Distributed Cortical Networks Represent Visual Object Categories based on a Hierarchical Semantic Structure

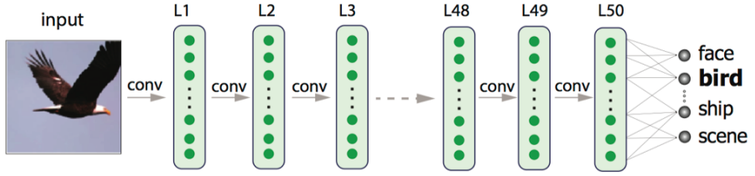
Haiguang Wen, Junxing Shi,Yizhen Zhang, Kuan Han, Zhongming Liu (zmliu@purdue.edu)

Weldon School of Biomedical Engineering
School of Electrical and Computer Engineering

Introduction

To map cortical representations of different categories of visual objects, scientists often use a cherry-picking strategy to only focus on a few categories, e.g. faces and houses. Here, we explored a new and high-throughput strategy to map the cortical activations with thousands of visual objects, and to offer unique insights to the distributed cortical network basis of categorical representations. Central to this strategy is a deep learning model, i.e. deep residual network (ResNet), which has enabled computers to recognize natural images with human-like performance. We built encoding models based on ResNet to predict the cortical responses to natural visual stimuli.

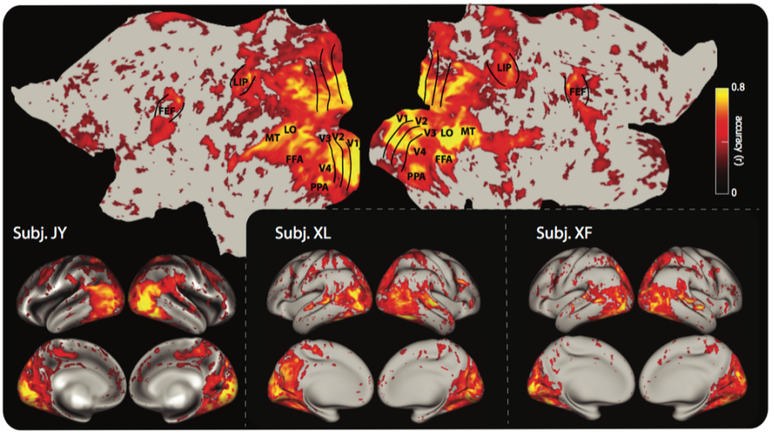
Deep Residual Network



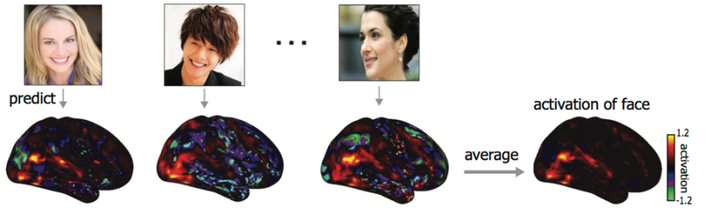
The ResNet is composed of 50 hierarchical convolutional layers for object recognition

Brain Encoding Model

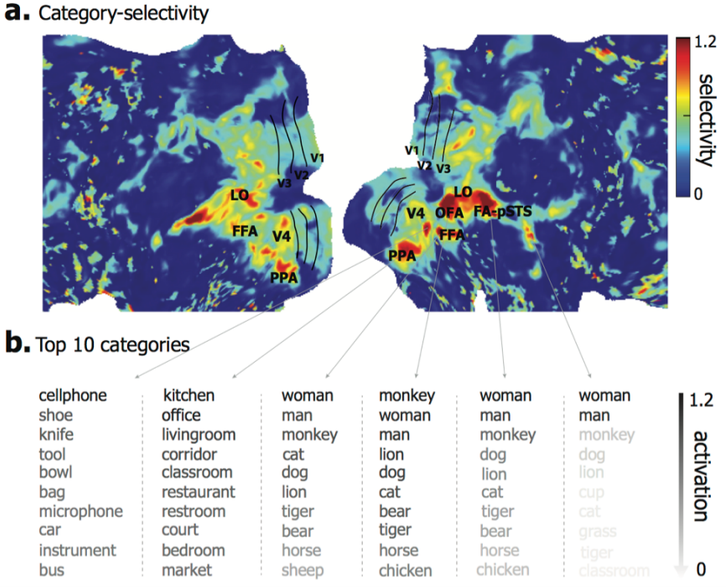
Encoding model predicted widespread cortical responses to natural visual stimuli



