

**Martin Schrimpf**

✉ [martin.schrimpf@epfl.ch](mailto:martin.schrimpf@epfl.ch)



**Neuro\_X Institute**

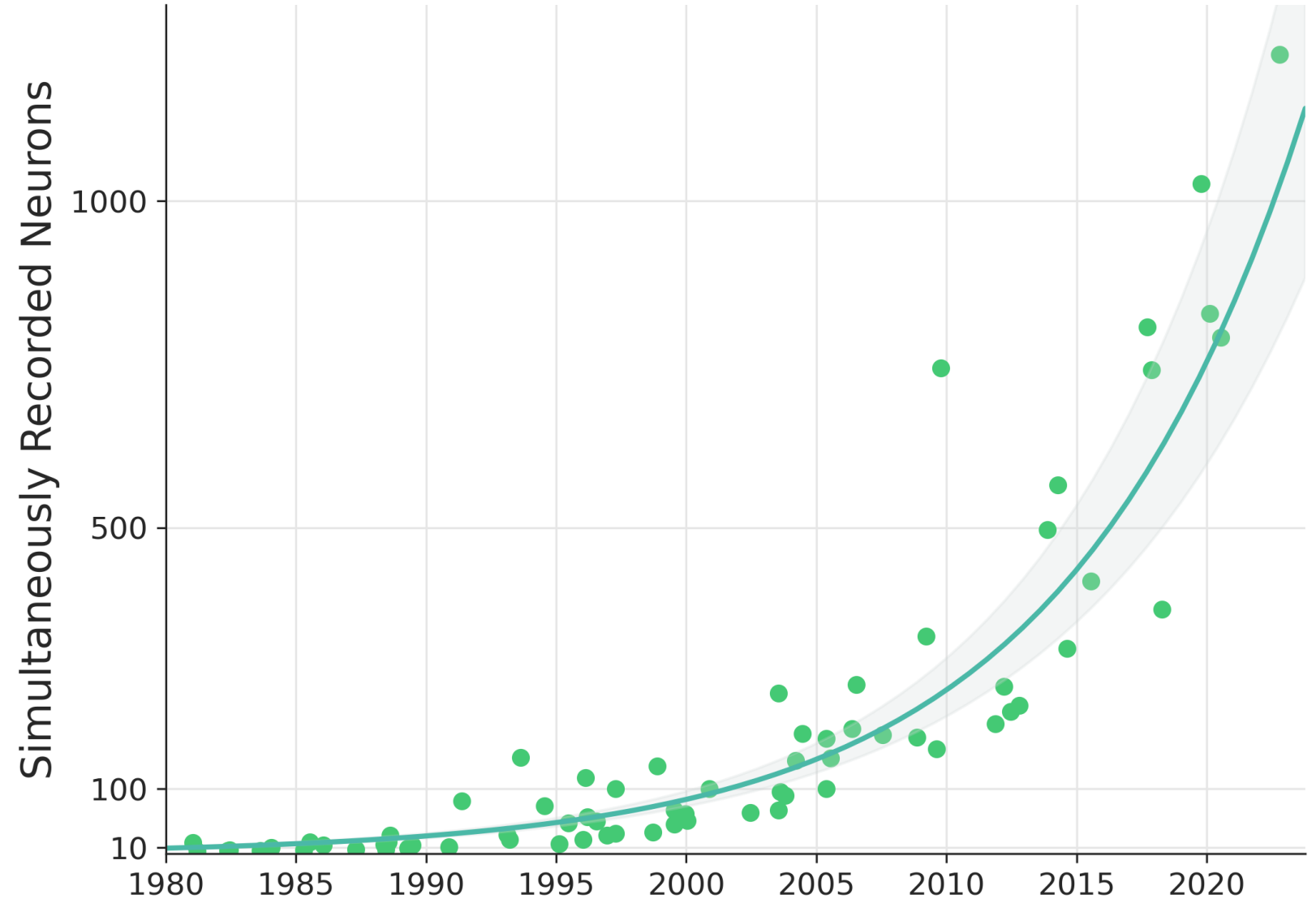
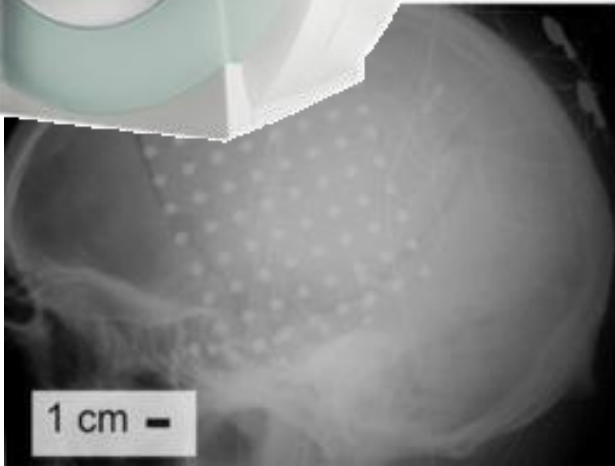


