Brain-Like Object Recognition with High-Performing Shallow Recurrent ANNs

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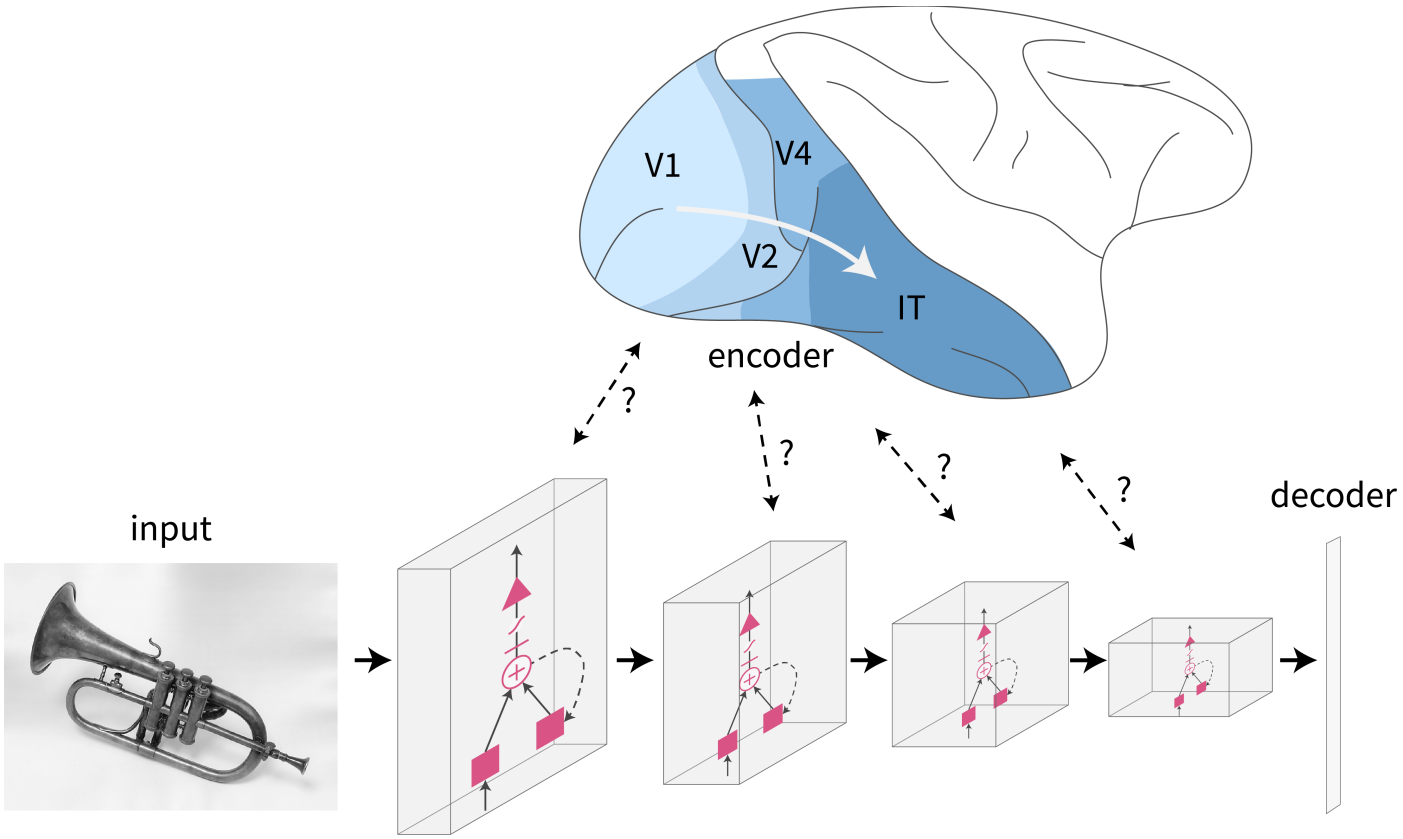
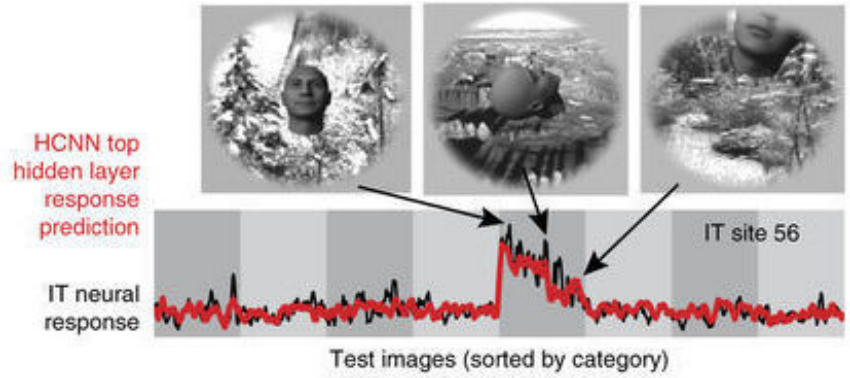
Predictive models

