System Models of Brain-Like Vision & Language

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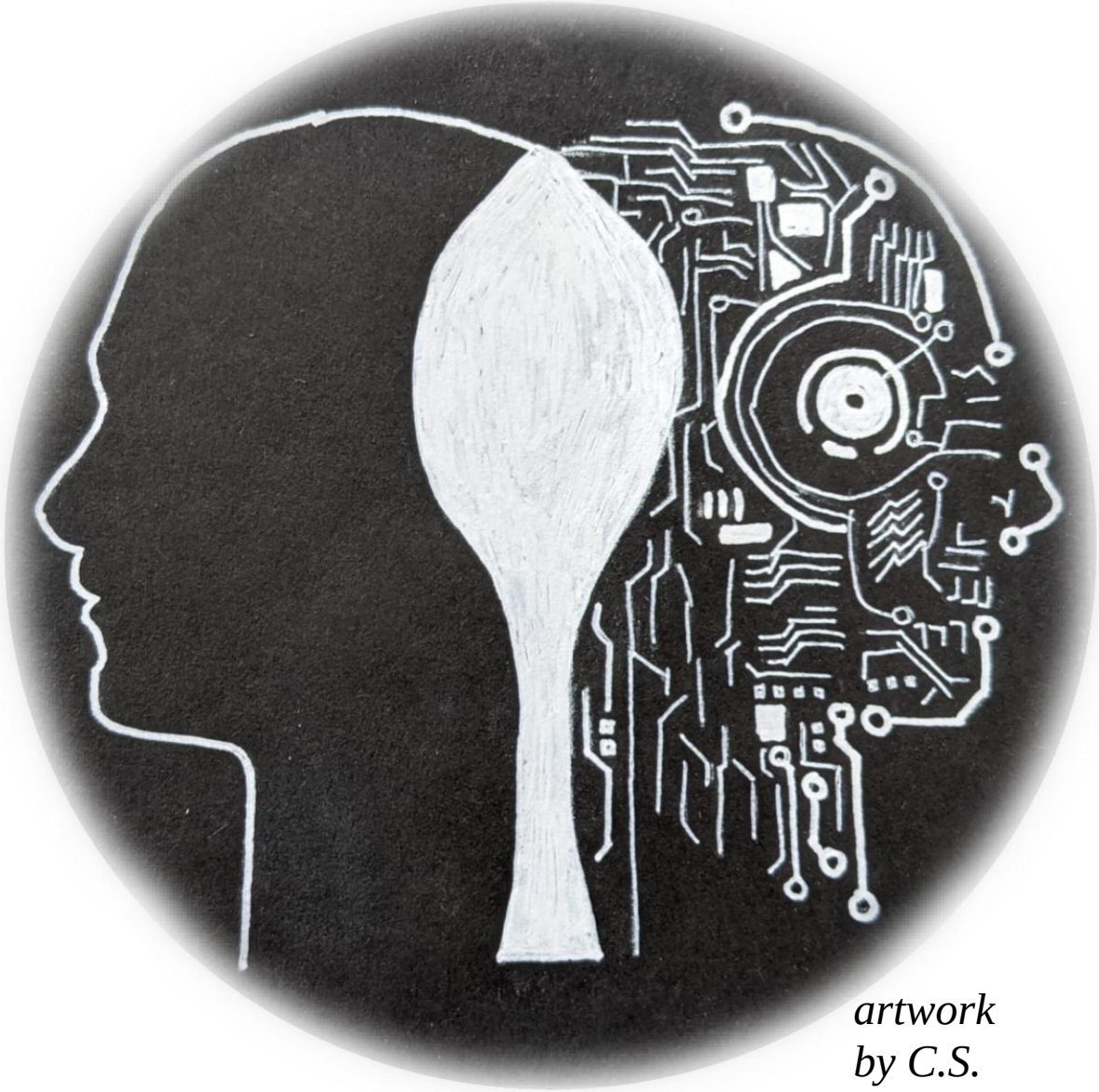

artwork by C.S.

MIT Quest for Intelligence

MIT → EPFL


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Kailyn Schmidt


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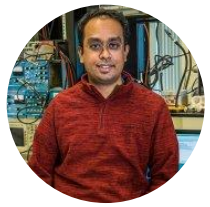
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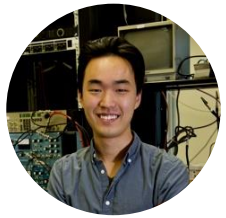
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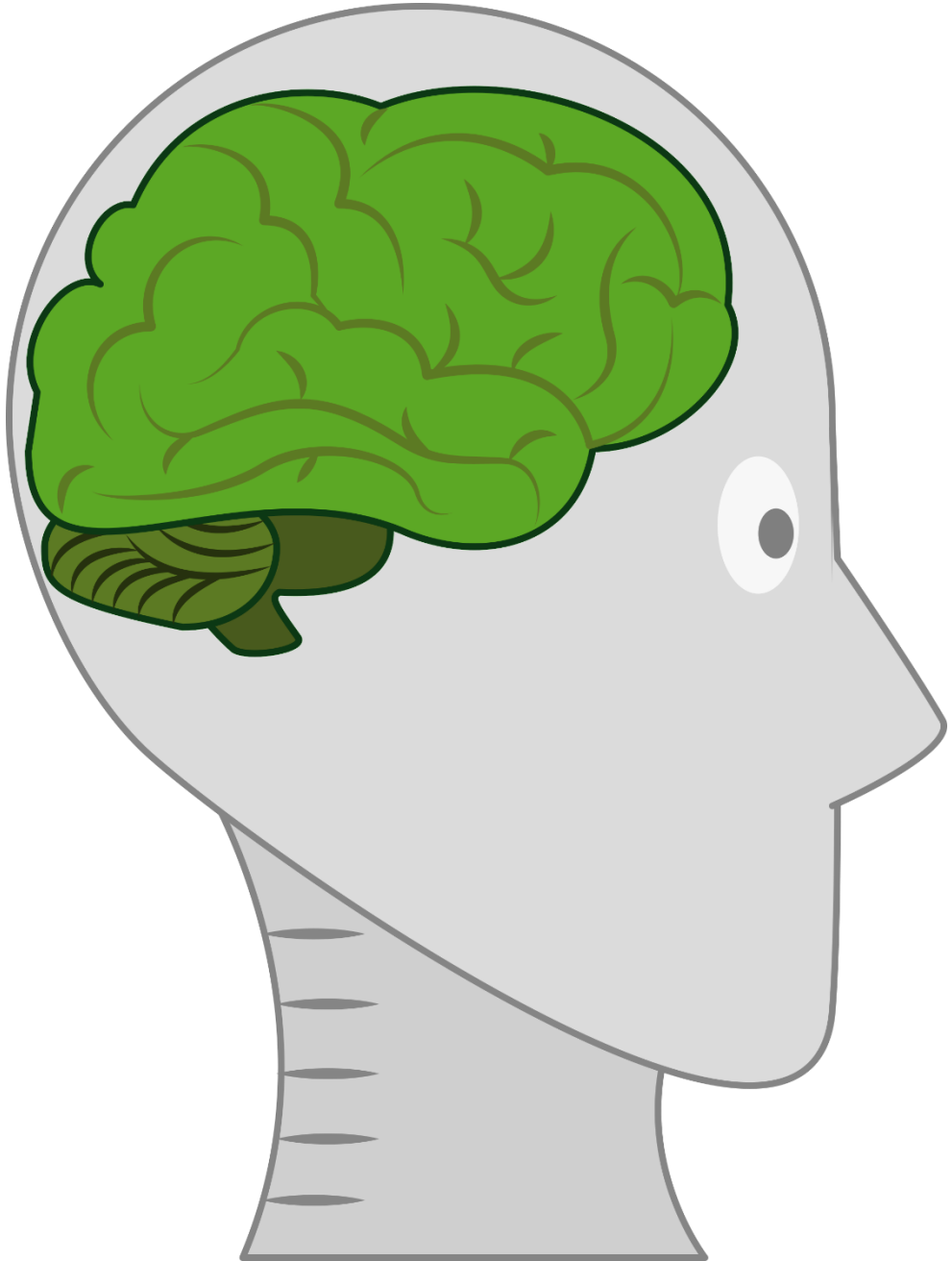
Funding: brain+cognitive sciences, McGovern Institute for Brain Research, Takeda, C-BRIC Center for Brain-Inspired Computing, MIT Quest for Intelligence



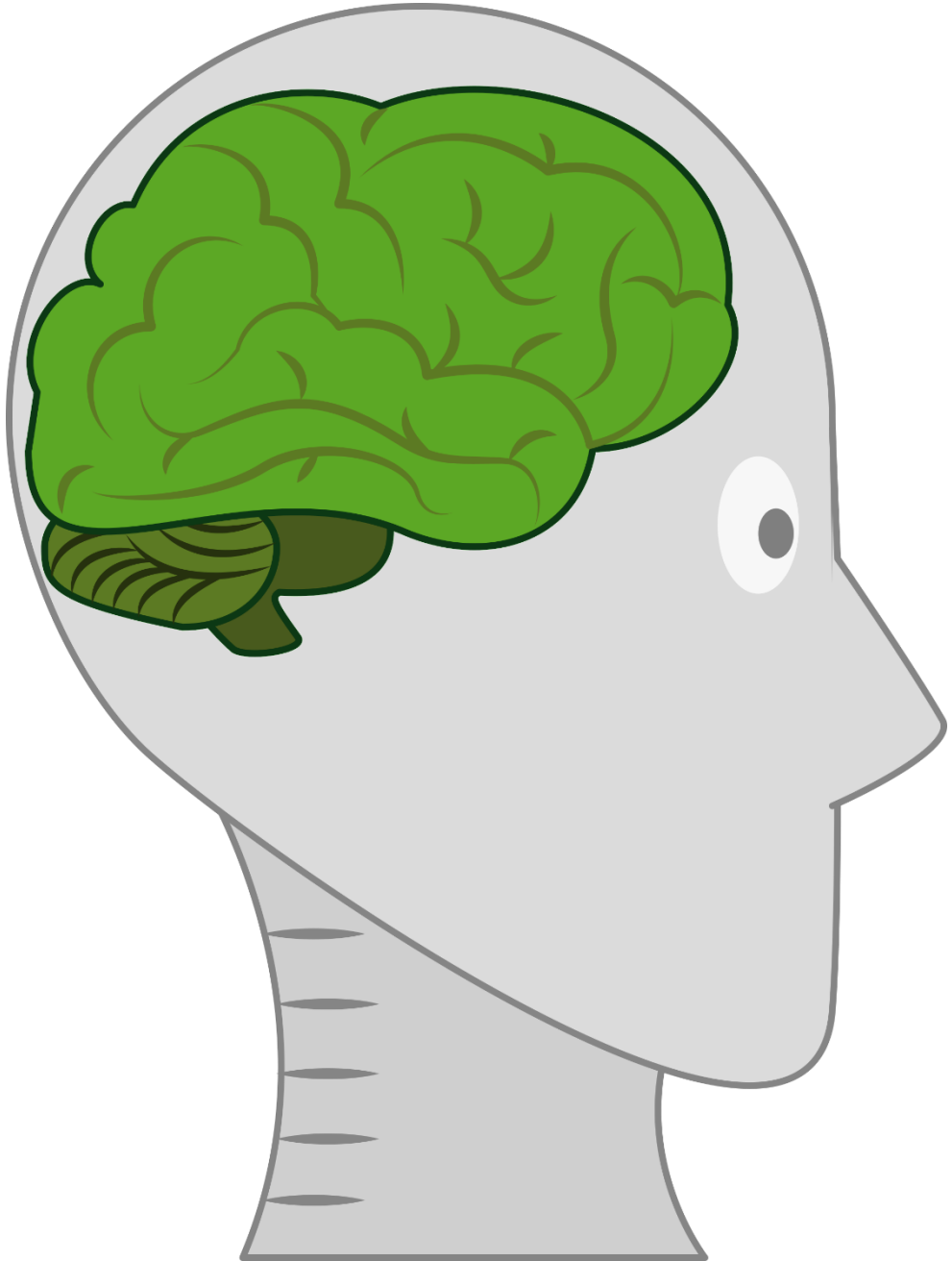
A core goal of our field:

model human intelligence and underlying neural mechanisms

Computational understanding of natural intelligence

Next-generation AI algorithms

Future clinical applications



A core goal of our field:
model human intelligence and underlying neural mechanisms

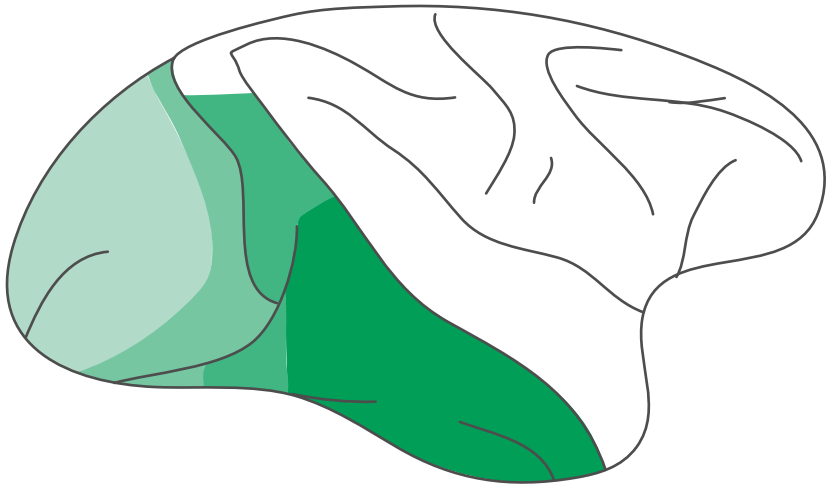
How can we even tell we're making progress?

