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Neural Signaling and Communication

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Abstract

To understand the complex nature of the human brain, network science approaches have played an important role. Neural signaling and communication form the basis for studying the dynamics of brain activity and functions. The neuroscientific community is interested in the network architecture of the human brain its simulation and for prediction of emergent network states. In this chapter we focus on how neurosignaling and communication is playing its part in medical psychology, furthermore, we have also reviewed how the interaction of network topology and dynamic models of a brain network.

Keywords: cognitive science, brain imaging, neural networks, network topology

1. Introduction

Network science makes advances for modeling and analyzing the variations in communications. Network science has proved useful for functional brain connectivity assumptions and predicting incipient network states. Research in neural network science or neural information processing has been proven fruitful in the past, providing useful methods both for practical problems in computer science and computational models in neuroscience [1, 2].

The human brain shows a discrete spatiotemporal organization that aids brain function and can be imitated via local brain simulation [3]. Such disturbances to local cortical dynamics are globally merged by discrete neural systems [4, 5]. Brain function depends upon complicated active interactions between distinct brain regions that define neural systems. This system-level architecture and dynamics can be discovered across different scales, from microscopic groups of cells to macroscopically defined brain areas [6–9]. Late neuroimaging works have been subservient in mapping the structural and functional architectures of the human brain at the macro scale [10, 11].

Recent developments in the field of cognitive neuroscience require computational and theoretical apprehension of neural information processing models which accomplish standards and constraints from cognitive psychology, neuroscience, and computational efficiency [12, 13]. Nowadays, mapping structural connections and recording temporal dependencies among local time series have become feasible, yet signal transferring across the network in flexible and adaptive computational manner remains unidentifiable.

1.1 Psychiatric disorders and network science

Psychiatric disorders have conflicts related to progression arbitrated by the brain. Developing sign recommends that precise biomarkers might use from integrating information about several brain realms and their connections with one another for psychiatric disorders, instead of seeing local disturbances in brain structure and function [14]. Current progress in the discipline of applied mathematics mostly and network science explicitly offer a language to captivate the complication of cooperating brain sections, and the use of this language for essential inquiries in neuroscience forms an incipient field of network neuroscience. This chapter provides an outline for the application and usefulness of network neuroscience in psychiatry and how network science may cooperate with it.

Most approaches are generally used for animal or human models reckoning however the approach is invasive. The term invasive is specified in this framework as a process that needs a carving in the skin or insert of an apparatus in the body [15].

2. Use of scientific and clinical tools to reconcile unhinge brain activity

Non-invasive brain stimulation such as transcranial magnetic stimulation and invasive brain stimulation such as profound brain stimulation is employed for scientific and clinical tools to unhinge brain activity. Incomparable conditions in which procedures classically kept for experiments on animals, for instance, invasive electrophysiology, can be morally employed in humans. For instance, throughout convinced sorts, I human brain surgery, clinical decisions are controlled by invasive electrophysiological measurements (e.g., ECoG). Along with their medical employment, these recordings also provide expressive information for scientific studies.

Equally, human neuroscience application tools and modeling in animal neurology has aided to expose a fundamental mechanism of these systematic ways. A major illustration is the research separating, cause of practical MRI (fMRI) signal by joining invasive electrophysiological measurement with fMRI in animal experiments.

3. Psychiatry experiments on living being

Naturally, experimenting on animal use invasive electrophysiology, in which electrodes are entrenched straight in the brain for recording action potency and local field potential (LFP and EEG). Furthermore, recording neuronal action by ocular means, calcium and voltage imaging mostly, have become a coercive observational strategy that embellishes electrophysiology in animals although it is well invasive [15]. Optogenetic manipulations (optical measurements and perturbations) can use light to unhinge neuronal activity.

In humans, MRI (magnetic resonance imaging) empowers detailed, non-invasive visualization of brain anatomy. Measurement in blood oxygenation variation as a substitution for neuronal activity can also employ corresponding expertise. On the other hand, electroencephalograph can noninvasively measure electric fields generated by the neuronal activity. Magnetoencephalography and electrocorticography (ECoG) are two less commonly used but significant methods that measure brain signaling. Electric and magnetic fields stimulations record from the brain along with modulating neuronal activity.