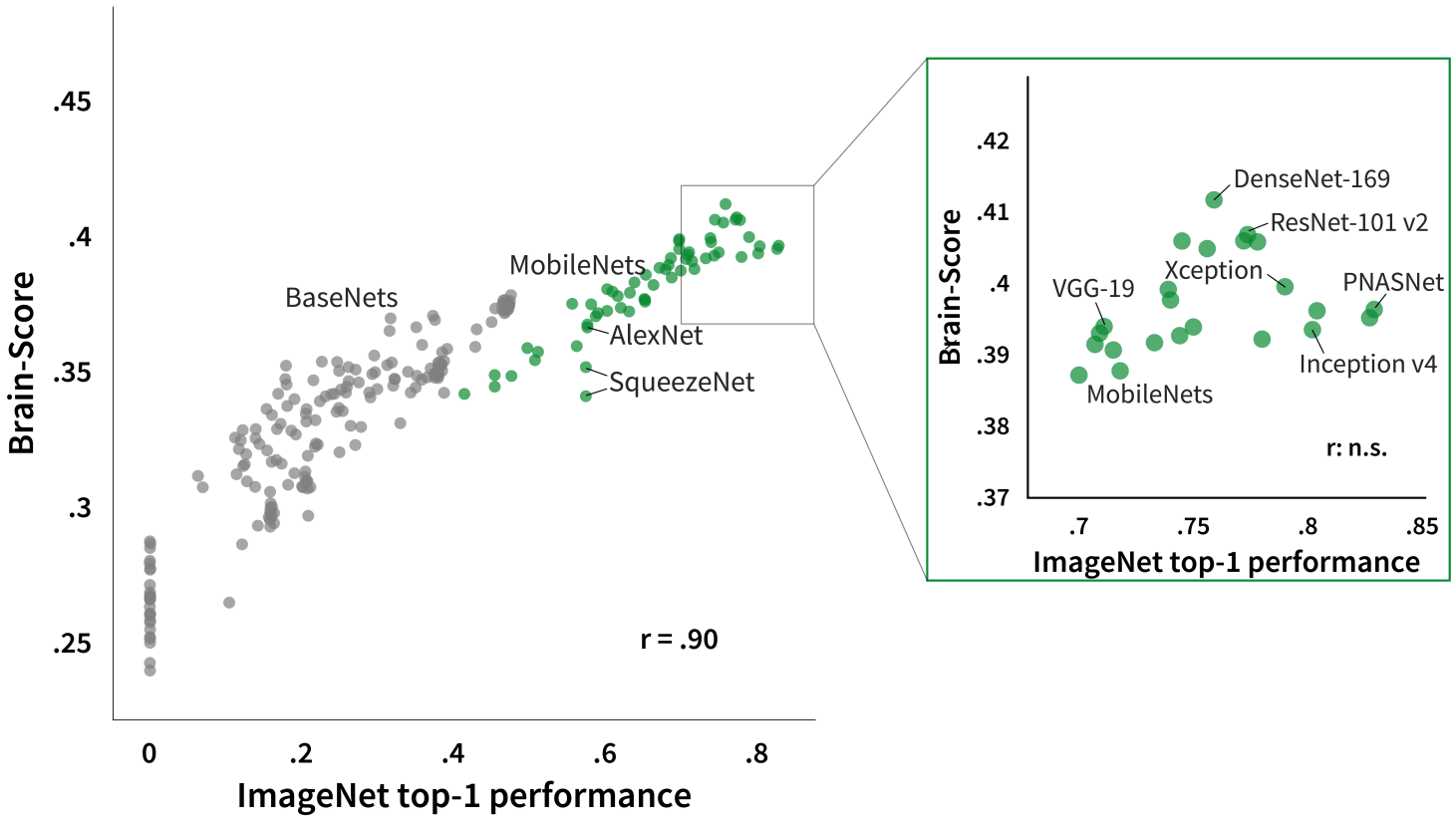


We aim to build models that predict neural and behavioral responses to visual inputs in the ventral visual stream.



Yamins, Hong*, Cadieu, Solomon, Seibert, DiCarlo (PNAS, 2013)*

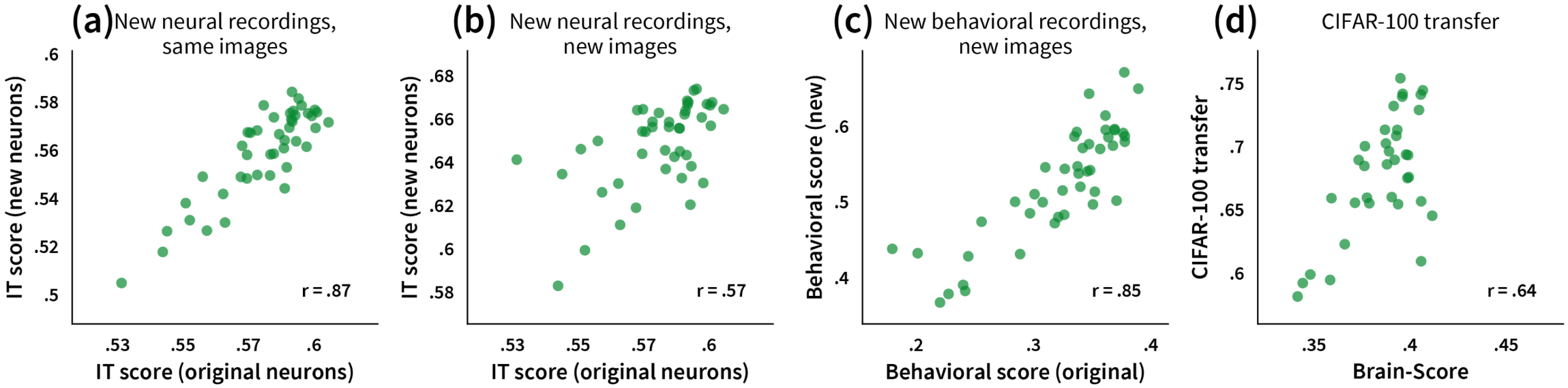
Brain-Score



In order to quantify how well current models predict brain responses, we developed Brain-Score, a framework for evaluating models on integrative brain measurements.

