A NOVEL PANDEMONIUM ARCHITECTURE BASED ON VISUAL TOPOLOGICAL INVARIANTS AND MENTAL MATCHING DESCRIPTIONS

Arturo Tozzi (Corresponding Author)
Center for Nonlinear Science, University of North Texas
1155 Union Circle, #311427 Denton, TX 76203-5017 USA
Computational Intelligence Laboratory, University of Manitoba, Winnipeg, Canada
Winnipeg R3T 5V6 Manitoba
tozziarturo@libero.it

James F. Peters
Department of Electrical and Computer Engineering, University of Manitoba
75A Chancellor's CircleWinnipeg, MB R3T 5V6 CANADA and
Department of Mathematics, Adıyaman University, 02040 Adıyaman, Turkey
James.Peters3@umanitoba.ca

A novel daemon-based architecture is introduced to elucidate some brain functions, such as pattern recognition during human perception and mental interpretation of visual scenes. By taking into account the concepts of invariance and persistence in topology, we introduce a Selfridge pandemonium variant of brain activity that takes into account a novel feature, namely, extended feature daemons that, in addition to the usual recognition of short straight as well as curved lines, recognize topological features of visual scene shapes, such as shape interior, density and texture. A series of transformations can be gradually applied to a pattern, in particular to the shape of an object, without affecting its invariant properties, such as its boundedness and connectedness of the parts of a visual scene. We also introduce another Pandemonium implementation: low-level representations of objects can be mapped to higher-level views (our mental interpretations), making it possible to construct a symbolic multidimensional representation of the environment. The representations can be projected continuously to an object that we have seen and continue to see, thanks to the mapping from shapes in our memory to shapes in Euclidean space. A multidimensional vista detectable by the brain (brainscapes) results from the presence of daemons (mind channels) that detect not only ordinary views of the shapes in visual scenes, but also the features of the shapes. Although perceived shapes are 3-dimensional (3+1 dimensional, if we include time), shape features (volume, colour, contour, closeness, texture, and so on) lead to *n*-dimensional brainscapes, $n \geq 5$. We arrive at 5 as a minimum shape feature space, since every visual shape has at least a contour in space-time. We discuss the advantages of our parallel, hierarchical model in pattern recognition, computer vision and biological nervous system's evolution.

Pandemonium, initially introduced by Selfridge (1957) for Morse translation purposes, is a hierarchical, parallel processing, adaptive, self-improving model, where "computational demons" perform non-trivial binary functions on two variables. A Pandemonium architecture has been proposed also in order to elucidate some brain functions, such as pattern recognition by human perception. The entire process resembles a kind of natural evolution, by selecting the "best" processing daemons and eliminating the relatively poor ones. Indeed, we are in front of a mechanism of "the-winner-takes-all": the cognition demon whose output far outshines the rest activates the so-called "decision demon", responsible for the final output of Pandemonium. The model is able to recognize, with no direct supervision, patterns which have not been specified, by using a feature weighting that can be described as a hill-climbing problem. In touch with the issue of "neural darwinism" (Edelman, 1978, 2004, 2017; McDowell 2010; Rosenbaum, 2014), cognitive demons' selection generates new subdemons for trial and eliminates inefficient ones with low worths, every time reweighting the assembly. The brain is a selection system that put things together via pattern recognition (Edelman, 2017) leading to perceptual categorization (McDowell, 2010). For the philosopher Hume, *ought* does not come from *is* (MacIntyre, 1959). Instead, we build our thoughts on the basis of the brain's activity (Edelman, 2017, 2014).
Here we introduce a novel version of Pandemonium, BUT-Pandemonium, equipped two novel features (**Figure 1**) that take into account recent claims from the neuroscientific literature.
The first way to improve the Pandemonium is to allow its cognitive demons to perform not non-trivial binary functions on two variables, but operations of computational proximity. The feature demons in "classical" Pandemonium are built in order to perceive image features, such as, e.g., short straight lines or curved lines of the letter A. However, when we watch a segment in a visual scene in the environment, we perceive elements seemingly melted together in a single, in Mach's terms, "complex of sensations" (Mach 1885). To make an example, we are able to detect, in the indistinctness of a rural scene at sunrise time, an increasingly distinct world of trees, hills and moving particles, e.g., birds flying from one tree to another. In effect, we appear to be sewing pieces of a changing scene together. In touch with these observations, recent findings suggest that nervous structures process information through topological as well as spatial

mechanisms. For example, it has been hypothesized that hippocampal place cells create topological templates to represent spatial information (Dabaghian, 2014; Arai, 1014; Chen, 2014). Therefore, our novel cognitive daemons will process topological, as well as spatial, image invariants.

The second feature of our novel Pandemonium is based on the recent claims that brain activities lie in functional dimensions higher than the 4D spacetime environment (Tozzi and Peters, 2016a; Tozzi et al., 2017). If such claims hold true, what happens to 3D (plus time) inputs (say a visual scene) when they are projected onto functional higher brain dimensions? In our BUT-Pandemonium, the final brain output, i.e., the motor response, dictated by a single dominant cognitive daemon, stands for TWO, instead of ONE, decision daemons with matching description. We show how, in touch with the Borsuk-Ulam theorem, where two matching descriptions in higher dimensions (in this case, the level of the cognitive daemons), give rise to a single description in lower dimensions (in this case, the final output of the decision demon). Note that we used the term "daemons" instead of "demons", to call the attention to the advent of new actors that hand feature extraction and projections to various inter-dimensional spaces.