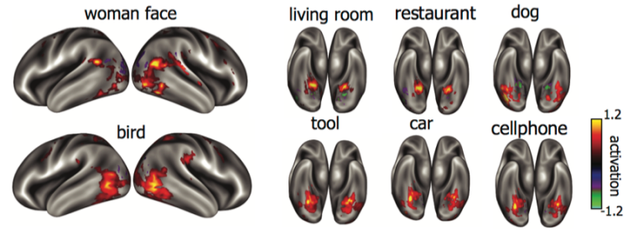
Model-Predicted Categorical Response



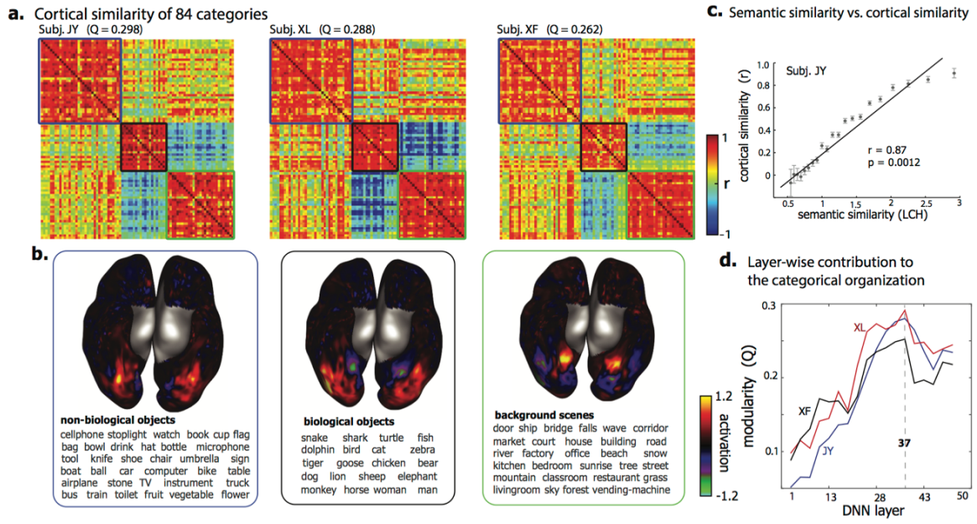
Cortical Category-Selectivity



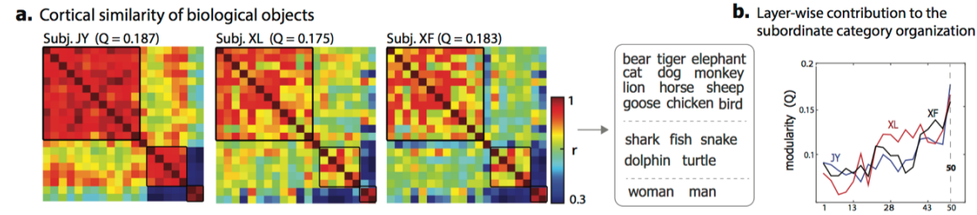
Cortical Representation of Object Category



Categorical Organization in the Brain



Subordinate Categories in Finer Scale



Discussion

Object categories are represented by distributed and overlapping cortical networks, instead of localized regions. Similar activation patterns reflect similar semantic meanings for different categories. Visual areas on the ventral pathway tended to be category selective. There are generally three characteristic network patterns representing non-biological objects, biological objects and background scenes. Subordinate object categories were modularly organized in finer scales. Interestingly, the brain processed higher-level information about visual objects for distinguishing finer level categories.

