The Whole Brain Connectome Architecture

Connectome informatics

The goal of our research project is to establish connectome informatic, a methodology for exploiting brain networks to unveil the architecture of information processing in the brain. A key strategy of connectome informatics is to reveal the community structure of brain networks, where the word 'community' refers generally to a group of vertices of the network that are connected at higher probability with each other than with those outside the group [1]. This strategy is based on the hypothesis that communities of brain networks are associated with functional modules of information processing in the brain [2]. As a first step of our research project, here we demonstrate the validity of this strategy applied to the mouse connectome data of Allen Brain Atlas (http://connectivity.brain-map.org/) [3, 4].

Mouse visual cortical network

We have focussed upon the visual cortex [5]. Taking 10 visual cortical regions (Table 1, Figure 1) as vertices and exploiting the high-resolution connectivity data recently published from Allen Brain Atlas (https://github.com/AllenInstitute/mouse_connectivity_models), we have calculated the connection strengths between these regions. The obtained connection strengths are summarized in Table 2.

Community detection

The method of community detection used here is briefly described follows. Suppose a random walker in the network. Let $p(n)$ be the probability that the random walker is at vertex n; $p(n|k)$ be the probability that the random walker is at vertex n conditioned that he/she is staying in community k. The probability $p(n)$, which is distributed over the entire network, can be decomposed as a linear sum of probabilities $p(n|k)$ $(k=1,\cdots,K)$, which are more locally distributed around individual communities:

$$p(n)=\sum_{k=1}^{K}\pi(k)p(n|k) \quad , \qquad (1)$$

where K is the putative number of communities and $\pi(k)$ is the probability that the random walker is staying in community k. Community detection is achieved if the decomposition (1) is solved with respect to $\pi(k)$ and $p(n|k)$. Indeed, we have recently derived a machine-learning algorithm to solve this [6].

The membership of vertex n in community k is expressed by $p(n|k)$, which defines the relative importance, or the rank order, of vertex n in community k. Such a community is associated with no clear distinction between members and non-members of this community. In this sense, communities detected by our method are characterized as 'pervasive'.

Community structure of the mouse visual cortical network

Our algorithm [6] has a single parameter, α, that controls the resolution of decomposition of the network into communities; for larger/smaller α, the network is decomposed into less/more communities of larger/smaller sizes.

For $\alpha=0.1$, the visual cortical network is decomposed into two communities (**Table 3**). Comparing

Table 3 with **Fig. 1**, one finds that in one community, ventrally located regions are highly ranked (VISp, VISl, VISpor, VISpl and VISli in descending order of $p(n|k)$); in the other, highly ranked regions (VISp, VISpm, VISam, VISa, VISl, VISal and VISli in descending order of $p(n|k)$) are more dorsally located. The visual cortical network of human and primate is known to functionally differentiate into ventral and dorsal streams; the ventral stream is engaged in object recognition, whereas the dorsal stream is associated with recognition of visual context. Our findings suggest that the visual cortical network of mouse also has similar functional as well as structural differentiation.

For $\alpha = 0.05$, the network is decomposed into three communities (**Table 4**). Two communities inherit the ventral and dorsal streams found for $\alpha = 0.1$. The third community, in which VISp is ranked the first by a long shot, is supposed to be associated with primary input to the visual cortex.

For $\alpha = 0.01$, the network is decomposed into four communities (**Table 5**). Three communities inherit those found for $\alpha = 0.05$. The fourth community involves highly ranked regions associated with either the ventral or dorsal stream. This community is supposed to bridge between the ventral and dorsal streams.

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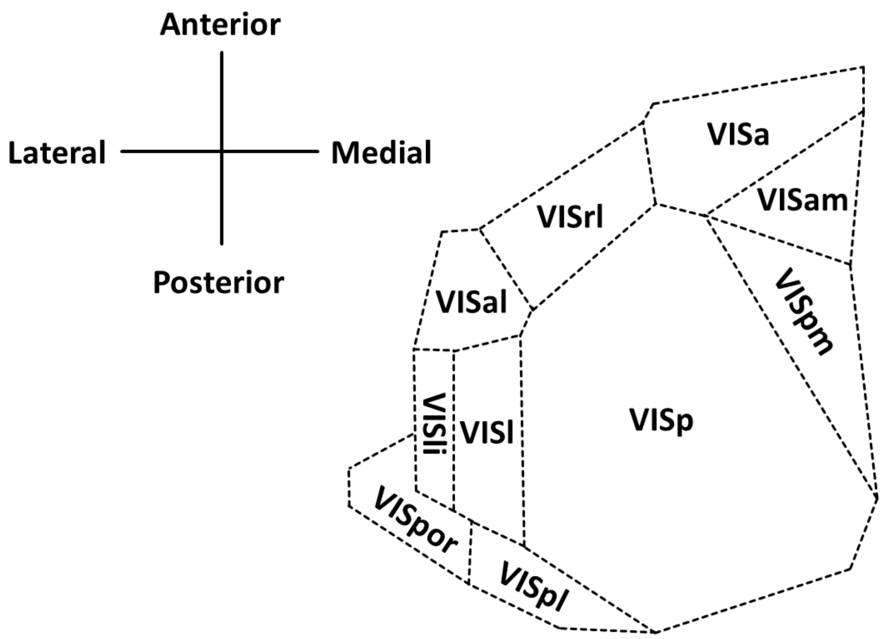
Anterior
Lateral
Medial
Posterior
VISa
VISam
VISrl
VISal
VISpm
VISli
VISl
VISp
VISpor
VISpl

Figure 1