# Urban Soundmarks Psychophysical Geodimensioning: Towards Ambient Pointers Geosystemic computation

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# Urban soundmarks psychophysical geodimensioning : Towards ambient pointers geosystemic computation

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## ABSTRACT

The presented research work within AMBIOFLUX project aims to model the ambient soundscape system onto an urban pedestrian pathway using GIS spatial dynamical mapping. Pathway's acoustic fingerprints are discreetly built through informational evaluation of spatial interaction between sound ambience (soundscape) and urban walker spatial trajectory (soundwalk).

To do this, relevant "impressing" soundsources, "soundmarks", are defined through their psychophysical emergence dimensions, implying energetical and perceptual event entropy interdimensional scaling.

In order to built the corresponding psychophysical model, geocomputation of physical emergence indice will be implemented, the $L_{EPN}$ (Effective Perceived Noise Level), together with the informational emergence indice $E$ (maximal entropy index).

Obtained soundwalk pathway integrated results using GearScape (a customization of OrbisGIS) spatial formalism will therefore be presented. Geospatial knowledge modelling and representation techniques will be used for this task, leading to a methodology for semantic integration of the urban ambient soundscape model. This methodology will then be implemented through a case study in Strasbourg, with soundwalks made across the city.

This is a first step for integrating psychophysical informations into a powerful geocomputational basis for pedestrian acoustic exploration of the city, in order to feed structured actions plans relative to E U cities sound mapping.

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# 1. INTRODUCTION

Indicators of urban long range sound situation comfort assessments stumble over the lack of qualitative soundscape descriptors, describing both the physical structure of the sound signal and the associated noise- or sound perception. For this aim, we'll propose an innovative space-time event-dimensioned emergence indicator to be applied in complex soundscapes, taking soundscapes informational dimensioning into account.

This research work is developed within an interdisciplinary research project, called AMBIOFLUX, funded by CNRS, French National Center for Scientific Research, and MEEDDAT Ministry (French Ministry dedicated to Ecology, Energy, Sustainable Development and land use planning) under PIRVE's (Programme Interdisciplinaire de Recherche Ville et Environnement) contract. This work aims to produce dynamical urban acoustical indices for spatial interaction indicators between sound ambience (soundscape) and man urban spatial trajectory (soundwalk).

With defining ambiences as an anthropocentric view of the global environmental production through physical, human and built constraints of architectural and urban design, we consider urban space as a field of data, aimed to ambiences physical parameters description through multiphenomenal characterization [1]

In order to exploit those data for building production process, the objective of this work is to produce dynamical urban environmental indicators through « ambient pointers » definition [2].
This work will focus on informational indices production, in order to provide dynamical GIS-powered outdoor ambience representation tools, with taking the sensorial aspect of phenomenal perception, mainly auditive, into account [3, 4].

From an instrumental point of view, GearScape innovative spatial formalism processing aims to qualify pedestrian spatial interactions with producing a set of ambient dynamical indicators. To do this, dedicated methods to proceed soundscape informational analysis are sound sources observation, description, organization, recognition, hierarchic identification and systemic modelling [5, 6]

# 2. SOUNDSCAPE PHYSICAL AND PERCEPTUAL COMPLEMENTARY INDICATORS

## A. Quantitative approach: Physical Emergence Indicator

First indicator corresponds to « energy temporal average », which is defined as an energy fluxes, classically expressed through a temporal integration as equation (1):

$$L_{eq} = 10 \times \log\left(\frac{1}{T}\sum_{i} 10^{\frac{L_{eq_i}}{10}} \times \Delta T_i\right) \tag{1}$$

Equivalent Sound Level is formulated in terms of the equivalent steady noise level which, in a stated period of time, would contain the same noise energy as the timevarying noise during the same time period [7].

Those regulation-indices has been built to characterize "macroscopical" sound situations, they stands unable to define environmental noise in terms of perception. This can be approached through other indices, physical ones built from energetical emergences, or perceptual ones built from event structuration of the soundscape.