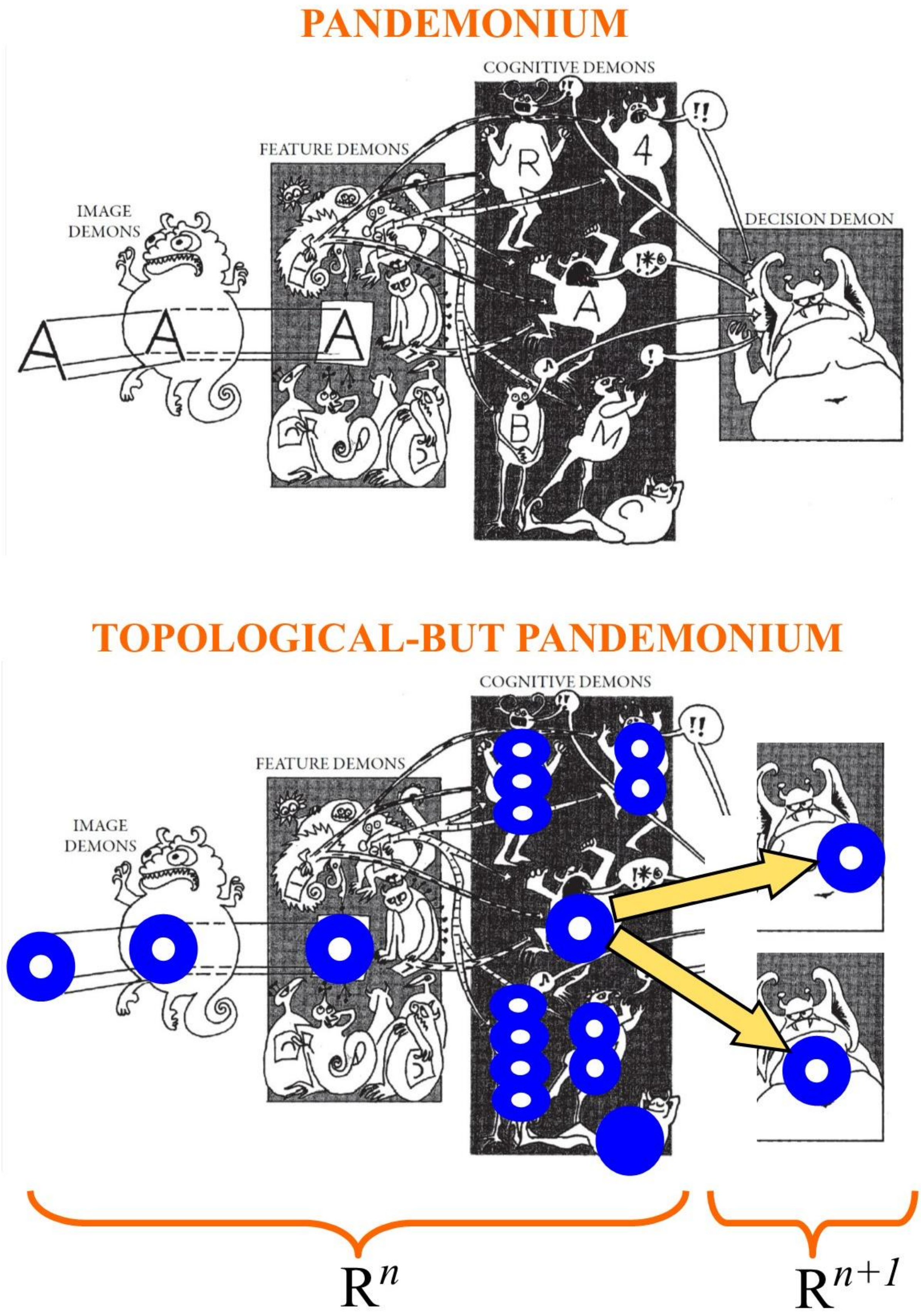


Figure 1. Differences between the classical Pandemonium and the novel model.

IMAGE AND FEATURE DAEMONS RECOGNIZE TOPOLOGICAL FEATURES FROM VISUAL IMAGES

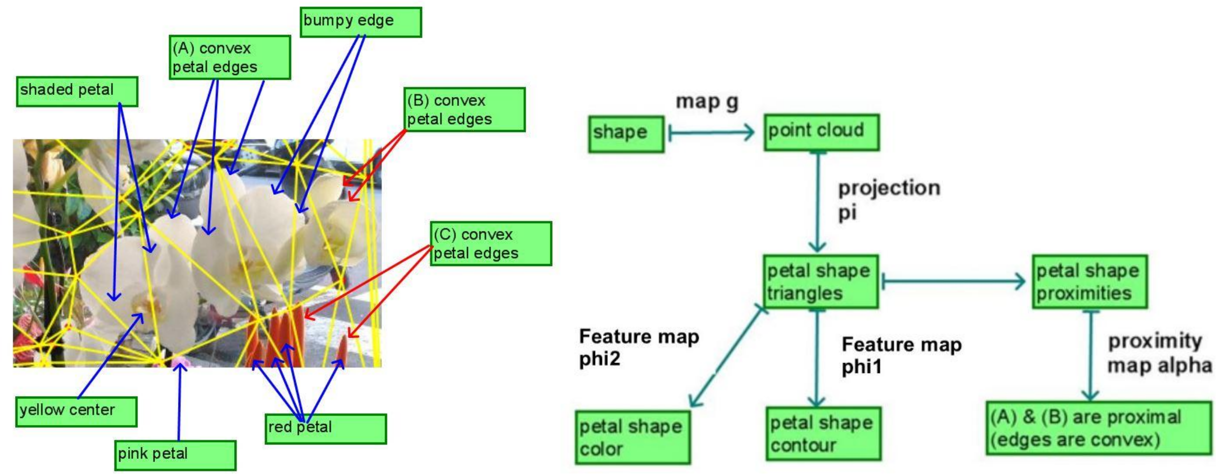
Here we show how to build image, feature and cognitive daemons that recognize topological, instead of spatial cues, in visual images. There is a straightforward bridge between the polygonal partition of plane regions (Alexanadroff, 1932) and visual perception of proximities of shapes in nerve complexes in polygonal-partitioned visual images (Peters, 2017a; Peters, 2017b; Peters JF, 2015; Peters, İnan, 2016). See **Figure 2** for an example: the conjecture here is that features daemon, in touch with dynamical systems accounts of random paths (Friston 2010), would first hunt for features of the shapes of the scene nuclei, before moving outwards in the hunt for features of shapes in the larger picture.

