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Research article

Multidimensional brain activity dictated by winner-take-all mechanisms

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ABSTRACT

A novel demon-based architecture is introduced to elucidate brain functions such as pattern recognition during human perception and mental interpretation of visual scenes. Starting from the topological concepts of invariance and persistence, we introduce a Selfridge pandemonium variant of brain activity that takes into account a novel feature, namely, demons that recognize short straight-line segments, curved lines and scene shapes, such as shape interior, density and texture. Low-level representations of objects can be mapped to higher-level views (our mental interpretations): a series of transformations can be gradually applied to a pattern in a visual scene, without affecting its invariant properties. This makes it possible to construct a symbolic multi-dimensional representation of the environment. These 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. Although perceived shapes are 3-dimensional (plus time), the evaluation of shape features (volume, color, contour, closeness, texture, and so on) leads to *n*-dimensional brain landscapes. Here we discuss the advantages of our parallel, hierarchical model in pattern recognition, computer vision and biological nervous system's evolution.

Pandemonium, initially introduced by [1] 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 to elucidate some brain functions, such as pattern recognition during human perception. The process resembles natural evolution, by selecting the "best" processing demons and eliminating the relatively poor ones. A winner-take-all mechanism is introduced, because the cognition demon whose output far outshines the rest activates the "decision demon", responsible for the final output. The model is able to recognize, with no direct supervision, patterns which have not been specified, by using a feature weighting described as a form of hill-climbing. In keeping with the issue of "neural darwinism" [2], cognitive demons' selection generates new subdemons for trial and eliminates inefficient weak ones, every time reweighting the assembly. The brain is a selection system that put things together via pattern recognition [3] leading to perceptual categorization [4]. For the philosopher Hume, *ought* does not come from *is* [5]: instead, we build our thoughts on the basis of the brain's activity [6].

Here we introduce a novel version of Pandemonium, equipped two novel features (Fig. 1) that take into account recent claims from neuroscience. The first way to improve the Pandemonium is to allow its cognitive demons to compare retractions of shape contours in visual scenes through computational proximity, rather than trivial single-valued functions on two variables [7,8]. The feature demons in "classical" Pandemonium are built in order to perceive image features, such as, *e.g.*, short straight lines of the letter A. However, when we watch a segment in a visual scene, we perceive elements seemingly melted together in a single "complex of sensations" [9]. For example, we are able to detect, in the faintness 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. 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, hippocampal place cells create topological templates to represent spatial information [10–12]. Therefore, our novel cognitive demons will process topological, as well as spatial, image invariants.

The second feature of our Pandemonium is based on the recent claims that brain activities lie in functional dimensions higher than the 4D spacetime environment [13]. If such claims hold true, what happens to 3D (plus time) inputs (say a visual scene) when they are projected