Therefore, physically scalable indices can be calculated from events date and length by time windowing, and through sound sources emergence threshold levels.
At this aim, previous equivalent steady noise level formulation leads to well-known emergence indices rating such as $L_{EPN}$ (Effective Perceived Noise Level), as equation (2):

$$L_{EPN} = 10 \cdot \log\left(\frac{1}{T_0}\sum_k \Delta t \cdot 10^{L_{PNTk}/10}\right) \tag{2}$$

With $T_0$, 1s reference period and $\Delta t$, 500ms short-time interval. Empirical event frequency distribution is therefore computed from the correspondent dynamical emergence indicators. Showing specified emerging modes, the resulting emergence frequency distribution aims to define urban situations regarding acoustical structure of the soundscape signal, thus signing specified sound qualitative contents.

### B. Qualitative approach: entropy indexing as a Soundscape Emergence Dimensional Indicator

For a given subject and within a given observation period, soundscape knowledge is both relevant to sound sources physical emergence we have defined previously and constitutive sources occurrence frequencies within the observation time. Those two characteristics constitute the main psychophysical scaling dimensions which has to be defined for Qualitative approach [8].

Therefore, together with $L_{EPN}$ that characterize sound sources energetical emergence for a done period, the complementary measure for soundscape informational characterization is frequency characterization of the observed main emergent soundscape events. This evaluation implies a teleological dimensioning of the event structure perception, taking forecasting quantization into account, to proceed to an event entropy measurement [9].

To do this, a soundwalk event distribution can be approached through its uncertainty evaluation with both local and global entropy indexing, related to a subjective territorial interaction. In terms of probabilities, as expression of soundscape composition is relevant to the soundwalker environmental knowledge, entropy, and all relevant quantities, is fundamentally subjective.

Among all variables, entropy is the thermodynamical simplest quantity to be applied to non-physical systems, as it is considered to be a measure of system disorder within informational datasets.

Unlike thermodynamic entropy being a “content-full” concept specific to thermodynamic systems, statistical entropy applied here qualifies informational probability distribution as a “content-free” syntactic concept, a quantity calculated from the numerical properties of the “virtual system” distribution laws. It is important to note that even Boltzmann's view of the second law of thermodynamics, with using the entropy term [10] as a law of disorder into an open system, confirms this “content-free” ontological status of statistical entropy [11]. Following this assumption, the challenge of the work pioneered by Shannon and Jaynes [12, 13] was to extend the entropy concept and to apply its measure in as many different contexts as possible.

Considering environmental, mainly acoustical, interaction process as a sensation vector from subject to the ambience complex, ambient pointer interdimensional data are sound source geolocalisation (*xy* location into the urban maze), together with the two psychophysical saptial extends: emerging noise level $L_{EPN}$ and soundmark entropy values (*H, E(x)*).
This last indicator refeers to Shannon entropy calculation [12] as following equation (3):

$$H = \sum_{x \in X} p(x) \log \frac{1}{p(x)} \tag{3}$$

which describes the uncertainty quantity by the information which we do not have about the state occupied by the concerned source. Entropy index is a measure of the uncertainty of the soundscape events occurrence: the higher the *H* value, the more unpredictable the constitutive sound events; in other words, entropy index *H* constitutes a reliable soundscape originality measurement.

In our case, considering n sound sources as discrete random variables $x_i$ with entropy $H_i$, the "largest remaining uncertainty probability distribution" can be estimated from the *2n-1* dimensional vector, called entropy vector *E(x)*, with the following equation (4):

$$E(x) = \frac{1}{n} \sum_{i=1}^{n} -\log\ p(x_i) = Max\{H_1, ..., H_n\} \tag{4}$$

Maximum entropy value aims to define the temporal behavior of the n-sources composing the studied soundscape. The related quantity *E(x)* quantifies the soundmark ability to reach the listener during an urban soundwalk. For a given soundscape, source emergence value scales from sound signals (maximum entropy sound event) to "Keynotes" [14] (null-entropy background sound).