Acknowledgement

The research was supported in part by NIH R01MH104402

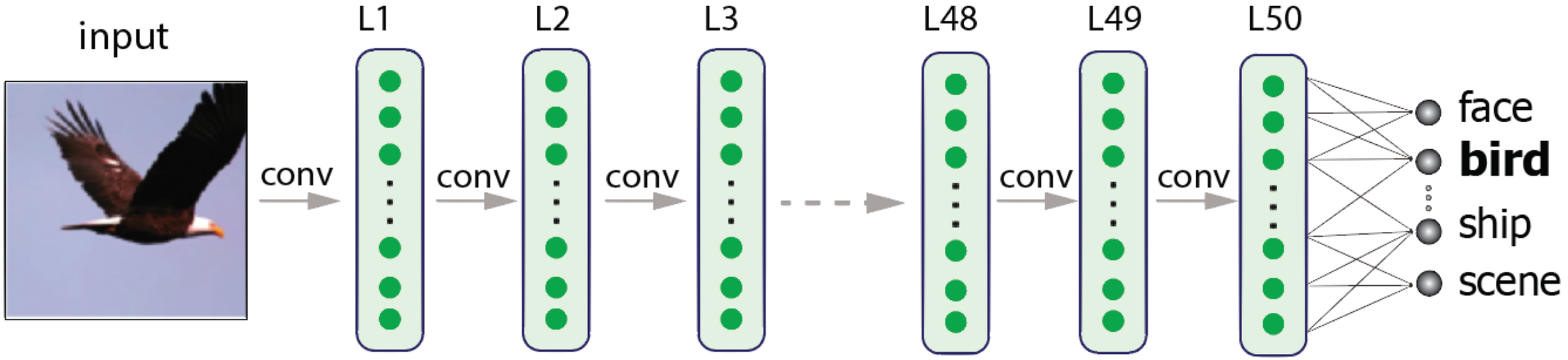
Distributed Cortical Networks Represent Visual Object Categories

Introduction

To map cortical representations of different categories of visual objects, scientists often use a cherry-picking strategy to only focus on a few categories, e.g. faces and houses. Here, we explored a new and high-throughput strategy to map the cortical activations with thousands of visual objects, and to offer unique insights to the distributed cortical network basis of categorical representations. Central to this strategy is a deep learning model, i.e. deep residual network (ResNet), which has enabled computers to recognize natural images with human-like performance. We built encoding models based on ResNet to predict the cortical responses to natural visual stimuli.