Using AI to explain the **brain**

Using neuroscience to explain **AI**



# Access to neural data is increasing exponentially



<https://stevenson.lab.uconn.edu/scaling>

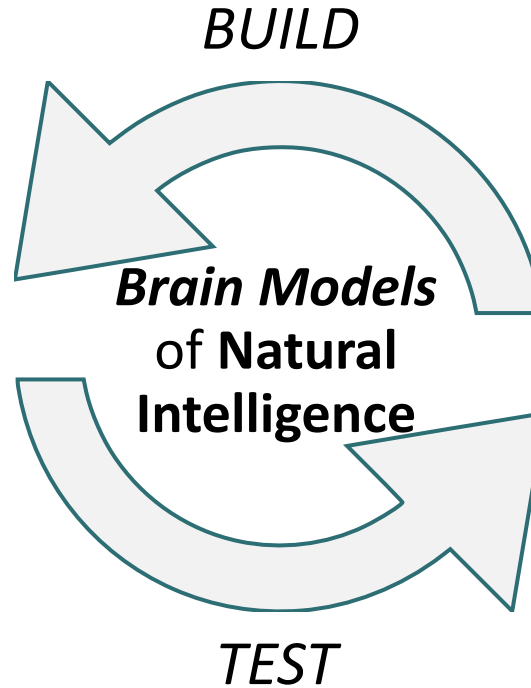


# Quantitative synergy between science + engineering

**Brain and  
Cognitive Sciences**



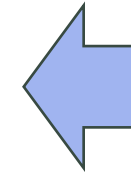
*Quantitative  
Measurements  
& Discoveries*



**AI/ML  
Engineering**



*Computational  
**Hypotheses** & Fine-  
grain **Predictions***





# Key messages today

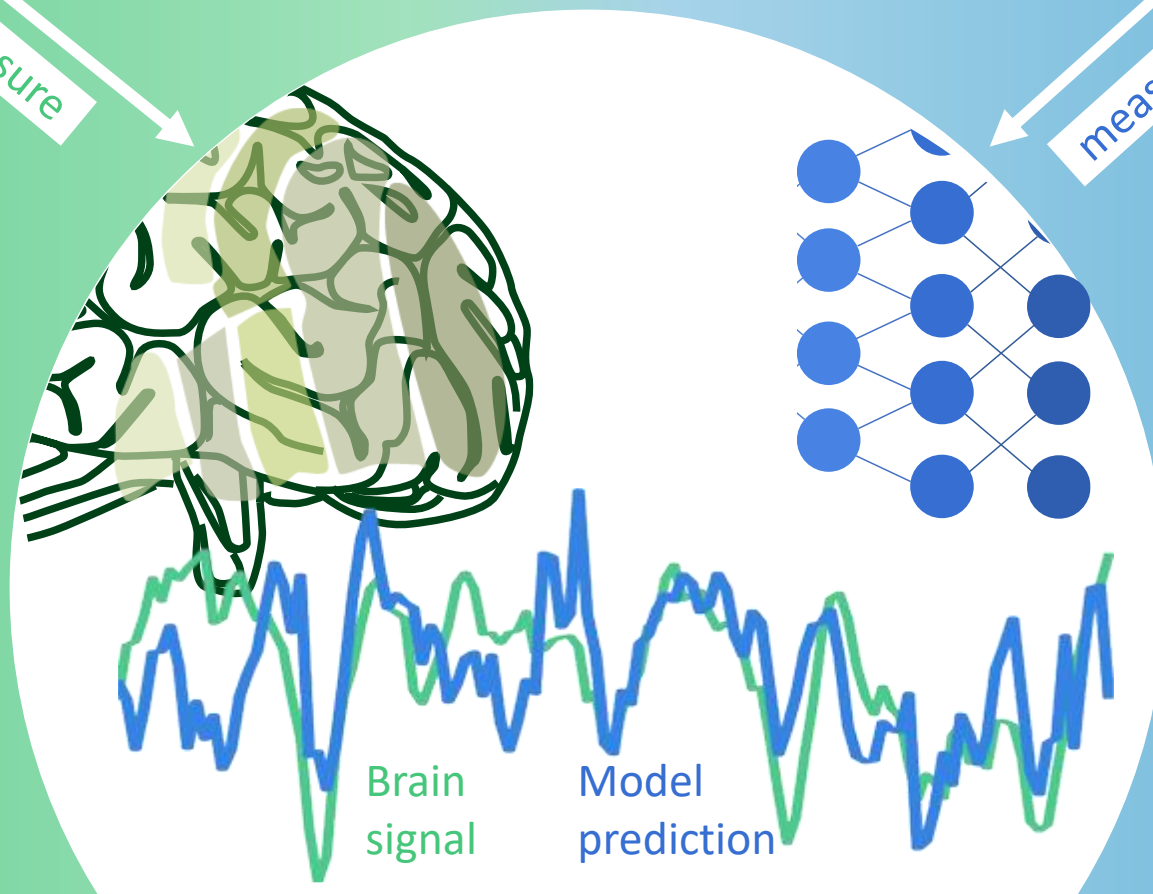
1. AI → Neuro: Particular neural network models are state-of-the-art at predicting brain function and human behavior.
2. Neuro → AI: Neuroscience has found very effective ways of identifying network function which are applicable to AI.