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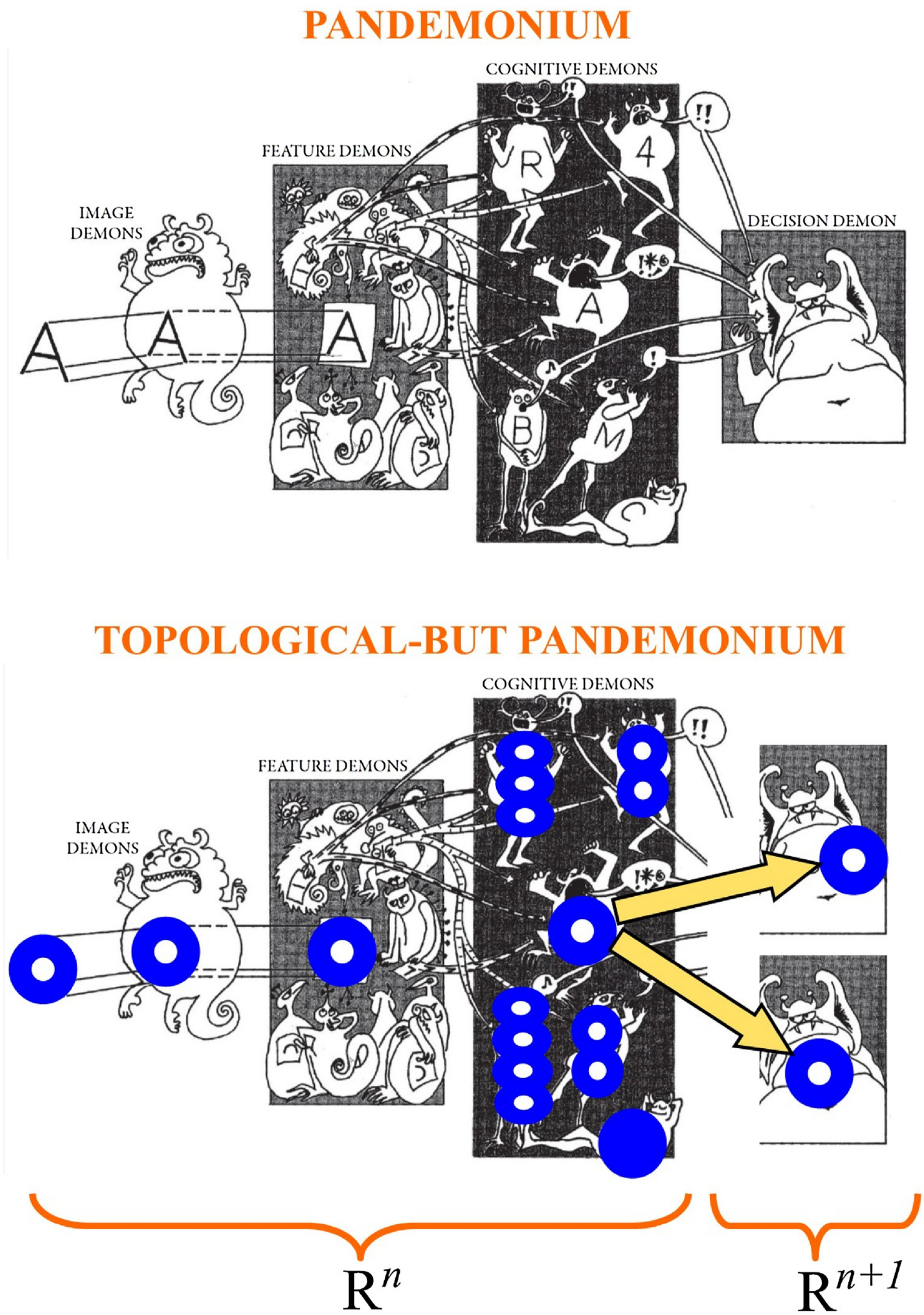

Fig. 1. Differences between the classical Pandemonium and the novel model.

onto higher brain dimensions? In our Pandemonium, the final brain output, *i.e.*, the motor response dictated by a single dominant cognitive demon, stands for TWO, instead of ONE, decision demons with matching description. We show how two matching descriptions in higher dimensions (in this case, the cognitive demons' level) give rise to a single description in lower dimensions (in this case, the decision demon's final output).

1. Image and feature demons recognize topological features from visual images

Here we show how to build Pandemonium's demons that recognize topological cues, instead of spatial ones, in visual images. There is a bridge between the polygonal partition of plane regions [14] and visual perception of shapes' proximities in polygonal-partitioned visual images [15–17]. See Fig. 2 for an example: the conjecture is that features demon, in touch with dynamical systems' accounts of random paths [18], would first hunt for features of the shapes in 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 Fig. 2B. This is an example of a Vietoris-Rips complex [16,19]. In lockstep with visual perception, triangular regions overlaying 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, illustrated in Fig. 2A. As the sun changes its position, the points-of-interest gradually modify, resulting in changing