Spatial Multiplexing: Solving Information Bottlenecks in Real Neural Systems and the Origin of Brain Rhythms

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ABSTRACT

Geometrical constraints limit how much information can be received and emitted along real pathways across the boundary of any processor. Applied to central nervous systems this imposes a seemingly impassable bottleneck to the evolution of large brains. A small brain could never access enough information to warrant a larger brain. A small brain could not send enough information to operate a large body. Larger bodies are needed to support larger brains. Thus, with a rare exception, there are no invertebrates with large brains or large bodies. It is proposed that a convergent-divergent scanning neural network developed which enabled vertebrates to squeeze more information through this bottleneck by “spatial multiplexing”. This reduces the number of pathways into, between and from processors by a factor of 16 while maintaining spatial and intensity accuracy. This paper describes spatial multiplexing using downloadable spreadsheet models and shows how the necessity of scanning likely introduced brain rhythms.

Keywords: Brain Evolution, Convergent-Divergent, Gamma Rhythms, Rent’s Rule, Scanning, Sensory Networks

1. INTRODUCTION: THE BOTTLENECK PROBLEM

The ability of any processor to access and send information is limited by the number of pathways that can enter and leave its surface. That number depends on the size of its “transmission boundary” as described by Rent’s Rule (Beiu, Madappuram, Kelly & McDaid, 2011). Consider a 2-dimensional case as shown in Figure 1. The processor, a ‘brain’, receives information from sensors around the body and uses that information to control the body. A double bottleneck arises here. One, the body can contain many more information receptors than can be connected to the brain through its transmission boundary. Two, the brain’s ability to control that body is limited by the number of pathways that can leave through its transmission boundary.

Rent’s rule is often applied to connecting inproprocessor components to the processor’s boundary (Christie & Stroobandt, 2000; Partzsch & Schuffny, 2012; Osaktas, 2004). A large number of intra-processor components is desirable to achieve complex calculations. However, this number is checked by two geometrical constraints: One, more components...
Figure 1. A small brain receives information from receptors in its surrounding body and operates that body by sending control signals. The number of physical pathways that can enter or leave the brain is limited by the brain’s “transmission boundary”, which is smaller than its actual surface for information pathways of finite size. (Copyright 2010 by the author and printed with permission.)

As brains increase in size to make room for more processors, distance now becomes a greater problem both with respect to conduction delays and the space required by longer transmission pathways past various sub-processors (Beiu, et al., 2011; Wen & Chklovskii, 2005). There would be no information bottleneck for the pathways connecting sensory receptors to the brain, sub-processors in the brain, or connecting the brain to operate the body if the pathways had infinitely small cross-sections. However, whether they be electrical wires, hydraulic pipes, or neural axons, real pathways have substantial cross-sections. This constrains how many can pass through any boundary:

number of pathways = transmission boundary size / pathway cross-sectional size

take up space and thereby the connections between them get longer thereby delaying their interactions. Second, the number of components within a processor increases with the cube of its linear dimensions while the area surface area available for connections to transmit the results increases only with the square of its linear dimensions. Together, these limit the complexity of information that can be usefully produced in a given processor. This leads to an optimum processor size - a “small worlds” organization of brains (Bullinaria, 2007; Changizi, 2007). The problem then repeats with connecting clusters of sub-processors to other clusters, and so on up a hierarchy (Bassett, et al., 2010; Sporns, 2013). As a plan is formed, the information proceeds in a reverse hierarchy to activate specific effectors such as muscles (Changizi, 2003; Levine, Lewallen & Pfaff, 2012).
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