Reverse-Engineering Neural Network Topology from Large-Scale Recording Dynamics

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Introduction

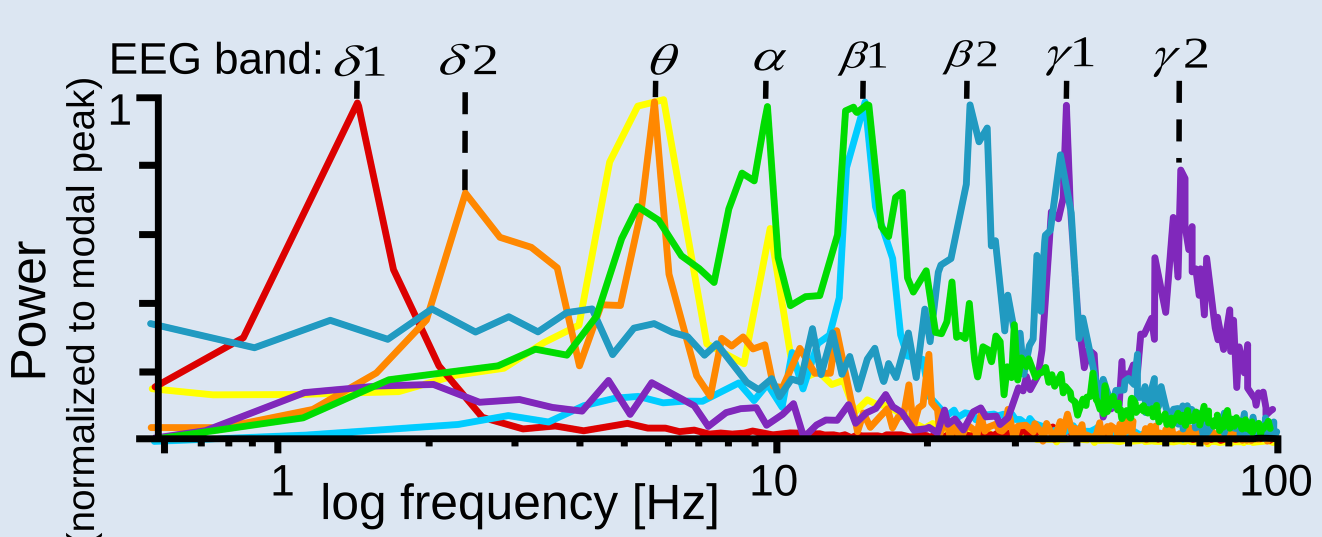
Power spectra from EEG recordings reveal that brain dynamics are multi-oscillatory with decoupled frequency bands [1] .

Large-scale connectivity in the brain is nonrandom, and is well characterized by a small-world topology [2].

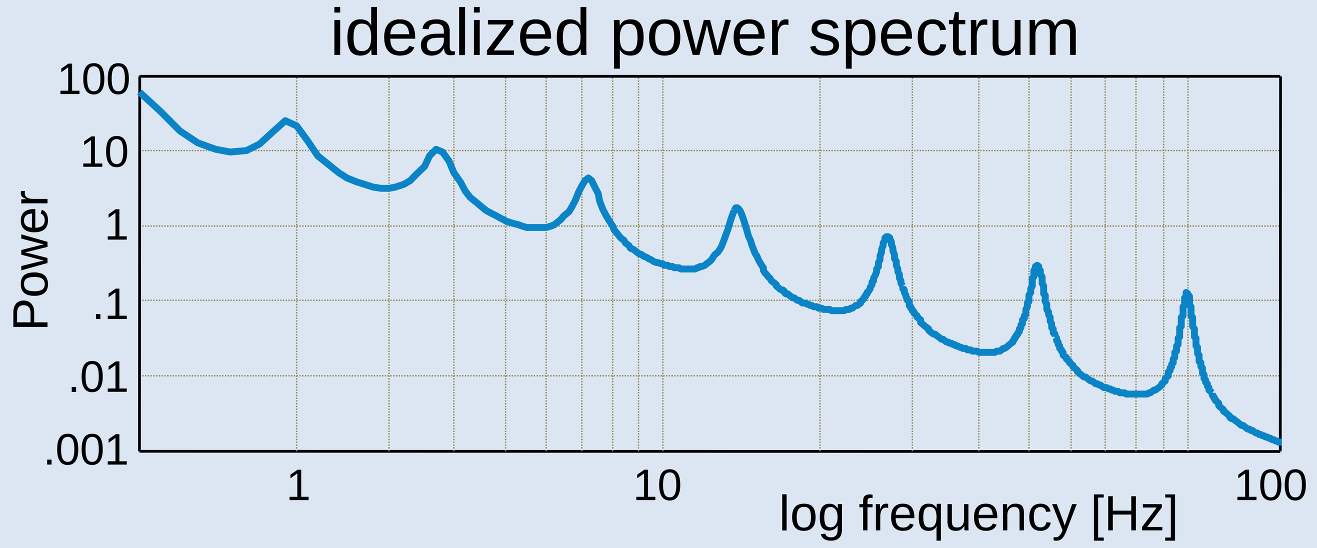
It is desirable to infer details regarding the connectivity of a neural network based on study of its dynamics.