Top ImageNet models turn out to predict brain responses fairly well.

Brain-Score is a robust measure

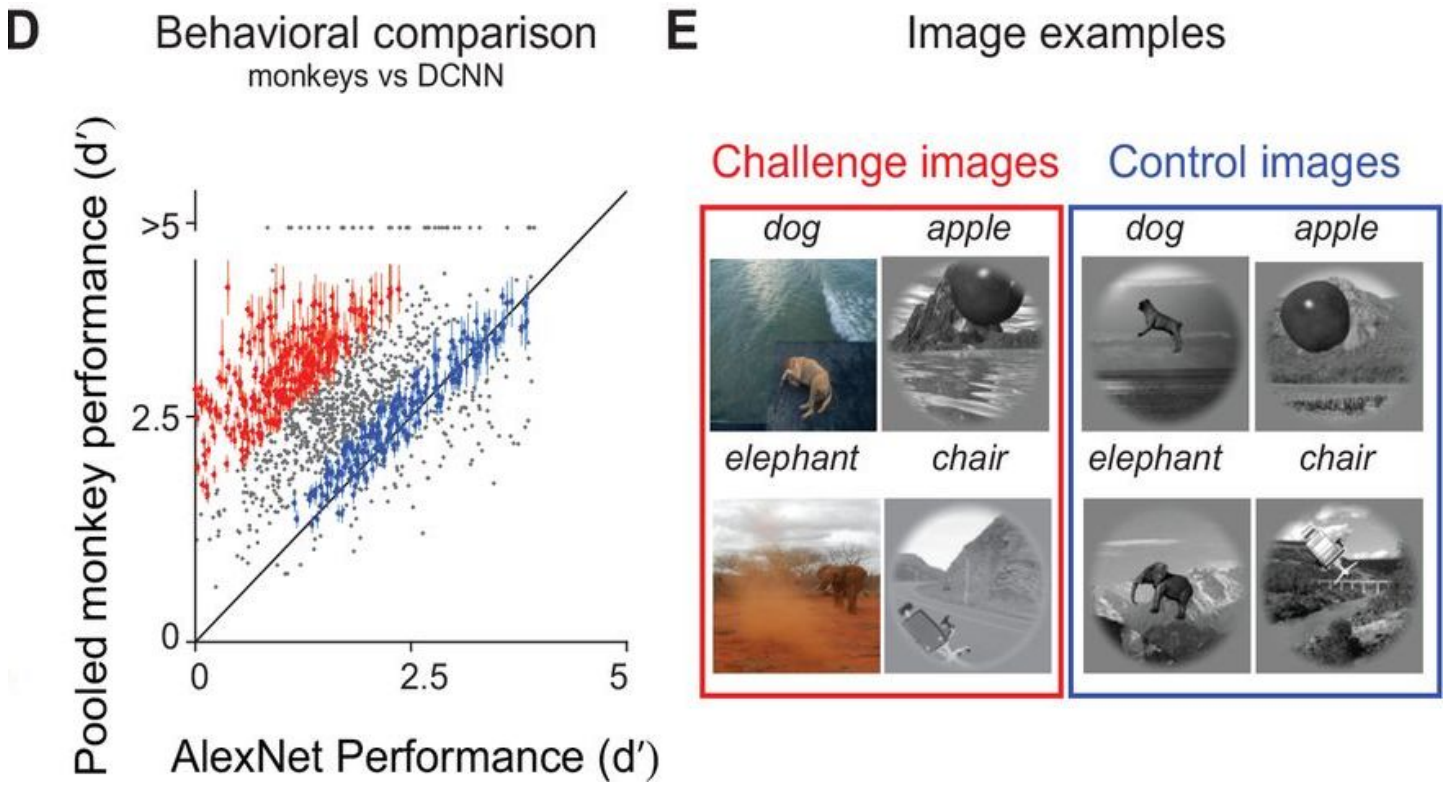


Individual scores within Brain-Score are rather robust when computed on new neurons or new datasets.

However, unlike the ventral visual stream, best Brain-Score models are feedforward and very deep.

Feedforward models suffice?