Moreover, classifying deliberated systematic ways as whichever noninvasive or invasive will concentrate on the *spatial or temporal resolution* these systematic ways provide.

3.1 Temporal resolution

Temporal resolution discusses how much time does a measurement requires to be completed, and hence states the quickest fluctuations in the signal of attention that can be seized exactly [16]. The sampling rate defines the temporal resolution. The frequency of measurement is referred to by the sampling rate. For example, only a second is required to obtain a single image of human fMRI activity scan (sample rate is 1 Hz i.e., 1/s). Thus, signals that expressively fluctuate in a given sub-second time scale (i.e., any given 1 s interval) are not captured properly. This contrasts noticeably to the typical sampling rate of an EEG device (1000 Hz and greater). A millisecond timescale of action potential fire is the fastest temporal scale [17].

3.2 Spatial resolution

Spatial resolution refers to the specified measuring strategy that can be taken for least events in space. As an illustration, the brain activity of a cubic millimeter resolution is commonly measured using an fMRI. Indifference, the EEG tested natural signals show deprived spatial resolution as they initiate from indefinite square centimeters of brain tissue [18, 19]. Now centering our attention to the spatial scales reaching out of the full brain to distinct neurons [18]. Since there are in cursive methods present for spatial and temporal resolution improvement. For instance, the spatial resolution for electrophysiological brain activities can be as slight as a 100 mm for transcription; electrodes are surgically implanted into the brain. The invasive transcriptions cater to perfect temporal and spatial resolution along with high temporal resolution of electrophysiological measurements. It is prominent that along with some omissions noninvasive approaches accompanying high temporal resolution (e.g., EEG) are subjected to poor spatial resolution and contrariwise (e.g., fMRI). Consequently, merging appropriate approaches has persisted as one of the utmost prevailing and electrifying procedural approaches in network neuroscience [19].

4. Network neuroscience framework

Network neuroscience conceives brain functions as egress from the collective action of various system elements and their common interconnections as shown in **Figure 1**.

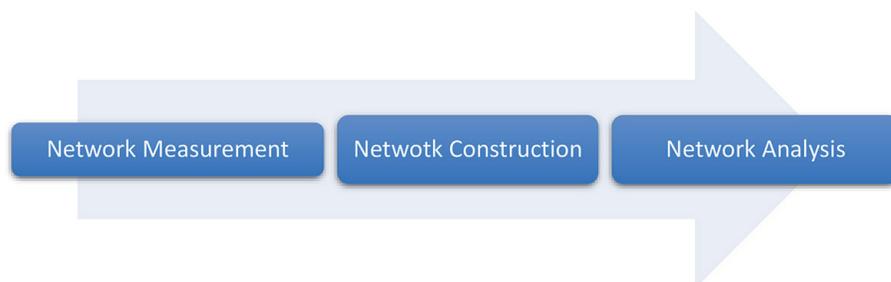


Figure 1.
Basic steps of neuroscience framework.

Currently, large-scale efforts to record neuronal connectivity in various species, including the nematode worm, fruit fly, mouse, macaque, and human, have led to a burst of data developed using a diverse array of measurement methods, and at scales fluctuating from a level of single cells to large brain areas. In similar, quick developments in physics of multifaceted network have directed to a new thoughtful of the association and dynamics of systems of interacting elements, with nervous systems being but one example. The confluence of these approaches lies at the core of network neuroscience, which is linked with understanding how nervous systems function as combined systems [20]. Network neuroscience offers one of the rarely incorporated frameworks for revealing different kinds of brain imaging data, needed in different species at various scales and have various measurements methods, by demonstrating all nervous systems in their most intellectual form: as assemblies of nodes connected by edges.

Network neuroscience technique has before now produced many novel visions into brain organization, for example, that nervous systems across scales and species illustrate a hierarchical, segmental and minor-world organization, that they contain decidedly connected hubs, they are economically reinforced. As the field develops, tools and methods settled in other areas of network science are being progressively polished and modified to the neuroscience context [9, 20].