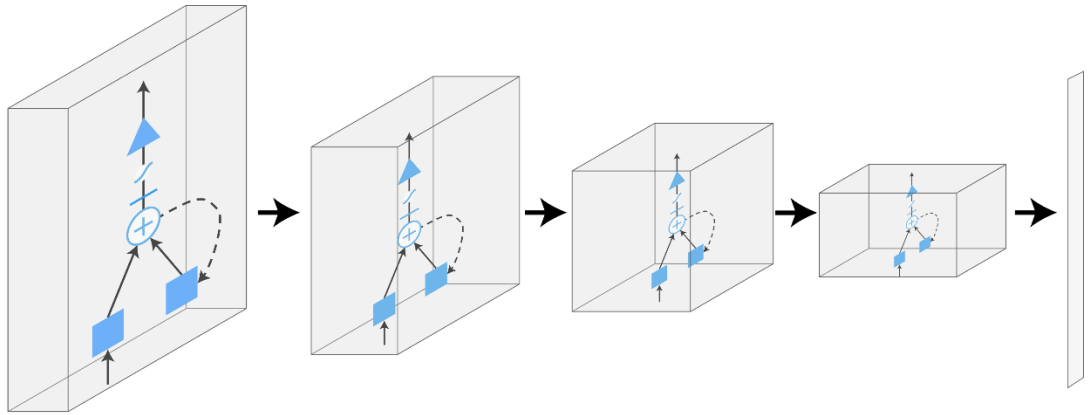
This talk: a proposal for <u>integrative model testing</u> in vision & language

Modeling Primate Visual Intelligence

Evaluate model **alignment to <u>all</u> experiments** in the domain of visual intelligence.

The alternative of **evaluating isolated models on isolated data is horribly inefficient**





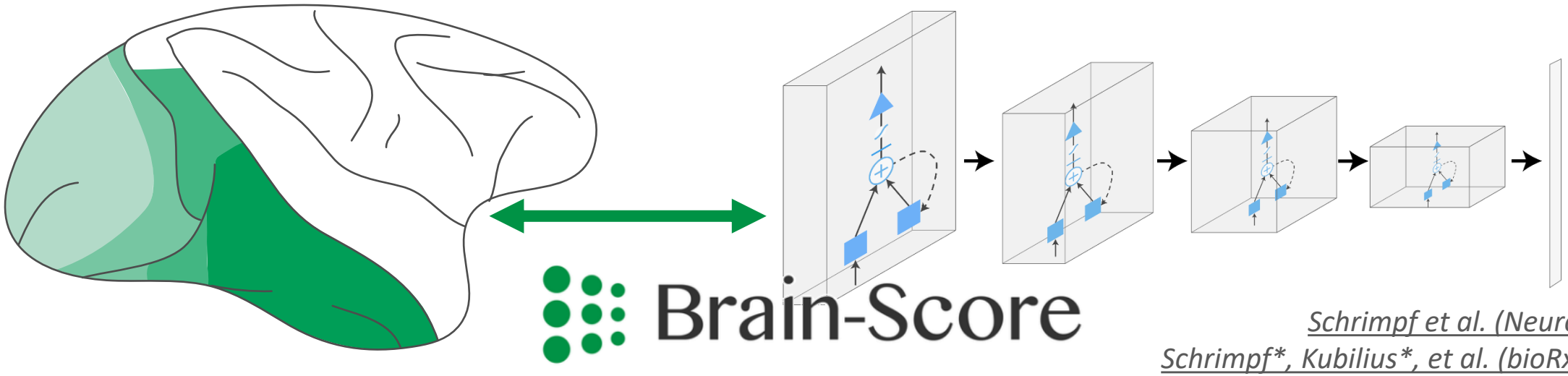
Schrimpf et al. (Neuron 2020)
Schrimpf, Kubilius*, et al. (bioRxiv 2018)*

Modeling Primate Visual Intelligence

Evaluate model **alignment to all experiments** in the domain of visual intelligence.

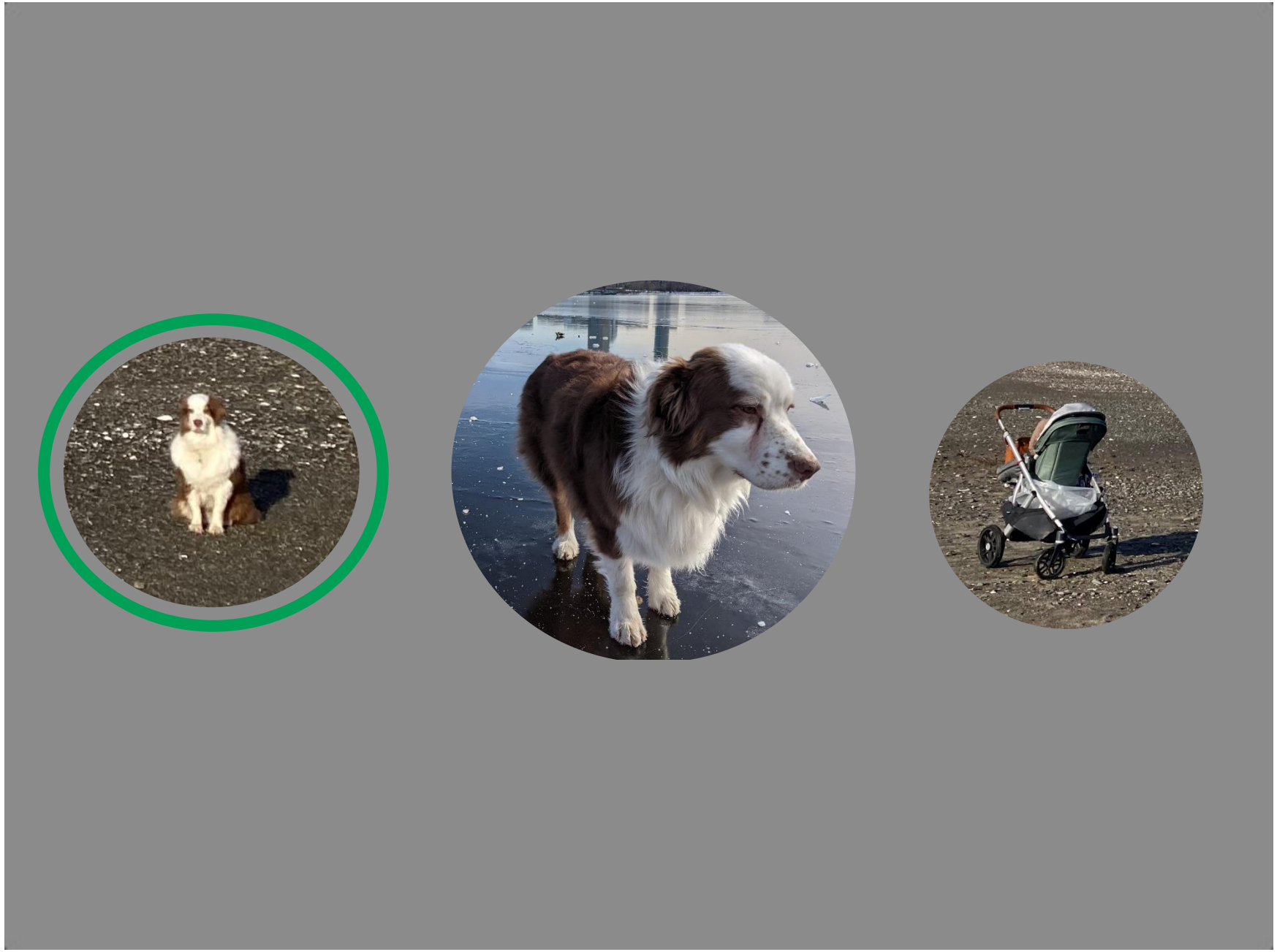
- Test <u>behavioral alignment</u> by showing the **same images** to humans and models and comparing their outputs

- Test <u>neural alignment</u> at the level of **spike rates** since they linearly predict visual behaviors *(*e.g. *Majaj*, Hong*, et al. 2015; I Gusti Bagus et al. 2022).* Include **non-human primates** since their visual behaviors and visual cortex are highly similar to humans (e.g. *Kriegeskorte et al. 2008; Rajalingham et al. 2018*)



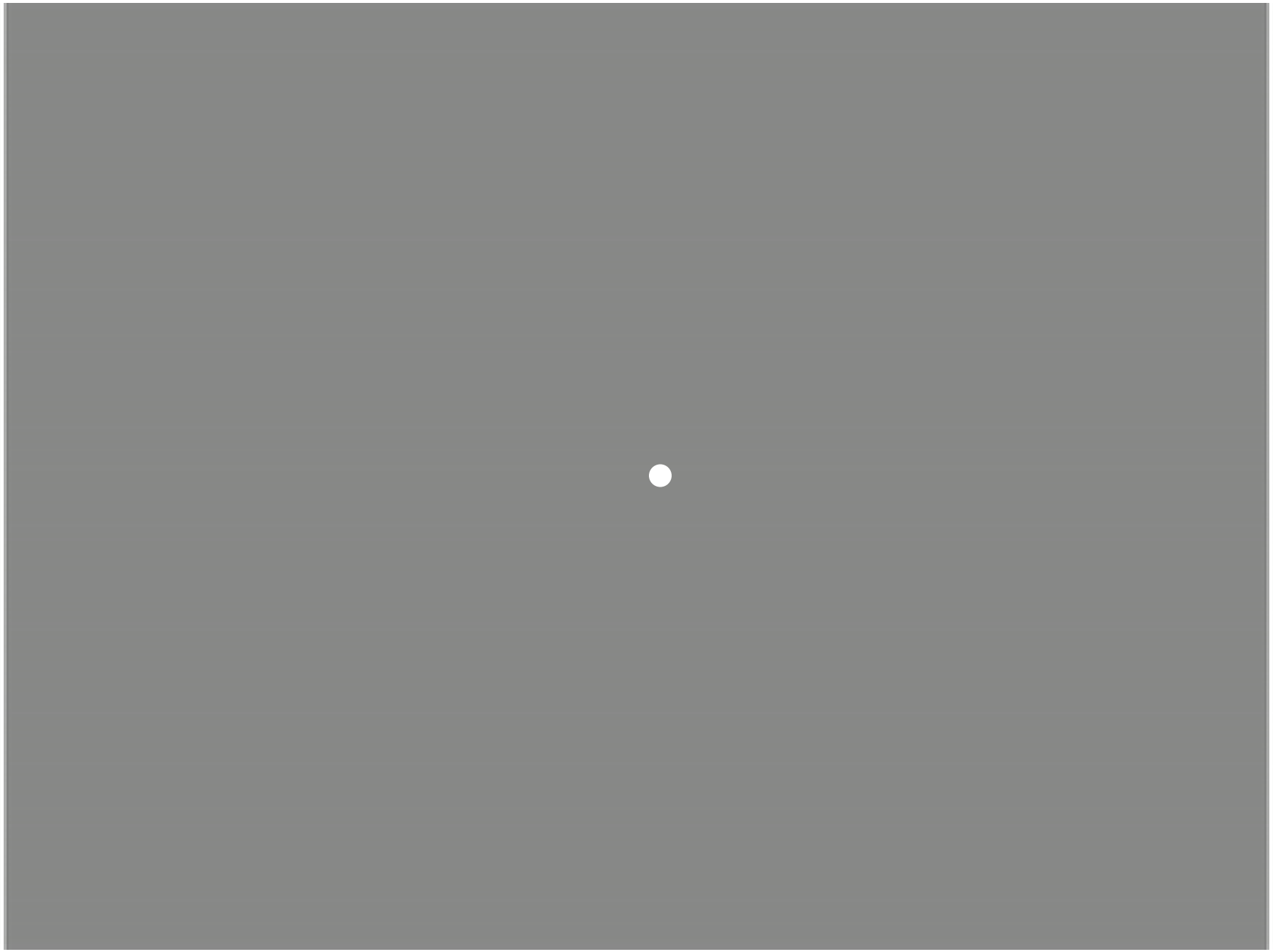
Schrimpf et al. (Neuron 2020)
Schrimpf, Kubilius*, et al. (bioRxiv 2018)*

