Build a semantic map of the brain activity / state of consciousness

We want to define a process able to build meaningful maps of the brain activity.

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While brain activity representation (i.e EEG or fMRI) are build on the basis of an anatomical representation of the brain, we want to identify a set of complementary representations of the brain activity, based on the semantics of the states of consciousness.

This representation could be useful to discover new brain activity patterns separating the “real” (and assumed unknown) functional basis of the brain activity from the anatomy of the brain, that today is the most common spatial frame on which representations of the brain activity are built.

Nevertheless we think that the approach can be adapted to work on a very general basis (i.e. with other biosignals), we focus on the application of the approach on EEG signals, that is supposed to be more connected with states of consciousness

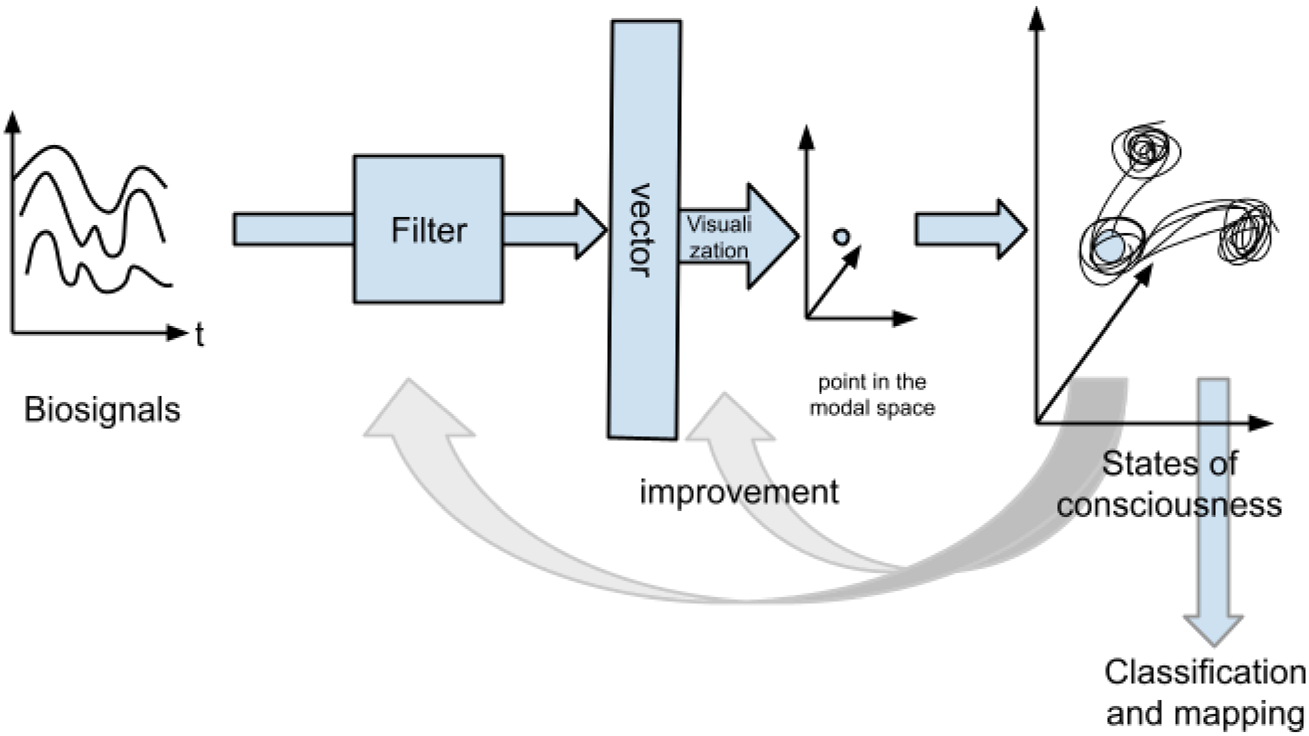
The conceptual steps are the following:

- Starting to the vector of temporal signals, apply a filter that reduce the dimensions to a low-dimensional vector
- The vector can be considered as a point in a low-dimensional space
- Visualize that point and its path during the normal activity. If we analyze what happens in a long enough period, we can find that the point (and so the signal) follows some sort of periodic trajectories and stay for the most time in confined regions of the modal space.