Because a soundscape sources composition is necessarily scattered over time, the use of aggregation in entropy indexing specifically addresses the issue of temporal reliability. Therefore, brief periods of soundscape observation have to be repeated over different periods (morning-afternoon, day-night, or seasonally). Temporal stability can then be appreciated through dispersion calculation of relevant entropy indices, so that the "informational portrait" of the soundscape can only be defined over a sufficient number of observations. Consequently, probability *p(x)* is based on empirical frequencies measurement issued from observation statistics from inquiries and soundwalkers expressions [15], and is actually calculated from the frequency occurrence of the related event *x* within the recorded soundscape; Huffmann's perceptual encoding can then be enacted through the relevant soundscape Zipf-Pareto law for the sources distribution [16]. As this law typically holds when the "objects" themselves have a property (such as length or size) which is modelled by an exponential distribution, we will use this law to evaluate a soundscape entropy level, as described in the following section.

## C. Zipf-Pareto law sources distribution dimensioning

First applied for English texts word occurrence frequency determination [17], empirical law known as "Zipf law" is an expression of universal regularities, and was applied in numerous domains, including musical composition [18] and audio medical signal, a notable exception of Zipf law application being soundscape acknowledgment. In an analogical way, sound sources are here considered as the soundscape words (sound items) to be analyzed, through ratio computation of their emergence vs. occurence frequency. As indicated equation (1), mathematical expression of Zipf law involves the number of occurrences of a done sound source, understood as an acoustic emerging event. Within a given soundscape, relationship between the constitutive sound sources emergence with respect to their occurrence frequencies should then provide a rank-order Zipf power law. The resulting event density probability distribution will then provide informationing and entropy indexing.

## 3. EXAMPLE CASE STUDY

### A. Entropy evaluations

In this section, we will apply entropy calculations processes presented in previous section to the main study area of the Ambioflux project. The site is located in the north suburbs of the french city Strasbourg.

It corresponds to a rectangular area of less than 2.9 km, from north to south, and 2.2 km, from west to east. In this area, 5 different pedestrian pathways were defined. Within those pathways, 7 soundscapes have been recorded and analyzed, as illustrated figure 1:

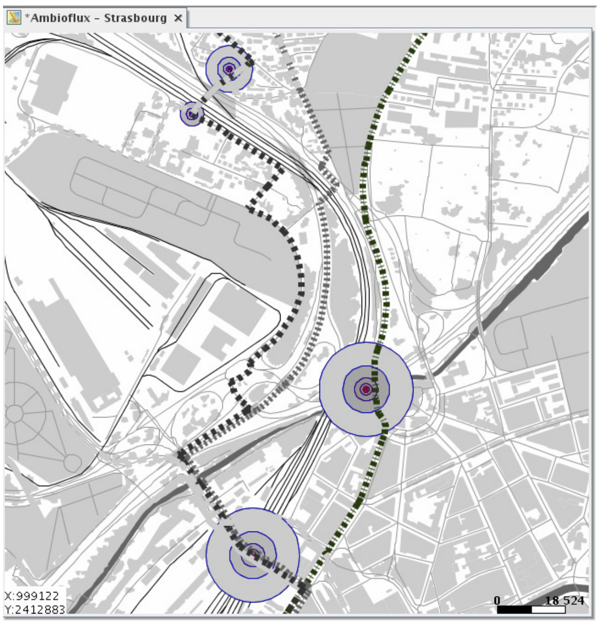


**Figure 1**: As shown in this figure, several layers are loaded as input data, such as the soundmarks (centers of the concentric discs), the pedestrian pathways (dotted polylines) but also buildings, roads and rivers as background maps.

After recording operation, qualitative analyze consists into operating a multisource description of the whole sequence. A statistic of the resulting description items will then provide their respective occurrence frequencies, in order to be plotted regarding their corresponding emergence levels.

Thereafter, a rank-order (Zipf) analysis have been made with taking each constitutive source within the soundmarked sequence into account.