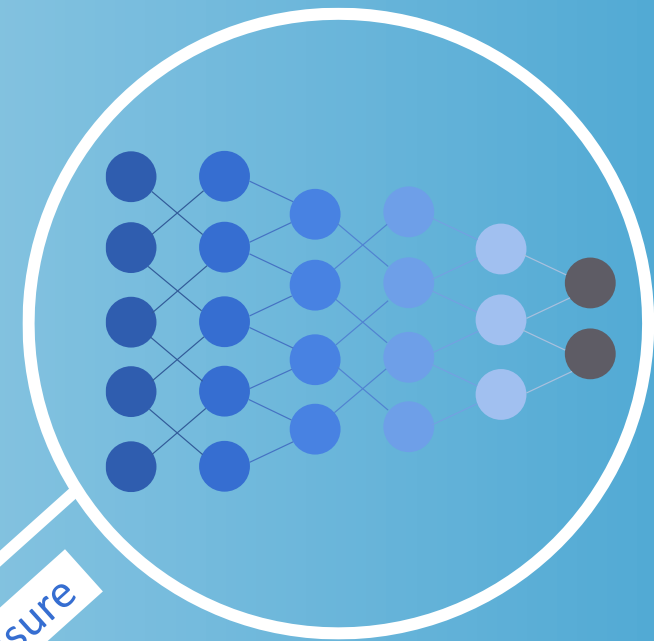
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measure