Kohitij Kar



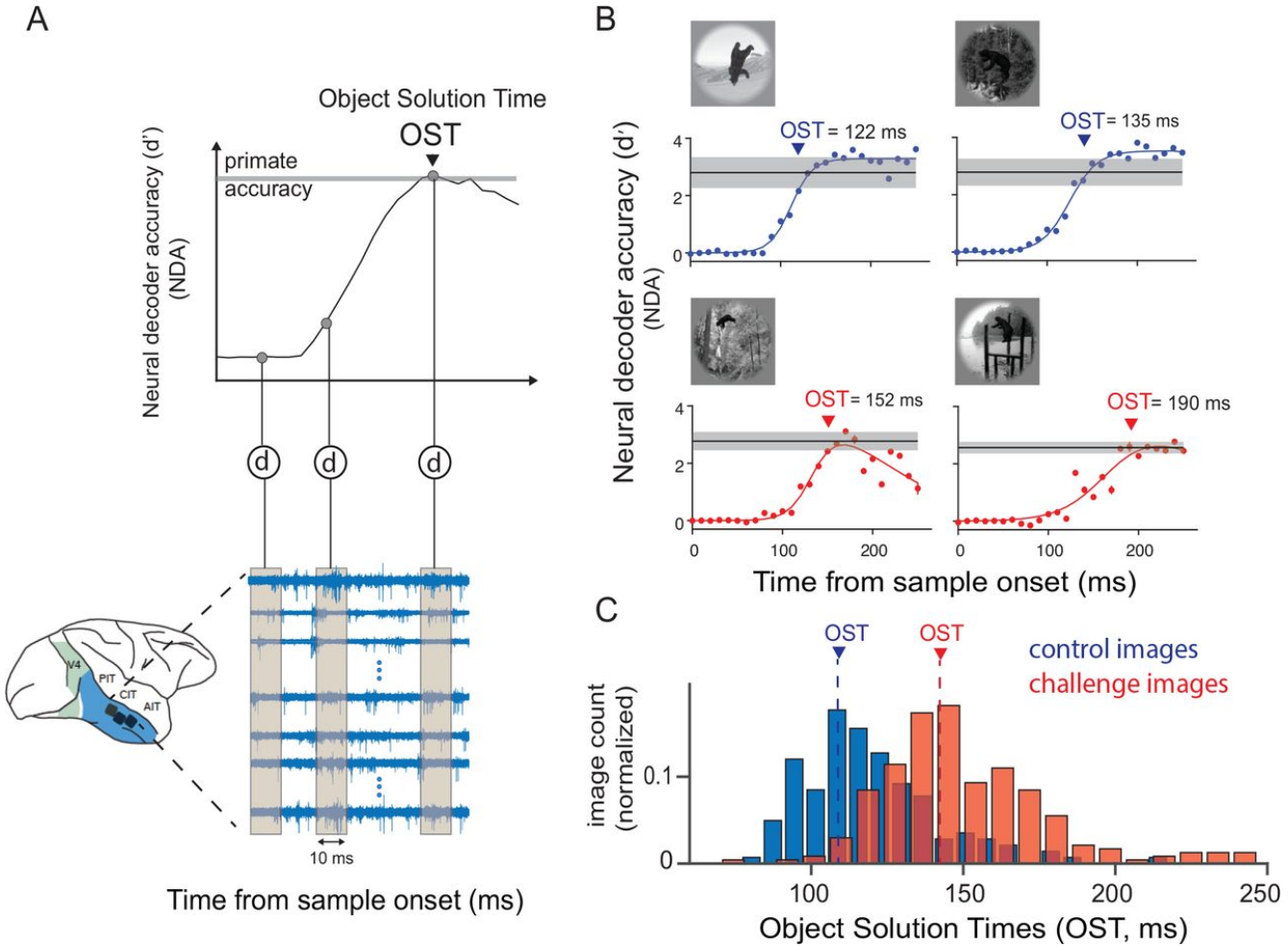
Does recurrent processing play a role in object recognition?

Let's define two sets of images:

- Images that are equally easy (or hard) for monkeys and AlexNet (control images)
- Images that are easy for monkeys but challenging for AlexNet (challenge images)

Kar, Kubilius, Schmidt, Issa, DiCarlo (Nature Neuroscience, 2019)

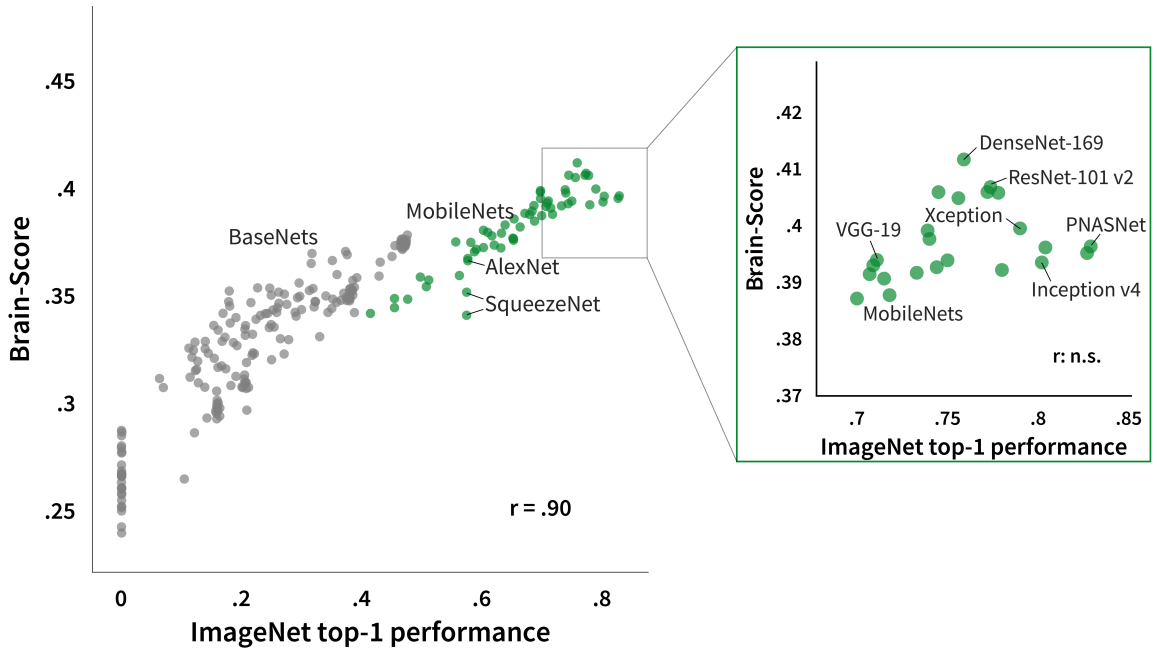
Feedforward models suffice?