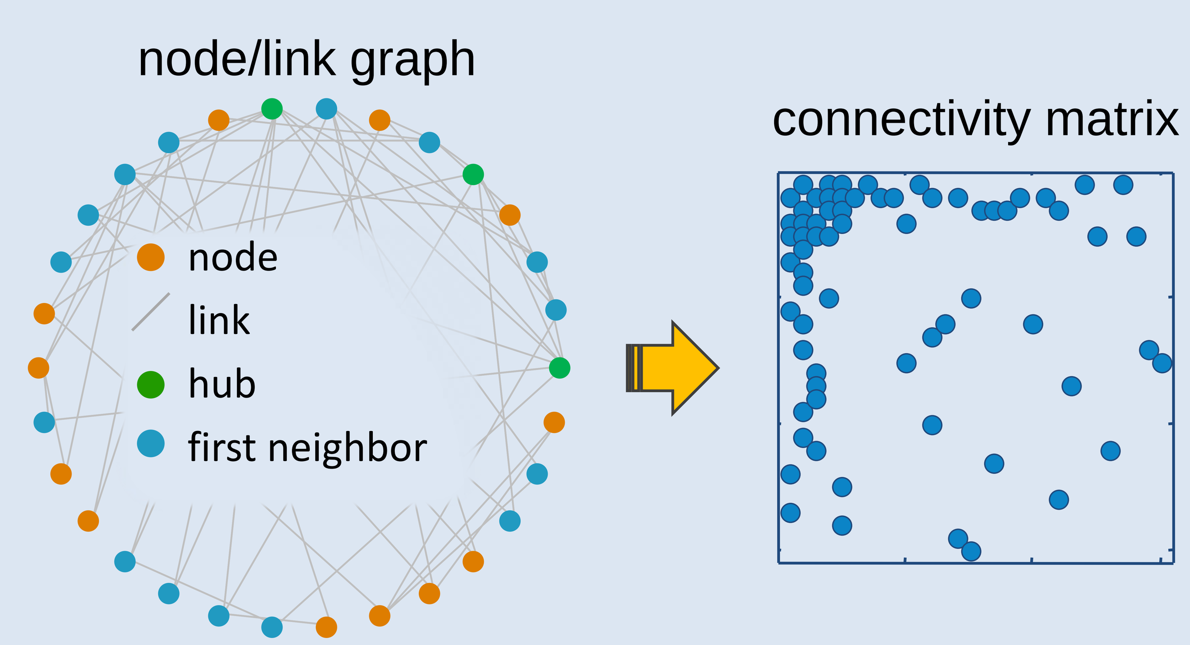
Goal: generate an ensemble of networks possessing a prescribed power spectrum, each network also exhibiting connective topologies similar to the brain's.