Behavioral benchmark



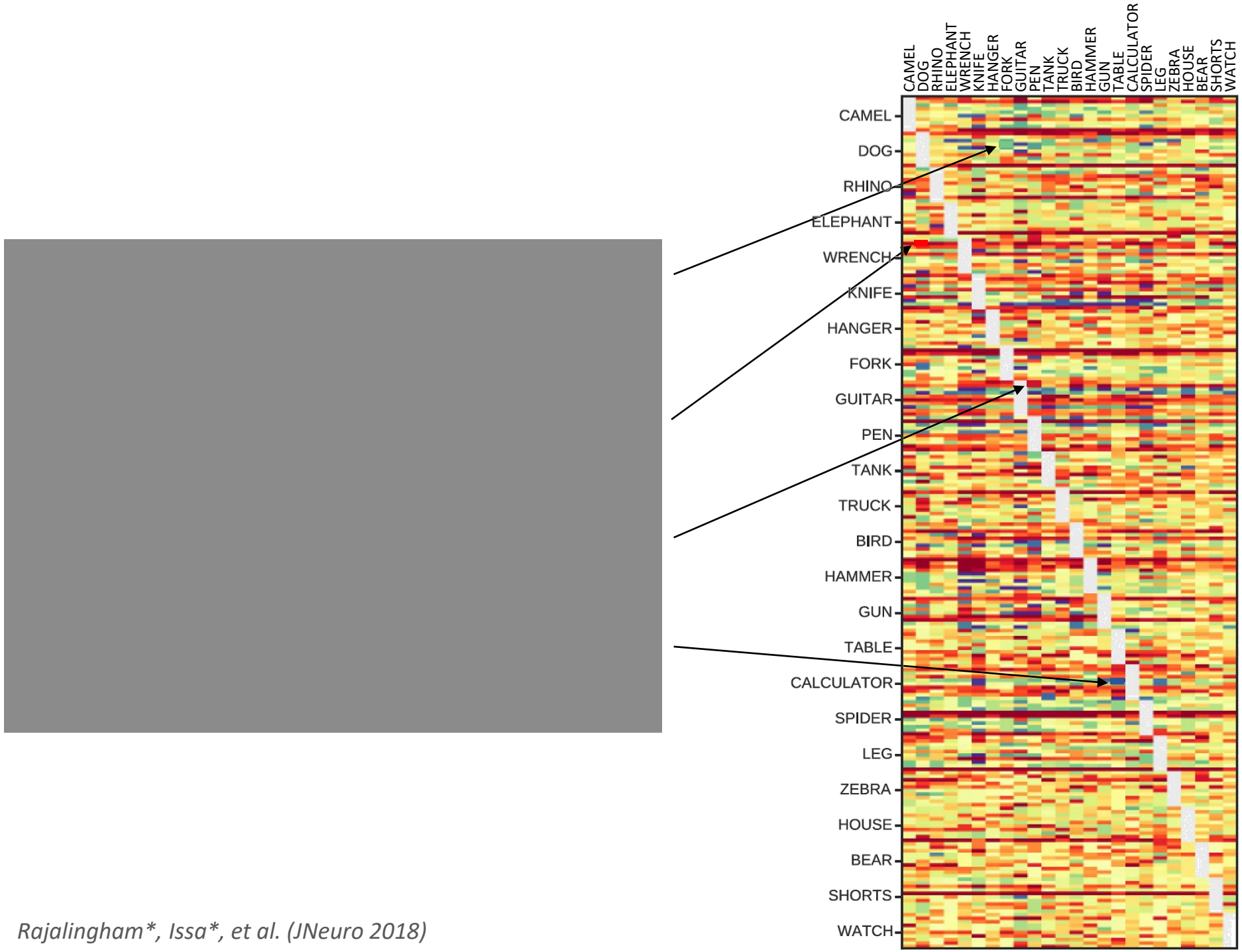
Rajalingham, Issa*, et al. (JNeuro 2018)*

Behavioral benchmark



Rajalingham, Issa*, et al. (JNeuro 2018)*

Behavioral benchmark



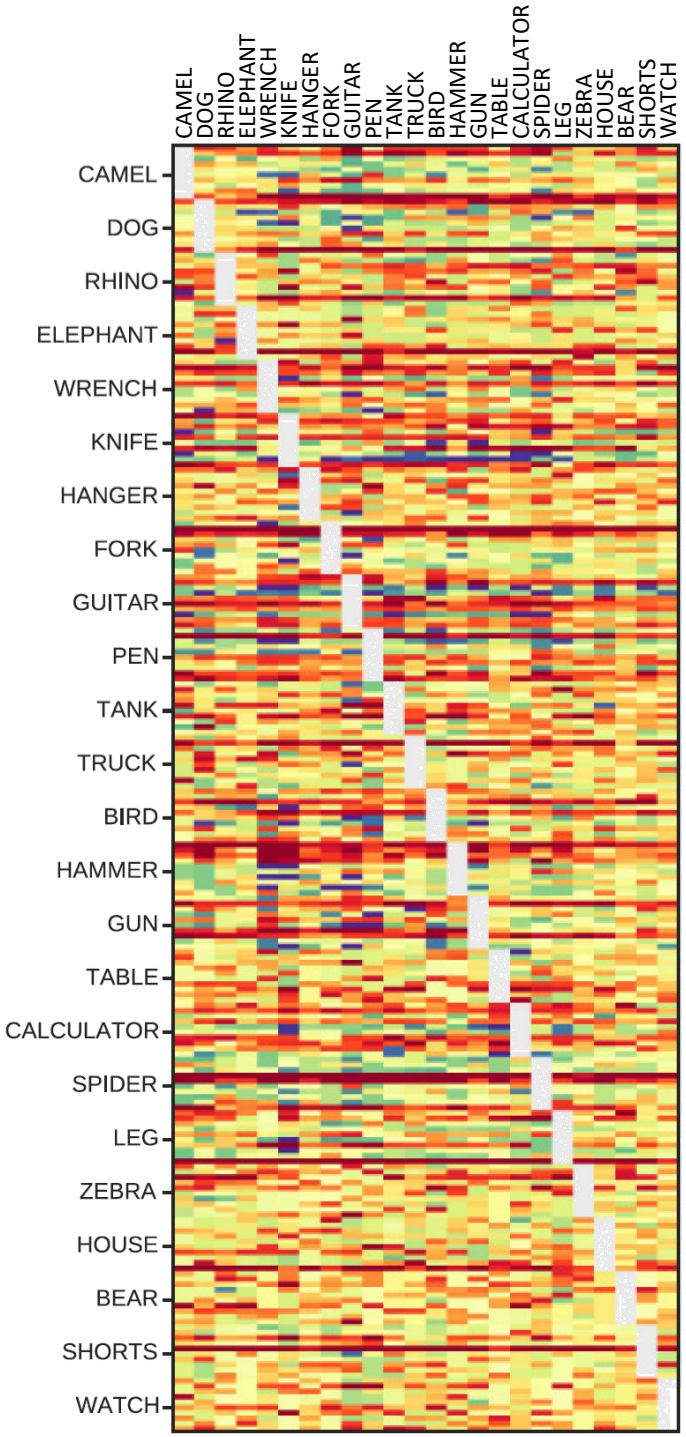
performance per binary categorization

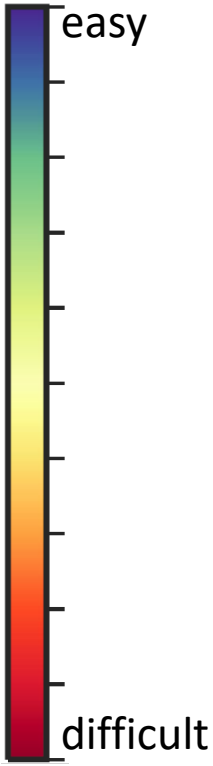
easy

difficult

Rajalingham, Issa*, et al. (JNeuro 2018)*

Behavioral benchmark

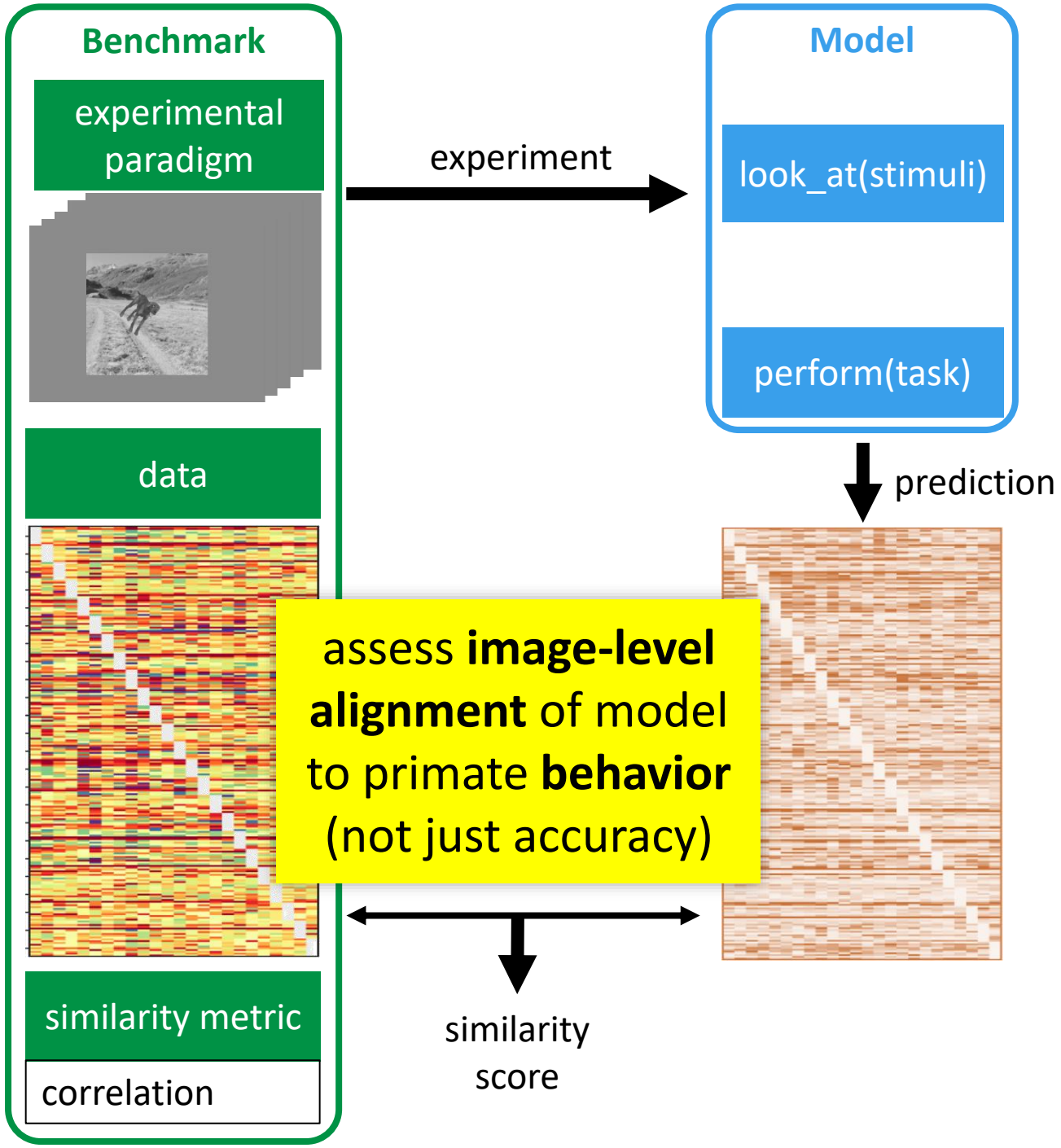




performance per binary categorization

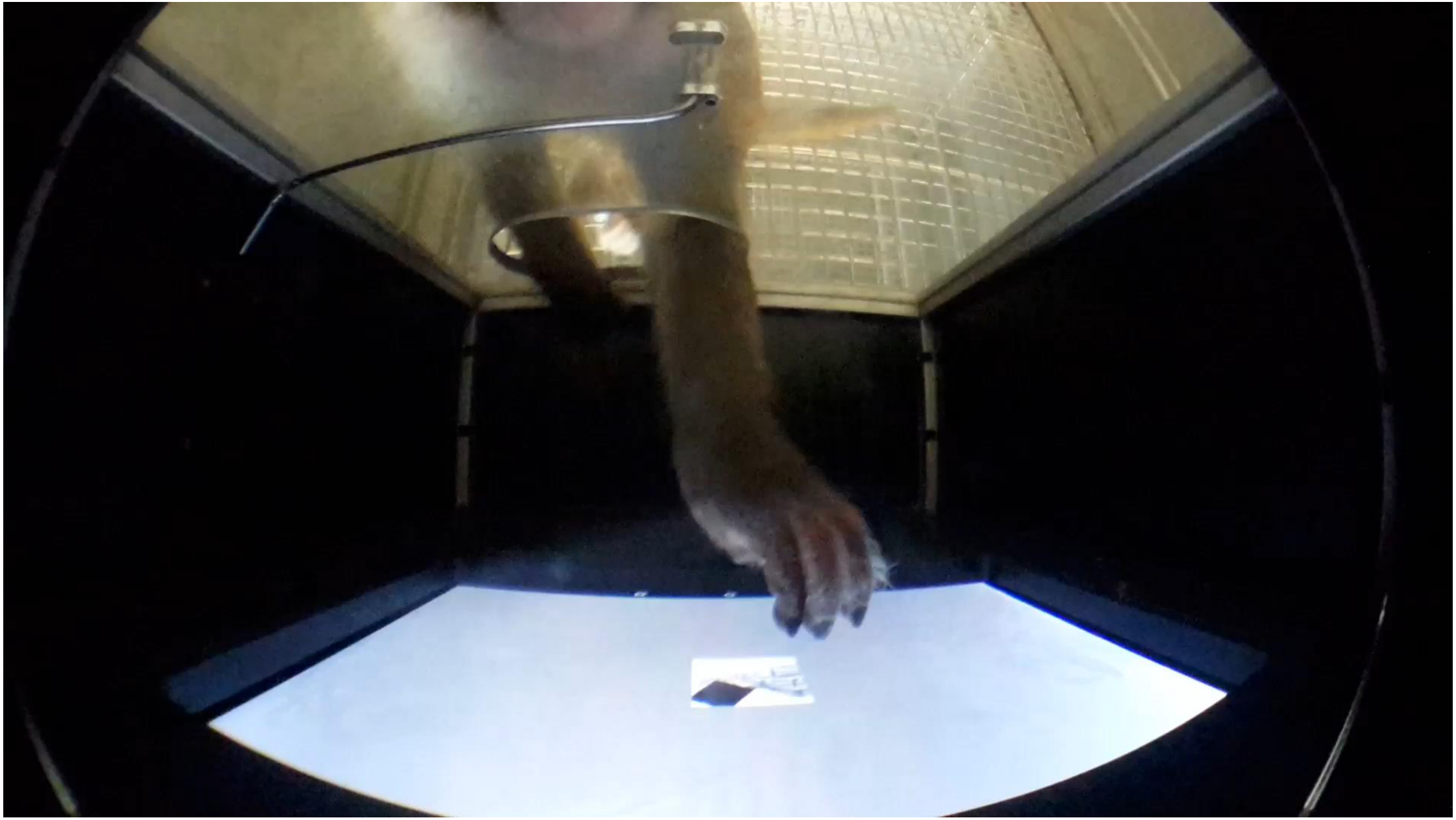
Rajalingham, Issa*, et al. (JNeuro 2018)*