Distributed Cortical Networks Represent Visual Object Categories

Deep Residual Network

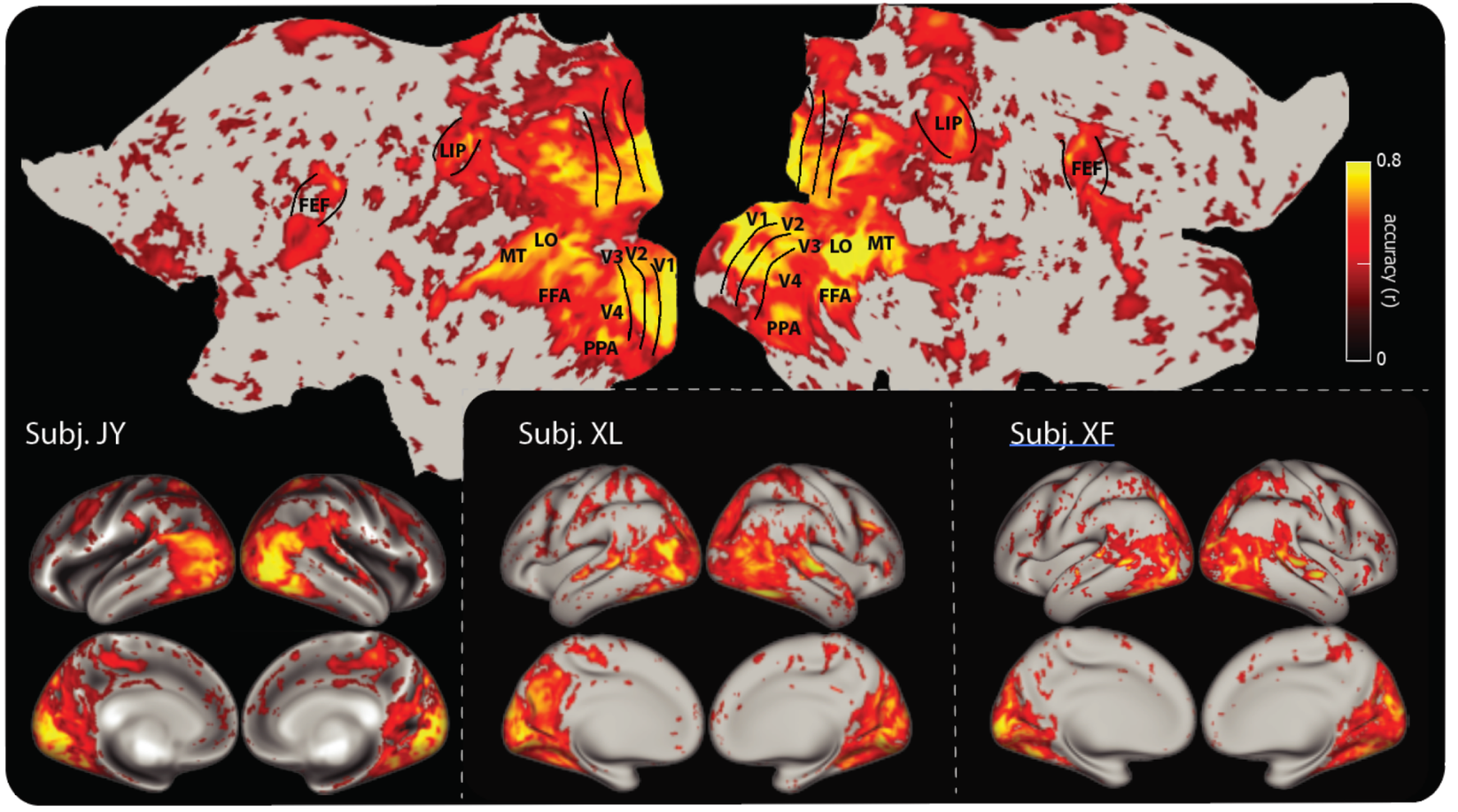


The ResNet is composed of 50 hierarhical convolutional layers for object recognition