Kar, Kubilius, Schmidt, Issa, DiCarlo (Nature Neuroscience, 2019)

Challenge images are solved later in primate IT cortex than control images, implying that recurrent processing is involved in object recognition.

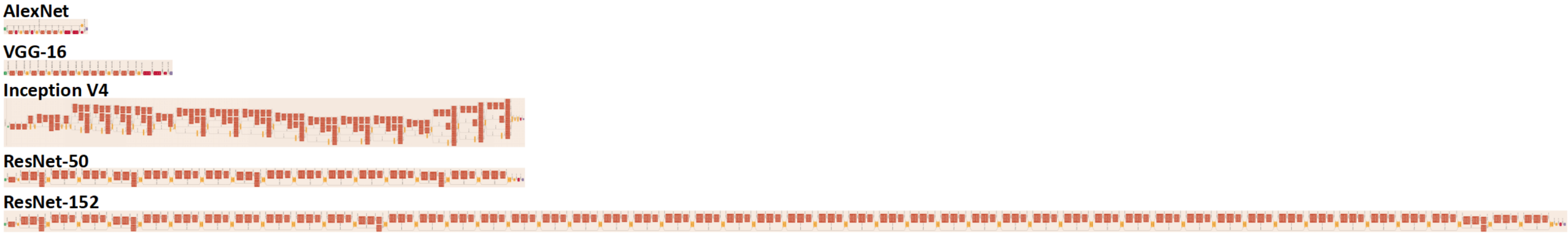
Deeper is better?



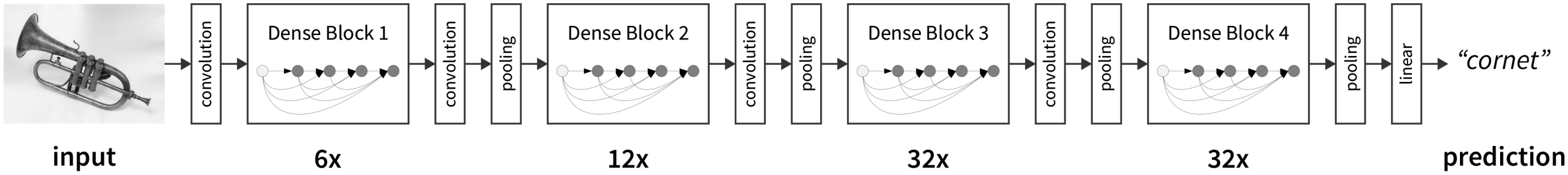
Moreover, best ImageNet and Brain-Score models are very deep.

But primate ventral visual pathway has few layers.

Could we leverage recurrence to also build shallower models?



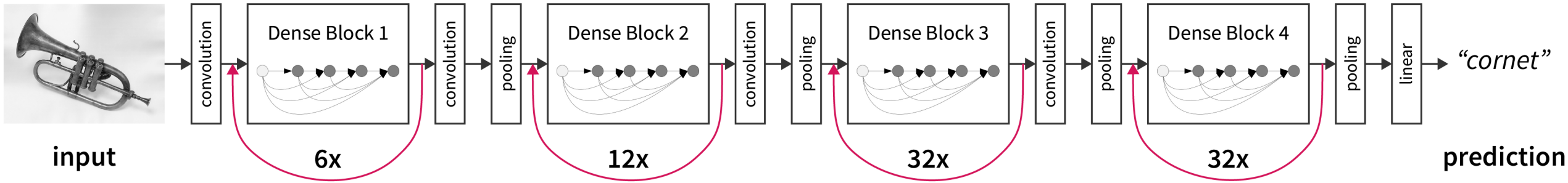
Deeper is better?



E.g., in DenseNets, Dense Blocks are repeated multiple times…

Adapted from Huang, Liu, van der Maaten, Weinberger (CVPR 2017)

Deeper is better?