An approximation of personal points-of-interest are shown as the vertices of a point cloud in **Figure 2(B)**. This is an example of a Vietoris-Rips complex (Peters, 2017b; Ghrist, 2014). In lockstep with visual perception, triangular regions that overlay shapes in a visual scene are formed by joining neighboring pairs of points-of-interest with straight line segments. Imagine a video that records the continuous changes in lighting conditions in the daytime shop window display in **Figure 2(A)**. As the sun changes its position and radiation reflected off the shop window flower shapes, the points-of-interest gradually change, resulting in changing triangulations of the visual scene shapes. Mimicking the narrowing of a human viewer of visual scene shapes, clusters of triangles with common vertices are shown in **Figure 2(C)**. Shapes become easier to measure and compare whenever they are covered with known shapes such as triangles. **Figures 2(D), 2(E), 2(F)** provide a polygonal view of the visual scene in **Figure 2(A)**. This polygonal view, called a Voronoī complex (Peters, 2017a), provides larger, rounder regional views of the visual scene shapes. For example, a Vietoris-Rips complex covering a visual scene makes it easier for feature daemons to detect shape features in higher-dimensional spaces. Smaller triangles in a Vietoris-Rips complex covering visual scene shapes make it easier to detect regional shapes. In **Figure 3(A)**, quite a number shapes features are displayed inside fairly small triangular regions, such as the triangles enclosing flower petals with convex regions. The actions of a feature daemon are approximated with mappings in **Figure 3(B)**, leading to shape feature spaces and shape proximities. In effect, the cognitive daemons recognize not only shape features (such as short straight lines or curved lines of the letter A), but also shape topological invariants (such as, for example, the donut-like shape of a coffee cup, or a flower pot, or the proximities of convex flower petals in **Figure 3(A)**.

2(A) Visual Scene **2(B)** Triangulated Scene **2(C)** Triangle Nerve Complex

2(D) Scene Polygons **2(E)** Scene Dual Nuclei **2(F)** Dual Nerve Complexes

Figure 2. **2(A)** A visual scene containing a shop window flower display. **Figure 2(B)** suggests the focus of attention with a triangulation, facilitating a description of the shapes in the visual scene, *e.g.*, flower petal shapes. **2(C)** Refinement of the focus of attention is provided by highlighted filled triangles in a collection of what is known as a Alexandroff nerve complex. **2(D)** suggests a more refined view of the visual scene in terms of a decomposition into a collection of polygons with varying numbers of sides that reflects greater or lesser importance in the perception of scene. **2(E)** gives a further refinement of the focus of attention in terms of shapes of interest, encapsulated in highlighted polygons called scene nuclei. Notice that the dual nuclei polygons have a common edge. In effect, proximal nuclei are the center of attention in the inspection of the flower display. **2(F)** shows highlight polygons that are satellites of the scene nuclei. Notice that only triangles adjacent to the nuclei qualify as nuclei satellites. Also notice that nuclei satellite polygons spread upward and downwards, possibly reflecting the wandering of our attention from the initial scene focal points.



3(A) **3(B)**

Figure 3. Feature Daemon Mappings on Triangular Shapes in a Vietoris-Rips Complex. **3(A)** Triangular regions of interest to an exploring feature daemon. This triangulation is a refinement of the initial Vietoris-Rips complex covering a visual scene in **Figure 2(B)**. Smaller triangular regions make it easier to discern individual shape features such as color, contour, convexity. **3(B)** Actions of a feature daemon are represented as sequences of mappings in what is known as a fibre bundle. The fibres are points-of-interest in a point cloud, obtained as a slice of shape (this is map g). A projection mapping π on the point cloud onto a set of shape triangles in a Vietoris-Rips complex (covering the shapes in a visual scene) sets up the playground for a feature daemon. Then projections are a pair of feature mappings (also called projection mappings) from the Vietoris-Rips complex into color and contour features spaces, leading to characterizations of particular shapes, such as the flower petals in **Figure 3(A)**. A proximity map α on the triangulated shapes in the Vietoris-Rips complex onto a set of proximities between shapes provides a cognition daemon with bases for comparisons between shapes.

DECISION DAEMONS ALLOW HIGHER-DIMENSIONAL TOPOLOGICAL CORRELATIONS BETWEEN STIMULI AND BRAIN ENERGETIC RESPONSES

Here we show how to build multi-dimensional decision daemons, starting from lower-dimensional cognitive daemons. We also show how decision daemons embedded in higher functional brain dimensions are able to produce lower-dimensional bodily motor responses.

The Borsuk-Ulam theorem and its variants. In such a theoretical context of perception, the Borsuk-Ulam theorem elucidates how we see an object and how we imagine it (Tozzi and Peters, 2016a).
The Borsuk-Ulam Theorem (Borsuk 1933) is given in the following form:
Let $f: S^n \rightarrow R^n$ be a continuous map. Then there exists $x \in S^n \subseteq R^{n+1}$ such that $f(x) = f(-x)$.

This means that antipodal points on *n*-sphere S^n map to R^n, which is the *n*-dimensional Euclidean space (Matoušek 2003).

Points on an *n*-sphere S^n are antipodal, provided the points are diametrically opposite. The original formulation of BUT displays versatile ingredients which can be modified, resulting in BUT with different guises: continuous mappings are replaced by piecewise continuous mappings, antipodal points are replaced antipodal regions with matching descriptions and mappings are from S^n to R^k, $1 \leq k \leq n$ or $k \geq n$, which is the *k*-dimensional Euclidean space. See Tozzi and Peters (2016b) for further details.
In other words, the sphere S^n maps to the euclidean space R^n, which stands for an *n*-dimensional Euclidean space. Note that the function needs to be continuous and that n must be a natural number (although we will see that it is not completely true) (Matoušek 2003; Tozzi 2016a; Tozzi 2016b).

