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Chapter VI

Solving the Sensory Information Bottleneck to Central Processing in Adaptive Systems

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Abstract

Information bottlenecks are an inevitable consequence when a complex system adapts by increasing its information input. Input and output bottlenecks are due to geometrical limits that arise because the area available for connections from an external surface always exceeds the area available for connections to an internal surface. Processing of the additional information faces an internal bottleneck As more elements increase the size of a processor, its interface surface increases more slowly than its volume. These bottlenecks had to be overcome before more complex life forms could evolve. Based on mapping studies, it is generally agreed that sensory inputs to the brain are organized as convergent-divergent networks. However, no one has previously explained how such networks can conserve the location and magnitude of any particular stimulus. The solution to a convergent-divergent network that

overcomes bottleneck problems turns out to be surprisingly simple and yet restricted.

Introduction

To improve adaptation to the environment by adding sensors, complex systems need to import the additional information without overcrowding their processors with more connecting pathways. Any interface between an external surface and the surfaces of inside structures always faces a potential bottleneck due to geometry. The external surface can always extend more finite paths than can be accommodated by the surface of an internal structure. Biological systems cannot overcome this bottleneck simply by using smaller connecting pathways because smaller dendrites and axons conduct nerve impulses more slowly. More information is useful only if it is also timely.

Adaptation by accessing more information produces bottleneck problems that do not end once the inputs have been internalized. A slightly different geometrical constraint now comes into play. The surface area available for connecting one structure to another grows with the square of each structure's linear dimensions, while the space for elements within a structure increases with the cube of those dimensions. This can create intraprocessor bottlenecks. Animals reduce this problem by structuring their processors as sheets. However, they can not avoid the consequences of additional information requiring additional processing elements. Larger brains result in longer distances over which to send information from region to region. The need for information that is timely requires larger internal pathways, which add to the intraprocessor bottleneck problem since space is limited.

Finally, achieving a greater variety of behaviors on the basis of the additional information may require a greater number of processor outputs to control a greater number of external effectors. The system now faces a third bottleneck that is the reverse of the problem encountered by importing more information. At a more general level, all three types of bottlenecks can be considered as a single problem of how to connect one set of elements to another set using fewer connecting paths than the number of elements. Until a solution to this fundamental bottleneck problem was found, the evolution of more complex biological systems was stalled.

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