From the psycho-physiological point of view, we can say that the subject is in a specific state of consciousness (presents a specific brain activity pattern) as the point is confined in a specific region of the modal space.

Once a “good” visualization has been identified, refine the process. The refinement can be guided by different aims. Those can be the improvement of the software or of the understanding about the global behaviour or of specific subzones of the map, or its generality.

Those steps are depicted in the following figure.



Notes

Biosignals: those should be EEG signals, but other biosignals (like breathing and muscular signals) can be integrated if they are supposed to be useful in order to define different states of consciousness.

The filter is preeminently a spatio-temporal filter. Perhaps it has to be informed with sex or age of the patient. Probably has to perform a wavelet analysis[1]. The role of the filter is to incorporate knowledge about the functionality of the brain in order to back-trace the modal space, separating interesting (or more important) signals from "noise".

The "vector" is the numeric representation of the state. Until evidence of the opposite, we can suppose that a vector of enough real numbers is representative of the state space.

The visualization is the way in which the numeric filter output is visualized. A key point of the project is the aim to maximize information transmission and the complexity of the brain activity phenomenon along the process. Once the "global map" is defined, the activity of refinement can be concentrated on specific and interesting sub-zones.

We can think that the global map[2] as we defined it can be universal in the same way other biological shapes (i.e. the shape of the human body) are universal. This means that there should be some common properties (i.e. topological and/or geometrical) and other properties

[1] Different states of consciousness show different eeg spectrograms, see (Buzsàki 2006), pag.106 for an example.

[2] We report in appendix an instance of such a 2D global map.

that are proper of sub-population or of single individuals.

Mental illness will probably mirror in a changing of the shape of the space (i.e. the point reaches some unusual sub-zones of the space, or the shape presents some global variations)

The (scalable) multidisciplinary knowledge that should guide process is about:

- knowledge about the different state of consciousness
- mathematical analysis of EEG, brain and neural networks computational modeling
- visualization/data exploration and interaction
- (perhaps) knowledge about complex system analysis

The key assumption of the project is that the different states of consciousness are a subset of attractor basins (or creods) in the (unknown?) modal space of the brain activity, and so there should be an isomorphism between the process of nomination performed historically by common sense and scholars and the permanency of the brain activity in some particular sub-zones of the modal space. Here we are trying to define an “objective” measurement device.

Christian Lovato, July 2012

General bibliography

Peter Gärdenfors. Mental Representation, Conceptual Spaces and Metaphors; Synthese Vol. 106, No. 1 (Jan., 1996), pp. 21-47 JSTOR

G. Buzsàki, Rhythms of the Brain (2006)

About states of consciousness
Charles Tart. States of consciousness, 1969. (IT) Charles Tart, Stati di coscienza. Roma : Astrolabio 1977