The notation S^n denotes an n-sphere, which is a generalization of the circle (Weeks). A *n*-sphere is a n-dimensional structure embedded in a *n*+1 space. For example, a 2-sphere (S^2) is the 2-dimensional surface of a 3-dimensional ball (a beach ball is a good example). An n-sphere is formed by points which are constant distance from the origin in (*n*+1)-dimensions (Marsaglia 1972). For example, a 3-sphere (also called *glome* or *hypersphere*) of radius *r* (where r may be any positive real number) is defined as the set of points in 4D Euclidean space at distance *r* from some fixed center point **c** (which may be any point in the 4D space) (Henderson 1996). A3-sphere is a simply connected 3-dimensional manifold of constant, positive curvature, which is enclosed in an Euclidean 4-dimensional space called a 4-ball. A 3-sphere is thus the surface or boundary of a 4-dimensional ball, while a 4-dimensional ball is the interior of a 3-sphere. From a geometer's perspective, we have different n-spheres, starting with the perimeter of a circle (S^1) and advancing to S^3, which is the smallest hypersphere, embedded in a 4-ball (**Figure 4**). Points on S^n are *antipodal*, provided they are diametrically opposite. Examples of antipodal points are the poles of a sphere. Further, every continuous function from an n-sphere S^n into Euclidean n-space R^n maps some pair of antipodal points of S^n to the same point of R^n. To make an example, if we use the mapping f: $S^3 \rightarrow R^3$, then f(x) in R^3 is just a signal value (a real number associated with x in S^3) and f(x) = f(-x) in R^3. Furthermore, when g: $S^2 \rightarrow R^2$, the g(x) in R^2 is a vector in R^2 that describes the x embedded in S^2. In other words, a point embedded in a R^n manifold is projected to two opposite points on a S^{n+1}-sphere, and vice versa.

BUT might explain how representations of objects in our environment are mapped to higher-dimensional views (our interpretations and coalescences), in order to achieve a form of pullback from descriptions to sources of descriptions, from a simplified view to multiple views of the same object. Indeed, a new form of shape theory (called homotopy) discovered by K. Borsuk makes it possible to assess the properties that are preserved through deformation, stretching and twisting of objects (Beyer and Zardecki 2004; Manetti 2015). Homotopy is a theory of shape deformation (Borsuk, 1971; Borsuk and Dydak, 1980), e.g., how some shapes can be deformed into other shapes. In this context, the term "shape" means "exterior form" and a "deformation" is a mapping from shape into another one. A classic example is the deformation of a coffee cup into a torus. The combination of various forms of BUT and homotopy theory provides a methodological approach with countless possible applications, especially in helping us understand perception and how we acquire visual imagination. The theory of shape, in simple terms, focuses on the global properties of geometric objects such as polyhedra and tori, neglecting the complications of the local structures of the objects (Borsuk and Dydak, 1980). What shape theory and BUT tell us is that cognitive processes relating to perception, storage, retrieval and reorganization interact with memory structures and construct a symbolic representation of the environment. For example, mesh view in **Figure 5** can be viewed as visualization of one among many symbolic views of Leonardo Da Vinci's Mona Lisa painting. In effect, an individual perceives [constructs] the features and events of the environment specified by this [pickup] information from the environment (Heft 1997).

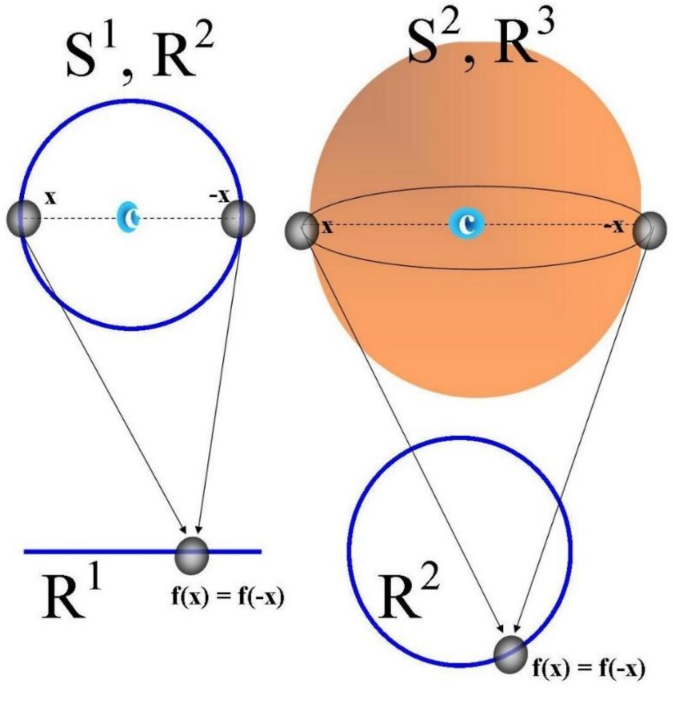


Figure 4. The Borsuk-Ulam theorem for different values of S^n. Two antipodal points in S^n project to a single point in R^n, and vice versa. Every S^n is embedded in a n+1-ball, and thus every S^n is one-dimension higher than the corresponding R^n.