Behavioral benchmark



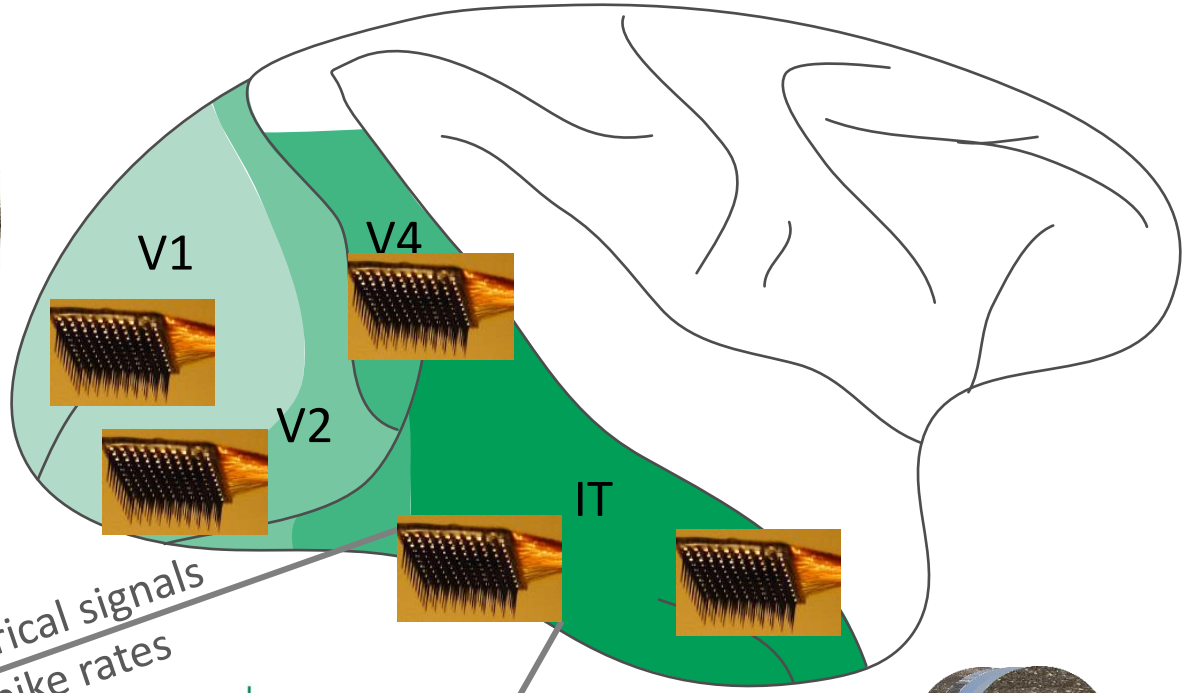
Neural benchmarks

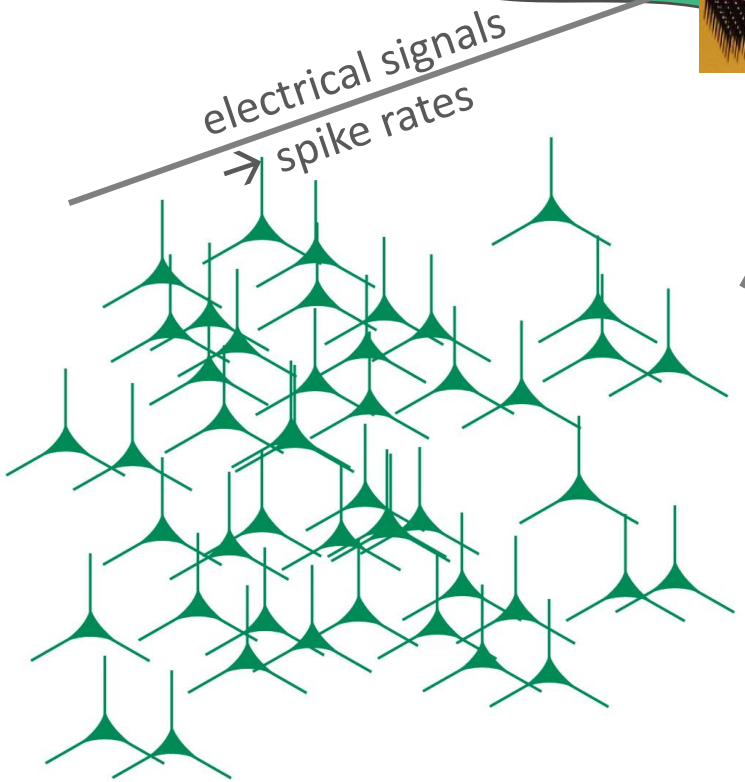
Neural benchmarks

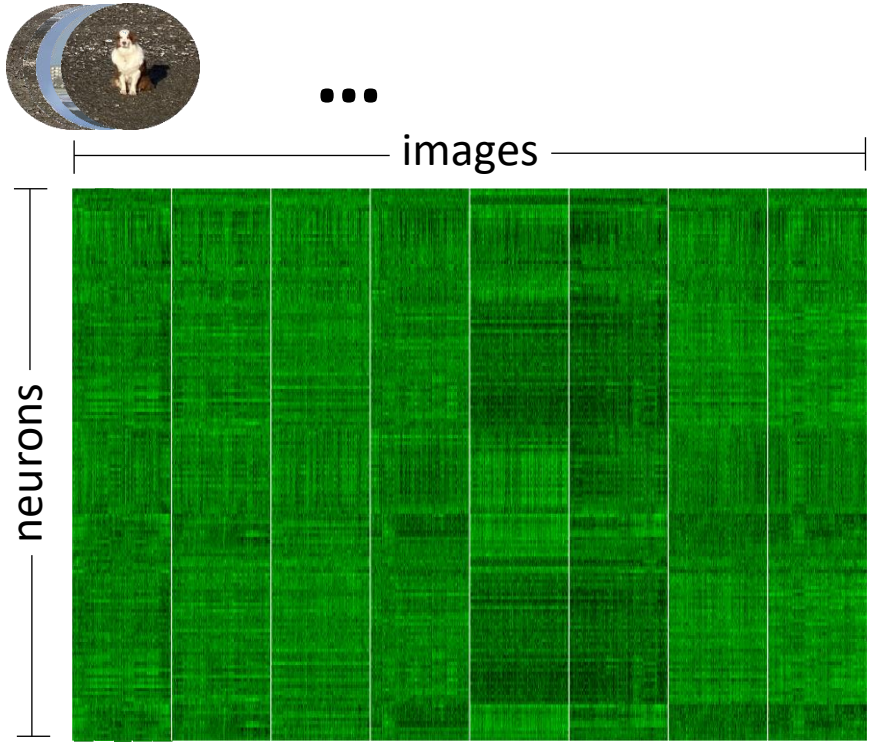


video courtesy of Kailyn Schmidt

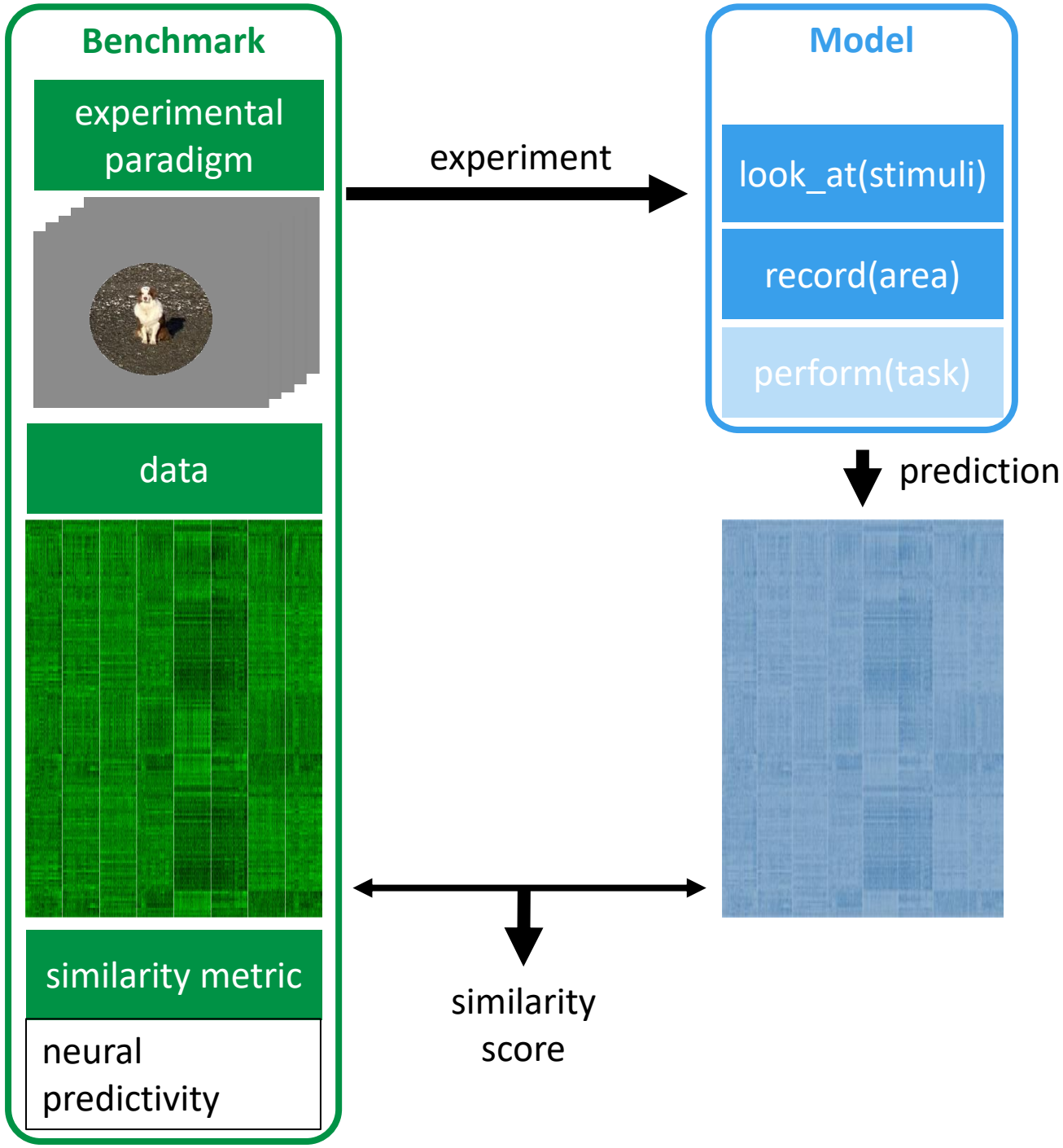
Neural benchmarks



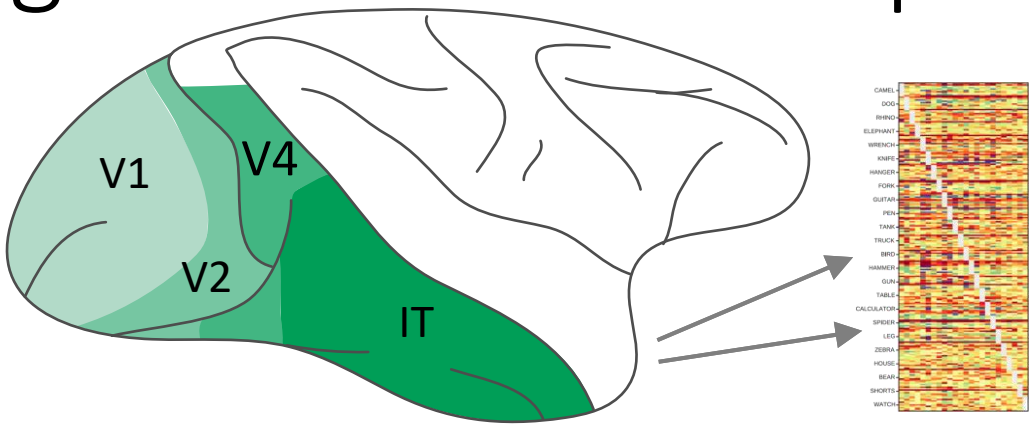


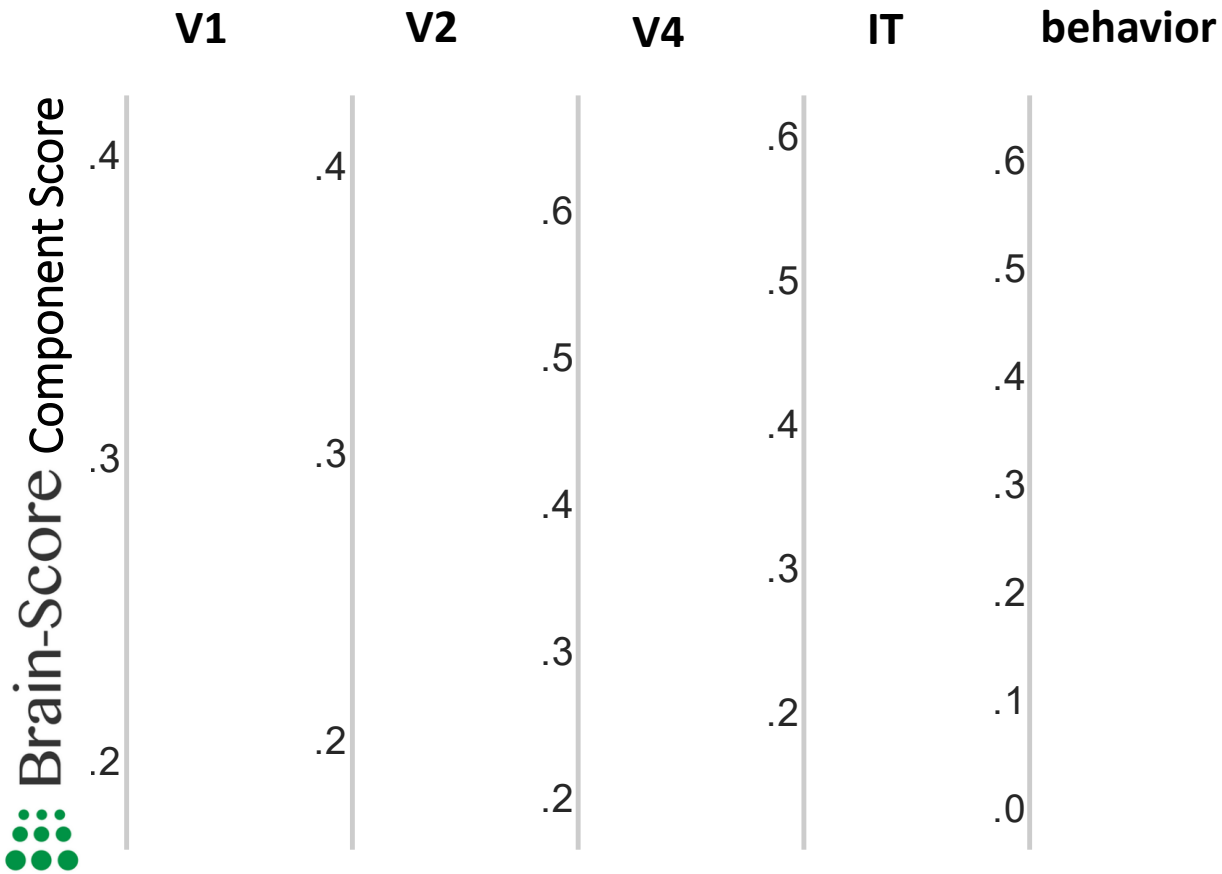


Neural benchmarks



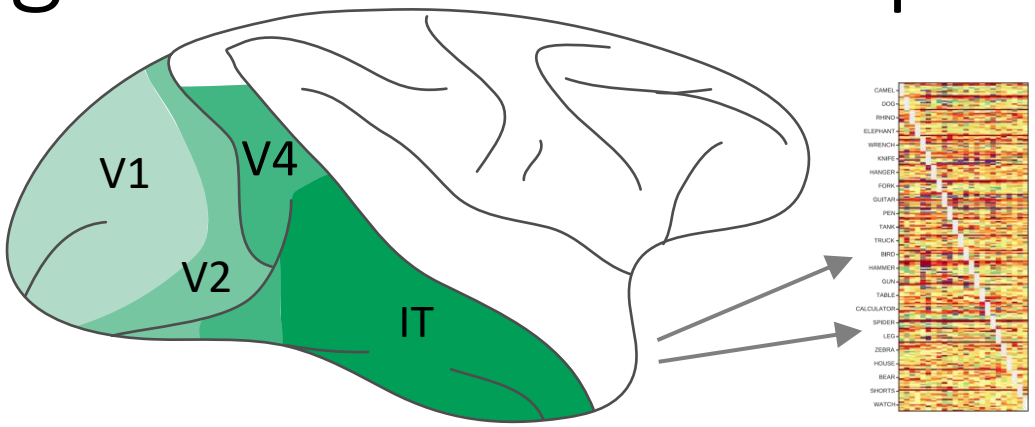
Integrative model comparison on Brain-Score

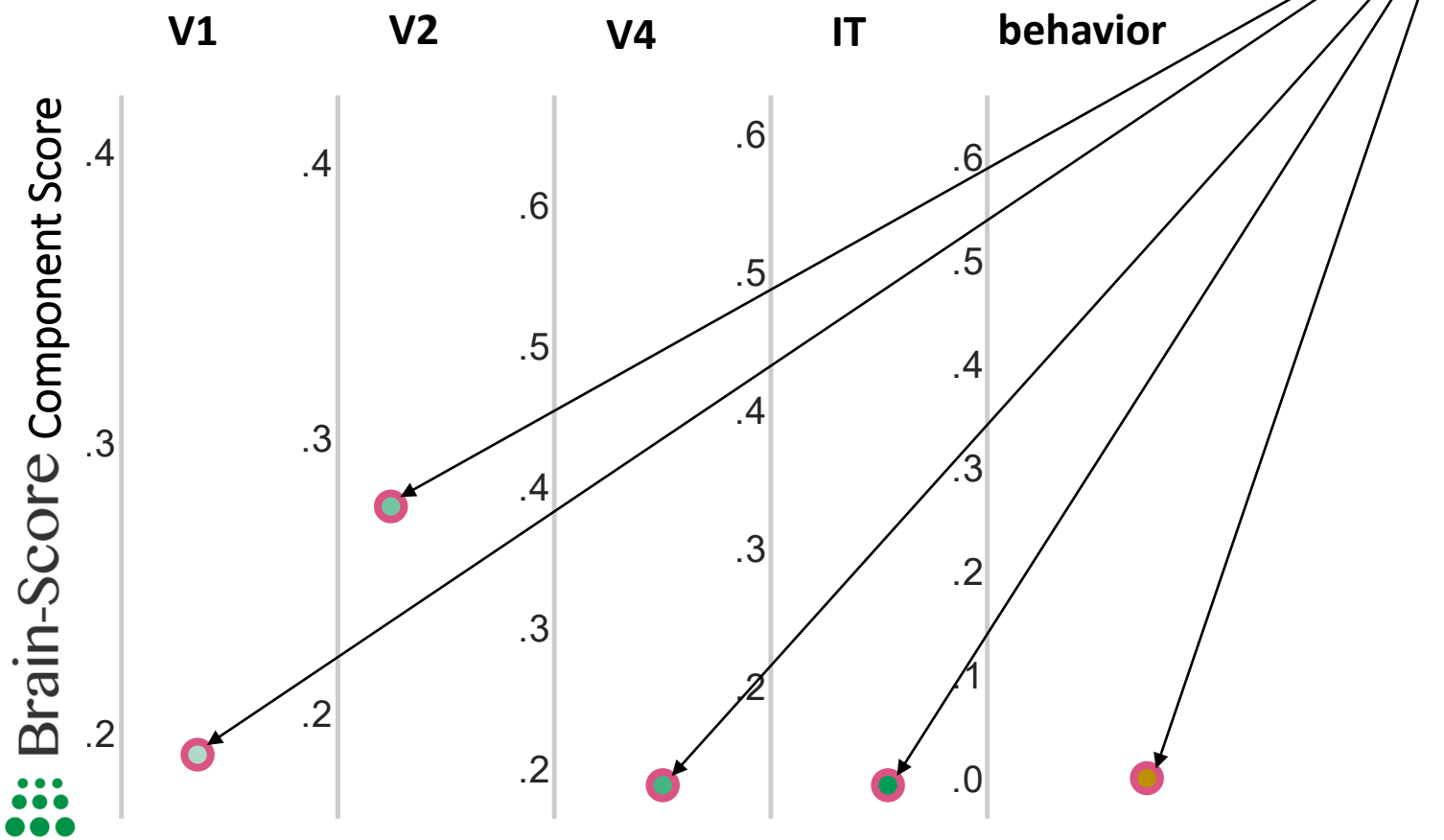




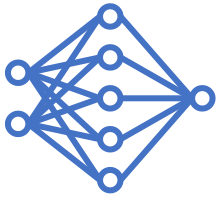
Schrimpf, Kubilius*, et al. (bioRxiv 2018)*