measure



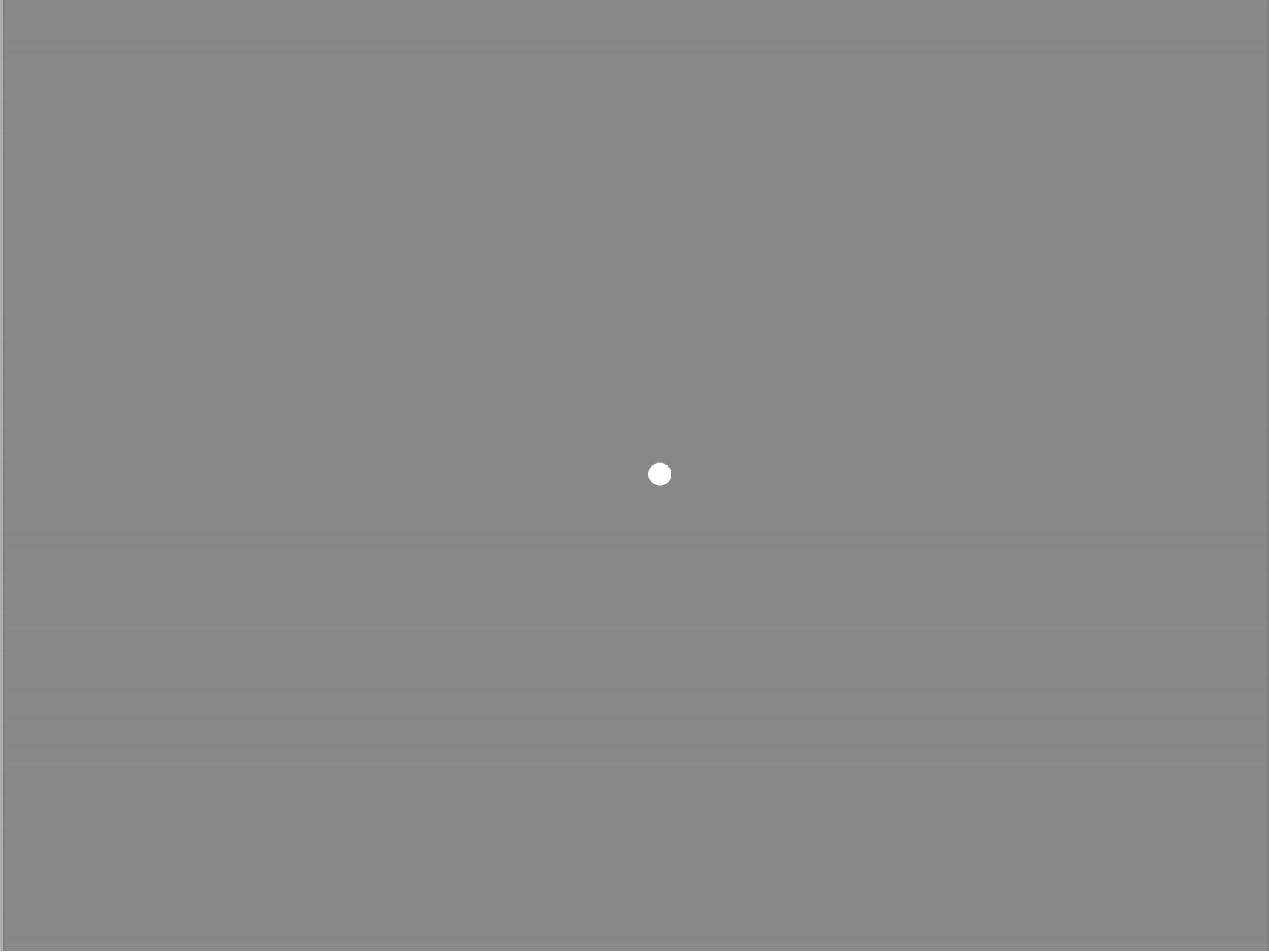


# Behavioral experiment