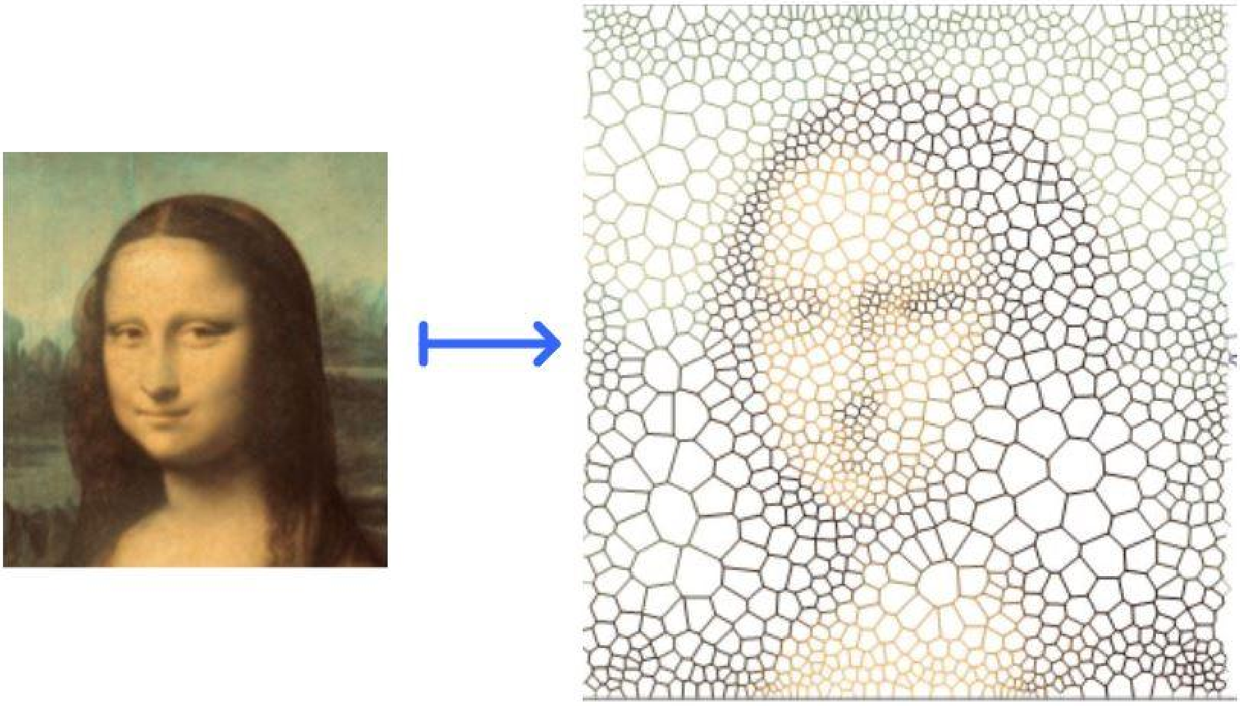


Figure 5. Mona Lisa shape deformably mapped to Mona Lisa Exterior Mesh Shapes. This mapping illustrates nascent persistence perception: we abstract away from the very complex structures in Da Vinci's painting to arrive a simpler, geometric view of the image as a collection of familiar convex polygons.

From cognitive to decision daemons. In the sequel, the notion antipodal point is extended to non-intersecting brain regions (standing for different decision daemons). A region on the surface of an *n*-sphere S^n is a part (subset) of S^n. A surface region $\neg x$ is the antipode of *x*, provided $x \neq \neg x$ and x has the same feature values (characteristics) as $\neg x$. For more about this, see Peters (2016). From a physics perspective, a cortical region (containing a decision daemon) is a relativistic mass in a slice of space swept out by the region. The particles on a *n*-sphere are moving at a velocity as the velocity *v*, which less or equal to the velocity of the planet. For every cortical region with mass $x \in S^n$, we can always find $\neg x$ (the analog of the antipode -x of a point on the surface of S^n) with the same characteristics of velocity and mass. In BUT-Pandemonium terms, we can always find two cortical decision daemons with matching description). In effect, for the cortical energy $e_x = m_x v^2$, we can find its antipodal energy $e_{\neg x}$ for $\neg x \in S^n$. To be an antipodal energy $e_{\neg x}$, we weaken the original notion to antipodes, with $\neg x$ being a particle on S^n that has characteristics that match those of $x \in S^n$. Let reA, reB be regions on S^n. A function $f : S^n \rightarrow R^k$ is piecewise continuous on S^n, provided reA close to reB implies that $f(reA)$ is close to $f(reB)$. This leads to an energetic form of BUT (energy-BUT) for antipodal particles $x, \neg x \in S^n$:

Energy-Borsuk-Ulam theorem.

Let $f : S^n \rightarrow R^k$ be a piecewise continuous map. Then there exists $x \in S^n \subseteq R^{n+1}$ such that $f(x) = f(\neg x)$ and $e_x = e_{\neg x}$.

Proof: $f(x), f(\neg x)$ a feature vectors in R^{n+1}. Since, for each $x \in S^n$ there is $\neg x \in S^n$ with the same velocity and mass, the result follows, *i.e.*, $f(x) = f(\neg x)$ and $e_x = e_{\neg x}$.

This means that two cortical decision daemons with matching description display the same energetic level. As shown by Tozzi and Peters (2017), such energetic levels are experimentally assessable and quantifiable, in terms of entropy detected in fMRI images.

Another variant of BUT is the region-based BUT. This is a straightforward extension of what is known as region-BUT (briefly, **reBUT**).

Region-Energy Based Borsuk-Ulam Theorem (ReEnergyBUT).
Let 2^X be a collection of nonempty physical surface regions (a collection of decision daemons) of an *n*-dimensional space X and let be a piecewise continuous map. Then there exists $x \in 2^X \subseteq R^{n+1}$ such that $f(x) = f(\neg x)$.
Proof: Let $f(x), f(\neg x)$ be feature vectors in R^{n+1}. We can always find a region $\neg x \in 2^X$ (a decision daemon) that is antipodal to $x \in 2^X$, i.e., $\neg x \cap x = \varnothing$ and $\neg x, x,$ (standing for two antipodal decision daemons) have matching descriptions in R^{n+1}, minimally, equal velocity and mass while moving through space. Hence, $f(x) = f(\neg x)$ and $e_x = e_{\neg x}$.

Cortical Response Fibres. This section introduces cortical response fibre bundles. They stand, in BUT-Pandemonium terms, for the decision daemons' outputs that produce a bodily motor response to the original environmental stimuli. In general, a continuous mapping $\pi : E \to B$ is called a projection on a set of fibres *E* to *B*. Every element $e \in E$ is called a *fibre*, *B* is called a *fibre bundle base* and the collection of all mappings $\pi(e)$ is called a *fibre bundle*. The set E is class of objects so each $e \in E$ has the same properties as every other member of *E*. The members of the class E are the result of a mapping $f : X \to E$.

In our BUT-Pandemonium framework, *X* is a set of visual objects (cognitive daemons) that are mapped by *f* to a set $Cl_{re}E$ of composite responses by the brain (a set of decision daemons). Each object is a topological region of visual field, making X a set of topological regions. Members of $Cl_{re}E$ are cortical cells (i.e., decision daemons in cortical regions) found on the surface of an n-sphere S^n. The set $Cl_{re}E$ is a class of elements, since the members of this set have similar properties. Such properties can be easily assessed in terms of available experimental procedures, such as, for example, Visual Evoked Potential response amplitude.
To complete the picture, we introduce the projection $\pi : Cl_{re}E \to B$, which is a piecewise continuous map on $Cl_{re}E$ to *B*, which is a set of response feature vectors in R^k. For simplicity, we assume that each feature vecture $\pi(e) = (response) \in R^1$, where *e* is a fibre (cortical cell).