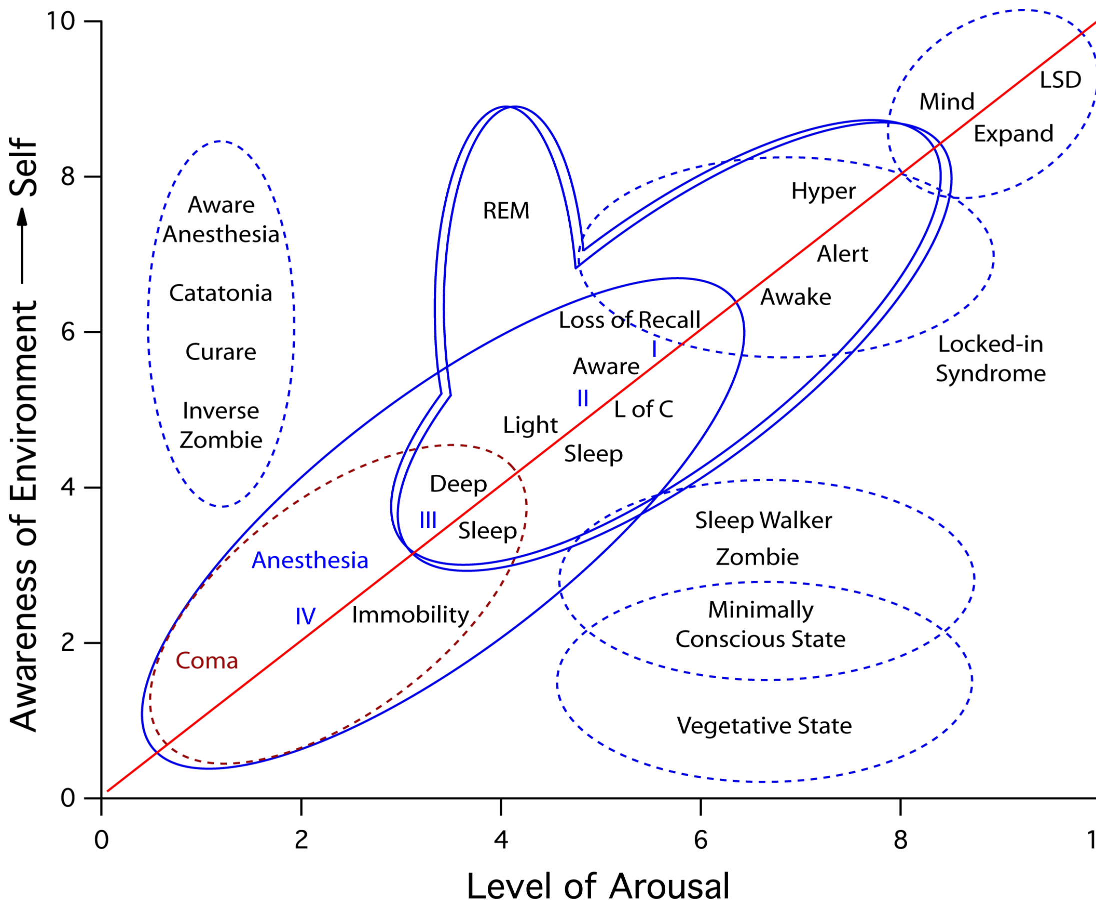
About topological representation of complex systems
Rene Thom. Stabilità Strutturale e Morfogenesi

Appendix A1

Arousal/Awareness map of the states of consciousness at Stanford University
http://www.stanford.edu/group/maciverlab/Concious.html

Stanford Institute for Neuro-Innovation &
Translational Neuroscience

Consciousness has multiple components, but philosophical, psychological, and physiological definitions remain works in progress. Laureys and coworkers have provided a useful graphical representaion of the more important components of consciousness, and of aberrant or pathological states of consciousness:



Awareness (the content of consciousness) is positively correlated to arousal (the level or degree of consciousness). Humans experience a continuum along this correlation (red line), ranging from ~ 3,3 (x,y) to 9,9 (bounded by double lines), also including a paradoxical dream state during REM sleep (~ 3,5 to 5,9). Pathological states (dashed ovals) include a range of conditions that often occur when awareness and arousal become uncorrelated, or exist at the extremes of the correlation continuum (i.e. < 3,3 or > 9,9). Anesthesia (single line oval) spans a wide range of the correlation continuum and can be quantified using loss of response metrics, such as loss of recall (6,6) and loss of consciousness (L of C; 5,5) as well as other measures like EEG and evoked potentials for deeper levels of anesthesia, such as loss of response to surgical pain (immobility; < 2,2). It is possible to quantify some of these levels using Guedel's classifications (I, II, III to IV) or by using name or face recognition EEG, evoked potentials, fMRI and neurological examination. Note that some normal physiological, pathological and anesthetic states appear to coexist along the continuum, such as: Deep Sleep, Coma, and Anesthesia, so there remain to be discovered mechanistic differences that discriminate these states at a more fundamental level. An important goal of neuroscience is to characterize conscious states at the level of circuits of neurons, synapses and molecules. Modified from Laureys et al 2007 (Consiciousness and Cognition).

Appendix A2

from *G. Buzsàki, Rhythms of the Brain (2006)*

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A practical "solution" to the time versus frequency orthogonality issue is the short-time Fourier transform, which attempts to quantify the frequency content changes over time. In this modified analysis, the brain signal is divided into multiple short epochs, and the Fourier transform is calculated for each epoch. The successive spectra can display the evolution of frequency content with time. The short-time Fourier transform can be viewed as a compromise of joint time–frequency analysis. The use of a wide temporal window will give good frequency resolution but poor time resolution, whereas the use of a narrow window will give good time resolution but poor frequency resolution. Accepting this compromise, these modified methods can analyze sequential short epochs, and the frequency structure can be displayed as a function of time (figure 4.8).