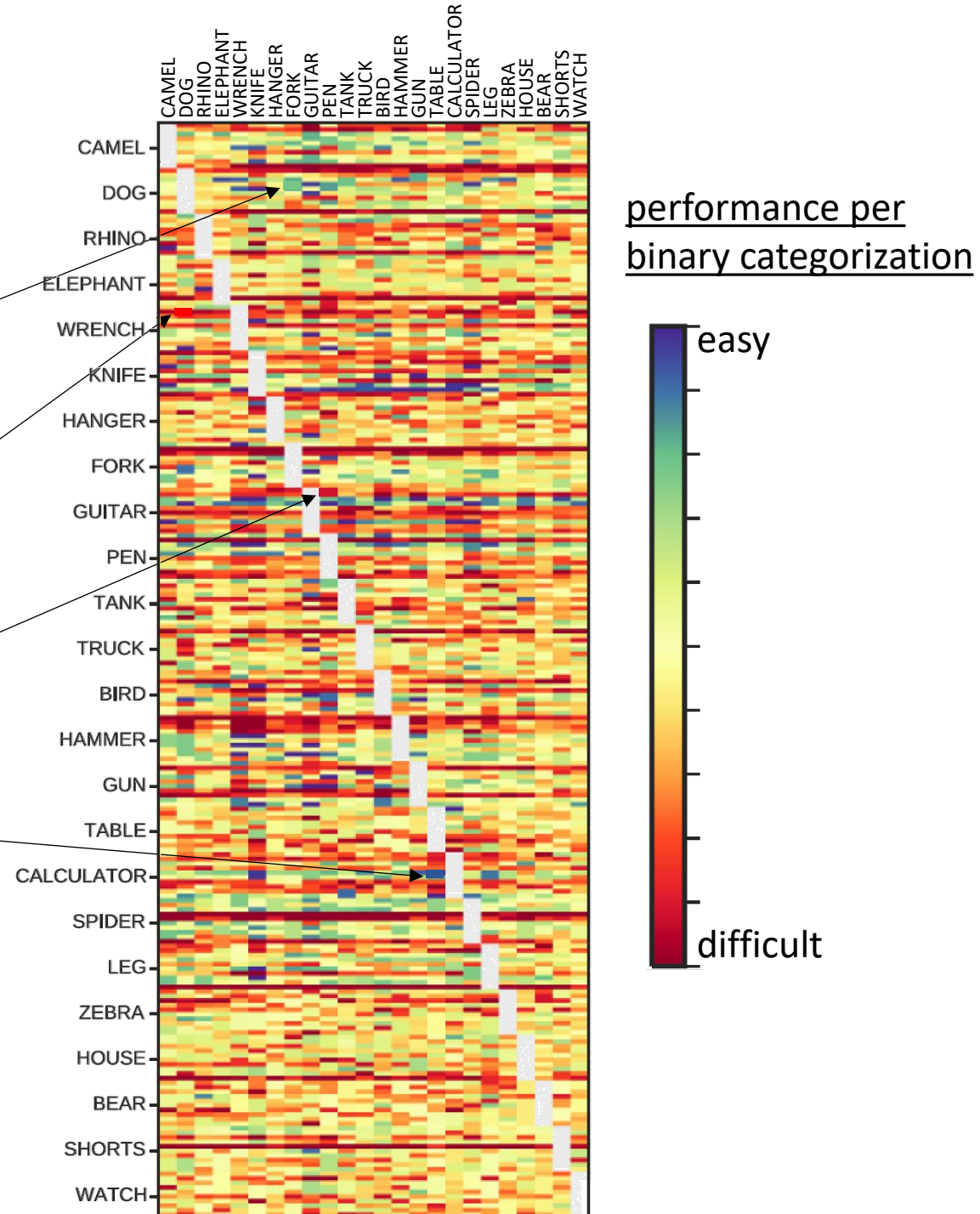




# Behavioral experiment

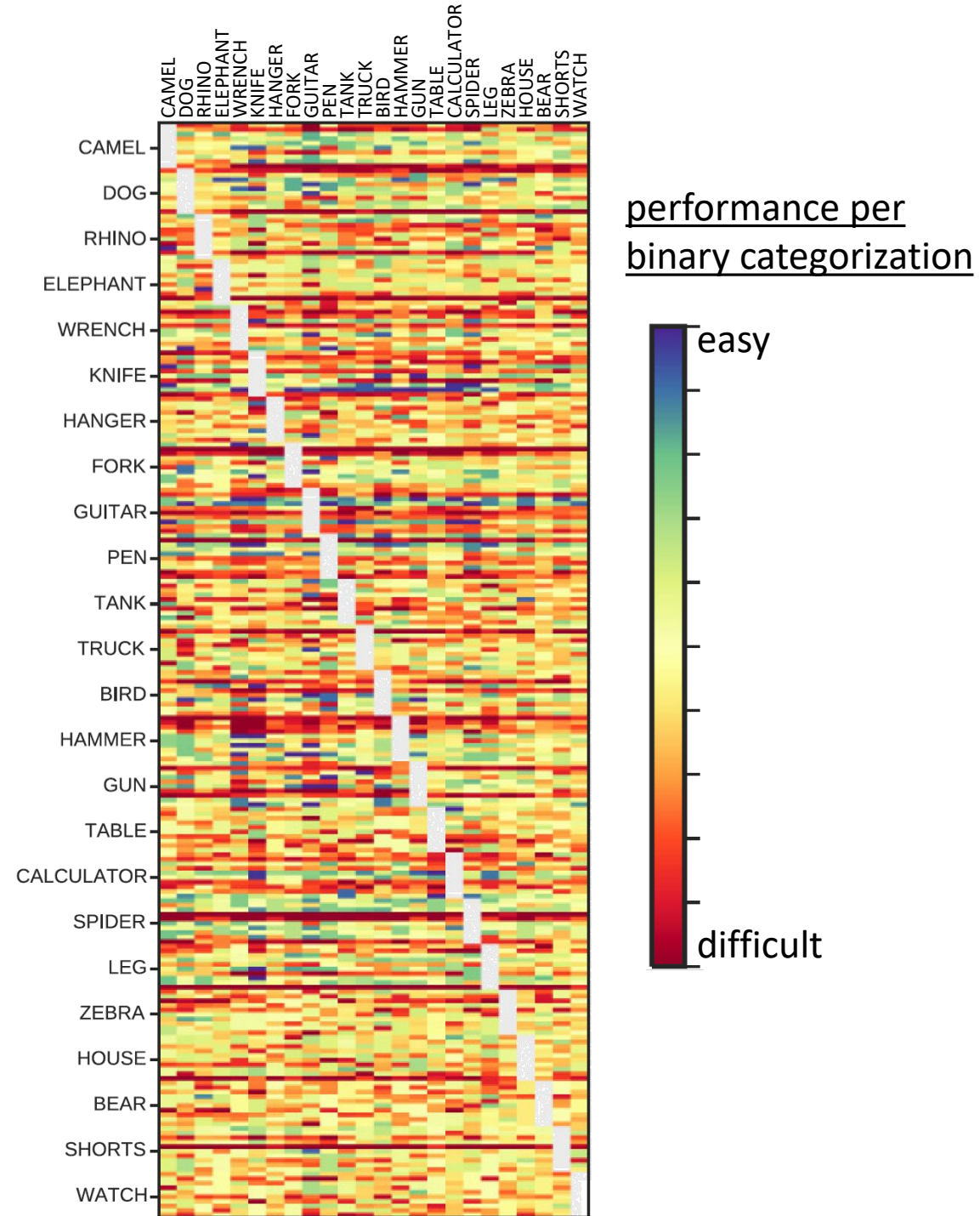


