Emergence: an Interdisciplinary Paradigm, and its Relevance for the Sound Arts

T.De Wolf, T. Holvoet **Emergence Versus Self-Organisation**
(Dept. of Computer Science, Leuven)

P.Tompkins, J.Lawley **What is Emergence?** (The Developing Group, researchers in Psychology and Administration Sciences, England)

D.Rudrauf, A.Lutz, et al. **From Autopoiesis to Neurophenomenology: Varela's exploration of the biophysics of being** (Laboratoire de Neurosciences Cognitives et Imageries Cerebrale, Paris)

and... Wikipedia article for **EMERGENCE**

- "towards a Theory of Sonological Emergence"
["Formal Processes of Timbre Composition Challenging the Dualistic Paradigm of Computer Music"], ICMC Aarhus and ISEA Helsinki, 1994

micro-time sound design
(micro-composition = sound synthesis)

based on time-finite representations of sound
- D.Gabor's *acoustical quanta* (→ granular sound synthesis)
- *digital samples*, as in C.Shannon's information theory and PCM (→ non-standard sound synthesis methods, computing the audio samples based on compositional premises, arbitrary?)

how one determines the organisation of a ground-level system or process that is capable of "bringing forth" a meta-level system or process of peculiar qualitative, morphological properties?

"emergence" ← [A.Wilden, "La scrittura e il rumore nella morfogenesi del sistema aperto", 1972 (language science & anthropology & synergetics)]

parallel with "sub-symbolic processing" (connectionism)
= composing at sub-symbolic level, disposing of units perceptually irrelevant when separate, but whose microlevel pattern or com-position let coherent higher-level constructs or units emerge that we can perceive and/or understand as discrete symbols in an overriding structure
---

- "**Emergence du Son, Son d'Emergence**"
[Intellectica, Revue de Sciences Cognitives, 2007]

how one determines the organisation of a (real-time) network of sound generating / transferring / distroying mechanisms such that the interactions among these are able to (a) preserve and support the existence of the network as a whole, (b) exploit noise in the environment as a resource to preserve and develop itself?

both (a) and (b) being emergence phenomena of the network dynamics

> self-organising [Von Forster, Ashby], self-reproducing systems (autopoeisis) [Maturana & Varela]

Audible Ecosystemics sound works (concert performances and sound installations), 2002-05

EMERGENCE IN GENERAL

defining
...
detecting and modelling
Baas ["Emergence, Hierarchies, and Hyperstructures", 1994] formal framework of emergence (as relative to an observer) in (a) phenomena caused in the coupling of dynamical systems; (b) large collections of objects get new behaviour like in phase transitions.

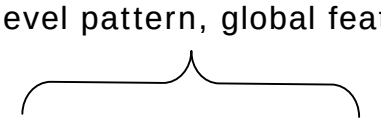
Bonabeau & Desalle ["Detection and Emergence", 1997] emergence as "complexity shift"; all characterizations are relative to the oberver's detecting tools

engineering and implementing
De Wolf, Holvoet "Towards a Methodology for Engineering Self-Organising Emergent Systems" [Self-Organization and Autonomic Informatics, 2005]