The interpretation of how brain egress from a large number of communicated patterns of neuronal elements stands as one of the most abiding challenges of modern neuroscience. The complex systems draw close to understanding the brain is similar to other disciplines that intermix concepts from network science, the study of social networks through statistical physics and dynamical systems, the propagation of epidemics, rumors or computer viruses, the effects of disturbances or assault on electrical grids or the World Wide Web, or the performance of gene regulatory or metabolic networks [21].

5. Brain network topology and communication

Brain network has a topology with prominent attributes that describe the system as a whole: heterogeneous level and strength dispersions, high clumping and short path lengths, a multi-scale modular organization and an obtusely connected core of high-degree nodes are some of the network characteristics which are shared across species and scales.

Similar to any new field, the best ways for manufacturing and analyzing brain networks are still undergoing development. Amid late evolutions is the understanding that brain networks are essentially multi-scale entities.

The term “scale” can have varying meanings depending upon the context; at present we concentrate on three possible definitions related to the study of brain networks. Foremost, a network’s spatial scale refers to the coarseness at which the nodes and edges are defined and can vary from that individual cell and synapses [18]. Secondly, networks can be qualified over temporal scales with accuracy varying from sub-millisecond to that of the entire lifespan, to developing changes across various species. Lastly, networks can be examined on divergent topological scales varying from individual nodes to the network as a whole [17, 21]. Conjointly, these scales specify the axes of a 3D space in which any synthesis of brain network data lives. Major brain network analysis subsists as points in the space—i.e., they concentrate on networks specified singularly at one temporal, spatial, and topological scale. We contend that, when studies have proven enlightening, in order to better understanding the brain’s actual multi-modal, multi-scale nature, it is important for our network analysis that we begin analysis to form bridges which join different scale to each other [1, 21].

5.1 Routing communication

Routing communication covers the control of paths that data can take over a network. Specified that physical networks have predetermined limits on links, and memory, the main work of routing is to assign paths so that one or extra communication goals are retrieved (e.g., cost, fidelity, fault-tolerance, speed, etc.). Routing is of strongly important for brain's communication via network: inferring sensory data, access of memory, decision making, and several further essential brain functions require that communications can be flexibly directed and acknowledged by several nodes at broadly parted positions on the network, in reply to fluctuating demands [19].

Though, for the reason that of new scientific growths, nowadays the brain is more dynamic than we supposed. The human brain continuously creates new neurons and makes neural pathways during our whole life cycle. Therefore, neurons are dynamic cells that are regularly familiarized to fluctuating situations. If some activity damages an individual's brain (such as an injury or stroke), the neurons have the potential to create a new communication route/path around the injured area. This capability is known as *neuronal plasticity*.

In communication networks, the abbreviated path between two nodes has a special role: the extent of the abbreviated path is taken to the topological distance amid nodes. Hence, the abbreviated path extent is referred to as the indicator of comfort with which signals can be transmitted amid nodes [19, 20].

5.2 Information routing and functional integration

Any solo cognitive function may contain numerous dedicated areas whose association is facilitated by the functional integration between them. Such integration is facilitated by information exchange between brain areas by the means routes that can change with highest timescales at which the structure is fixed, by providing changeable actual connectivity in spite of the inflexibility of the infrastructure on high timescales [9, 11]. The dynamic nature of the information routing and flexible effective connectivity is worth of the multistability of the cooperative dynamics of the brain networks. In addition, single structural connectivity can support numerous degenerate dynamical states, each of which information transfer by use of special pattern can be seen in **Figure 2**.

The modeling of spatiotemporal dynamics underlying integration and segregation can reveal casual mechanics insights into neuropsychiatric disorders. For being influenced by the full potential of whole-brain computational modeling, it is a requirement to capture temporal evolution of brain's functional network organization along with time-averaged representations of FC (which are strongly inhibited by the SC) *in silico* neural dynamics (a neuromorphic analog chip is presented that is capable of implementing massively parallel neural computations while retaining the programmability of digital systems).