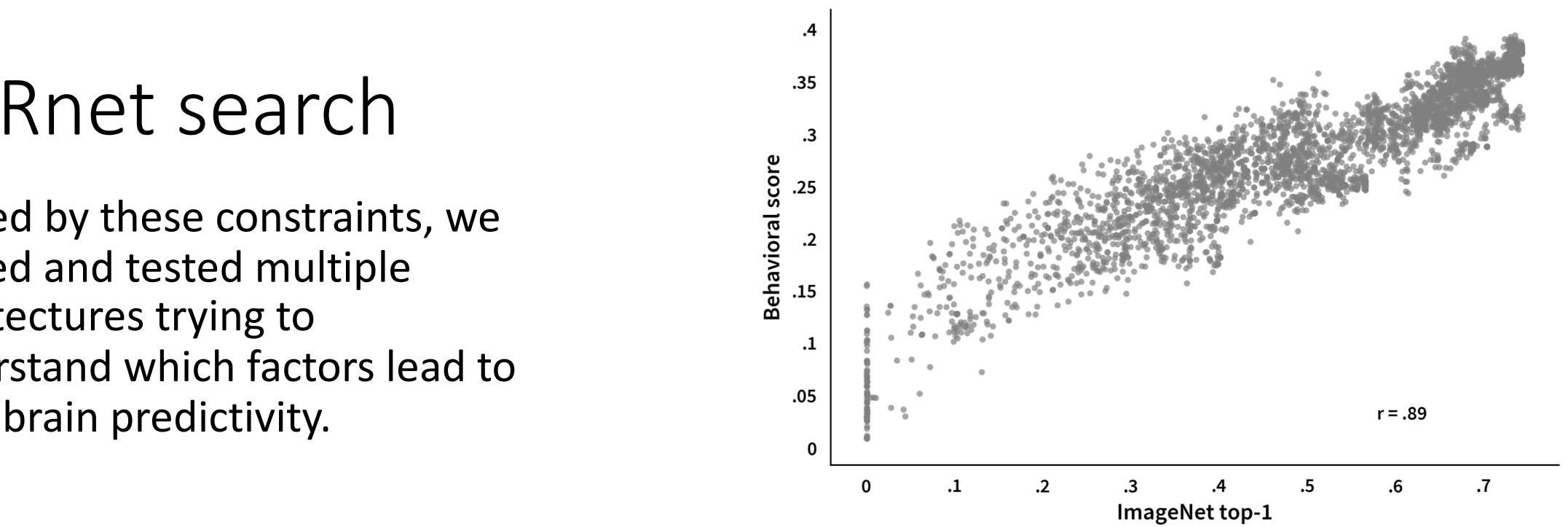


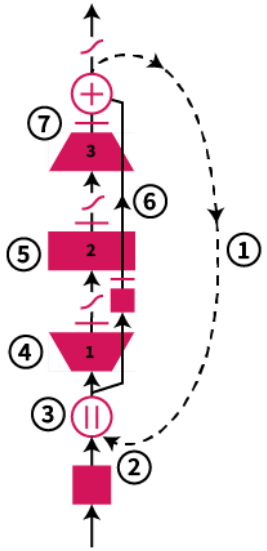
…could we perhaps reuse those blocks
by adding a feedback connection?

Adapted from Huang, Liu, van der Maaten, Weinberger (CVPR 2017)

CORnet search

Guided by these constraints, we trained and tested multiple architectures trying to understand which factors lead to good brain predictivity.





	Δ ImageNet top-1, %	Δ Brain-Score, %
① Number of recurrent steps in V2 / V4 / IT		
no recurrence (1/1/1)	-7	-3
2/2/2	-1	0
2/4/2	-	-
4/4/4	0	0
4/8/4	0	0
10/10/10	0	0
② Recurrent loop length		
from 3 to 1	-	-
from 3 to 2	-2	0