V1, V2 data: Freeman, Ziemba*, et al. (NatNeuro 2013)*
V4, IT data: Majaj, Hong*, et al. (JNeuro 2015)*
behavioral data: Rajalingham, Issa*, et al. (JNeuro 2018)*

Integrative model comparison on Brain-Score





Model candidates tested:



hmax *classic neuroscience model*

Schrimpf, Kubilius*, et al. (bioRxiv 2018)*
V1, V2 data: Freeman, Ziemba*, et al. (NatNeuro 2013)*
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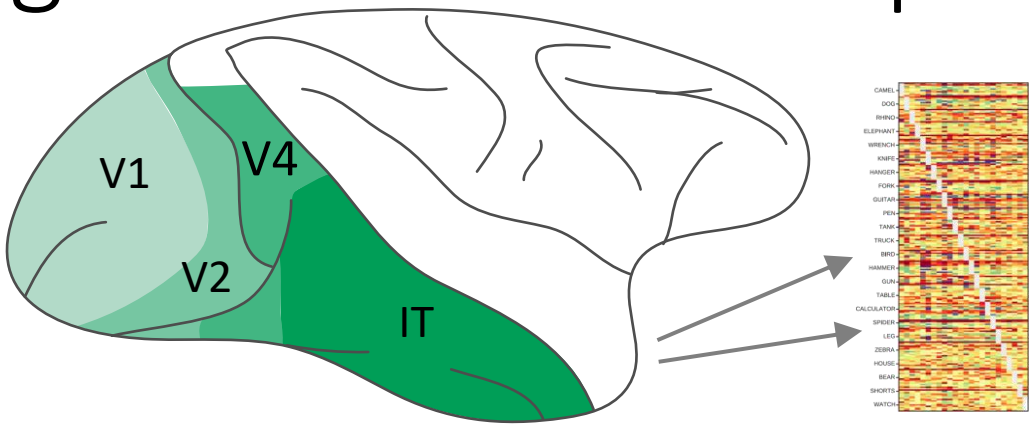
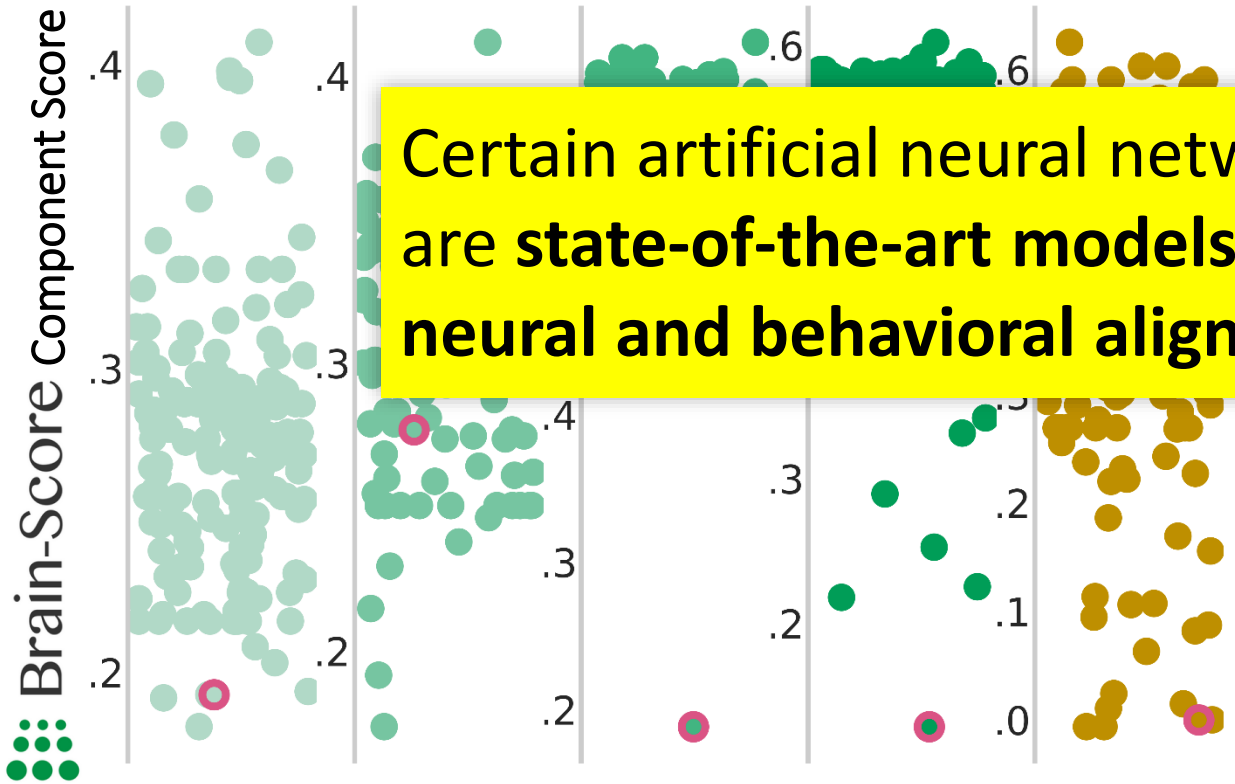
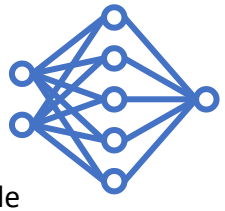
Integrative model comparison on Brain-Score