Neuronal collective oscillations are assumed to offer such a basis for the dynamic's communication among brain regions. Numerous lines of experimental evidence and theoretical influences specify that the stage relations amongst the oscillations of various brain regions can modify effective connectivity by modulating the result of mutual influence between them.

A more existent account of the consolidative capacity of neuronal systems needs a significant differentiation between the concepts of "communication efficiency" and the usually employed graph theoretic measure called "global efficiency." The mean of the reversed abbreviated length between all pairs of nodes is referred to as the global efficiency, hence captivating the global capacity of the network to transfer information in a collateral fashion [1, 9, 11, 19, 20].

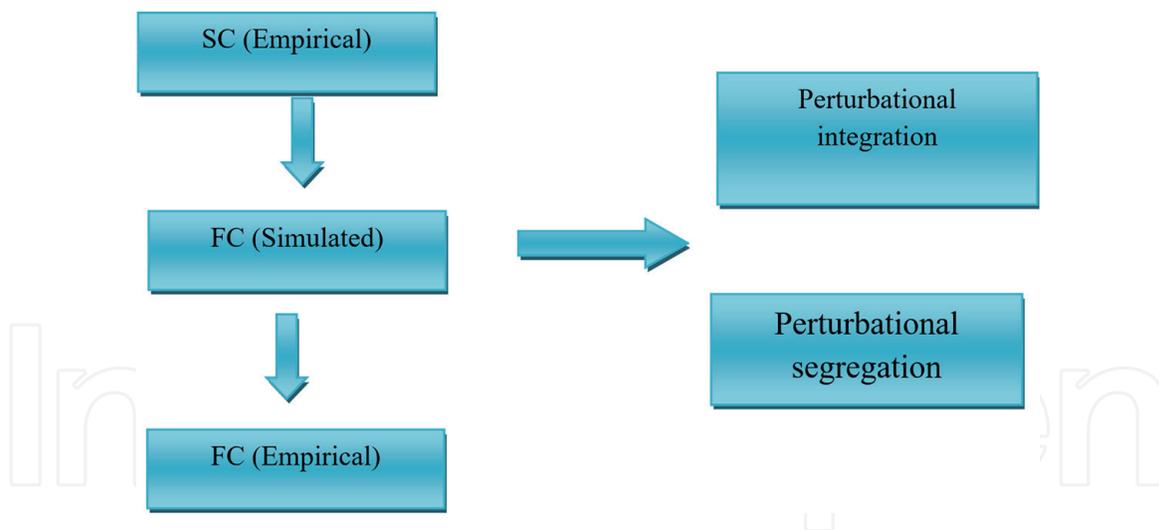


Figure 2.
Information routing and functional integration.

5.3 Network dynamics and communication

Synchronized complete brain neural dynamics are important for appropriate control of functionality in different brain systems, effectual integration of composite and multimodal information, and even adaption to transient regular circumstances. Specified such roles of macroscopic, brain dynamics in our mental and neural information processing, it is sensible to assume that the irrationality of large-scale neural dynamics is a main biological mechanism fundamental autism spectrum disorder (ASD), which is described as the weakening of global information processing.

Structural topology is constricting signal extension is a very important dynamical point of view the communication process. One of the eminent differentiations between dynamical and topological analyses of brain communication is the quantity of information (in the statistical sense) which is required for the extension of the communication process.