Distributed Cortical Networks Represent Visual Object Categories

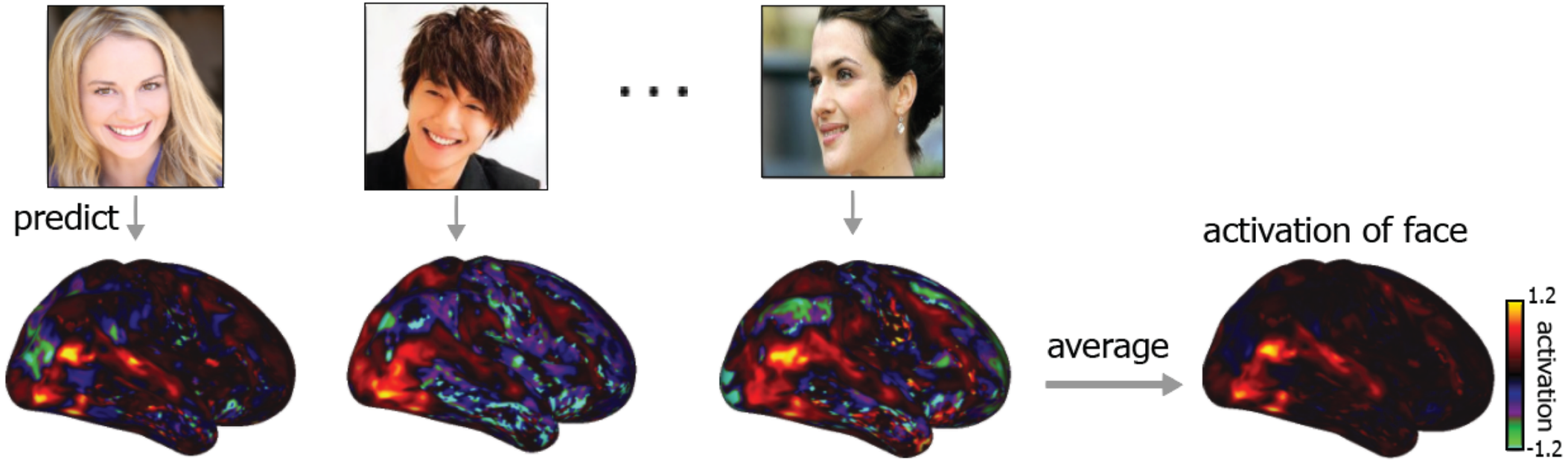
Brain Encoding Model

Encoding model predicted widespread cortical responses to natural visual stimuli



Distributed Cortical Networks Represent Visual Object Categories

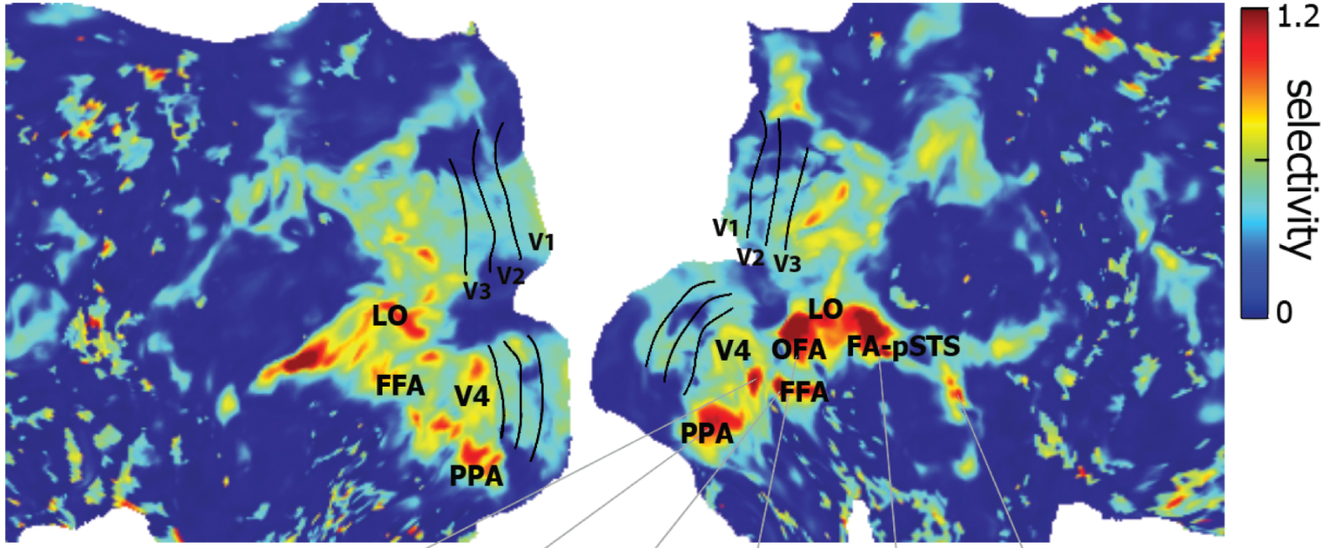
Model-Predicted Categorical Response



Distributed Cortical Networks Represent Visual Object Categories

Cortical Category-Selectivity

a. Category-selectivity



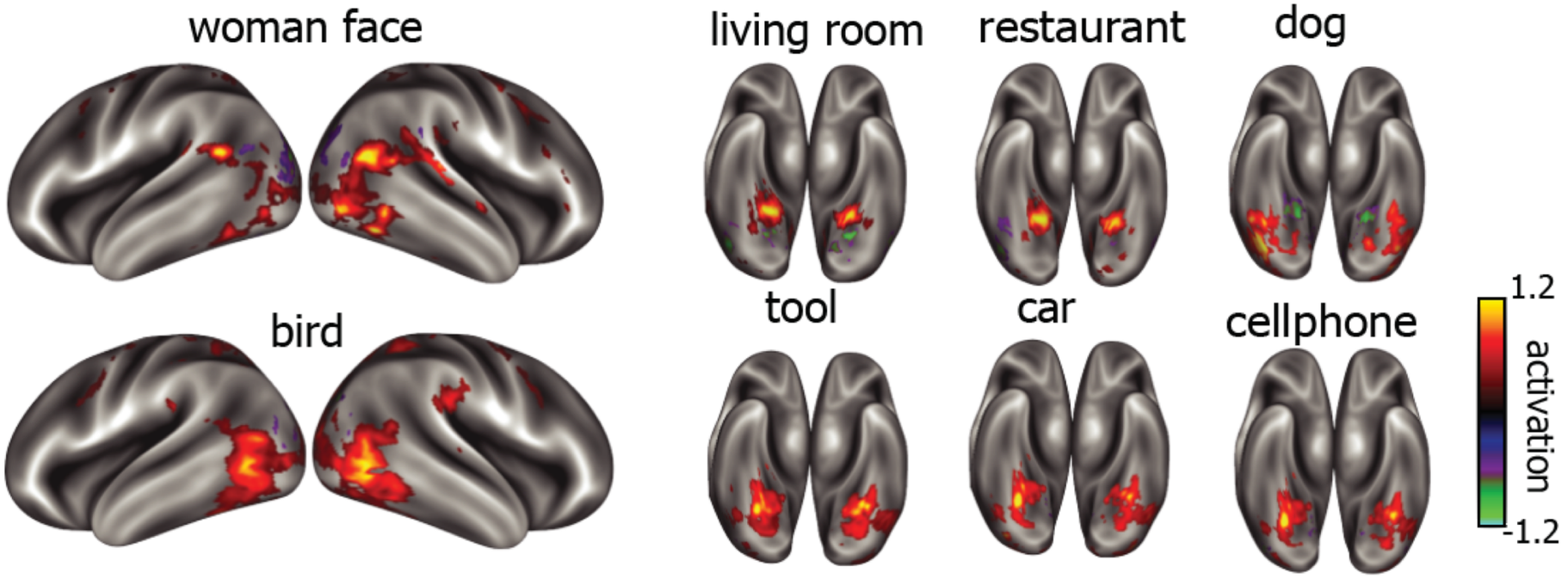
b. Top 10 categories