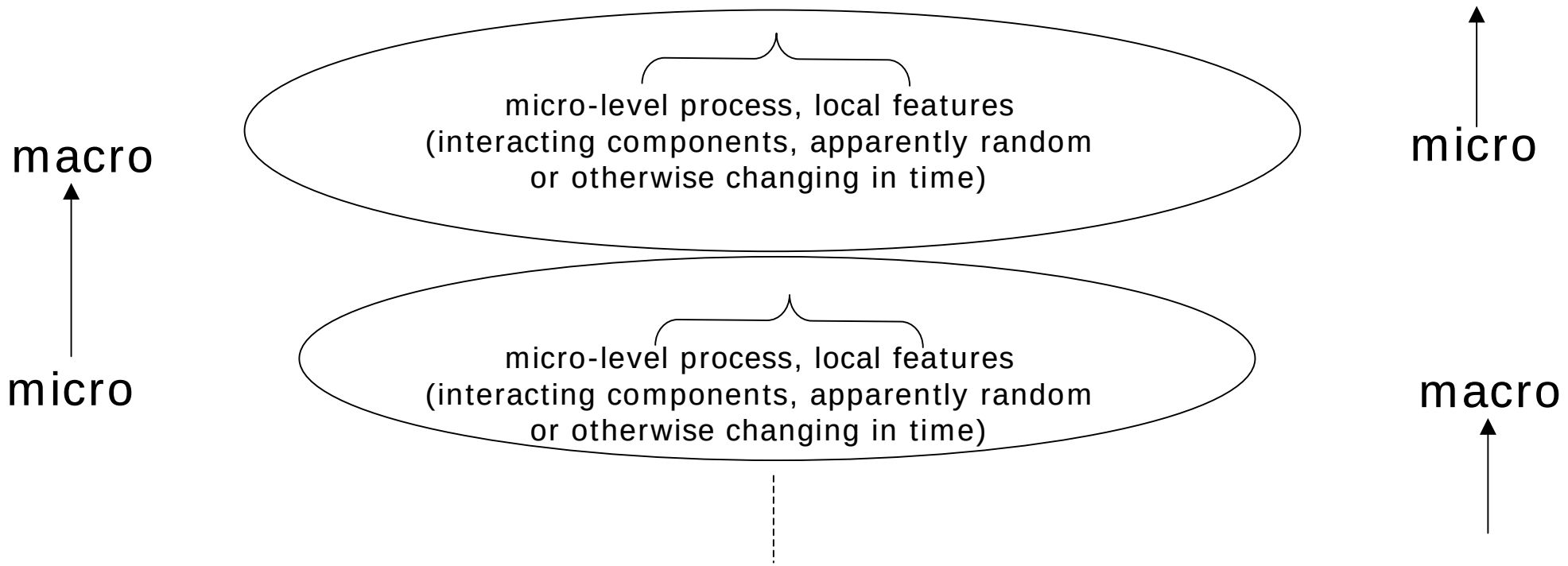
---

informal and general definition
global behaviour in a system arises from local interactions between component parts

"In the study of complex systems one often sees that a collection of interacting systems shows collective behaviour. This is intuitively what we understand by emergence" [Baas & Emmeche, 1997]



levels (micro, macro, multiple scales in the system organisation, multiple scales in observation)



<u>novelty</u> (macro-level behaviour irriducible the parts)

Gestaltic principle

the whole *before* the parts, or
the whole is more than the sum of the parts

H.Diebner : Emergenz (oder Erscheinung?) "...ist die moderne Variante der Heisenbergerschen Erkenntnis *Das Ganz ist mehr als die Summe seiner Taile*..." ["Grundbegriffe und Methoden der Komplexitätsforschung", 2001]

...problems ("weak" notion of emergence)...

G.H.Lewes [1875, "philosopher", or "psychologist", but working in... chemistry] distinguished between

resultant and ***emergent*** chemical compounds coming about from a chemical reaction

> "... although each effect is the *resultant* of its components, we cannot always trace the steps of the process, so as to see in the product the mode of operation of each factor. In the latter case, I propose to call the effect an *emergent*: it arises out of the combined agencies..." and "... cannot be *reduced* to their sum or difference..." [Lewes, 1875]

the properties of the whole cannot be *reduced* to the properties of the parts (= "cannot be described in terms of", "are not predictable nor deducible from")

> nothing in a bird tells you it will be able to enter or create a well-organized **flock** when flying with other birds
>
> elementary particles have no **colour**: only when they are arranged in atoms with a specific position in space they absorb or emit a specific light that, for the eye, is a specific colour
>
> no physical property of a **molecule of air** would lead one to think that a large collection of them will transmit sound

the sound of the wind is an **emergent auditory image**: we don't hear the single, feeble impacts between the leaves, nor the flapping of the single leaves, but we do hear "the wind" as it causes a process with myriads of feeble impacts (the emergent percept is a function of many variables: wind air speed, wind direction, leave size and morphology, leave weight, leave density in the tree, etc.)

