively quiet auditory events corresponds to the spread of black dots on a roughly painted wooden surface, as illustrated by figure 5. On the left hand side, a photo is shown, taken by the synesthet Matthias Waldeck. He reports that this picture closely correlates to his synesthetic impression of noise generated by a computers hard-disk drive. Thus, photography appears to be an appropriate alternative to drawn visualisations of synesthetic experience. Moreover, the example shows that common cross-sensory correlations can be part of individual synesthetic pictures. On the right hand side of figure 5, a result of objective noise analysis is visualised. This process of analysis implies measurement of a physical quantity (sound pressure) and mathematical transformation to distinguish temporal and spectral properties.

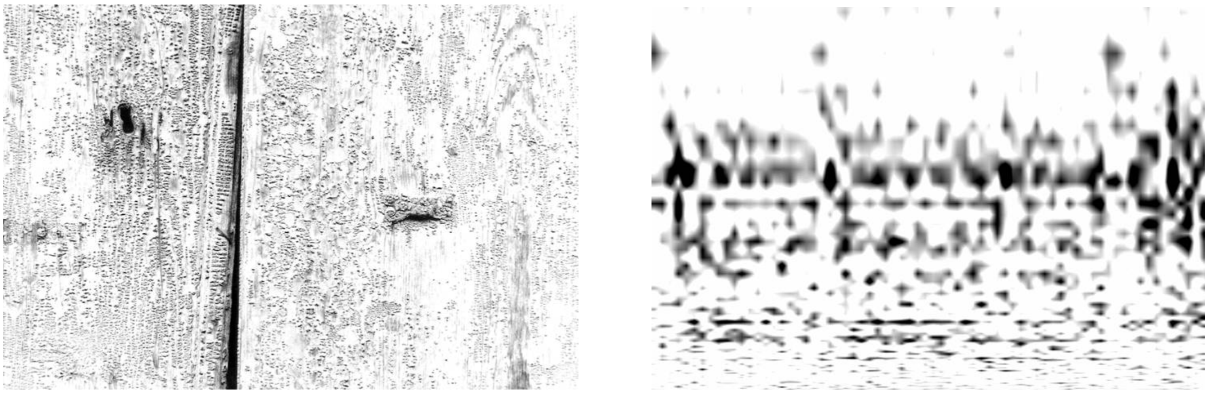

Figure 5. Comparison of subjective and objective processing of sound data of hard disk drives.
left hand side: photo selected according to synesthetic perception by Matthias Waldeck (Waldeck, 2009)
right hand side: result of technical sound analysis, prepared by the author.

Therefore the impulsive feature of the sound is clarified by physical/mathematical correlation between auditory and visual perception. The black and white appearance of the picture, however, is a result of specific choice of a colour scale, consciously designed to point out similarities to the synesthetic visualisation.

The capability to detect cross-sensory correlations as well as correlations of various attributes within one sensual space is an essential feature of the perceptual system. Without the ability of evaluating analogies, perception would not be possible because the build-up of multi-sensory perceptual objects would not be enabled. As mentioned before, a jingling bell can only be recognized if the jingling noise (auditory space) is connected to the image of the bell (visual space). If the necessary integration process fails, only a noise with unknown source is detected in parallel to a moving visual object that cannot be determined as sounding or not sounding. Identification of physical objects is not imaginable without determining correlations.

Analogies are capable to consolidate unknown or unexpected perceptual objects by correlating the perceived attributes. A sound source localized in a specific angle and distance will be coupled to a physical object seen near its location.

Functionality and reliability of operation of technical configurations can clearly be represented by their sounds. Development of new technologies poses the question how functional properties can intuitively be represented by sound. Figure 6 shows an example. The traditional hand held and manually operated coffee mill generated auditory features which contained clear information about the circular motion of the crank handle. A single rotation can clearly be observed either visually or auditory. The synesthetic graphic artists Hugo Meier-Thur visualized this by a circular line, added by a pattern of explosion-like structures which are correlated to the cracking of the coffee beans. A modern electric coffee mill, however, is operated at much higher rotational speeds. With look at the integration capabilities of the perceptual system, the motion is then not heard as a sequence of single events (rotations), but as a continuous noise. Rotational speed is represented by tonal sound with specific pitch and timbre, raising during the on-set phase of the process, decreasing after switching-off the drive. This tone can be seen as a thick line in the lower part of the sound analysis (figure 6, lower right picture). During processing of sensory data, the cracking noise of the coffee beans is merged to a high-frequency random noise, within which single cracks cannot be distinguished from each other. This sound is here visualized as dotted area in the upper left part of the diagram. It diminishes while more and more beans are milled. The movement and fine milling of fragments results in a mid frequency random noise, which is represented by a dotted line in the middle of the picture.