persistent LFP rhythms *in vitro*



idealized power spectrum





Methods

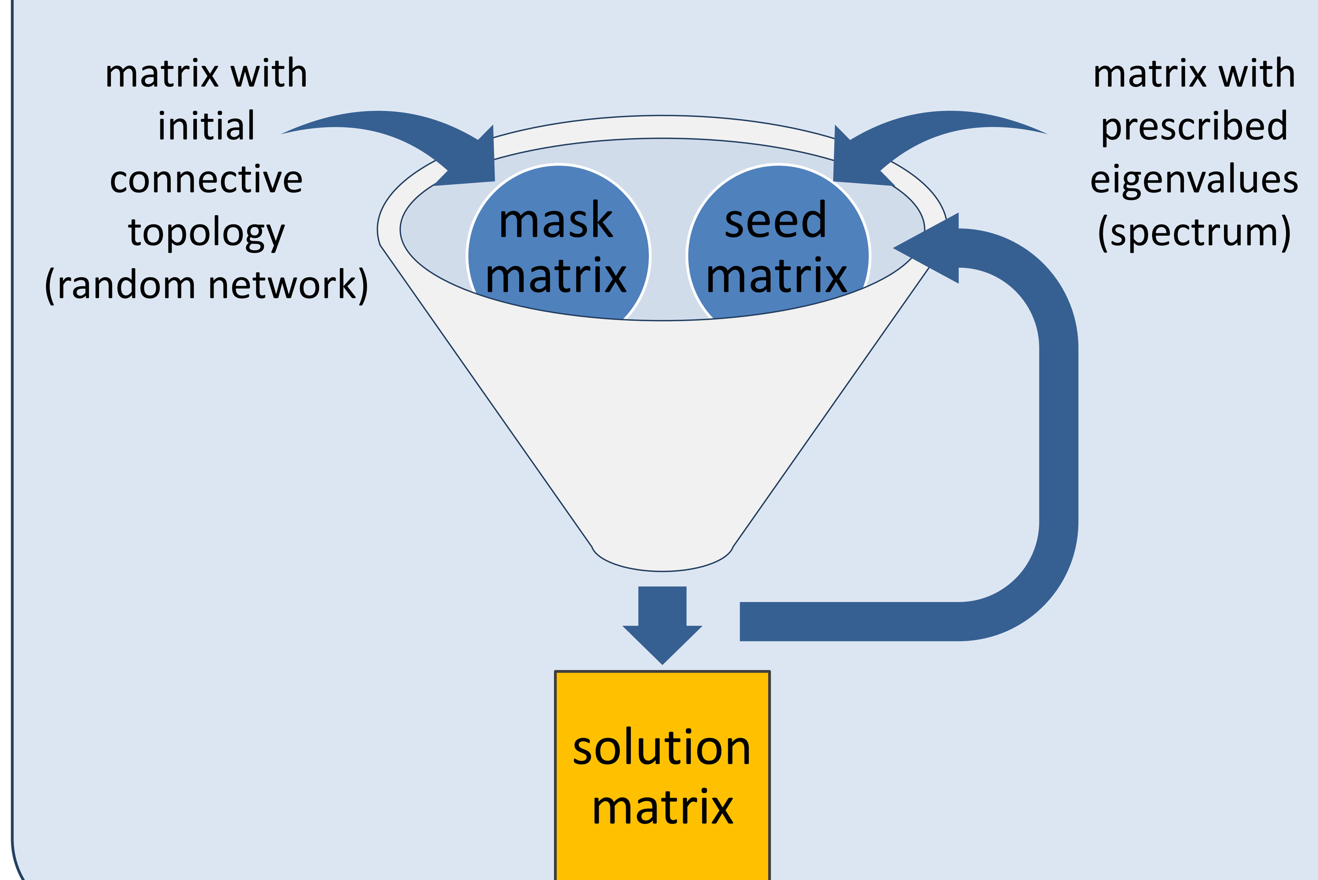
Inverse problem: reverse-engineer a network with prescribed spectrum as constraint.

The eigenvalues of the connectivity matrix of a graph determine the average power spectrum.

However, the power spectrum does not uniquely determine the connectivity matrix.

Inverse eigenvalue problem: Adapting recently developed mathematical techniques [4], we reconstruct realizations from the family of solution matrices with (identically) the prescribed spectrum.

iterative solution method



References

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Results

Conclusions: All reconstructed matrices exhibit globally balanced excitation and inhibition. Variance in networks is accounted for by neither the spectral energy nor the number of spectral peaks employed in their generation.

However, for each single node, the net excitatory and net inhibitory inputs are not balanced:

The capability of inferring large-scale brain connectivity from EEG signals among other non-invasive techniques may be used in the near future to identify structural alterations of the brain underlying abnormal cognitive function. The application of our network-reconstruction algorithm may help uncover these anatomical alterations.

Block 1 shows analyses performed for a spectrum with 8 peaks, with spectral energy normalized to 1. **Figure A** shows the connectivity in linear and $\log_{10}$ scale for the random matrix which initializes integration, which shows no structure. **Figure B** shows the connectivity for the thresholded solution matrix, which displays a power law and approaches a scale-free topology. This structure is emergent from the solution method. **Figure C** is the connectivity matrix for the 8 peak spectrum. **Figure D** shows excitatory (+) and inhibitory (-) inputs and outputs for the sorted (ranked) nodes; **Subfigure D** shows the ranked number of connections per node, which is shown in subfigure in **Block 2** and **3**. Note the balance between input and output on a per-node basis (nodes are not directed).