---

decentralised control (local mechanisms linked together influence global behaviour, distributed causation)

none of the parts includes a representation of the global behaviour

the whole is not directly controllable, you only access to the parts, and changes in any single part will spread across the network forming the whole (in time, and as a function of the kind of the kind of interactions among the parts)

despite the lack of centralized decision making, **ant colonies** have the ability of solving **geometrical problems**: the members of colony routinely find the maximum distance from all colony entrances to dispose of dead bodies

in the **WWW** there is no rationing of links, yet the number of links pointing to a each page follows a power law (a few pages are linked to many times, most pages are seldom linked to)

do **termites** build their complex nests according to architectural plans?

---

novelty + decentralized control : magic, mistery?

crucial is not the micro-level units as such, but the dynamics of the micro-level process, the kind of local interactions

<u>interaction dynamics (non-linear)</u>

parallelism of operations is not enough, without interactions macro-level changes do not occur

interaction = ***reciprocal causality*** [Varela], factual mutual determination, zusätliche Wechselwirkung [Diebner])

this dynamics may be highly complex (non-linear) to give rise to emergent properties

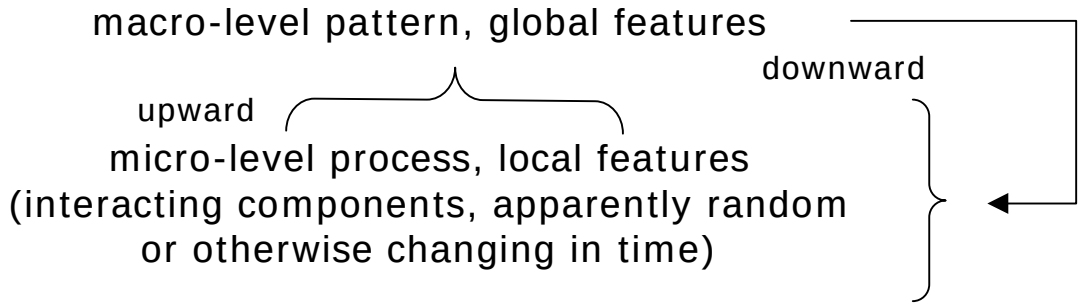
- **complex adaptive systems theory** (Santa Fe Institute)
- **nonlinear dynamical system theories (chaos theory)**
- **far-from-equilibrium thermodynamics** (Prigogine)

<u>downward causation</u> (not only upward)

also called **supervenience**

the dynamics include not only micro-level units interactions, but also **across-level interactions**, and emergent behaviours at any one level *supervene* on lower-level dynamics, creating constraints to the local interactions

bidirectional link of micro and macro: emergent properties affects the local process, higher-level properties have causal effects on the lower-level they were born of (feedback)



positive feedback (upward): a process where an action produces an effect which in turn **intensifies** the conditions responsible for the first action, …

negative feedback (downward): a process where an action produces and effect which in turn **reduces** the conditions responsible for the first action, …

upward causation	system existence, identity
downward causation	system persistence, control

positive and negative feedback are prerequisites in
the dynamics of any self-organising, stable (homeostatic) system [Wiener]

---

often the properties of the whole are *simpler* than the properties of the parts (higher-level simplicity vs lower-level complexity)

"in self-organizing systems, orderly patterns emerge out of lower-level randomness" (Tompkins & Lawley)

> the V shape of birdflocks is a simpler Gestalt, preserved under variable conditions, but the local dynamics between neighbour birds is much more complex
>
> in dissipative and self-organizing systems, lower-level random perturbations lead to symmetry breaking observed at higher-level, and the dynamics of the latter is somewhat simpler than the dynamics of the former
>
> the set of laws of classical mechanics can be said to emerge as a limit case of quantum mechanics applied through large enough masses: quantum mechanics is more complicated than classical