# Behavioral data

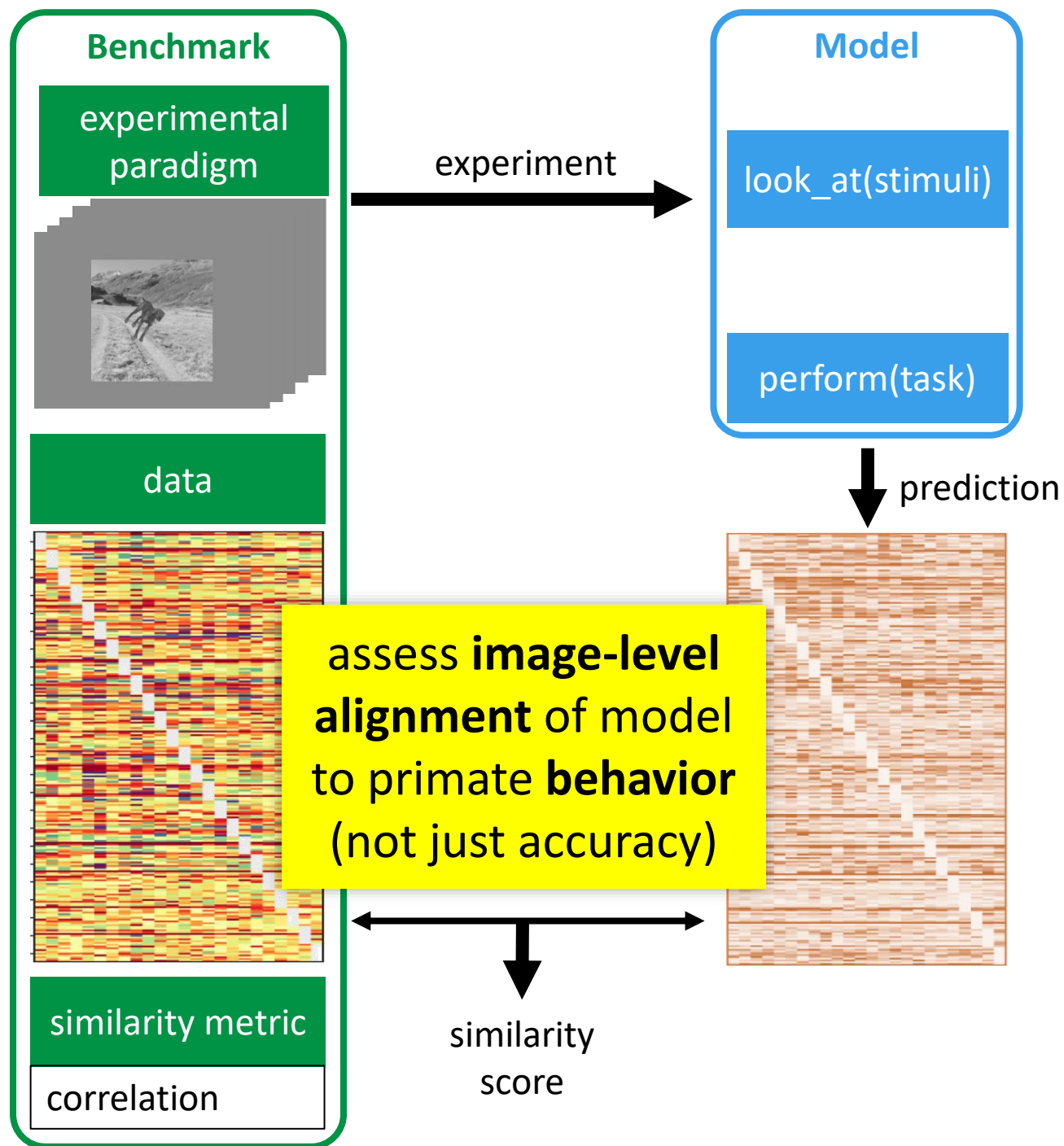


# Behavioral data