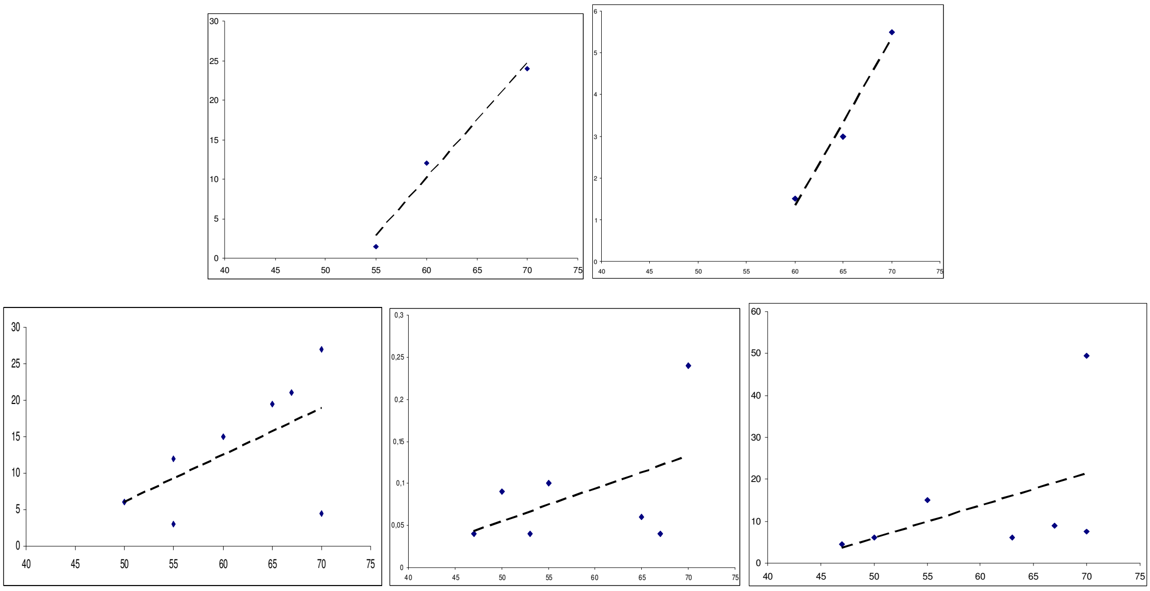

**Figure 2**: Rank-order laws of soundcapes 1 (Rempart), 3 (Autoroute de l'Est), 5 (Cité Nucléaire), 6 (Schiltigheim) and 7 (Z.A. Mittelfeld).

As showed figure 2, emergence density probability distribution of the recorded points clearly discriminates poor soundscapes ("low-fidelity" soundscapes in the sense of M. Schäfer [19], corresponding here to points 1 (Rempart) and 3 (Autoroute de l'Est)), from rich ones ("high-fidelity" soundscapes, composed with hierarchized numerous sound sources, corresponding here to points 5 (Cité Nucléaire), 6 (Schiltigheim) and 7 (Z.A. Mittelfeld)). As a result, we obtain a set of spatial punctual positions and, for each of them, ambient indicators such as the aggregated $L_{eq}$, coupled together with entropy evaluation. The numerical values we obtain are presented Table 1.

**Table 1**: *Aggregated Leq and entropy numerical values*

soundmarks_gs ×

| the_geom | gid | decibels | entropy | comment |
|---|---|---|---|---|
| POINT (998228.9 2412558 138... | 1 | 88 | 0,535572 | Rempart |
| POINT (996863.7 2414015.9 1... | 5 | 72 | 0,87891915 | Cite nucleaire |
| POINT (998062.7 2413763.3 1... | 3 | 81 | 0,29160928 | Autoroute de l'Est (W) |
| POINT (998163.9 2413886.3 1... | 4 | 83 | 0,441327 | Autoroute de l'Est (E) |
| POINT (998537.7 2413011 134... | 2 | 92 | 0,882345 | Place de Haguenau |
| POINT (997107.5 2414416.4 1... | 7 | 81 | 0,79148249 | ZA Mittelfeld |
| POINT (998944.3 2414195.7 1... | 6 | 79 | 0,83485832 | Schiltigheim |

## B. Soundscape GIS timeline implementation

As written before, one of our objectives is to adapt the GIS formalism to the specificities of the soundscape informational dimensioning. The main idea is indeed to take benefit from

Geographical Information well-known concepts and techniques and apply them to the spatial interactions between sound ambiences and an urban pedestrian walk.
Therefore, we have to map soundmarks effects onto the pedestrian pathways and compute the previous indicators to characterize the environmental interaction process, with the mentioned psychophysical soundscape indicator. Because this scalar indicator does not describe the soundwalk from a temporal point of view, we have also defined and developed a line chart representation of the soundwalk pathway: this constitutes the ontological basis of our time-line approach.