cellphone	kitchen	woman	monkey	woman	woman
shoe	office	man	woman	man	man
knife	livingroom	monkey	man	monkey	monkey
tool	corridor	cat	lion	dog	dog
bowl	classroom	dog	dog	lion	lion
bag	restaurant	lion	cat	cat	cup
microphone	restroom	tiger	bear	tiger	cat
car	court	bear	tiger	bear	grass
instrument	bedroom	horse	horse	horse	tiger
bus	market	sheep	chicken	chicken	classroom

1.2 activation 0

Distributed Cortical Networks Represent Visual Object Categories

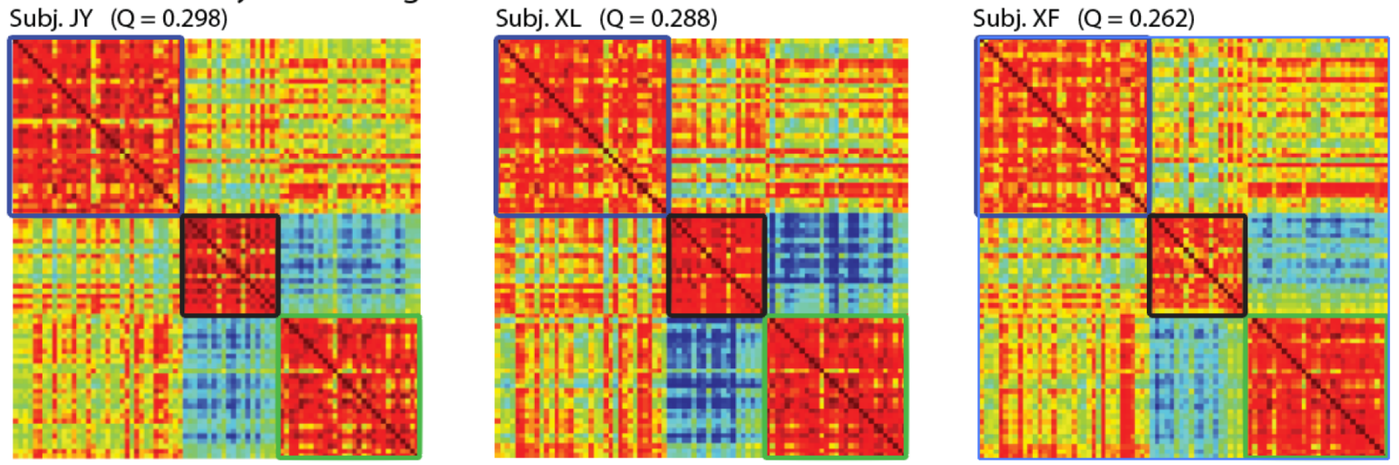
Cortical Representation of Object Category