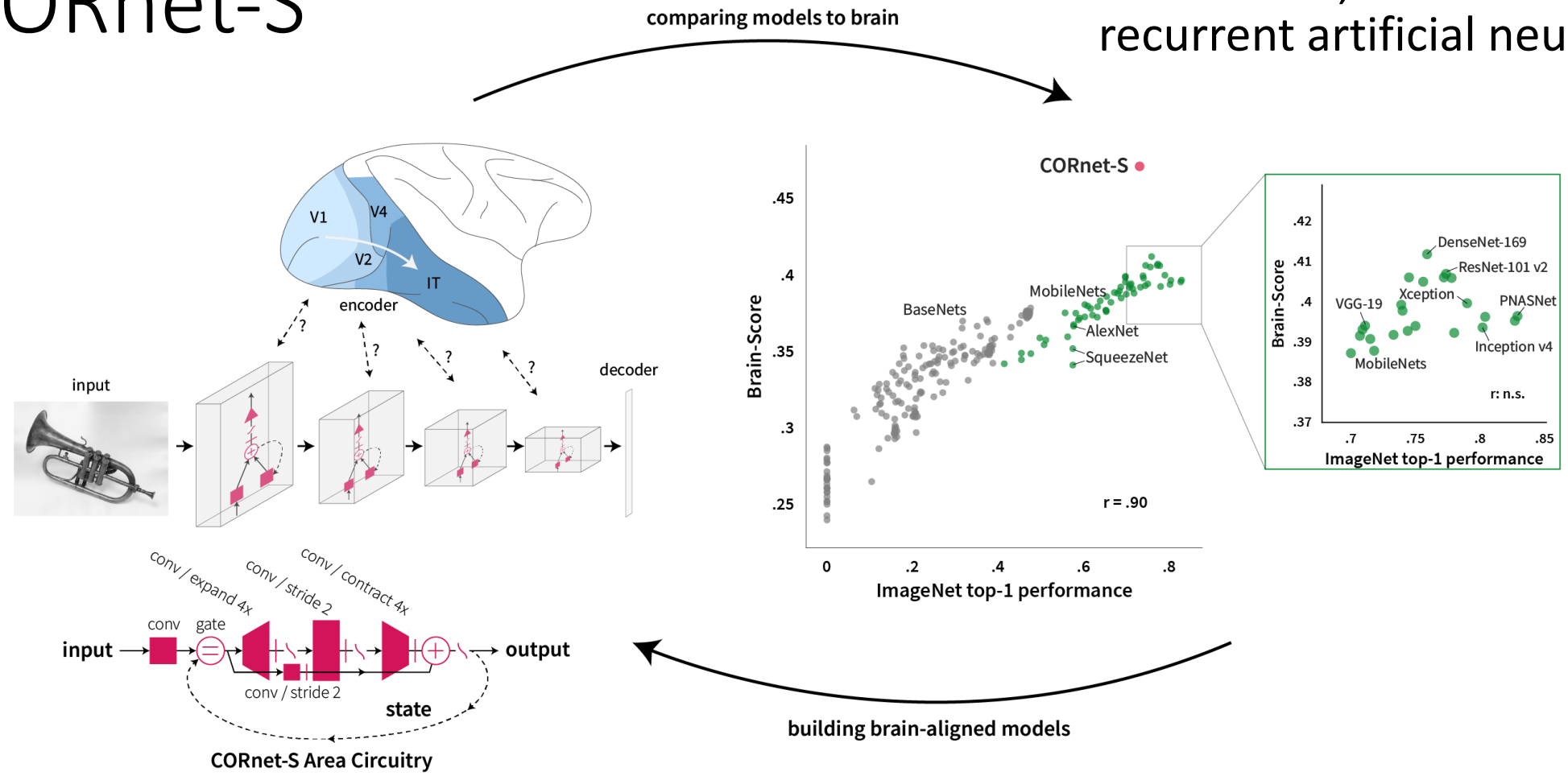
	Δ ImageNet top-1, %	Δ Brain-Score, %
③ Gating		
hard gate: input blocked at t > 0	-	-
soft gate: *sigmoid*(input + state)	0	0
④ Bottleneck size		
1x	-8	-1
2x	-4	-1
4x	-	-
6x	+1	0
⑤ Convolutional layers		
2nd and 3rd	-3	0
1st, 2nd, and 3rd	-	-

	Δ ImageNet top-1, %	Δ Brain-Score, %
⑥ Skip connection		
present	-	-
absent	-2	-1
⑦ Normalization		
Batch Normalization	-	-
Group Normalization	-1	0
Number of model areas		
4	-	-
5	-1	0

We found that even for predicting responses to static images, having recurrent and skip connections, as well as a large bottleneck leads to best Brain-Score.

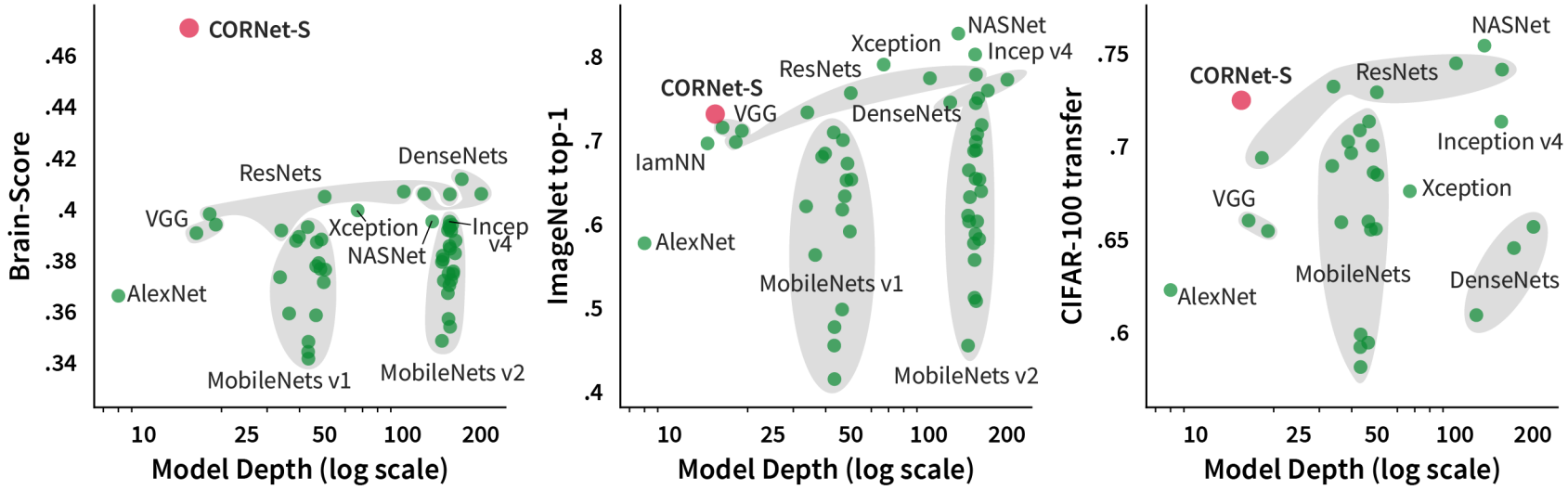
CORnet-S

Our current best Brain-Score model is CORnet-S, a ResNet-like shallow recurrent artificial neural network.