The cortical fibre bundle framework in **Figure 6(b)** provides a platform for the application of energyBUT. From **Figure 6(a)**, each visual region response $e1 \in Cl_{re}E$ (class of cortical regions) will have at least one other matching cortical region response $e2 \in Cl_{re}E$. (**Figure 6(c)**). The piecewise continuous mapping π on $Cl_{re}E$ to $B = R^k$, $k = 1$ is also represented in **Figure 6(c)**. The assumption made here is that $Cl_{re}E$ and *B* are topological spaces and π is a homotopic mapping. In that case, the mapping π is an example of a *fibration*. That is, $\pi(e1)$ is piecewise continuously transformed into $\pi(e2)$. In effect, there is always a path between the two shapes in *B*. The shapes in the situation in **Figure 6(c)** are just points (1-dimensional vectors) in R^1 that represent visual responses. The set $\pi^{-1}(B) = Cl_{re}E$ (*cortical fibre bundle*) is an example of a region-based fibre bundle (Peters 2016). EnergyBUT viewed in the context of cortical fibre bundles is represented in **Figure 7**.

BUT variants and Borsuk's theory of shapes are closely allied to the concept of "persistence of perception". That is, our perception of an object continues, even when the object is out of sight. This can concisely be explained by viewing regions on the surface of a hypersphere as multiple representations of object shapes, mapped continuously to an object that have seen and continue to see. It occurs thanks to the continuous mapping from shapes in our memory to shapes in Euclidean space. In effect, persistence perception can be viewed as signals matching, real-scene visual signals that are collectively the umbra of physical shapes. To make an example, **Figure 5** displays the Mona Lisa painting impinging on the optic nerves: we map it to similar shape representations, such as the Mona Lisa mesh. Therefore, the use of "topological" feature daemons might account for our knowledge of world objects by borrowing a concept of invariance in topology. In touch with the concepts of perception of shapes and perception as shape mapping, a series of transformations can be endlessly and gradually applied to a pattern without affecting its invariant properties. And, principal among the properties of world objects, is shape and the acquisition of persistent perception of object shapes, which we nicely explain with BUT variants.

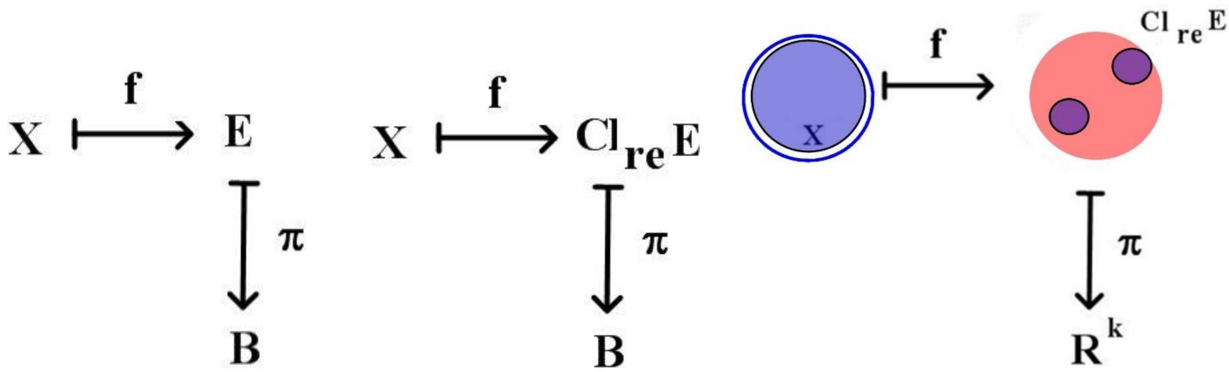


Figure 6. Framework for Cortical Fibre Bundles. **Figure (6a)** General fibre map π . **Figure (6b)** Region-based fibre map π . **Figure (6c)** VEP fibre map π . In this figure, x represents a set of trajectories on a random network and $Cl_{re}E$ represents a class of small-world networks $Cl_{re}E \subset S^n$ that have been achieved with a change in lattices' dimensions The mapping $\pi : Cl_{re}E \to R^k$ is piecewise continuous from $Cl_{re}E$ to cortical energy amplitudes. For $e \in Cl_{re}E,\ \pi(e) = (response) \in R^1$.