"...increase in order can only occur within a global level" [De Wolf, Holvoet]

the character of "novelty" (properties irreducible to the component parts) is an increase of order despite lack of

such kind of emergent phenomena seem to defy entropic principles (2^{nd} law of thermodynamics)

<u>system closure</u> (circular causation)

because of the mix of upward and downward causation, **levels or scales (micro, macro) are no more separate** (and thus cannot, in principle, be separetely addressed), as they form a closed loop (circular causation)

operational closure : the results of the system operations remain within the context of system operands [Ashby, 1957]

for Varela, closure is a prerequisite of systems that exhibit "properties emerging from, not added to, the elements taking part in the process" [Varela, 1981]

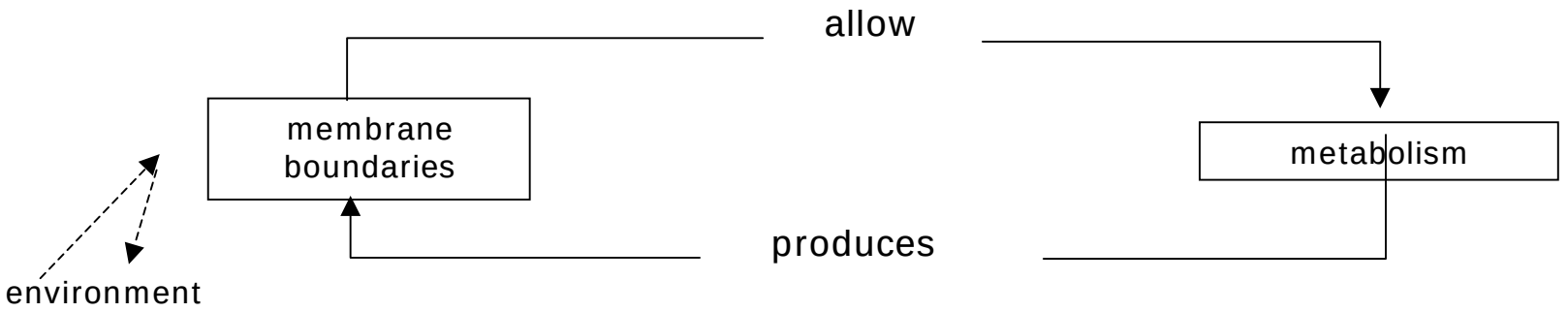
the dynamical process defining a system with "closure" can be represented in a general way as a system of non-linear differential equations

$\dot{x} = S(x, p, t)$

x set of co-dependent variables
S interaction functions
p parameter space

---

a whole produces effects on the parts not only in its closed internal dynamics in the system, but also as a subsystem in a larger environment, i.e. by means of its interactions with the environment



a whole produces effects on the parts not only in its closed internal dynamics in the system, but also as a subsystem in a larger environment, i.e. by means of its interactions with the environment

> human features like "intelligence" or even the sense of "self" emerge from the connections and interactions among neurons, as the neurons' activity is (via the sensory-motor system of the body) affected by the environment [Varela]
>
> "Consciousness is not a property of individual neurones, it is a natural emergent property of the interactions of the neurons in nervous system of the body in an environment. It makes a structure that is related to lower level interactions as well as higher level thoughts, and it represents a new observational mechanism of the entire system" [Baas 1996]

upward causation	existence, identity
downward causation	persistence, control
environment	change, re-organisation (ambiguity, but preserving identity)

