Predictive cost functions in the neocortex

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HIBALL
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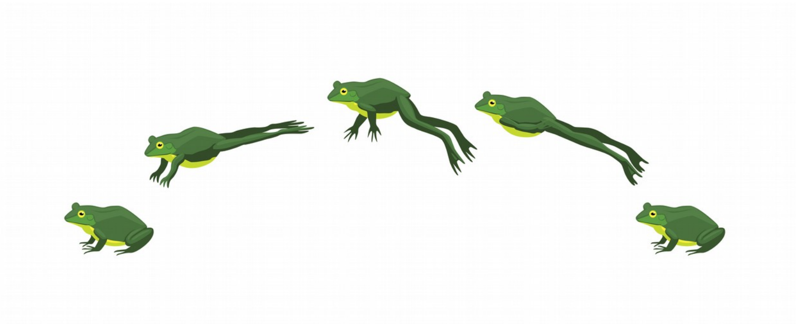
A potential general principle of intelligence:

In order to successfully predict future inputs an agent must have a model of the world that captures important latent variables, variables that will then be useful for guiding actions.

If so, learning to predict stimuli is a means of learning the structure of the world that is relevant for decision making.

Thus, agents can learn good representations in an unsupervised (or self-supervised) manner by predicting future stimuli.

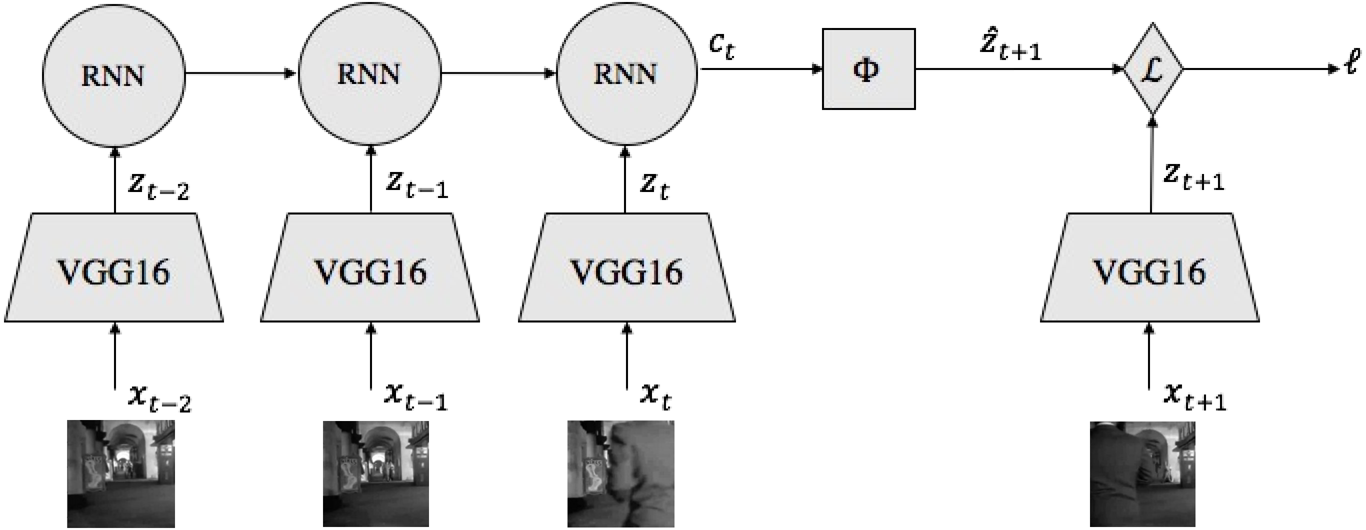


We wanted to investigate whether different regions of the mouse visual cortex may be using an unsupervised predictive cost function.

To explore this we used open 2-photon calcium data from the Allen Brain institute and ran representational similarity analyses to artificial neural networks trained in a self-supervised manner.