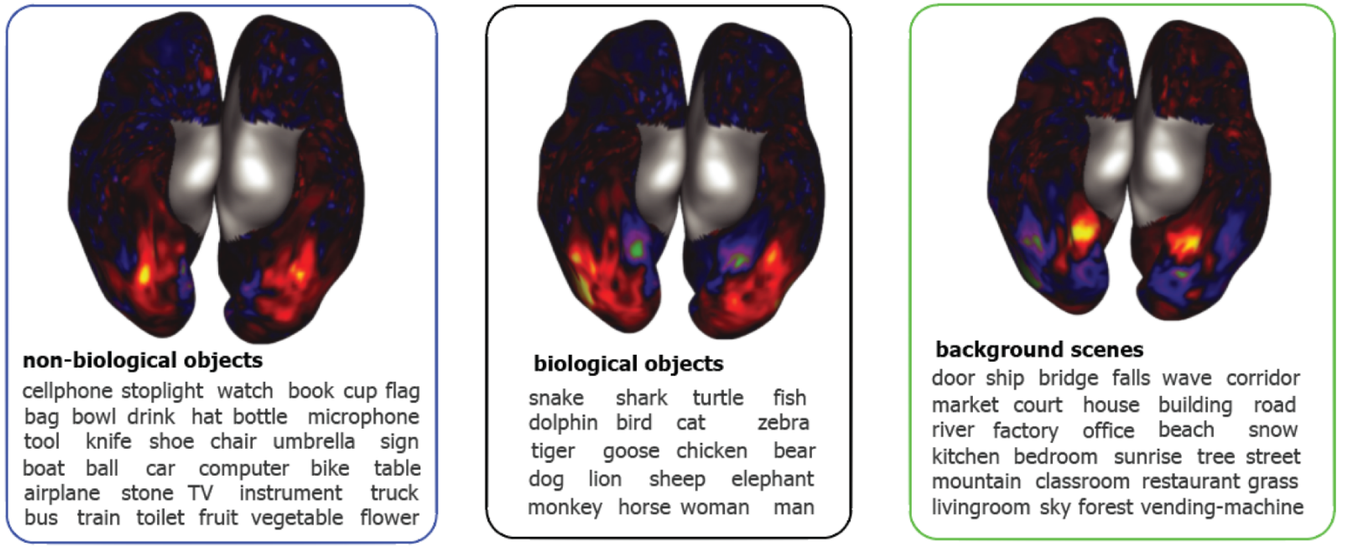
Distributed Cortical Networks Represent Visual Object Categories