Certain artificial neural networks are state-of-the-art models of neural and behavioral alignment

Model candidates tested:



hmax		nasnet_large
vgg-16		nasnet_mobile
vgg-19		pnasnet_large
densenet-121		resnet-101_v1
densenet-169		resnet-101_v2
densenet-201		resnet-152_v1
inception_resnet_v2		resnet-152_v2
inception_v1		resnet-18
inception_v2		resnet-34
inception_v3	*ML models*	resnet-50_v1
inception_v4		resnet-50_v2
mobilenet_v1_0.25_128		squeezenet1_0
mobilenet_v1_0.25_160		squeezenet1_1
mobilenet_...		xception
mobilenet_v2_1.3_224		...
mobilenet_v2_1.4_224		

*translated into System Models:
- assign layers to regions
- assign pixels to visual degrees

Schrimpf, Kubilius*, et al. (bioRxiv 2018)*
V1, V2 data: Freeman, Ziemba*, et al. (NatNeuro 2013)*
V4, IT data: Majaj, Hong*, et al. (JNeuro 2015)*
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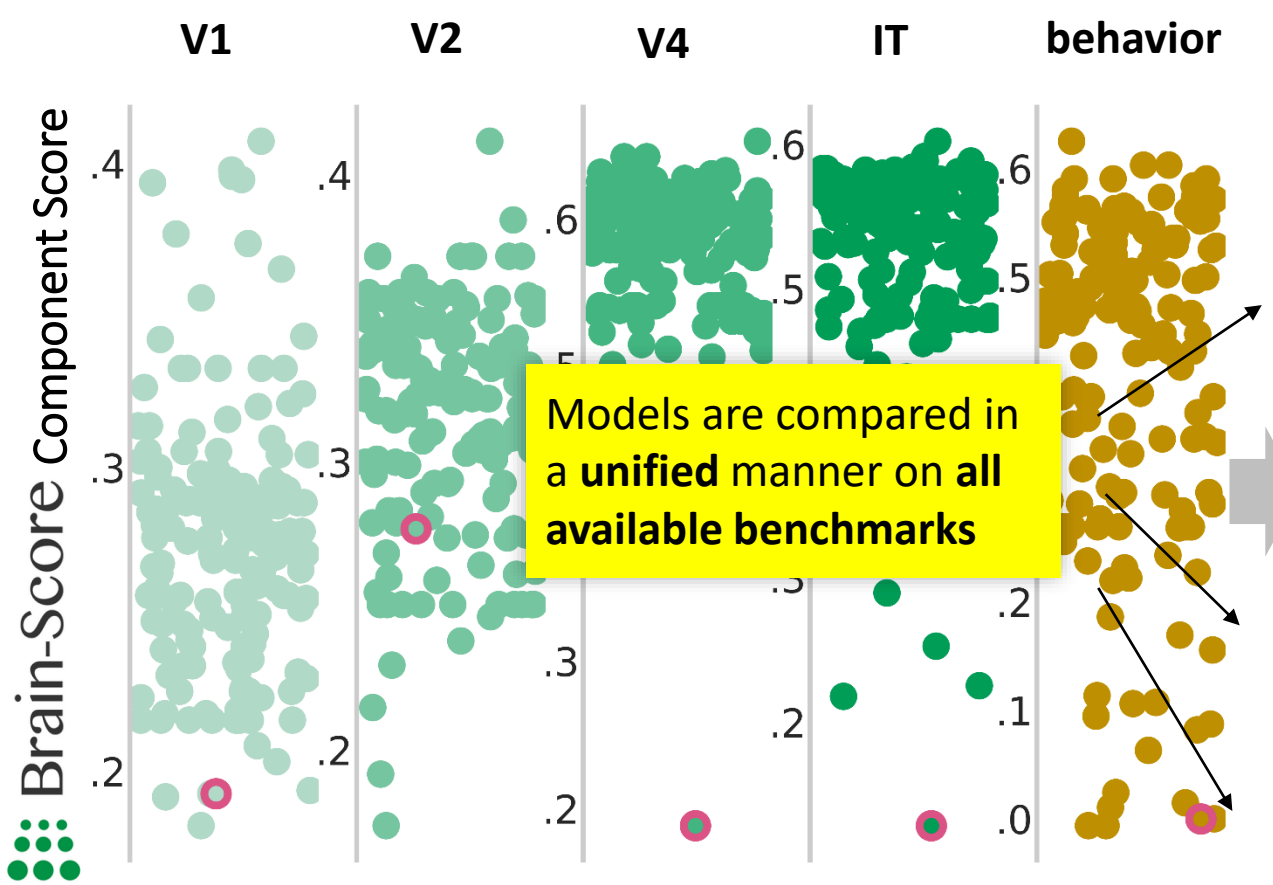
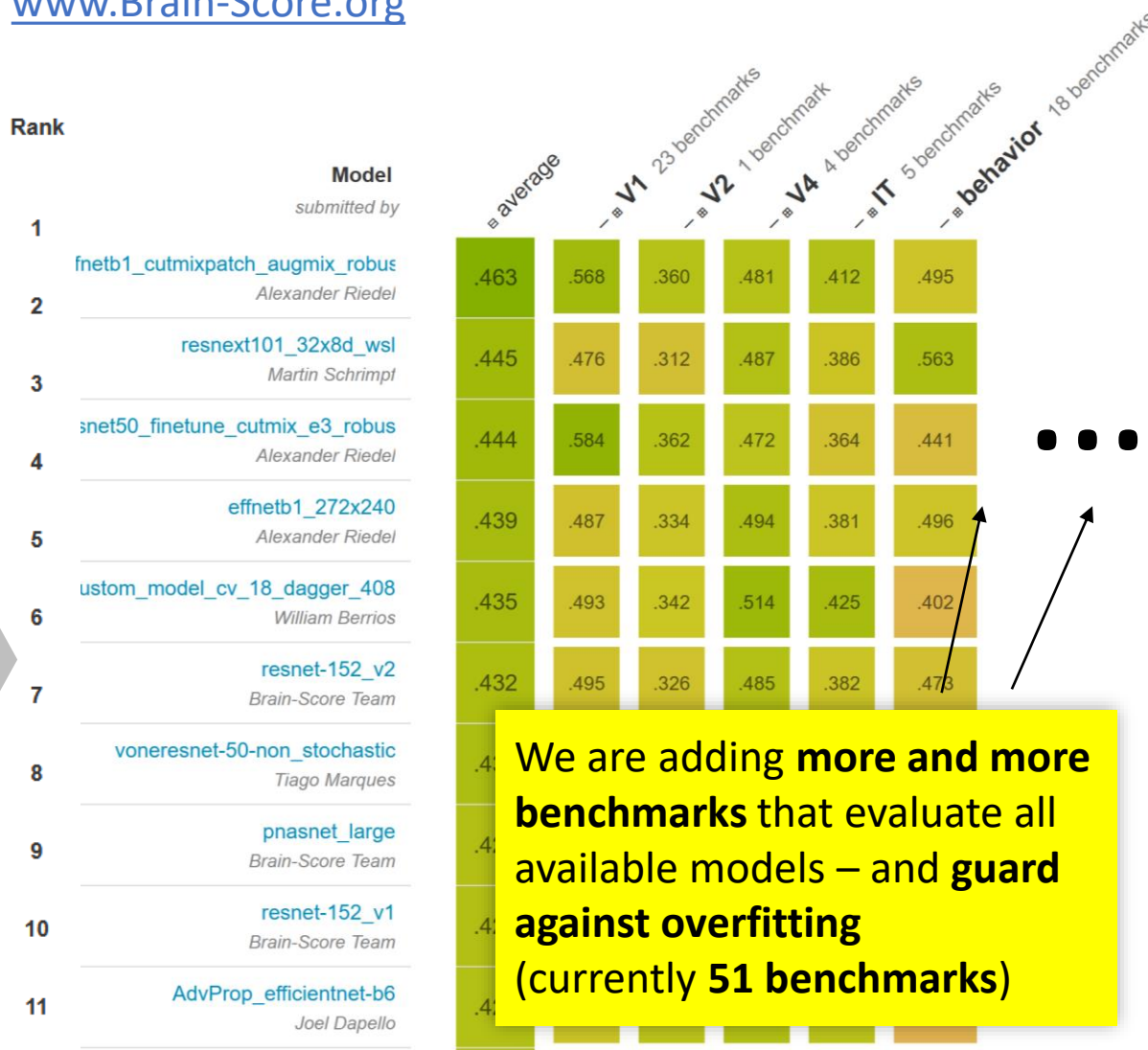
Brain-Score: Integrative Benchmarking

Brain-Score

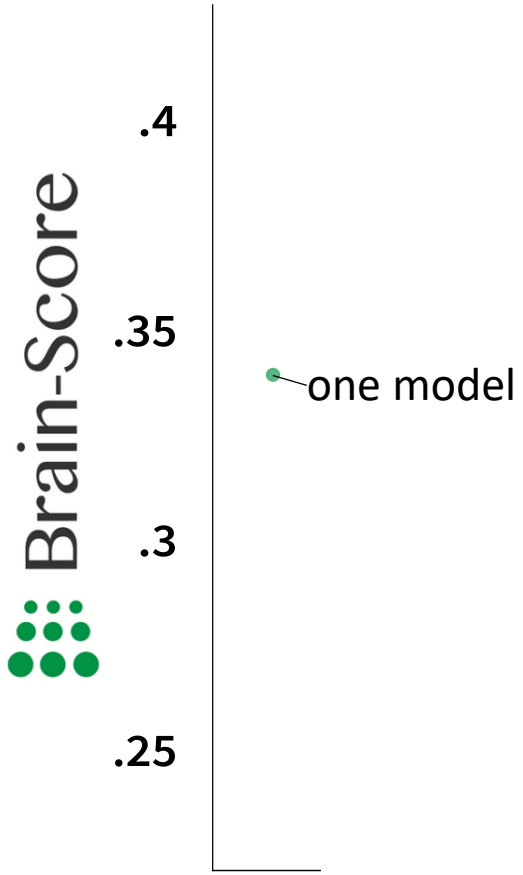
www.Brain-Score.org



Models are compared in a **unified** manner on **all available benchmarks**

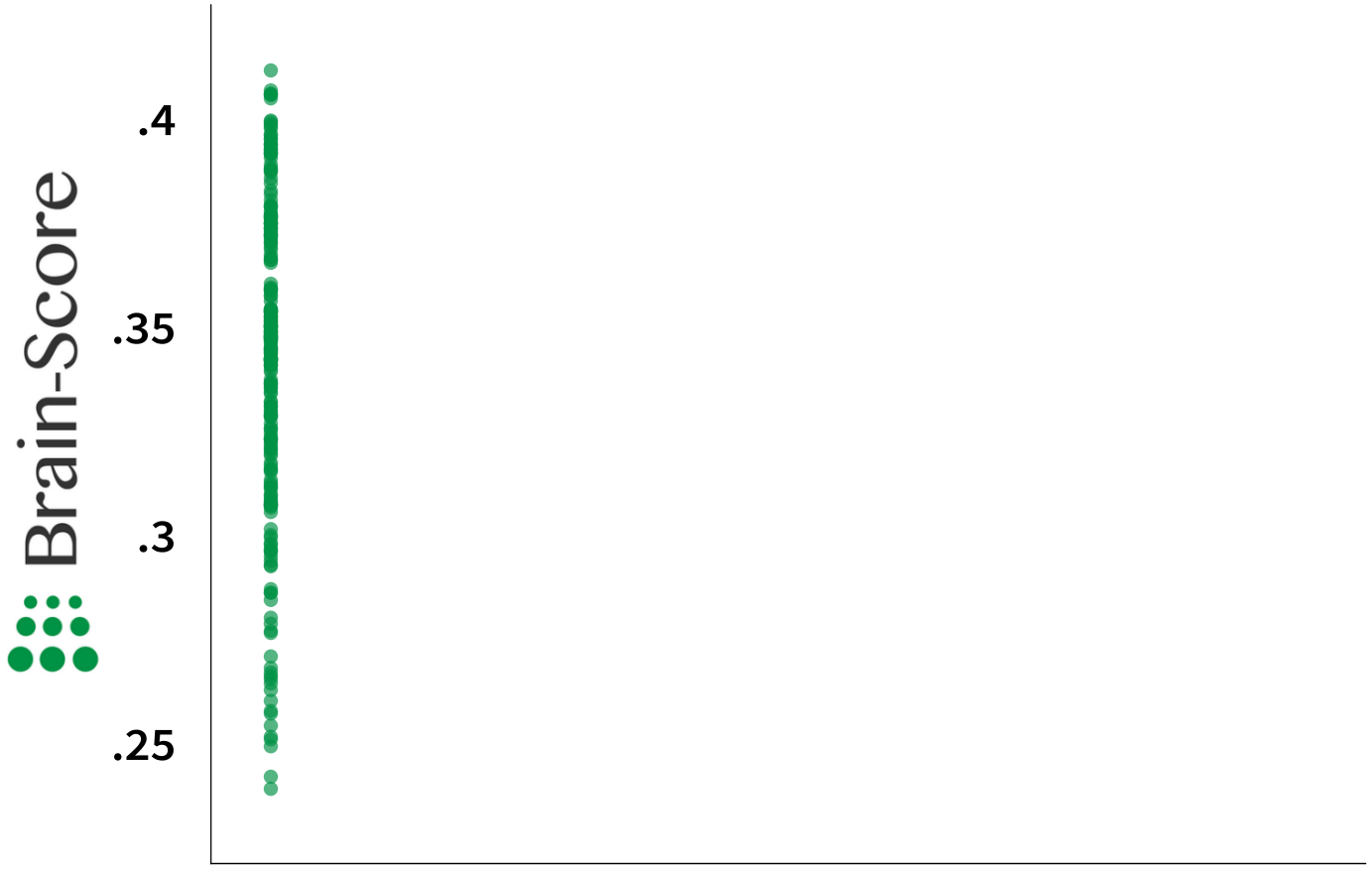


We are adding **more and more benchmarks** that evaluate all available models – and **guard against overfitting** (currently **51 benchmarks**)



Schrimpf, Kubilius*, et al. (bioRxiv 2018)*

What explains the model differences?