---

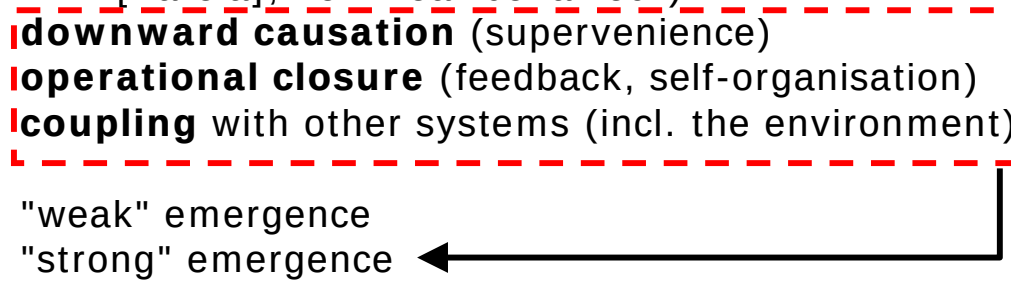
levels (micro, macro, multiple scales)
novelty (macro-level behaviour irriducible the parts)
decentralised control (distributed causation, local mechanisms linked together influence global behaviour)
interactive dynamics (interaction = *reciprocal causality* [Varela], nonlinear behaviour)
downward causation (supervenience)
operational closure (feedback, self-organisation)
coupling with other systems (incl. the environment)

TYPES OF EMERGENCE

levels (micro, macro, multiple scales)
novelty (macro-level behaviour irriducible the parts)
decentralised control (distributed causation, local mechanisms linked together influence global behaviour)
interactive dynamics (interaction = *reciprocal causality* [Varela], nonlinear behaviour)

"weak" emergence

levels (micro, macro, multiple scales)
novelty (macro-level behaviour irriducible the parts)
decentralised control (distributed causation, local mechanisms linked together influence global behaviour)
interactive dynamics (interaction = *reciprocal causality* [Varela], nonlinear behaviour)
downward causation (supervenience)
operational closure (feedback, self-organisation)
coupling with other systems (incl. the environment)



"weak" emergence
"strong" emergence

TYPES OF EMERGENCE

Y.Visetti ["Constructivismes, emergence: une analyse semantique et thematique", Intellectica, 2004]

synchronic components interact among them in a way that exhibits global properties as relative to a certain scale of observation; the emergent phenomenon is there until the particular micro-level process causing it (upward causation) is there
diachronic the micro-level dynamical process causes *changes* in macro-level properties; current local interactions have consequences on later interactions, and that causes a shift in emergent properties
genetic synch and diach are not separable, and their combination involves a permanent and continual re-emergence of the whole:
autonomous, self-organising mechanisms are involved in the micro-level process
resources are sought for in the environment, and the environment is an intergral part of the system dynamics [Ashby, von Foerster], it is **the medium of the system autonomous emergent behaviour** [Maturana & Varela])

Gestaltic principle the whole is **more** than the sum of its parts
[after von Ehrenfels, 1890s]

Gestaltic principle extended
the whole is not merely more, but very **different** from the sum of its parts [Anderson, 1972]

Ecological principle(s)

the whole is **more and less than the sum of parts**
the whole is **less than each single part**
[after Edgar Morin, 1970s and 1980s]

apply only in a "strong" and "genetic" notion of emergence
the whole is **less than each single part**

a bureaucracy can behave in ways quite different (rigid, less flexible) as compared to the way an individual behaves within that bureaucracy (the part is more complex and richer in dynamical behaviour, but it is *sacrificed* for the sake of the whole's efficiency)

the pray/predator dynamics in a given environment is much
simpler (a nonlinear oscillator modelled with a recursive logistic equation) than the autopoietic dynamics of each individual pray or predator (and their respective group dynamics)

---

von Ehrenfels' fundamental example for **Gestaltqualitat** (whole > sum of parts) was "musical melody"

the melody is a definite perceptual Gestalt:
one hears the melody, not a sequence of notes

