Identifying object representations in the rodent visual system

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Caltech
Vision: knowing **what** is **where** by seeing

Semantic segmentation  
Instance Segmentation

How does the brain perform object segmentation?
Integrate over spatial scales
Outline

✴ Neural responses in primates indicative of integration over visual space

✴ Diversity of models that could account for these responses

✴ Data from the rodent visual system that show these neural responses are present

✴ Modeling these responses using nonlinear neural encoding models
Spatial integration in the brain

figure/ground (V1)

border ownership (V1)
Diverse model classes can account for these responses

Source: [http://www.scholarpedia.org/article/Border-ownership_coding](http://www.scholarpedia.org/article/Border-ownership_coding)
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Which of these models best accounts for the segmentation responses observed in the visual system?

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Recording and perturbing neurons in the rodent

**Recording**
- 2-photon calcium imaging
- Electrophysiology

**Perturbation**
- Optogenetic activation/inhibition

![Image of recording and perturbation techniques]
Texture and location invariant figure behavior
Assaying figure ground and border ownership

= neuronal receptive fields
Assaying figure ground and border ownership

= neuronal receptive fields

Low response | High response
Assaying figure ground and border ownership

= neuronal receptive fields

Low response  High response
Assaying figure ground and border ownership

Figure/Ground

Low response

High response
Assaying figure ground and border ownership

**Figure/Ground**

**Border Ownership**

Low response - High response
Maps are consistent across days
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Maps are consistent across days.

Texture invariant figure/ground and border ownership signals are exceedingly rare!
While we do not find explicit, texture-invariant representations of figure ground and border-ownership in single cells.....

is it nonetheless present at the level of the neuronal population?
First approach:

Linear regression of figure location to population activity
First approach: Linear regression

- Predicted X position
- Predicted Y position
- Actual X position
- Actual Y position

$r = 0.6$

$r = 0.55$
Population information about figure location seems to be driven by feedforward inputs.
Second approach:

Model population level representations using distributed neural networks

*preliminary work
Towards distributed representations using machine learning
Towards distributed representations using machine learning

Deep Neural Network (e.g. CNN)

“DOG”
Towards distributed representations using machine learning

Deep Neural Network (e.g. CNN)

Conv-DeConv: Noh et al. 2015

Recursive Cortical Network: George et al. 2017
Towards distributed representations using machine learning

**Deep Neural Network (e.g. CNN)**

- **A** Feedforward
- **B** Horizontal propagation
- **C** Feedback

**Conv-DeConv : Noh et al. 2015**

- **A** Feedforward
- **B** Horizontal propagation
- **C** Feedback

**Recursive Cortical Network:  George et al. 2017**

- **A** Feedforward
- **B** Horizontal propagation
- **C** Feedback
An alternative goal driven approach

**The Black Box**

Linear-Nonlinear-Poisson encoding mode (LNP)

```
stim → Stimulus Filter → Nonlinearity → Poisson Spiking → response
```
An alternative goal driven approach

"The Black Box"

Linear-Nonlinear-Poisson encoding mode (LNP)

DNN + LNP

Cadena et al. 2017 *biorxiv*, Yamins et al. 2014 *PNAS*
Preliminary results

1. Fit the model to natural images

2. Test on parametric figure stimulus
DNN-LNP model has >10 million parameters

Have we gained anything?
How to interpret DNN?

Maximize a neuron’s output under some regularization constraints

Preferred textures of given layer

Novel stimuli for our model neuron

Here might be an example of a novel stimulus that is predicted to drive our neuron’s response…

Model → Experiment
Moving Forward

• Figure information is distributed across population and can be used to linearly decode figure position

• Fitting neural data to DNNs is a promising avenue for understanding population codes in the brain

• Segmentation provides a great framework for studying general neural circuit function as it involves:
  • Integration of information
  • Distributed representations
  • Generating abstract representations