Another popular way of analyzing short-time segments of selected EEG patterns is called "wavelet" analysis. The wave refers to the fact that this function is

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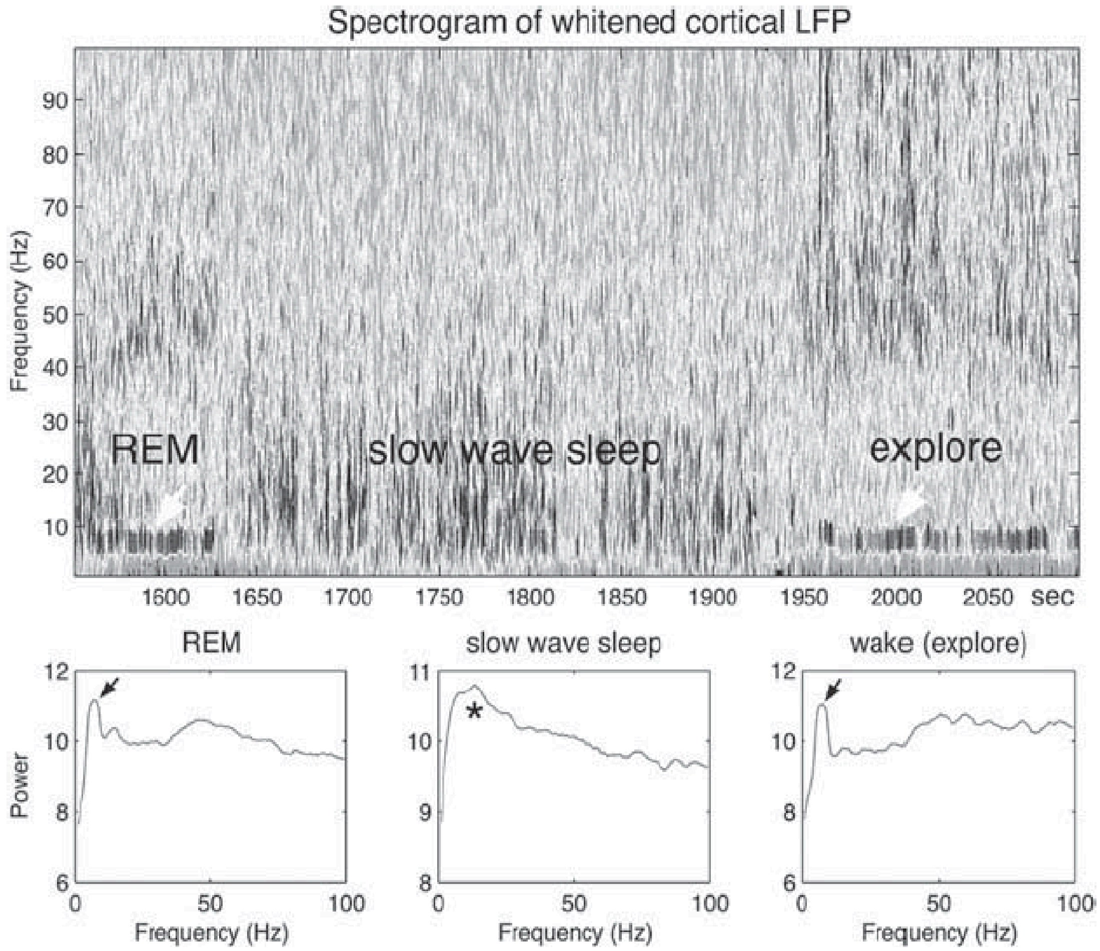

Figure 4.8. Frequency spectral dynamics of an EEG. Top: Gray-scale–coded power of neocortical local field potential in the rat during REM (rapid eye movement) sleep, slow wave sleep, and waking exploration. Arrows indicate volume-conducted theta frequency (7–9 hertz) oscillation from the underlying hippocampus. Bottom: Fourier spectra of lumped epochs. The asterisk indicates the power peak in the sleep spindle band (12–18 hertz). Note the distinct theta and gamma (40–90 hertz) frequency power increase during REM sleep and waking. The spectra have been "whitened" by removing the $1/f$ correlated power (see Cycle 5 for explanation of this term). LFP, local field potential. Figure courtesy of Anton Sirota.