As a soundwalk among a composite soundscape can be fundamentally considered as a time-line process, soundscape perception integrates not only sound sources emergence and occurrence frequency as parameters but also the temporal structure of the events' perception. Therefore a slice-time has to be set so as to sequence each pathway, so that we adopt a discrete decomposition approach. Both pathways and soundscape continuous features are thus transformed into discrete counterparts, in order to make real data suitable for computational treatment. The discretization scale we use is based on a nominal cell size of 2m x 2m, with regularly spaced grid. Then, multidimensional valuated discrete pathways are produced merging discrete pathways with extended soundscape, as illustrated figure 3.

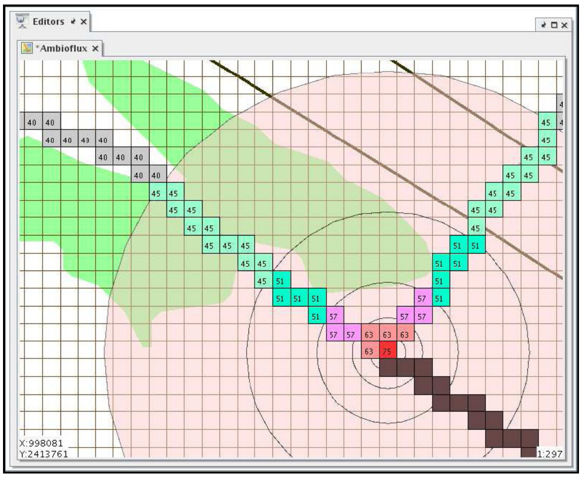


**Figure 3:** The energetic indice of each cell of the 5th pathway decreases little by little as we move away from soundmark center.

Aim is here to order each cell of the discrete pathway - starting from the beginning - on a time-line. This step is achieved using a dedicate development that makes a strong use of the GDMS (Generic Datasource Management System) efficient spatial index implementation [20]. Dedicated first map presents the distributed sound pressure integrated levels along the 5 mentioned pathways, time-line approach of the equivalent sound level all along the sound-walk, readable following figure 4:

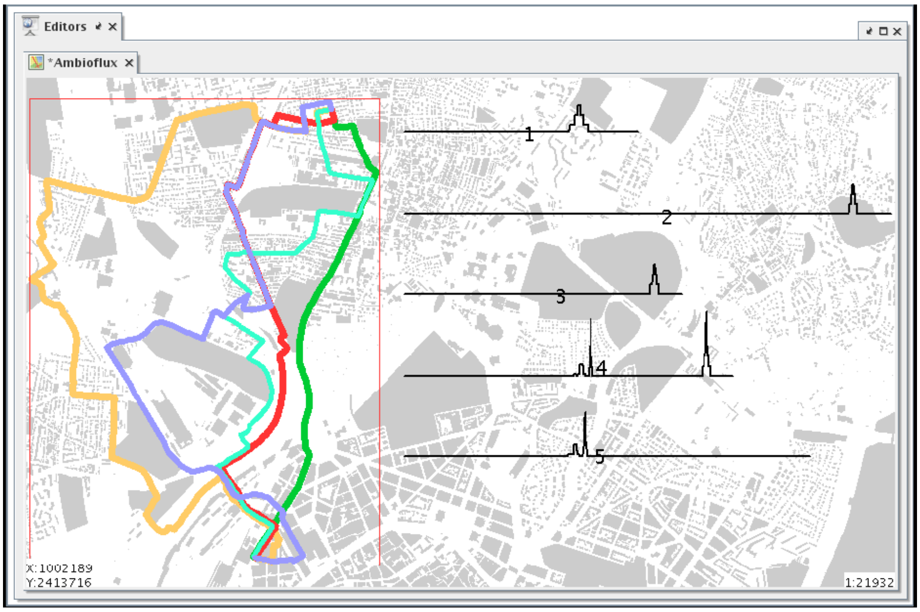


**Figure 4:.** Timeline approach of the equivalent sound level pressure all along the soundwalk: one line chart per pedestrian pathway is plotted

Second map integrates event density probability distribution into GIS spatial dynamical mapping. The corresponding time-line representation of the entropy Zipf analysis along the soundwalk shows an expected synchronicity between emerging sound levels and entropy values. Moreover, the last 5th path reveals an unexpected signature of the corresponding soundwalk, as entropy value is not correlated with the last emerging sound level (figure 5).