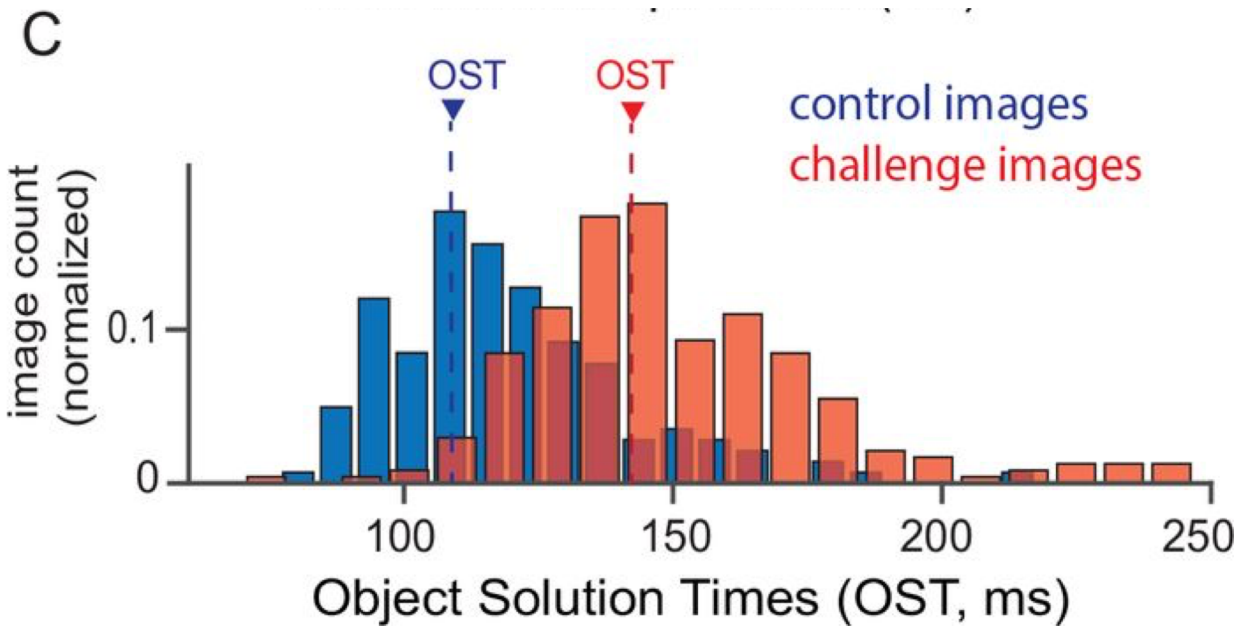
CORnet-S is composed of four blocks corresponding to visual areas V1, V2, V4, and IT.

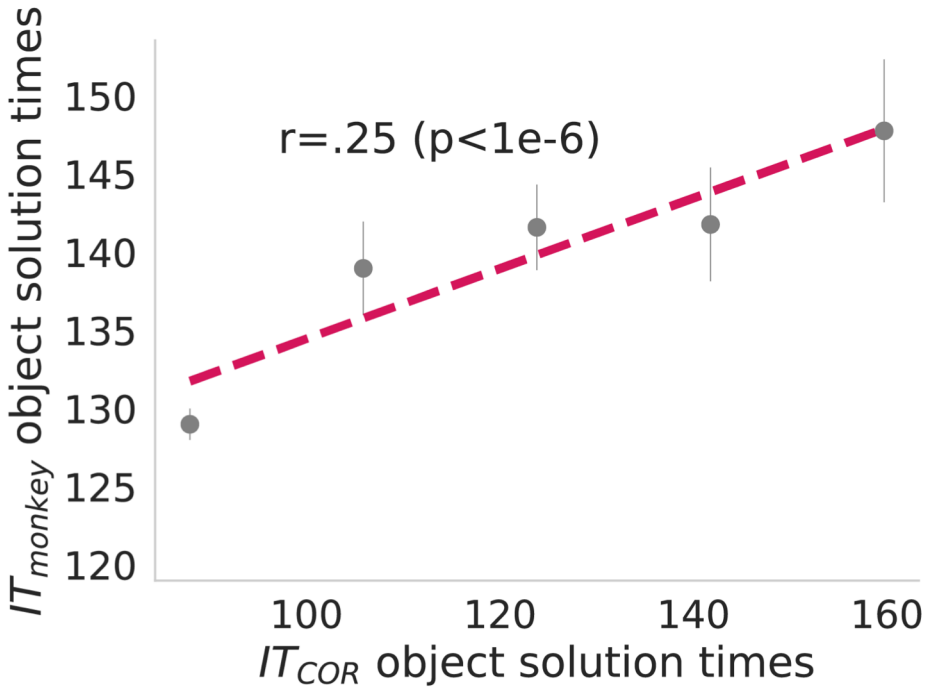
Generalization



CORnet-S is shallower than most other models yet has a compelling ImageNet performance and shows the best transfer to CIFAR-100 performance among similarly shallow models.

Object Solution Times





Unlike feedforward models, CORnet-S can predict neural responses over time.

Kar, Kubilius, Schmidt, Issa, DiCarlo (Nature Neuroscience, 2019)

Thank you!

Code / figures:
github.com/dicarlolab/neurips2019

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