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



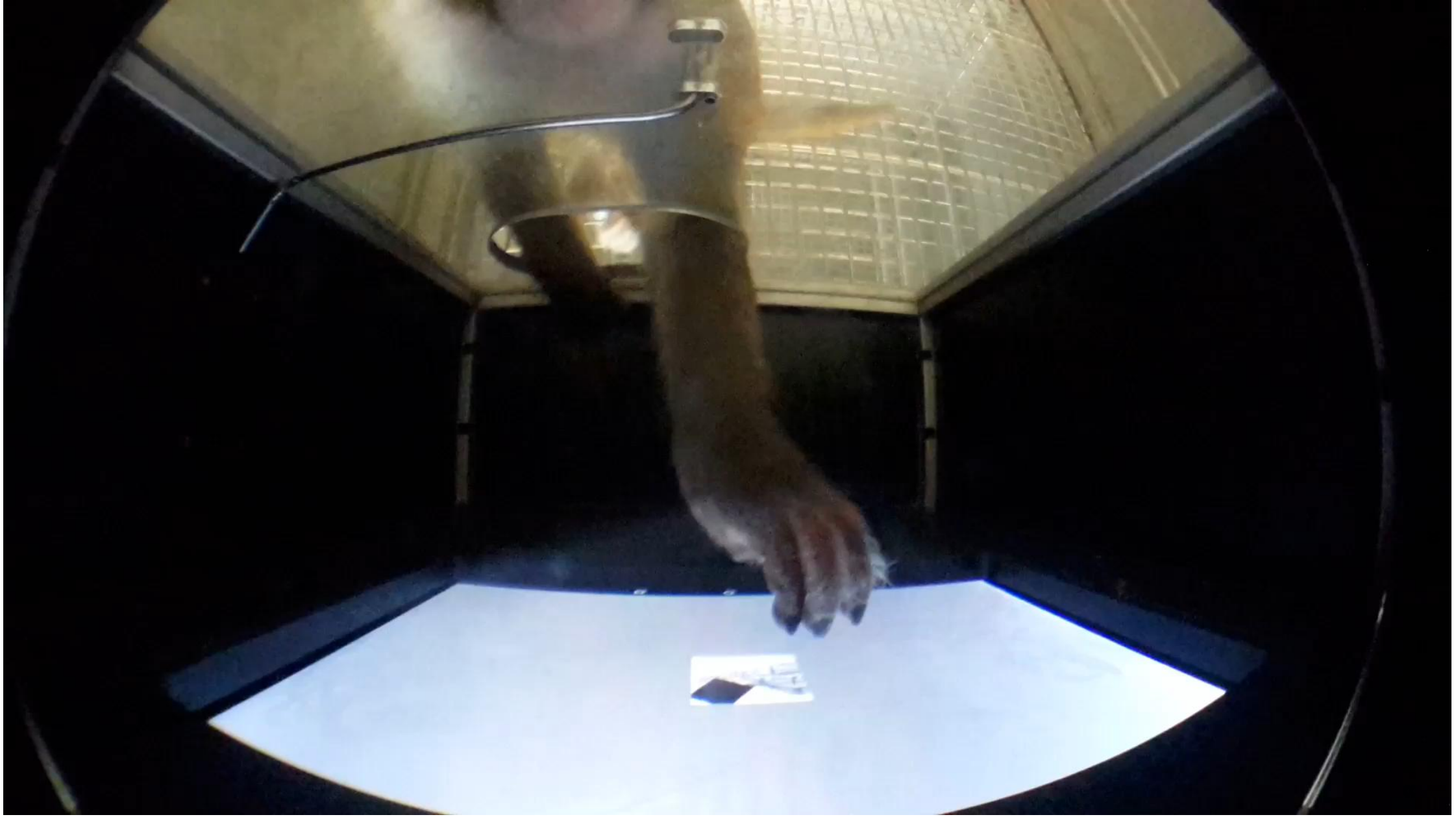