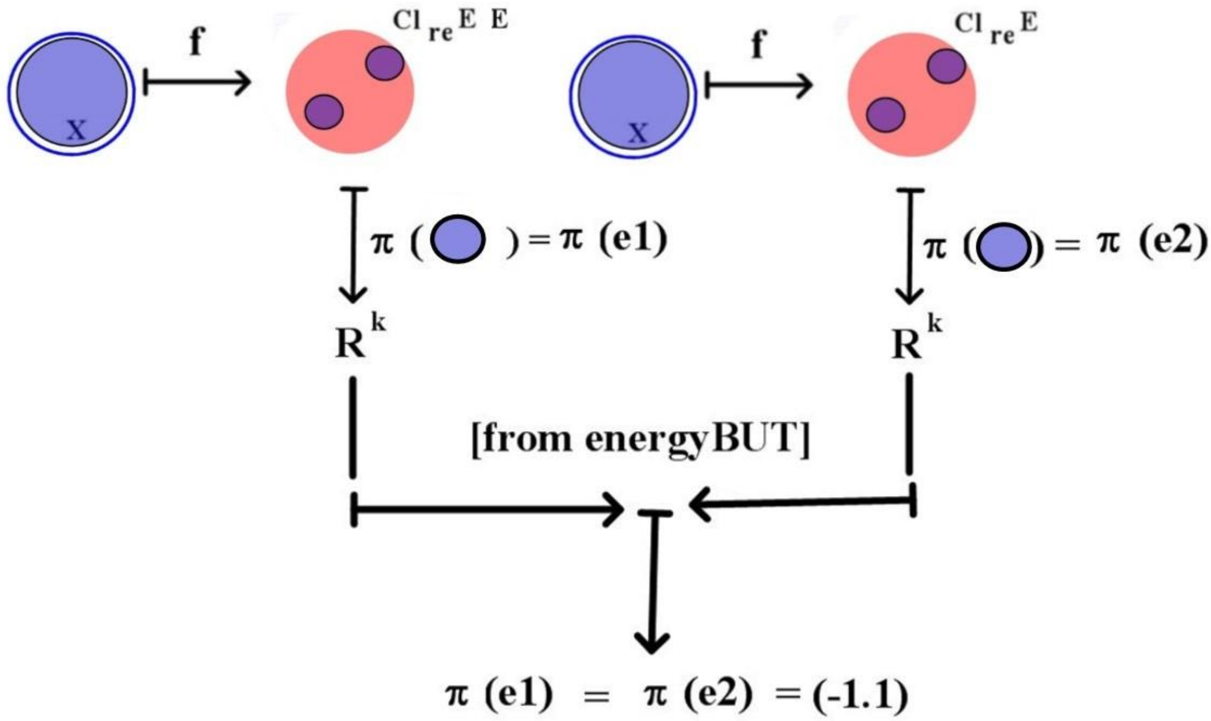


Figure 7. A pair of fibrations, denoted with π, are represented. It is also the case that π(e1) = π(e2) = -1.1, which is predicted by energyBUT.

CONCLUSIONS

We proposed a novel model of Pandemonium, based on "the-(topological)-winner-takes-all-(the-brain-multidimensions)", that is able to solve some of the concerns raised by this otherwise very powerful computational method. Pandemonium, contrary to the template matching models (Hirai 1980) and the gestaltic accounts of perception (Pastukhov 2017), postulates that an image is first perceived in its basic individual elements and features, before it is recognized as a whole object. The apparently unsolvable dichotomy between different models of pattern recognition could be just apparent. Indeed, if we build a Pandemonium equipped with feature daemons able to firstly recognize topological invariants and global patterns instead of straight or curved lines, the two models are automatically melted: in this novel Pandemonium, a global topological pattern is recognized at the very first stages of sensation/perception.

Why to allow TWO decision daemons, instead of one, to respond to the activation of the loudest cognitive demon? The main limit of the Pandemonium is the need, in order to achieve unequivocal, correct decisions, to have one, and just one, cognitive demon, whose output far outshines the rest and that projects to a single decision daemon. Despite our BUT-Pandemonium seems to be more computational expensive at the higher levels of the hierarchical system, because it requires a larger amount of stored information and pattern memory inside the calculator, nevertheless it allows a more accurate feature detection, improves image constancy (e.g., if you rotate a letter, you recognize it the same), is able to explain pareidolia (i.e., it is more difficult to identify a letter in isolation than when it is part of a word). Furthermore, our model explains also a typical feature of our own perception, e.g., error predictions based on overlapping features (for example, R and P, that are topologically equivalent, can be confused more frequently than R and B, or R and I). If the final output of the machine stands for TWO, instead of ONE, decision daemons with matching description, this means that another criticism of the Pandemonium architecture is solved, *i.e.*, the latter adopts a completely bottom-up approach, forgetting the predictive top-down code. Indeed, the presence of two instead of one decision daemons could be dictated by top-down constraints in the brain.

According to this novel conception, during the processes of sensation and perception, the individual's brain is forced to coalesce together some components of the environment, in a complex interaction between external affordances and the motivated humans who perceive them. The melting of parts of the environment into a single perception is thus compelled, and is not a free choice made by the individual. The brain needs to perceive different elements together and cannot split them, because the perception may occur and operate just in this way.

The evolutionary advantage is self-evident: the perception of different elements is useless by itself, while the perception of a complete object, or of a concept or an idea, is mandatory in order to survive in an explorable environment, full of possibilities, but also of dangers. In sum, the need to join things together in a single perception is mandatory for our brain. It is important to emphasize that the antipodal points with matching description do not need to be causally correlated: their relationship is a topological one, meaning that the surface features of an object are "linked" together in a single complex of sensations by projections, affine connexions and proximity. In other words, the concept of *connexion* means that the joined parts if the environment are not necessarily in causal relationship, rather they are simply functionally correlated. The individual, with the habituation, learns, from childhood forward, to join together the elements which are more useful for his surviving. Avenarius was the first to suggest that a Darwinian fight among different organs might take place in our bodies, and the brain exerts his prevalence among the other sub-systems (Russo Krauss 2015). In the BUT-Pandemonium, the highest dimensional brain is able to control the anatomical/physiological levels equipped with lower dimensions (where higher dimension stands for higher complexity). This means that the influence on the central nervous system of inputs from different organs (such as the intestinal bacteria) is more limited than thought, because the brain, located at higher levels of complexity, is able to dictate his own laws of preservation. The whole brain prevails, dictating behaviors, sometimes at the expenses of other organs: think to a smoker, where the brain demands prevail over the preservation of other systems.

"Perception is based on information, not on sensations" (Gibson, 1979). This means that the BUT-Pandemonium, rather than sensation-based, is information-based, because it emphasizes an analysis of the environment, and the concomitant information that the organism detects. The human behavior is radically situated. In other words, you cannot make predictions about human behavior unless you know what situation or context or environment the human in question was in. Individuals stand in an ecological relation to the environment, such that to adequately explain some behavior it is necessary to study the environment or niche in which it took place and, especially, the information that "epistemically connects" the organism to the environment. Thus, an appropriate analysis of the environment, made in terms of BUT-Pandemonium, becomes crucial for an explanation of perceptually guided behavior.

Our work strengthens and brings to the front the primary question of "what" is perceived, before questions of mechanisms and material implementation are introduced (Rao et al., 1997). Together with a contemporary emphasis on dynamical systems theory as a necessary methodology for investigating the structure of ecological information, our approach is framed in the light of the modern tools of algebraic topology. Future work will be devoted to assess whether other sensations, such as hearing, display topological invariants that can be evaluated. Such invariants would encompass topological changes that occur not just in space, but also in time, as it occurs for our perception of sounds.