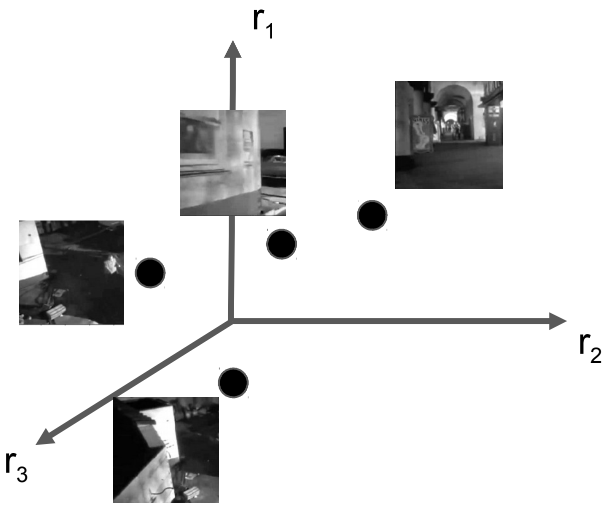
Brain mapping with the **contrastive predictive coding cost function**

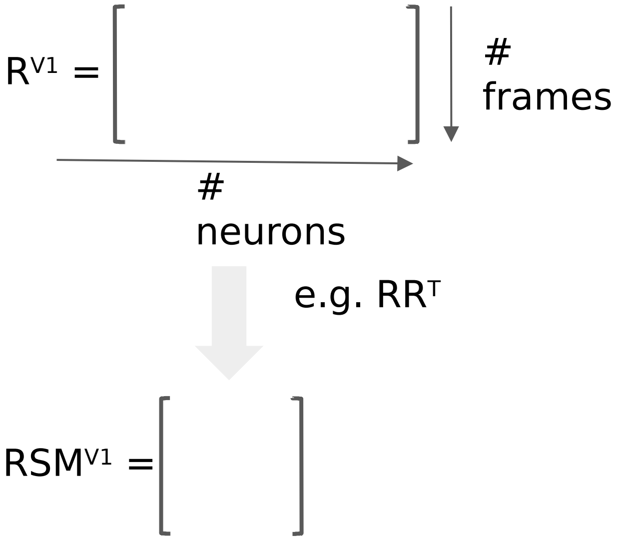
$$\mathcal{L} = -\sum_{i,k}\left[\log \frac{\exp(\hat{z}_{i,k}^{\top} \cdot z_{i,k})}{\sum_{j,m}\exp(\hat{z}_{i,k}^{\top} \cdot z_{j,m})}\right]$$