5.4 Network computation and communication

The crucial role of communication dynamics in neural computation attracts a great amount of curiosity. Some important and distinct features of brain network communication that enlightens mechanisms by which the brain network carries out computation are as follows:

1. Communication dynamics are effective connectivity.
2. Computation by networks.

6. Multi-scale community structure

The attributes of local and global networks are unambiguous to calculate as the unit analysis of individual nodes and the entire network are closely manifest and no extra search is required. Multi-scale structure, though are not always apparent. The occurrence or nonappearance of multi-scale structures is contingent upon the formation of edges between the nodes of a network known as network topology. Real-life networks consist of numerous nodes and edges organized in complicated

outlines which can be ambiguous structural symmetries. Because of such complication, if anyone wants to see a mesoscale structured network, he will have a necessity to algorithmically quest for it. In community structure circumstances, there is no lack of algorithms to do so. They depend on how they describe communities along with computational complexity. The range of the method is observed as a deficiency or a benefit, the originality in community detection and repeatedly increasing sub-fields of network analysis are desirably settled. Although respectively community detection methods suggest its own possessive exceptional perception on how we can classify communities in networks, the technique that is furthestmost extensively employed and debatably the often useful is modularity expansion. Modularity expansion divides a network's nodes into communities so as to make the most of a verifiable function acknowledged as modularity (or just "Q"). The comparison of the practical pattern of connections in a network contrary to the perceptual structure that would be likely below a stated null model of network connectivity is performed by the modularity function. The weight of a respective existent edge is compared directly to the weight of the similar edge if, connections were to be shaped under the null model. Nearly, the ascertained connections will be improbable to subsist under the null model or might it be worthier in comparison to the null model expectations.

The efforts to locate several conceivable robust than predictable connections inside communities is done in the maximization of modularity. Much clearly, if the weight of the ascertained and anticipated connections between the nodes i and j are specified as A_{ij} and P_{ij} , separately, and $\sigma_i \in [1, \dots, K]$ shows the communities of K in which i can be allotted, then modularity can be calculated as:

$$Q = \sum_{i,j} [A_{ij} - P_{ij}] \delta(\sigma_i \sigma_j). \quad (1)$$

Where Kronecker delta function is denoted by δ and is equal to 1 only if arguments are not 0 and are the same. Various methods used in fact to maximize Q , however in conclusion the entire outcome in the estimation of community network structure, a separation into communities. Unfortunately, in the partition, the number and size with the biggest Q represent communities not always demonstrated in the network. Other alike quality functions and modularity show a "resolution limit" which bounds detectable communities' size. Smaller size communities are rather undetectable. In one way to determine all size communities, modularity prolonged in current years to comprise γ , a resolution parameter, which can be used for exposing different sized communities. Augmented modularity equation then shows like this:

$$Q(\gamma) = \sum_{i,j} [A_{ij} - \gamma P_{ij}] \delta(\sigma_i \sigma_j). \quad (2)$$

Primarily familiarized method for avoiding resolution limit is known as the resolution parameter. Accidentally, it has imparted the flexibility of modularity measure. The resolution parameter acts as a turning protuberance, making attaining of estimated small communities probable when it is at one situation and bigger communities while it is an alternative situation: while γ is big or small maximizing modularity will give parallel minor or major communities. With a smooth tune, from one extreme, the resolution parameter can efficiently find evaluations to the other extreme of a network's community structure, from the finest scale from where network nodes form singleton communities to the unrefined scale where all nodes fall in the same communities. Multi-scale community detection can be recognized as the changing resolution parameter for notifying the communities about various sizes. It must be renowned that there subsist possible descriptions of modularity functions which do not endure from resolution limits in the initial place.

7. Conclusion

In the recent past, the network cognitive science has revealed that how the network topology and dynamics outline the flow of neural signal under the brain function to great extent but still there are many gaps remain in our understanding due to data limits and of recording tools. For example, the limited availability of observational tools limits empirical access to communication dynamics. Now a day, it has become possible to map structural connection and recording temporal dependencies among local time series, but the possible mechanism involved in signal transfer across the network in a various manner that allows flexible and adaptive computation remain elusive. In spite of limitations, there is a wide range of opportunities to learn how the brain network functions. The nature of communication may vary, for example, dynamic network model is kind of theoretical framework that is helpful in an understanding of our knowledge of behavior and cognitive science, it also includes the pattern of change with aging and development. Furthermore, it can become an important tool for predicting the effects and outcomes of perturbations, including lesions and focal stimulation. Building on topology and dynamics, the confluence of empirical and theoretical studies are poised to add significant new insights into the network basis of brain function.

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