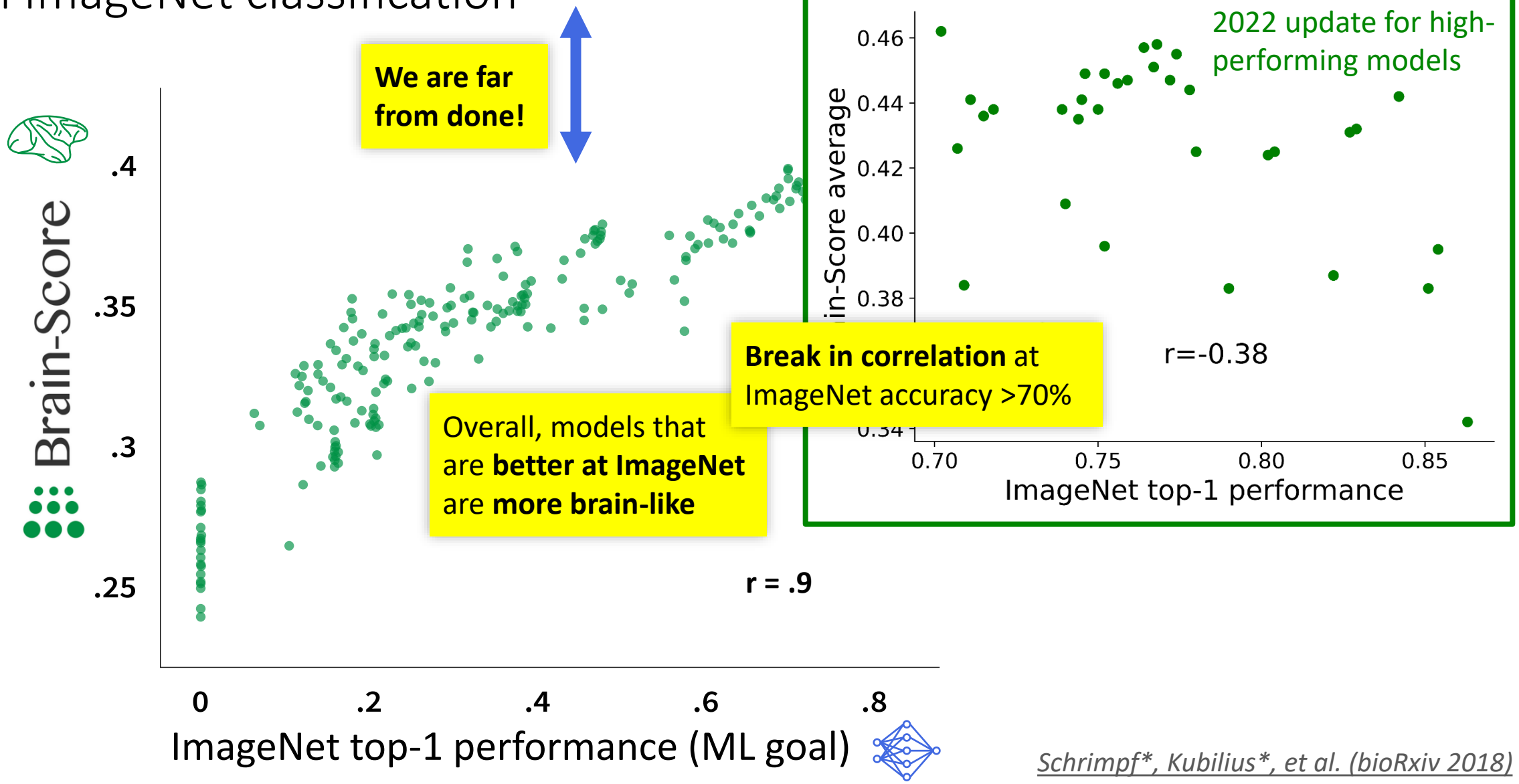


Normative variable

cf. Yamins, Hong*, et al. (PNAS 2014)*
Schrimpf, Kubilius*, et al. (bioRxiv 2018)*

Task performance correlates with Brain-Score

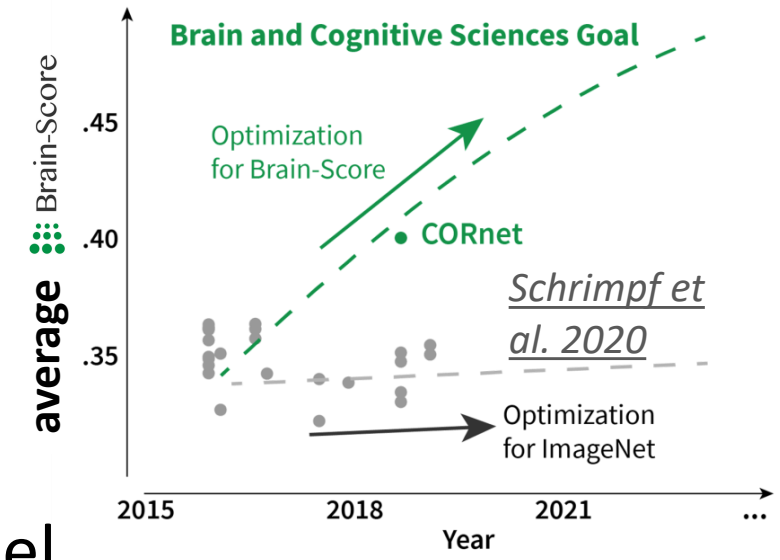
on ImageNet classification



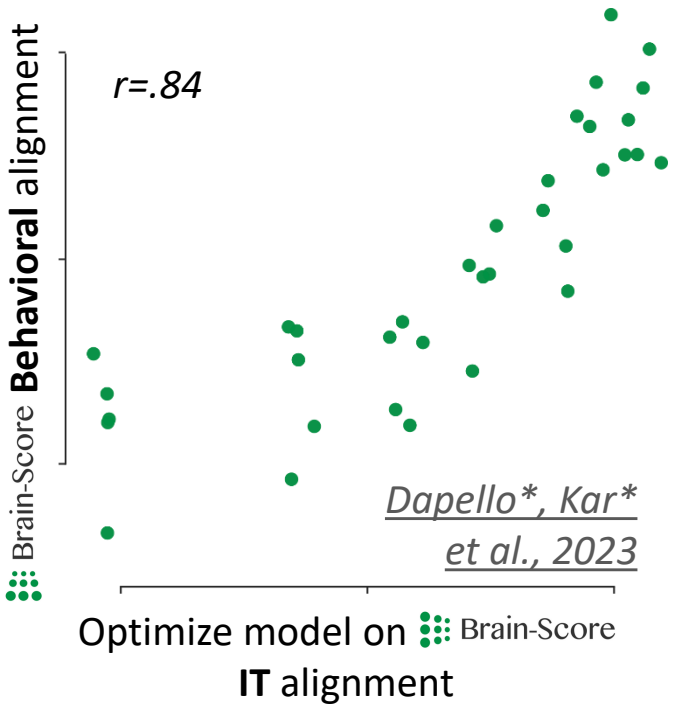
Schrimpf, Kubilius*, et al. (bioRxiv 2018)*

What Brain-Score enables

1. **Track and guide progress of modeling primate vision**

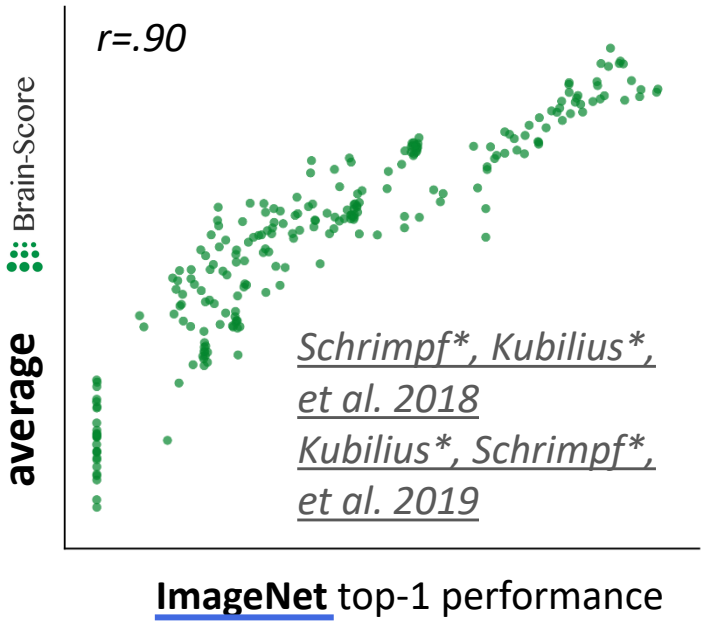


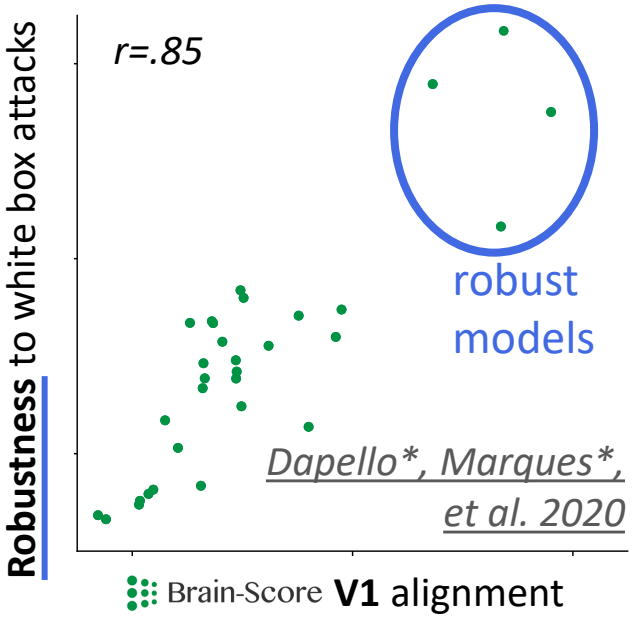
2. **Relate brain benchmarks to one another.**
Improve IT component of model
→ improve behavior



3. **Relate brain benchmarks to engineering desiderata**
ImageNet → Brain-Score;