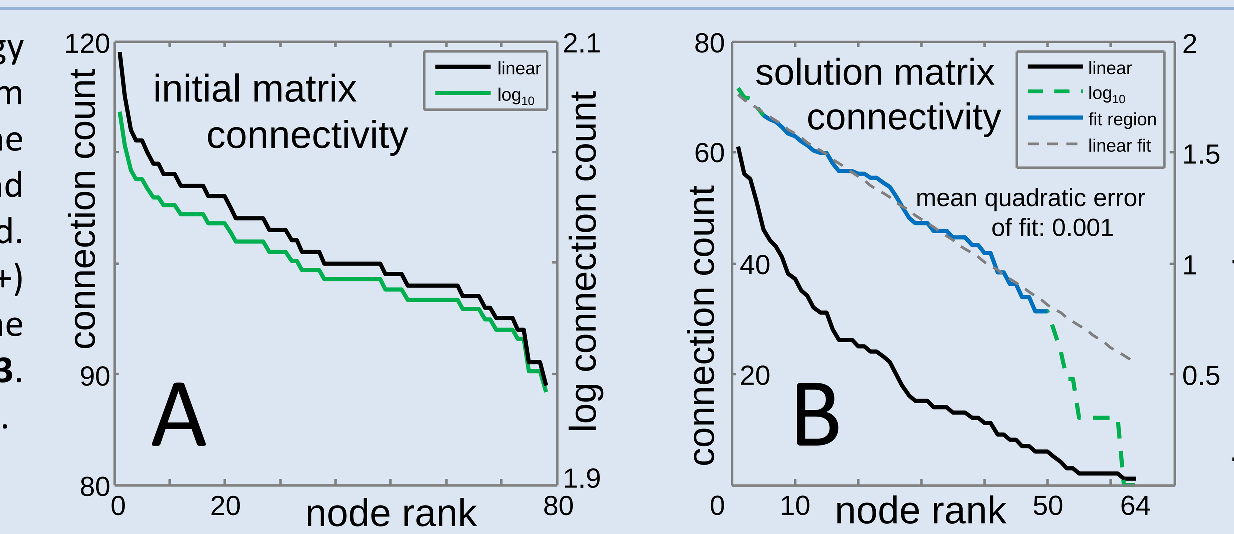
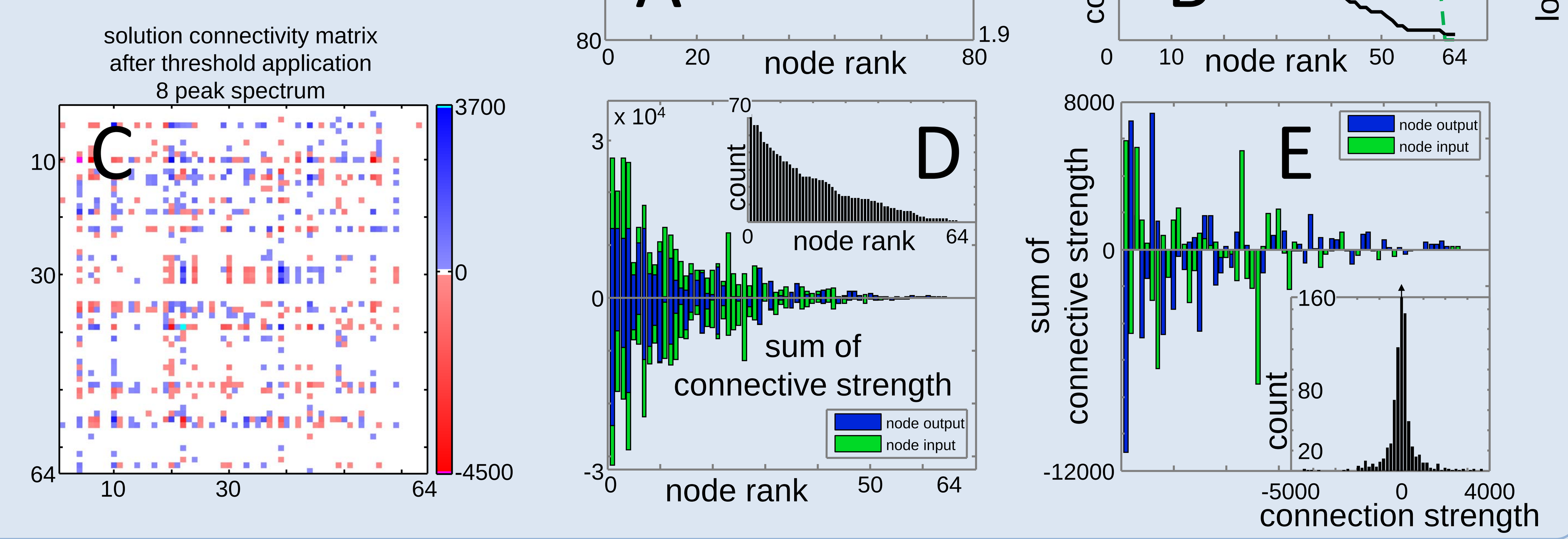
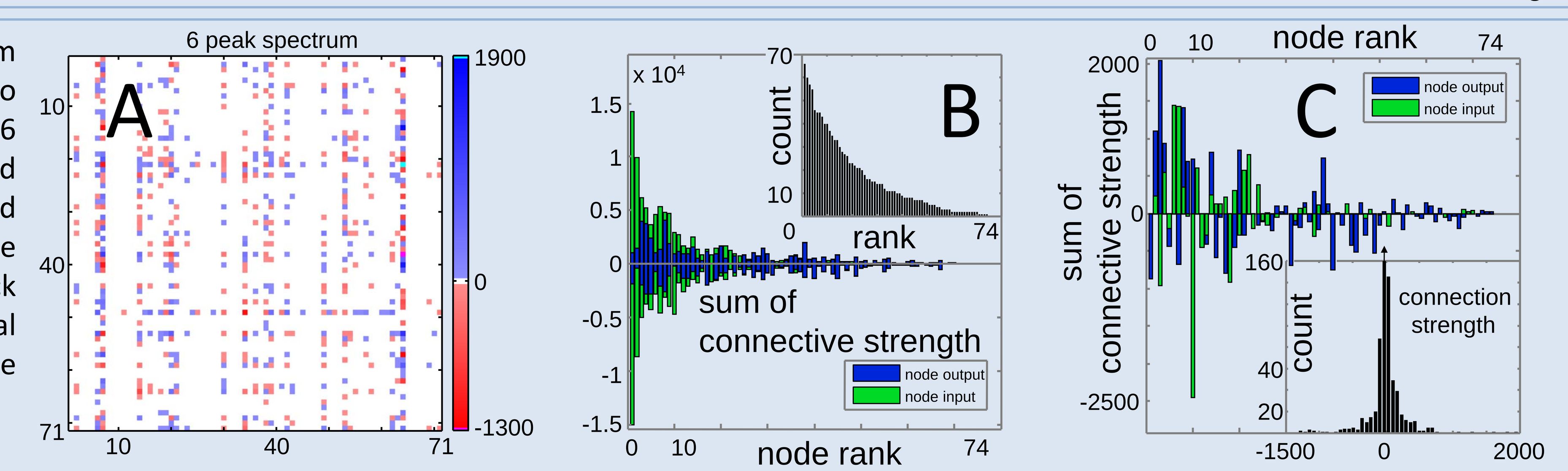