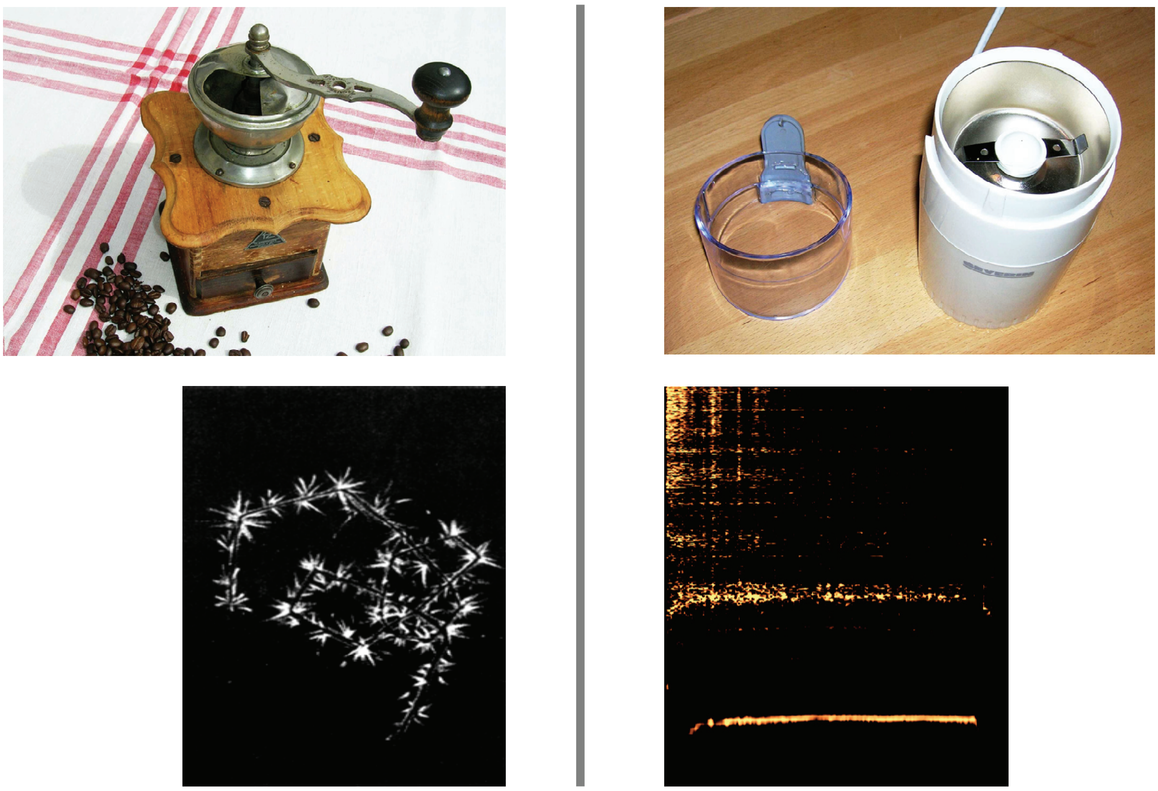

Figure 6. Assigning multi-sensory features to specific technical processes: traditional and modern coffee mill.
Visualizations:
bottom left: Hugo Meier-Thur (Anschütz, 1927).
bottom right: result of objective sound analysis, prepared by the author.