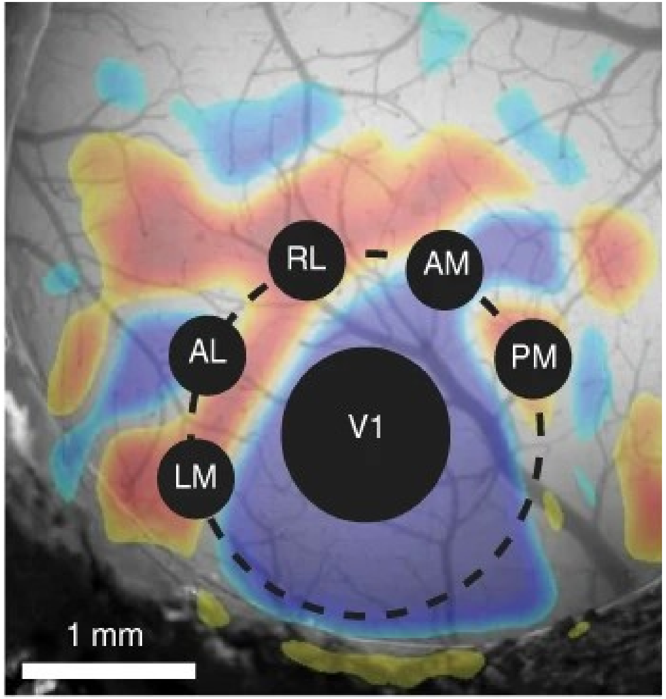


Representation Similarity Analysis

r_i : response of neuron *i*

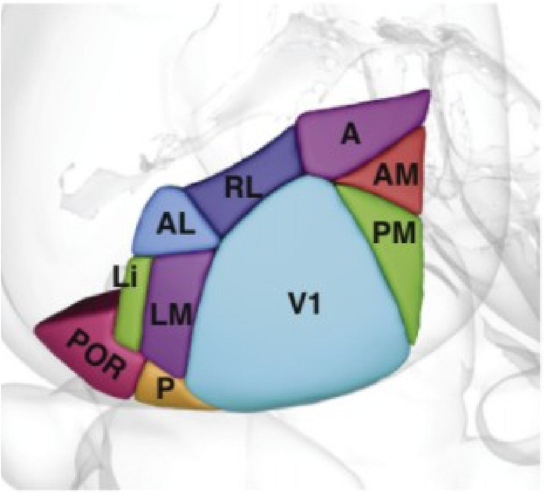


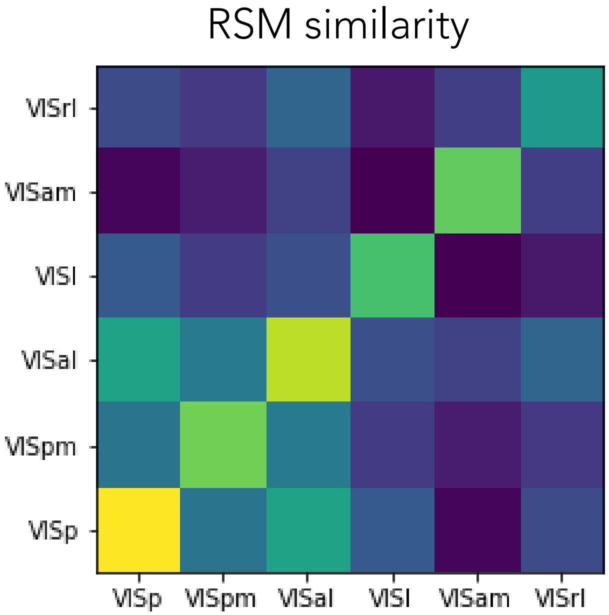


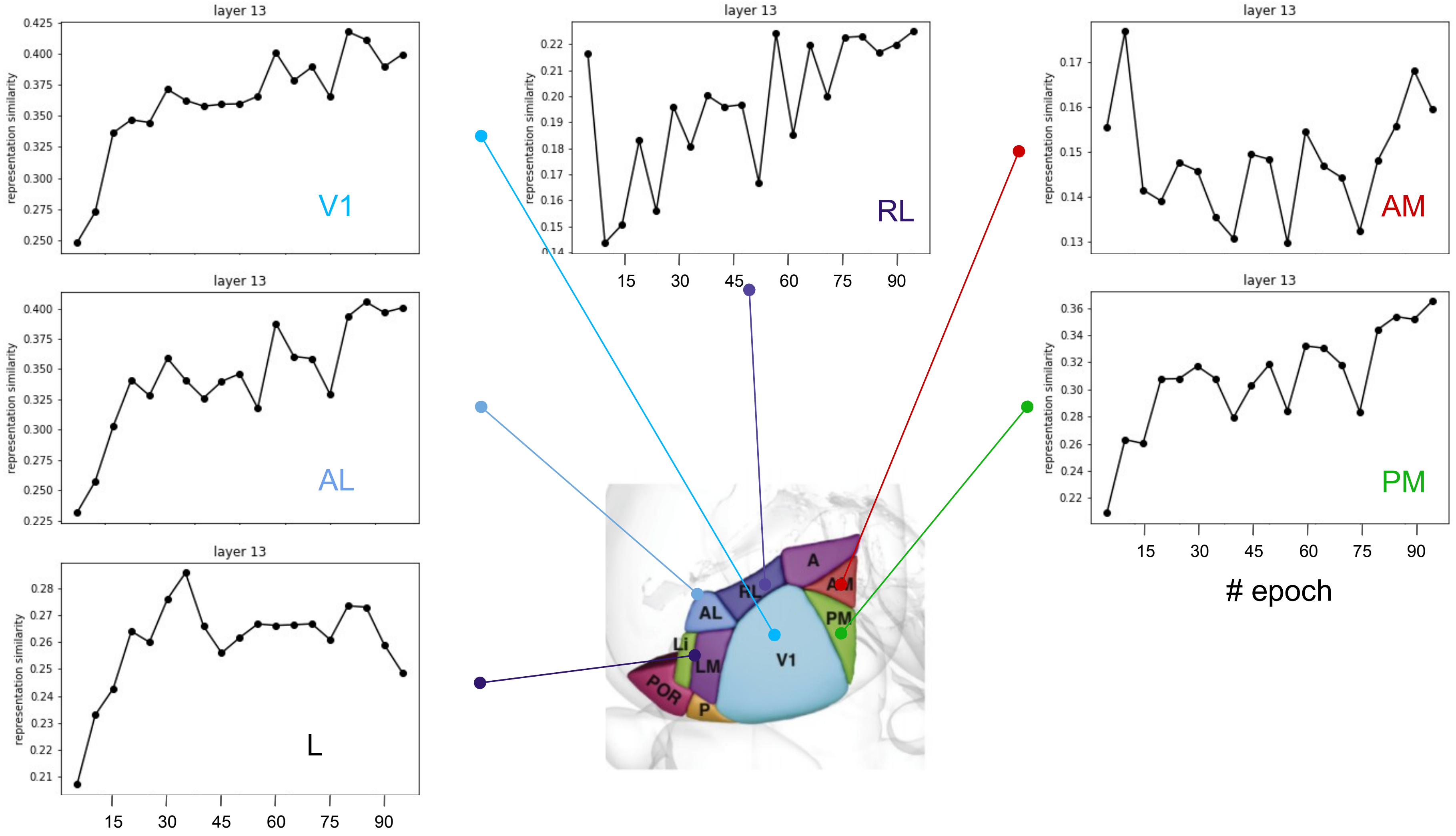


De Vries et al. (2020), *Nature Neuroscience,* 23: 138