Figure E shows the sum of the input & output of the ranked nodes. Note that individual nodes do not on average balance excitation and inhibition – that is, if a given node receives a net excitatory input, it does not on average provide a net inhibitory output. This is, however, generally true for the top ranked nodes (those with the greatest number of connections in the graph). **Subfigure E** shows the histogram of connective strengths, which is shown also in **Block 2** and **3**. The bin for 0 extends beyond the figure bounds in all cases.



Block 2 shows analyses performed for a spectrum with 6 peaks, with spectral energy normalized to 1. **Figure A** is the connectivity matrix for the 6 peak spectrum. **Figure B** shows excitatory (+) and inhibitory (-) inputs and outputs for the sorted (ranked) nodes. **Figure C** shows the sum of the input & output of the ranked nodes. This block demonstrates that the removal of a single spectral peak does not radically alter the behavior of the solution networks.



Block 3 shows analyses performed for spectrum with 7 peaks and non-normalized spectral energy. **Figure A** is the connectivity matrix for the 7 peak spectrum. **Figure B** shows excitatory (+) and inhibitory (-) inputs and outputs for the sorted (ranked) nodes. **Figure C** shows the sum of the input & output of the ranked nodes. This block demonstrates that networks based on spectra with different energies do not exhibit radically different behaviors.