Categorical Organization in the Brain

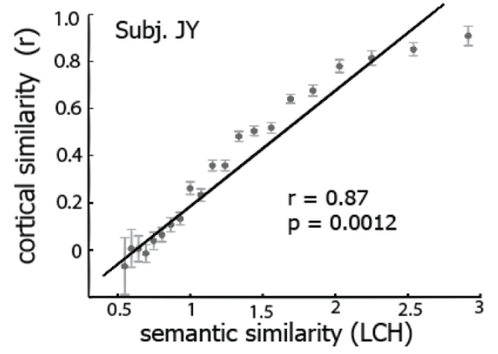
a. Cortical similarity of 84 categories



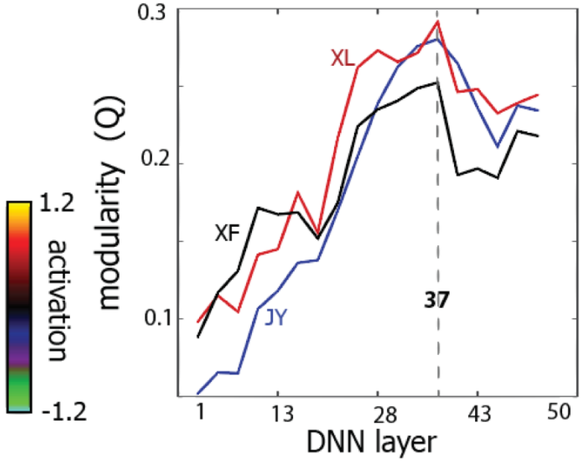
b.



c. Semantic similarity vs. cortical similarity



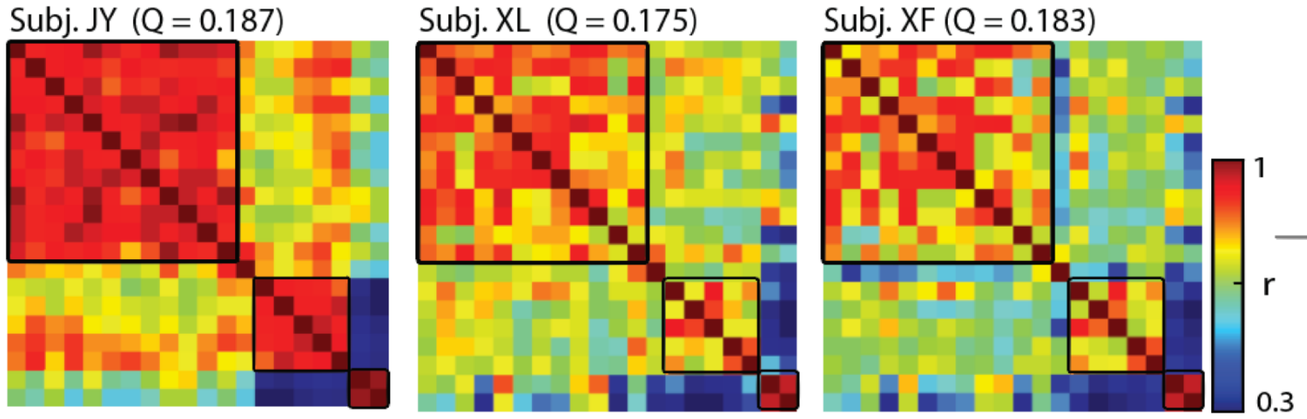
d. Layer-wise contribution to the categorical organization



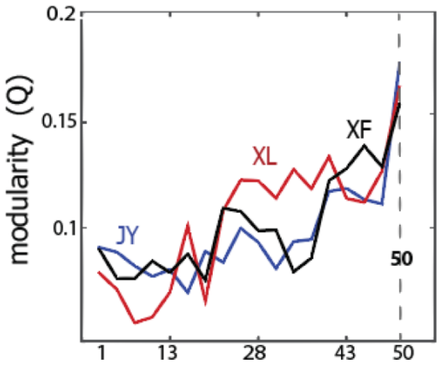
Distributed Cortical Networks Represent Visual Object Categories

Subordinate Categories in Finer Scale

a. Cortical similarity of biological objects



b. Layer-wise contribution to the subordinate category organization



Distributed Cortical Networks Represent Visual Object Categories

Discussion

Object categories are represented by distributed and overlapping cortical networks, instead of localized regions. Similar activation patterns reflect similar semantic meanings for different categories. Visual areas on the ventral pathway tended to be category selective. There are generally three characteristic network patterns representing non-biological objects, biological objects and background scenes. Subordinate object categories were modularly organized in finer scales. Interestingly, the brain processed higher-level information about visual objects for distinguishing finer level categories.