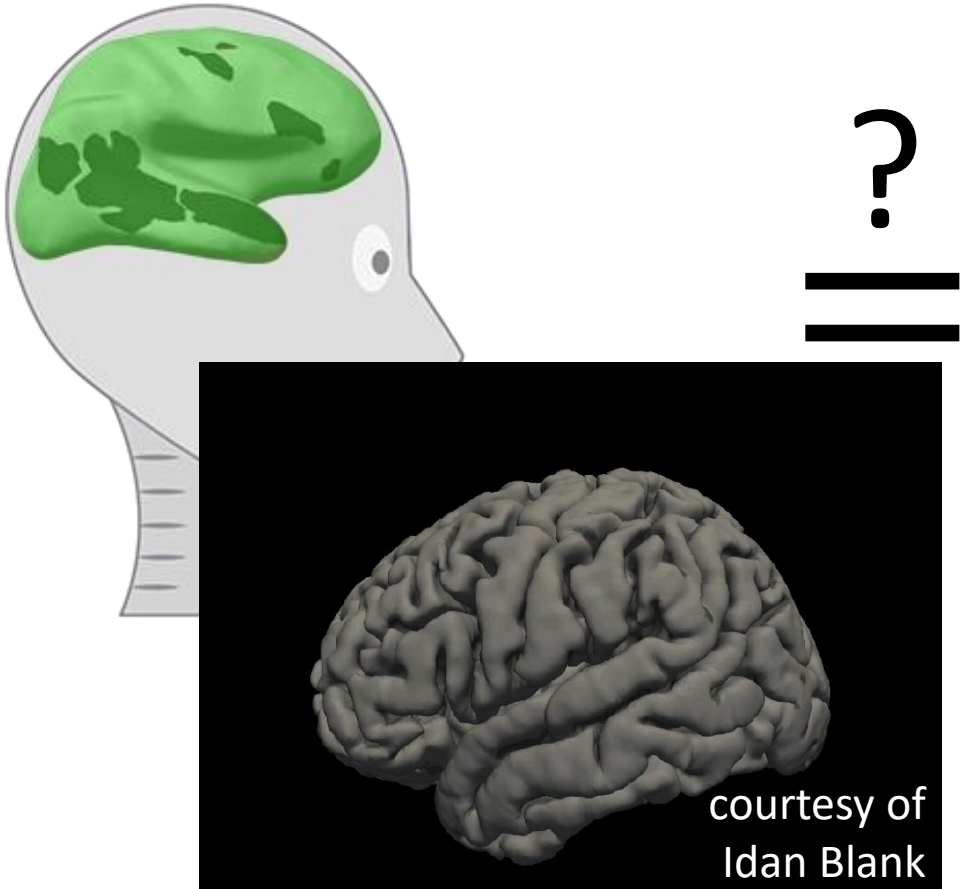
More V1-like
→ improved robustness





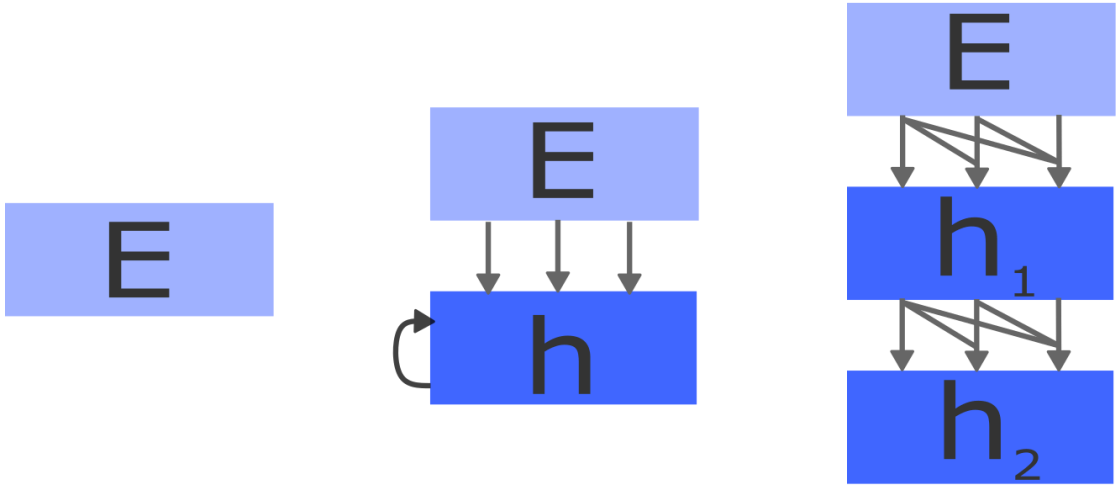
Integrative testing yields insights across domains of intelligence such as language

Humans

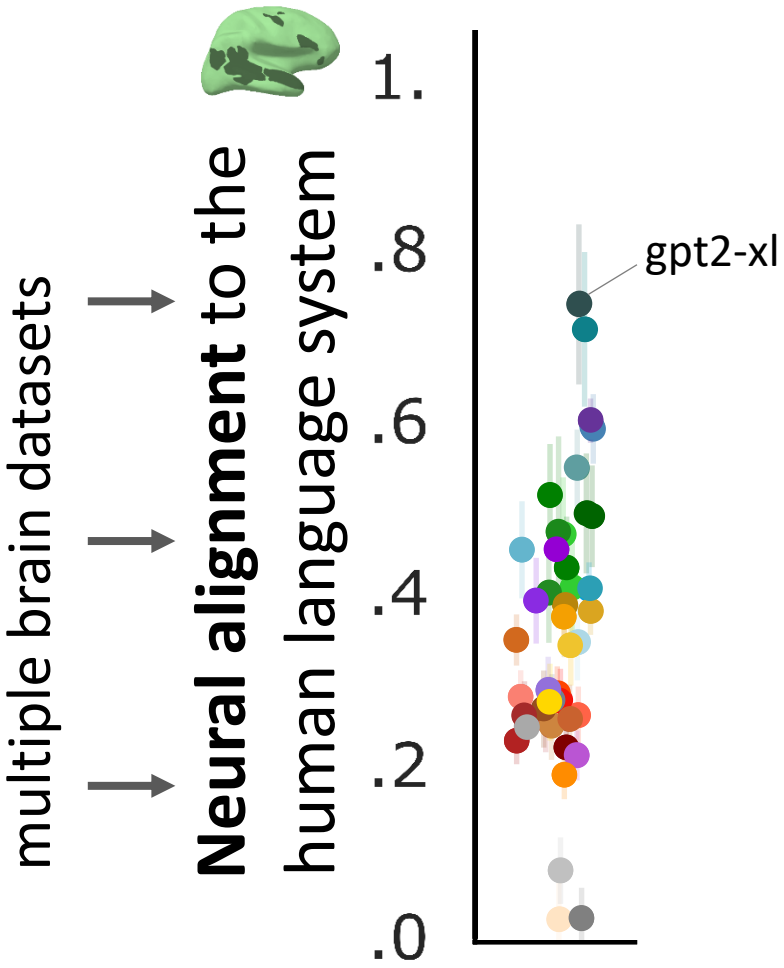


?

Models

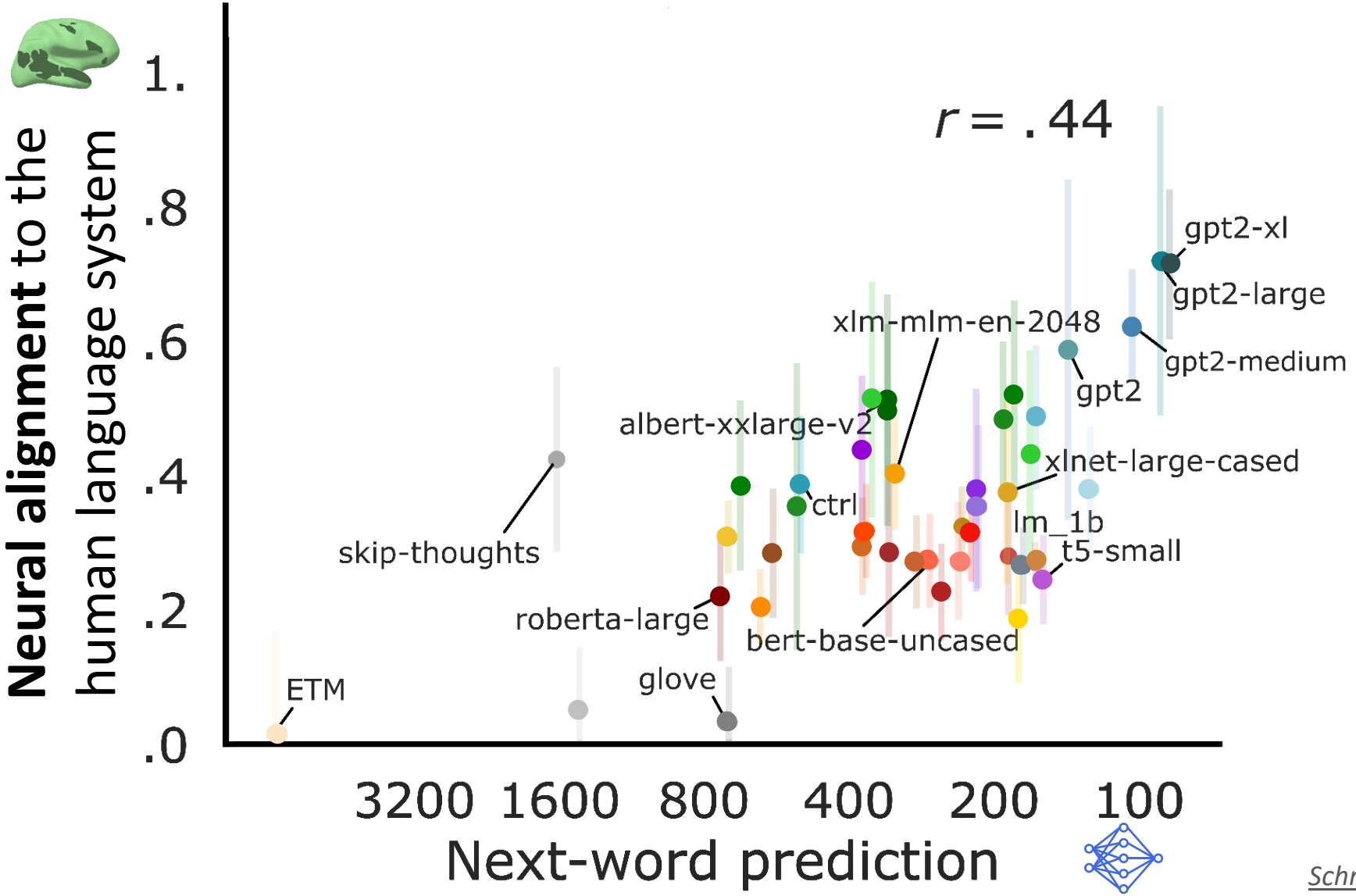


Particular ML language models predict the human language system



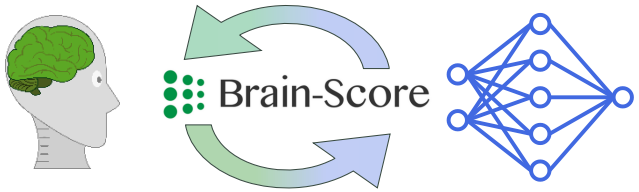
Schrimpf et al. (PNAS 2021)

The better models can predict the next word, the more brain-like they are

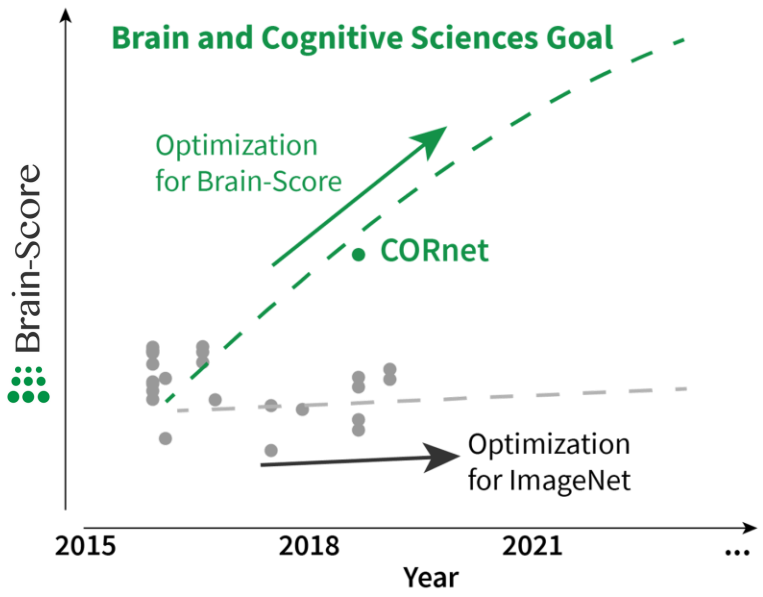


Schrimpf et al. (PNAS 2021)

Contributions

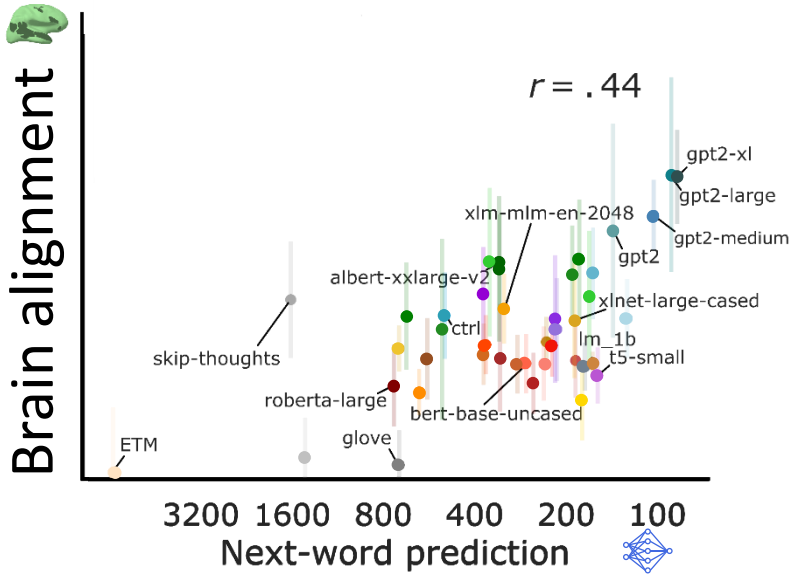


To meaningfully **make progress** in modeling human intelligence (behavior + underlying neural activity), we must *integrate experimental results*.



Brain-Score is an implementation of this approach, currently in the domains of vision and language.

- *Identify* most brain-like models
- Provide *empirical constraints* for developing new models
- Discover key *relationships* between neural function, behavior, and computation



Brain-Score.org github.com/brain-score