Sanity check: brain regions map to themselves with RSM







layer 13
representation similarity
V1
AL
L
RL
AM
PM
15
30
45
60
75
90
epoch
A
RL
AM
AL
PM
Li
LM
V1
POR
P

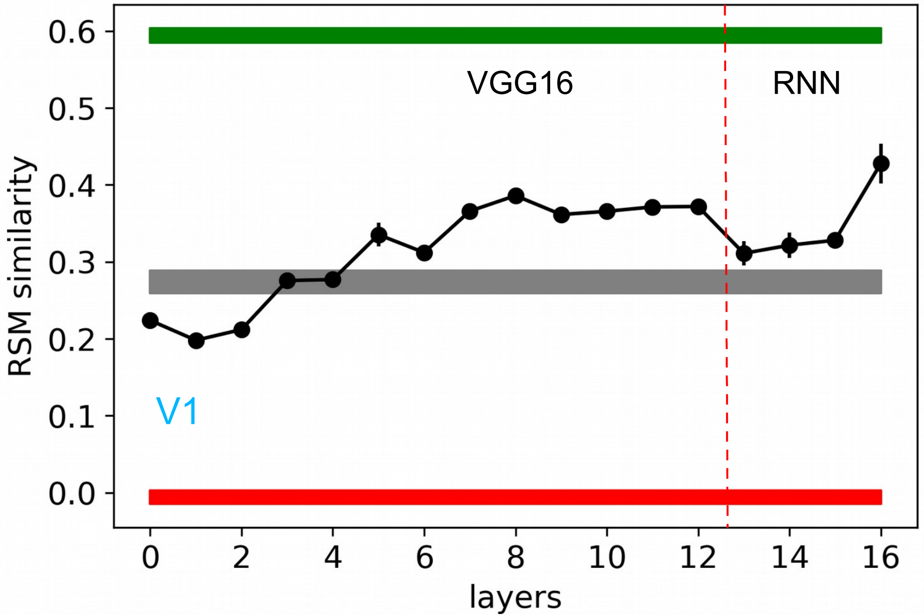
When is RSM similarity high?