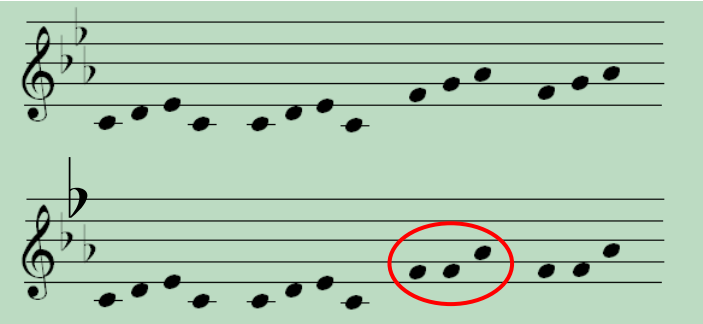
notes and the intervals "disappear" when one hears the melody

in more recent reserach, tonal musical functions have been modelled in terms of emergent cognitive categories

e.g. [M.Leman, "Emergence Properties of Tonal Functions by Self-Organization", 1990; "Symbolic and SubSymbolic Descriptions of Music, 1993]

---

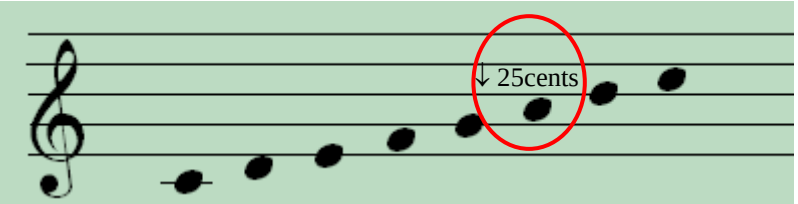
phenomenon of perceptual **categorization**



the Gestalt is preserved despite profile is distorted: the emergent cognitive structure "melody" *binds* the perceptual process to drop information not consistent with the context

---

categorization in **pitch perception** [D.Deutsch, C.Kruhmansl]



the cognitive construct "C major scale" (may be not explicitly labelled by listeners) supervenes the perceptual process in further organizing sensory data where any one note in the scale is higher or lower than it should (within margins): in this context, the sixth note remains consistent with the emergent group property, so it is perceived as "A", not as "A a-quarter-tone lower"

downward causation : the emergent, higher-level properties (tonal context) forces the process of perceptual organisation to discard information that contradicts the Gestalt

---

categorization in **timbre** perception

first time hearing a voice on the telephone

→

no matching with any already-established mental template (spectrum, intonation, articulatory details of language)

- ...is it Rachel?...can't be Alexandra... -

...

- ah, it's YOU, Julia !!! -

emergence of a new cognitive template

next times (within a certain time-span), Julia's voice will be recognized soon and will not be mistaken

---

SONOLOGICAL EMERGENCE : ITS STATUS?

Sound-Research Methodology

Ecologically-informed Studies on Perceptual and Cognitive Research dealing with Sound

Development of clever "interactive" musical means (see the "Enaction in the Arts" Conference, development of "haptic" interfaces, etc.)

Theory (Music Theory, Sound Art Theory)
fundamental reworking of notions of **timbre** and **space**

> urgent after more than one-hundred years of history where "timbre", "space" and group-dynamics are crucial expressive media (modern orchestration, electroacoustic music, collective improvisation, sound installations, radio art, etc.)
>
> approaching new musical dimensions (e.g. "texture", "sound masses", "environmental sound", etc.)

Analysis

descriptions of emergence (formal and/or intuitive) provide tools for scrutinizing and communicating specific sound art works, for which the renovated theoretical framework seems fit

Sound-Research Methodology
STUDIES ON AUDITORY PROPERTIES AS EMERGENT

implicit in some historical work such as

C.Stumpf's *theory of consonance based on spectral properties*
[early 1900s]

W.Meyer-Eppler "formal criteria of various order" should be considered in studying sound: "the first order contains all observations concerning the statistical distribution of sound elements themselves … The second order ('Markoff chains') and all higher orders take into account the … transfer from one element to another or between further distant elements and their contextual relationships…"
[mid 1950s]

J.C.Risset's experiments with pitch and timbre paradoxes, (1960s and 70s) indicates that the perception of a definite "pitch" arises from lower-level details (pattern of spectral components) to a much larger extent than previously suspected

S.McAdams' micro-level criteria for the "fusion or fission" of partials in harmonic and inharmonic series [late 1970s]

sequential grouping and auditory streaming (van Noorden, McAdams & Bregman, 1970s and early 1980s), based on, and extending, Gestalt principles (proximity, common fate, etc.)