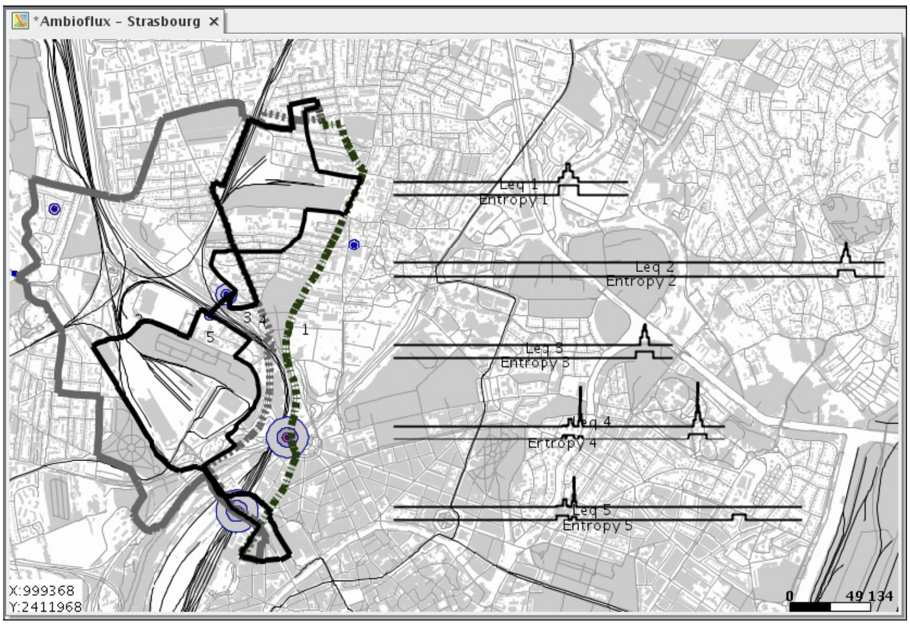


**Figure 5:** An additional line chart per pedestrian pathway is plotted. It represents the timeline approach of the entropy index all along the soundwalk

It is important to note that this uncorrelated entropy signal signs the soundwalk passage into the “South” soundscape (point 1 “Rempart” ) emergence zone. Moreover, we can deduce that qualitative sensivity of entropy does not depend on the corresponding source physical emergence characterization. One can conclude that the two components of our psychophysical indicator are dimensionally independent. This property enables this indicator to describe sound ambient phenomenon with being implemented into our GearScape geosystem.

## 4. CONCLUSIONS

For many years, architectural and urban ambiences have been the main subject study of our researches, dealing with the urban built shape interactions. Furthermore, our interests for ambience characterisation is motive for the importance of sound in architectural and urban spaces, denounced through the sonic pollution increasing.

Nevertheless, and mainly for sound characterisation, classical GIS phenomenon visualisation provided with parameters related to physical factors can not afford a satisfying representation without integrating the sensitive aspect of phenomenal perception, which can’t be expressed without time-dimensioning. Major originality of the geosystemic model we propose with GearScape is that, when cloning the input pathways layer is cloned with adding a numeric field corresponding to an ordered index, a sort of temporal dimension is added to the whole spatial implementation process : we do not only handle spatial data, but also spatio-temporal ones! Thus, entropy-dimensioned inference rules mechanisms through land-, sound- or ambient- territorial marking will allow to constitute a “live” interaction model together with physical simulation process. In that aim, the resulting hybrid GIS-powered ambiences representation model will qualify global environmental interaction sets as a collection of interacting systems, showing collective behaviour at different scales.

With applying those principles to soundscape analysis, psychophysical integration of physical emergence and global entropy provides a powerful geocomputational information basis for pedestrian ambient exploration of the city. To do this, acoustical ambient system dynamical representation will display a psychophysical fluxes indicators dashboard within the timeline of an urban walker, to enable realtime territorial ambient mechanisms observations during the exploration process.


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