REFERENCES

1) Alexandroff P. 1932. Einfachste Grundbegriffe der Topologie [Elementary Concepts of Topology trans. by A.E. Farley, Dover Pubs., Inc., 1961].
2) Arai M, Brandt V, Dabaghian, Y. 2014. The effects of theta precession on spatial learning and simplicial complex dynamics in a topological model of the hippocampal spatial map. PLoS Comp. Bio. 10 (6): e1003651.
3) Beyer WA, Zardecki A. 2004The early history of the ham sandwich theorem. American Mathematical Monthly, 111, n. 1, 2004, 58-61
4) Borsuk K. 1971. Theory of Shape. Lecture Notes Series 28, Matematisk Institut, Aarhus Universitet, **MR0418088**
5) Borsuk K, Dydak J. 1980. What is the theory of shape? Bull. Austral. Math. Soc. 22, no. 2, 161-198, MR0598690.
6) Chen Z, Gomperts SN, Yamamoto J, Wilson MA. 2014. Neural representation of spatial topology in the rodent hippocampus. Neural Comput. 26, 1–39.
7) Dabaghian Y, Brandt VL, Frank LM. 2014. Reconceiving the hippocampal map as a topological template. Elife 3, e03476.
8) Edelman G. 2017. Neural Darwinisim, New Perspectives Quarterly. January 2017, 31, no. 1, 25-27.
9) Edelman G. 2014. Wider than the Sky: The Phenomenal Gift of Consciousness. Yale University Press, 2004.
10) Edelman G. 1978. The Mindful Brain. MIT Press.
11) Friston, Karl. 2010. "The Free-Energy Principle: A Unified Brain Theory?" *Nature Reviews Neuroscience* 11 (2). Nature Publishing Group: 127–38. doi:10.1038/nrn2787.
12) Ghrist R. 2014. Elementary Applied Topology. Createspace, ISBN 978-1-5028-8085-7.
13) Gibson, J.J. (1979). The theory of affordance in the ecological approach to visual perception. Hillsdale, Erlbaum.
14) Heft H. 1997. The relevance of Gibson's ecological approach to perception for environment-behavior studies. In G.T. Moore, R.W. Marans, Adances in Environment, Behavior, and Design. Plenum Press, NY, 1997, 71-107.
15) Henderson DW. 1996. Experiencing Geometry on Plane and Sphere. New York: Prentice Hall.
16) Hirai Y. 1980. A template matching model for pattern recognition: self-organization of templates and template matching by a disinhibitory neural network. Biol Cybern. 1980;38(2):91-101.
17) Mach E. 1885, 1896. Analysis of the sensations. The Open Court Publishing Company, Chicago
18) MacIntyre, AC. 1959. Hume on "is" and "ought", The Philosophical Review 68, no. 4, 451-468, URL: http://www.jstor.org/stable/2182491.
19) Manetti, M. 2015. Topology, Springer, Heidelberg. DOI 10.1007/978-3-319-16958-3.
20) Marsaglia, G. 1972. Choosing a Point from the Surface of a Sphere. Annals of Mathematical Statistics 43 (2): 645–646. doi:10.1214/aoms/1177692644
21) Matoušek J. 2003. Using the Borsuk–Ulam Theorem. Lectures on Topological Methods in Combinatorics and Geometry. Springer-Verlag Berlin Heidelberg.
22) McDowell JJ. 2010. Behavioral and neural Darwinism: Selectionist function and mechanism in adaptive behavior dynamics, Behavioural Processes 84, no. 1, May 2010, doi.org/10.1016/j.beproc.2009.k11.011
23) Pastukhov A. 2017. First, you need a Gestalt: An interaction of bottom-up and top-down streams during the perception of the ambiguously rotating human walker. Sci Rep. 2017 Apr 25;7(1):1158. doi: 10.1038/s41598-017-01376-1.
24) Peters JF. 2015. Proximal Delaunay triangulation regions, Proc. of the Jangjeon Math. Soc. 18, no. 4, 501-515, MR344736.
25) Peters JF. 2016. Computational Proximity. Excursions in the Topology of Digital Images. (I. S. R. Library, Ed.). Berlin: Springer-Verlag. DOI: 10.1007/978-3-319-30262-1.
26) Peters JF, İnan E. 2016. Strongly proximal Edelsbrunner-Harer nerves. Proc. of the Jangjeon Math. Soc. 19, no. 3, 563-582, Zbl 06665117.
27) Peters JF. 2017a. Postscript. Where do shapes fit into the computer vision landscape. In: Foundations of Computer Vision. Computational Geometry, Visual Image Structures and Object Shape Detection. Intelligent Systems Reference Library 124, J. Kacprzyk, J.C. Jain, Eds. Springer Int. Publishing AG, DOI 10.1007/978-3-319-52483-2.

28) Peters JF. 2017b. Proximal nerve complexes. A computational topology approach. arXiv 1704, no. 95909v1, 1-16.
29) Rao SC, Rainer G, Miller EK. 1997. Integration of what and where in the primate prefrontal cortex.Science. 1997 May 2;276(5313):821-4.
30) Rosenbaum DA. 2014. It's a Jungle in There: How Competition and Cooperation in the Brain Shape the Mind. Oxford University, ISBN 978-0-19-982977-4.
31) Russo Krauss C. 2015. L'empiriocriticismo di Richard Avenarius tra psicofisiologia e teoria della consocenza, in R. Avenarius, Il concetto umano di mondo, Morcelliana, Brescia.
32) Selfridge OG. 2017. Pandemonium: a pradigm for learning. In: Mechanization of thought processes: proceedings of a Symposium held at the national Physical Laboratory, London: HMSO, 513-526.
33) Tozzi A, Peters JF. 2016a. Towards a fourth spatial dimension of brain activity. Cognitive Neurodynamics 10, 189-199, DOI 10.1007/s11571-016-9379-z
1) Tozzi A, Peters JF. 2016. A Topological Approach Unveils System Invariances and Broken Symmetries in the Brain. Journal of Neuroscience Research 94 (5): 351–65. doi:10.1002/jnr.23720.
2) Tozzi A, Peters JF. 2017. From abstract topology to real thermodynamic brain activity. Cognitive Neurodynamics. DOI: 10.1007/s11571-0-17-9431-7.
34) Tozzi A, Peters JF, Fingelkurts AA, Fingelkurts AA, Marijuán PC. 2017. Topodynamics of metastable brains. Physics of Life Reviews. (PLREV 871), DOI: http://dx.doi.org/10.1016/j.plrev.2017.05.00