2- or 3-voice poliphony in Bach's and Telemann's solo pieces

Albert Bregman : "emergent features" are "global features that arise at a higher level when information at a lower level is grouped" (Auditory Scene Analysis, 1990)

"group properties" cannot be reduced to the "unit properties"

(novelty)

Bregman et al. seem to follow only this path of **upward causation**, yet from other approaches on music cognition (see the categorisation examples) we know that **downward causation** is also likely to have a role

Bregman parses the problem of modelling **compound auditory percepts** (like e.g. environmental sounds, sound rich in noise components, dense sonorities made of many smaller particles) in two factors

a) characterizing the unit sonic particle
b) characterizing the process of assembling the unit sonic particles

that is, he requires "granular" representations, especially useful when considering "sound textures" and the perception of very dynamical sound events (see also [J.MacKay, "On the Perception of Density and Stratification in Granular Sonic Textures", 1984])

the "sound of wind" (mentioned above)

to what extent the properties of units in the group are relevant?

Warren & Verbrugge's research in modelling complex auditory events (Journal of Ecological Psychology, 1984)

bottle falls on the floor: the auditory emergence of "crashing" is independent of the material (of the bottle, of the floor) : the modelling of the sound event (breaks and impacts), was succesfull with synthetic sounds were used: the process would result into a gesture of "crashing", independent of the units

in research on visual field perception a similar approach has been taken base on the notion of *texton* - the atomic element of texture [B.Julesz, "The elements of Texture Perception and their Interactions", Nature, 1981]

a musical-analysis application of Julesz' theory to music is [Gabel, Proc. of the Arts & Technology Symposium, 1993].

MUSIC THEORY

all sound art where TIMBRE and SPACE are relevant dimensions of expression and communication involves, at one or more levels, emergent phenomena

TIMBRE

(traditional negative definition) the quality of a sound that allows one to distinguish one instrument from another

late 19th-century acoustics : shape of the harmonic spectrum (wrong)

various redefinitons including transient phenomena, and
summerized (in the context of electroacoustic music) in Smalley's concept of **spectromorphology**

these are all definitions pretending to explain "timbre" as a perceptual attribute somehow proper of the waveform of acoustical vibrations (or its spectral content) as the vibrations are transferred to the ear

---

TIMBRE

> the morphology emerging from the interplay among a system's physical constraints, and from the external conditions under which that system operates (including agencies operating in the surrounding)
>
> = identity, "form"
>
> various ecological approaches on auditory perception in recent years
>
> research work bridging between physical modelling and auditory perception studies (e.g. The SoundingObject Project, early 2000s)

in this theoretical framework, timbre can be viewed no more as a predetermined property of given materials or sound-producing devices, but as an **emergent properties** of interacting forces AND a **medium of music making**, a GOAL of composition (composing-the-sound, composing-through-sound)

not an objective objectively belonging to some external reality (Nature) but as man's construction (Culture, Art)

an auditory dimension shaped up by a designed process, by composition (micro-composition, sound synthesis)

timbre-as-emergent feature, timbre-as-form

applies not only to electroacoustic music (yet the latter does require a novel theoretical characterization, otherwise not having gone further than Smalley's spectromorphology, late 1970s) but to previous domains of musical expression, too, such as

> modern orchestration (the orchestra sound is more than the sum of the instrumental parts, and something of that "more" lays in room acoustics)
>
> > by extension: extended instrumental techniques
>
> dense counterpoint (Flemish, Venetian, Bachian), resulting into **textural** perception, and strongly connected to the space (room acoustics)
> textural modern composition (Xenakis, Ligeti, etc.), often with spatial arrangement of the orchestral instruments (X's *Terretektor*, Stockhausen *Gruppen*, etc.)

