

Preface

The Neural Field — a Framework for Brain Data Integration?

This book presents a perspective on the advancing subject of neural fields — that is, theories of brain organization and function in which the interaction of billions of neurons is treated as a continuum. The intention is to reduce the enormous complexity of neuronal interactions to simpler, population properties that are tractable by analytical mathematical tools. By so doing, it is hoped that theory of brain function can be reduced to its essence, without becoming lost in a wealth of inessential detail. Naturally, this begs the question of what the “essence” is, and what detail is inessential [3]. The questions themselves are timely for more than neural field theory. Putting aside the most profound of philosophical issues — the existential relation between objective brain function and subjective consciousness — at the cellular level research has achieved detailed knowledge of individual neuron physiology, and at the gross level, considerable knowledge of sensory processing, the generation of movement and the functional locations in the brain of memory, learning, emotion and decision-making. Yet our knowledge of the functional details of all these processes remains vague, and little surpasses the views held by Sherrington [7]. The ever-accumulating body of experimental data, gathered with ever-improving observational techniques, continues to promise that fundamental understanding of the modes of operation of the brain may be possible — yet the goal seems also to move away, like a mirage, because, despite the mass of data, there is no agreed means to achieve the needed integration. A crisis of confidence looms. It is to be hoped that such a crisis is a healthy state — the darkness before the dawn — analogous to the problems of systematic biology before Darwin, or of astronomy before Kepler, or, more recently, of atomic physics before Bohr — but hope alone will not suffice.

Aware of the risk of becoming trapped in an overwhelming mass of undigested detail, large groups of scientists are joining forces to address the problems of integration. While organizing collaborative efforts of scale un-

precedented in neuroscience, all concerned agree on the importance both of technological advances and of theoretical development, but there are many differences of opinion on the best and shortest route to success. In Europe the *Human Brain Project* [4] is aimed at large scale simulation of the brain, employing very detailed cellular properties. In the United States, the *Brain Activity Map* [1] seeks to establish a functional connectome of the entire brain, and the *MindScope Project* [6] intends to obtain a complete model of the mouse visual cortex. The *BRAIN (Brain Research through Advancing Innovative Neurotechnologies)* Initiative [2] aims to accelerate techniques for study of the brain.

Unresolved questions and fears, around which controversy centres, are:

Do we yet have enough detailed data on structure? How much knowledge of exact connectivity in the brain is enough? Established anatomical techniques are not depleted of possibility to resolve more detail, and very sophisticated new technology is being deployed to add further to this. Yet the capacity of individuals to undergo profound brain damage or deformity of brain development without loss of essential function makes the need for such precise detail seem questionable.

Might some crucial type of data still be missing? Controversy over the role of electrical coupling of neurons, and that of glial cells, over and above signal transmission via axon-synaptic couplings, continues to simmer. Might there be rules of synaptic connection that are not apparent, because the pattern cannot be ascertained within the billions of neurons involved?

To reveal essential patterns of activity, do different types of data have to be obtained using concurrent recording methods? All existing techniques offer a window on brain function limited in scale or in resolution in space or time. That is, only a comparatively few cells can be observed at once, the brain's electric and magnetic fields are relatively blurred in space, and the brain's blood flow, as observed by functional Magnetic Resonance Imaging, is limited to relatively slow variations. None match the scale, speed, and detail relevant to cognition, and the task of making sufficient conjoint observations, in realistic waking contexts, is daunting to say the least.

What then, is a reasonably observable, explainable unit of the brain? Professor Eric Kandel advocates the complete analysis of a fly or worm brain, as an initial step in the mega-collaborations [5], but in what way, exactly, is a worm's brain more fundamental than, say, a sympathetic ganglion, or a fly's brain than a sensory-motor reflex?

If all the most important observable data is already available, or will become so, will sufficient computer power enable a working brain to be simulated? If this were achieved, would we be any the wiser, or simply unable to

understand the functioning of the simulation, just as we cannot understand that upon which the simulation would be based? And would the simulation not, itself, be a person? Thus making our justification for subjecting it to manipulation and interference in the interests of science a little ethically questionable?

Obviously there is no way of knowing the answers to such questions without already having a sufficient unified theoretical understanding of brain function, within which old and new observations can be seen in context. Neural Field Theory hopes to discover such a unification, using as its guiding light explanation of the large scale observable fields of brain activity, and expecting as this account proceeds an emergent insight into neural information processing. In contrast to its close relative, neural network theory, it seeks explanations beyond the interaction of smaller numbers of neurons, depending instead on the properties of small neural groups to define the properties of the continuum. The layout of this book reflects these intents.

After a brief tutorial, in the first half of the book and beginning from an historical perspective, differing approaches to formulating and analysing equations for neural fields are presented, and in their variety also revealing an underlying unity of conception. Stochastic dynamics are discussed, as well as means of introducing more anatomically and physiologically realistic properties to neural field equations.

The second half of the books begins by addressing the question of embodiment of universal computation within neural fields, and moves on to cognitive processes. Detailed models with cortical connectivity approaching that of the mammalian brain, and the relationship to the large-scale electrical fields of the brain follow, and the book concludes with an attempt to show how fundamental field dynamics may play a part in the brain's embryonic development.

Thus a preliminary framework is discernible — methods now exist with the potential to unify material drawn from many branches of neuroscience, guiding their synthesis towards working models that can be tested against observable physical and cognitive properties of the working brain. The framework remains frail, and although the concepts involved seem largely internally consistent, in detail — for instance in the choice of parameters applied in different work — the work reported here is not entirely so. It is not yet possible to say the elusive “essence” referred to in the first paragraph has been captured. But the hopes held at the dawn of this subject appear to have been justified, and future prospects encouraging.

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