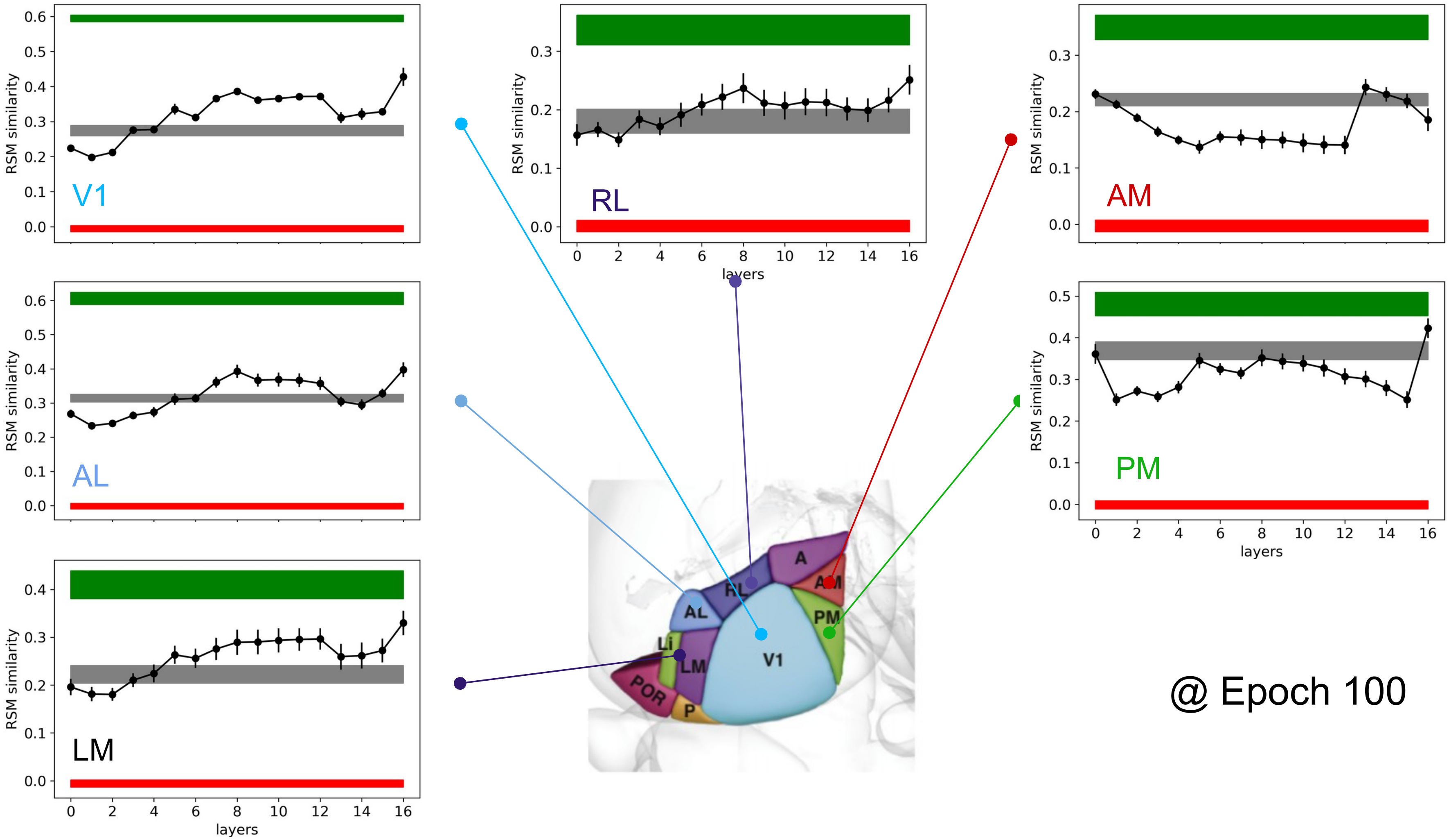
$$\text{RSM similarity} = \langle RSM^{cpc}, RSM^{V1} \rangle$$

Noise ceiling

Pixel RSM

Shuffled V1 RSM





RSM similarity
layers
V1
RL
AM
AL
PM
LM
A
Li
POR
P
@ Epoch 100

Two recent papers have similar results in macaque and human!

Unsupervised Neural Network Models of the Ventral Visual Stream

Chengxu Zhuang, Siming Yan, Aran Nayebi, Martin Schrimpf, Michael C. Frank, James J. DiCarlo, Daniel L. K. Yamins

doi: https://doi.org/10.1101/2020.06.16.155556

Instance-level contrastive learning yields human brain-like representation without category-supervision

Talia Konkle, George A. Alvarez

doi: https://doi.org/10.1101/2020.06.15.153247

Next step: use HIBALL data to do this in ANNs with <u>human-like architectures</u>

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Can we get better RSA matches to the human brain?

Can we get networks with good inductive biases for downstream RL?

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Funding:

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