(considering a "strong" notion of emergence)

the dynamical process from which sound properties emerge exists in an environment; exchanges with the environment happen as it produces sound

> **space** must not be connected or linked to the notion of sound and its form (timbre) as an external entity, as something added to sound

must be recognized as an integral component in the coming about of the emergent properties of sound

before it can be "spatialized", **sound is not** (and is not born) **without space**

"spatialization" (acousmatic music) is a second-order process dependent on the first-order, inseparable from the space-coming-in-and-with-the-sound

ecological awareness: **sound is never "an sich"**
it's always (in) a relationship

sound is relational (B.Labelle, sound installation artist, 2007) it binds, it is (born of) interactions among components in a system

> Tartini's 3rd sound (differential tones reinforced by the violin soundboard) is a emergent property, as a singularity in an otherwise linear, predictable mechanical system
>
> it shows that
>
> > timbre, as sonorous identity (in this case, deformed by the appearence of novel partial tones, changing the shape of sound),
> >
> > and
> >
> > space (the room that the violin body is)
> >
> > are always, inextricably coupled

MUSIC ANALYSIS

examples from the electroacoustic music repertoire

> Xenakis' ***Analogique B*** (1958) : granular synthesis in several layers, aiming at "2nd-order and higher-order sonorities" [Musiques Formelles, 1963]: higher-order sonorities emerge from the statistical distribution of units (sonic quanta) at various temporal levels
>
> (cfr. Meyer-Eppler's 1958 paper)

a formalism of emergence as "hierarchical organisation" or "hyperstructure" [Baas, 1994] could be applied

> Stockhausen's ***Studie II*** (1954) : additive synthesis with permutational laws governing the spectrum, resulting into a (small) variety of *klangmixturen* : variations of spectral density are a byproduct of the lower-level permutational process
>
> few categories of timbre come about from the spectral variations, and they represent a second-order musical structure (of more consistent perceptual salience than the ground-level permutational process)

in both cases (Xenakis and Stockhausen)

> "weak" emergence (no feedback, no downward causation implemented, no environment or external conditions creating constrains in the process)
>
> "synchronic emergence" (no change in time)

Lucier's ***I am sitting in a room*** (1970), implements a long-delayed feedback process, taking on the spectral coloration specific to the room acoustics

variations in sound do not occur without the surrounding space, and all events at some given time may engender long-term changes

"weak" or "strong"? ... "weak" : at the beginning some sound is *provided* (*emergence* come only as it is acted upon and transformed in time);

"strong" : there is some downward causation (the emergent spectra coloration binds the further development in the process)

"diachronic" (the system process may give rise to temporary changes in emergent properties)

D.Tudor's ***Microphone*** (late 1960s)

Reich's ***Pendulum Music*** (1968)

Cage's ***Electronic Music for Piano*** (late 1950s) as recently implemented by C.Burns [“Emergent Behavior in Idiosyncratic Feedback Networks” (2003), “Designing for Emergent Behavior: a John Cage realization” (2004)]

…

the work emerges from the real-time coupling of the electroacoustic setup and the room hosting the presentation

---

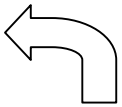
the ***Audible Ecosystemics*** project can be viewed as an effort to implement a real-time system capable of manifesting emergent behaviours of the "genetic" type

"strong" (downward causation, feedback, closure)
"synchronic" (emergence of existence, identity) and "diachronic" (emergence of new configurations in the system process)

via the tight coupling with the room (noise is the only source)

---

defining emergence
detecting and modelling emergence
engineering and implementing emergence



necessity of more work