5. ICONIC COUPLING

The iconic strategy to establish cross-modal connections is based on associations suitable to identify known physical objects. A single stimulus can refer to a multi-modal perceptual object stored in memory. Thus a specific sound stimulus can evoke imagination of the sound source with all of its cross-sensual attributes, if the variety of features was experienced before. In example, the sound of splashing water refers to the image of tumbling waves, as shown in Figure 7. This work of a pupil shows the typical shape of waves which is associated to the sound of water. Iconic content is often found within sound drawings of people who do not experience genuine synesthesia (Haverkamp, 2003). In this example, the arbitrary use of colours points in the same direction.

Figure 7. Visualisation of water sound with reference to iconic features: “Surge of the Sea”, pupil’s work from the 1920^{s} (Anschütz, 1930).

Water sounds are often used for description of musical structures in an associative manner. Miles Davis described the piano playing of Bill Evans, who joined the Miles Davis Sextet in 1958: "Bill had this quiet fire that I loved on piano. The way he approached it, the sound he got was like crystal notes or sparkling water cascading down from some clear waterfall." (Davis, 1991) It has to be noted that this is not only a comparison of two auditory events, the music and the sound of water, but moreover sound perception builds-up a reference to multi-sensual perceptual objects, like waterfall, fire and crystal.

Furthermore, listening to music often evokes imagination of landscapes or interiors which fit to the associative content of the music or a comparable atmosphere. Onomatopoeia in speech and music is also a common application of iconic features, because the imitation of natural sound generates an intuitive connection to multi-sensory objects or to the atmosphere of an environment.

While iconic coupling refers to objects in memory, it is based on learning and experience of the subject. It therefore depends on living environment and cultural background of an individual. It provides an identification of sources (the cause) of stimuli. A focus on iconic features of sound can be understood as *causal listening*, often indicating material properties by means of *materializing sound indices* (Chion, 1994). Iconic features of various sensory channels are feasible to amplify each other: The effects of awful sounds like squeal of fingernails on a blackboard or the grinding noise of a dentists drill are intensified when the specific situation is also visually perceived (Cox, 2007).

6. SEMANTIC RELATIONS

Semantic relations can also define elements of synesthetic drawings. A sacral musical motif can lead to visualization of religious symbols or elements of sacral architecture. A painting by Hans Sündermann, which refers to Anton Bruckners 3rd movement of the 8th symphony, Adagio, c-minor, shows shapes of gothic church windows or temple domes (Fig. 8, Adam, 2000, plate 84). Those visual elements are triggered by a sacral, dignified character of the music, which Bruckner assigns to be “feierlich langsam, doch nicht schleppend” (*maestoso, slow, but not sluggish*). The finish of the picture follows the methodology of *Musical Graphics* which was firstly developed by Oskar Rainer during various student’s projects (Rainer, 1925).

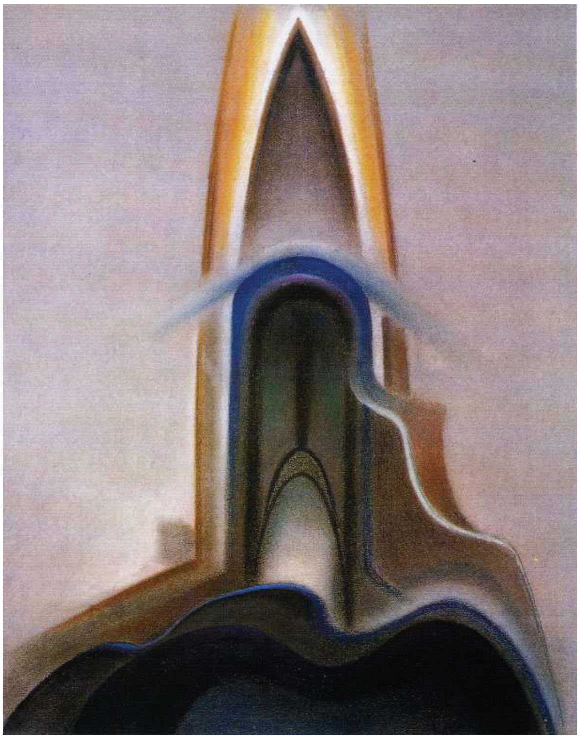

Figure 8. Musical graphics referring to Anton Bruckners 8th symphony, 3rd movement, Adagio. Hans Sündermann, 1935.

As mentioned above, sound is a strong and reliable medium for transmission of meaning in case of spoken language. In general, semantic relations influence the interpretation of sound stimuli and the perception of industrial products (Jekosch, 2005). Therefore meaningful sounds are of special interest for design of warning signals and to establish corporate sounds of companies and institutions (Bronner, Hirt, eds., 2009). Linguistic processes also play a part in perception of sound (Augoyard, 2006). If hearing is focused on semantic content, this is a process of *semantic listening* (Chion, 1994).

Meaning of auditory or visual symbols can be strong, but quick changes of the recipients interpretation can also happen. One example shall clarify this effect: The motif used to identify broadcast and television transmissions of the European Broad-casting Union was assigned to the visual logo of those *Eurovision* events. It thus represents television gala and sporting events on an international, at least European level. The music, however, was composed during the quiet different era of Baroque, far away from any media technology of the 20th century. It is the first motif of the overture of a *Te Deum*, composed by Marc-Antoine Charpentier around 1690.

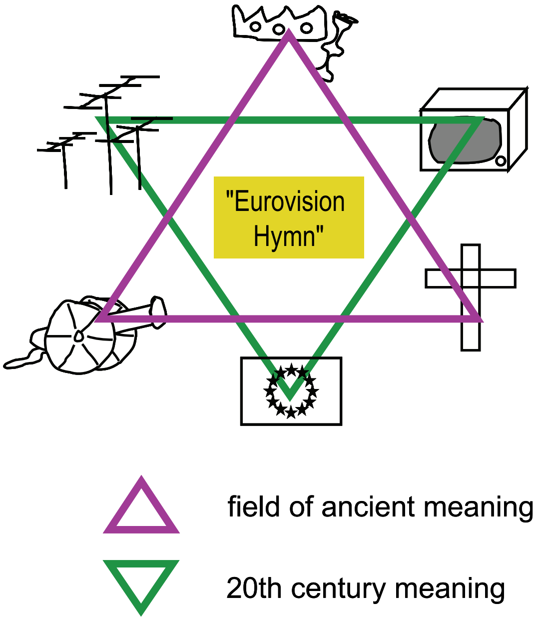

Figure 9. Semantic relations of a sound logo. Marc-Antoine Charpentier: Te Deum D-major – Ouverture.
Field of ancient meaning at the time of composition (magenta) compared to recent understanding as hymn of the Eurovision (green).

Figure 9 illustrates the semantic relations (field of meaning) of that music. It initially included a sacral environment, an introduction of the Sun King, who is set on an equal level with God, and it also hints to military sounds, which may be connected to the victory of the French army at Steinkerque (1692). Church and king are represented by dotted rhythms of the overture, a typical element of royalty within French baroque music. The military aspect comes in with use of timbals and trumpets, supported by a drum roll at the very beginning of the overture. A further part of the complex symbolic is the key D-major, representing a “joyeux et très guerrier” (joyful and very martial) expression. Those meanings were clearly understood by listeners of that time. During the 20th century, however, the symbolic content of this *Eurovision Hymn* is quiet different: it is understood as typical medial, festive, exciting, but not related to king, government, church or war. The martial component was removed with cutting off the drum roll, while the dotted rhythms were partly disarmed. The motif has been powerful since it was composed, but it has strongly changed its meaning and cross-sensory references.

7. CONCLUSION

Perception and subjective effects of sound are influenced not only by auditory features, but by cross-sensory references build within the perceptual system. Therefore it is only possible to fully describe the perception of sound with respect to the multi-sensory perceptual objects to which it is referring to. This fact is evident for music as well as for everydays sounds. Amongst all sensual spaces, vision is the one that most closely (and most impressively) relates to the auditory stimulation. During multi-sensory perception, various common processes of cross-sensory coupling gear into each other, amongst which cross-sensory correlations, iconic coupling and semantic relations are of special impact. In contrary, genuine synesthesia seems to be a quiet different process, showing strictly individual, abstract phenomena. Drawings intended to present synesthetic visualizations, however, often show influence of common cross-sensory processes. From those findings it can be concluded that in many cases synesthesia is not a single, specific, isolated process, but rather is compound from individual and common processes of multi-sensory data processing.

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