# Behavioral benchmark





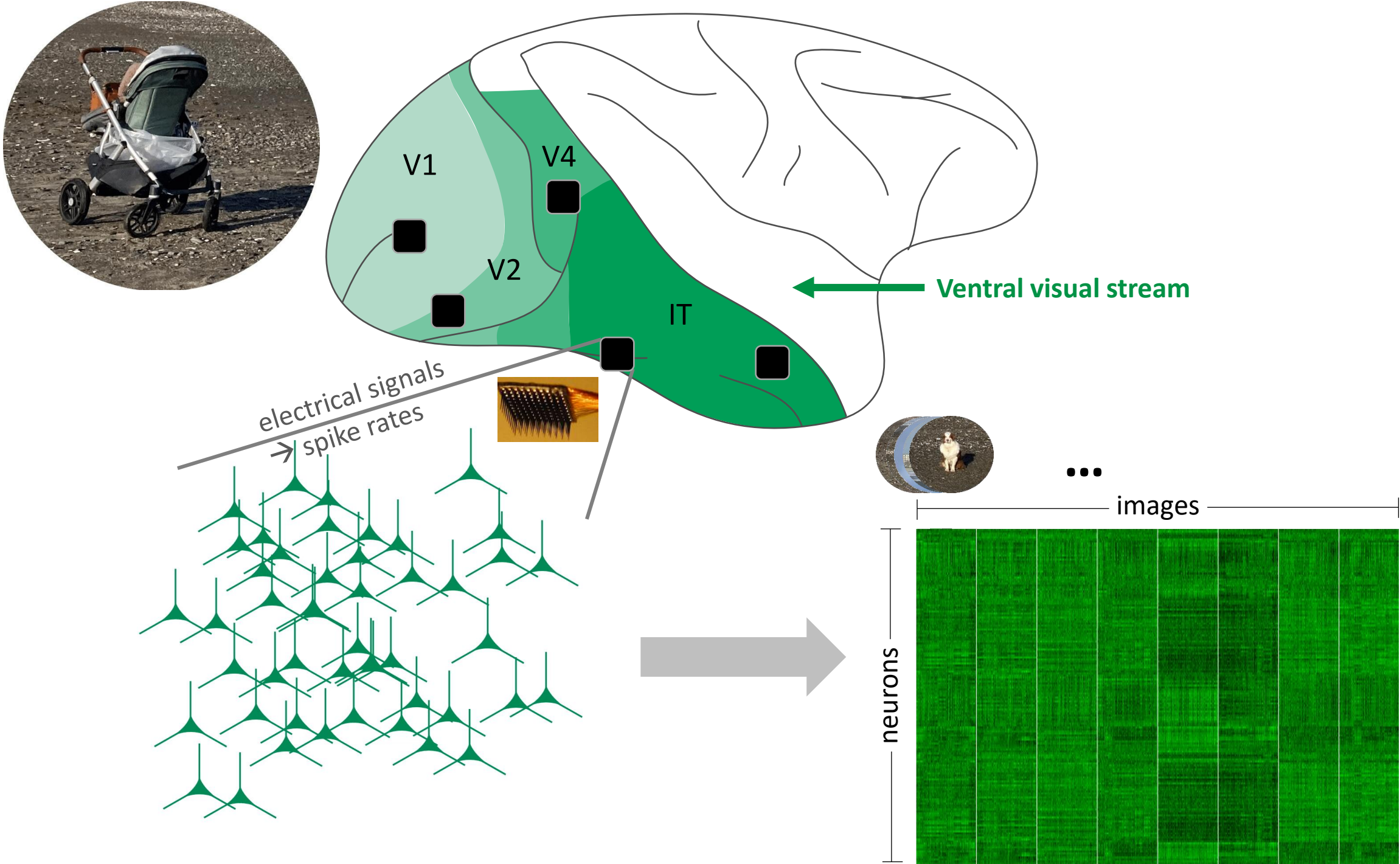
Neural data

# Neural data

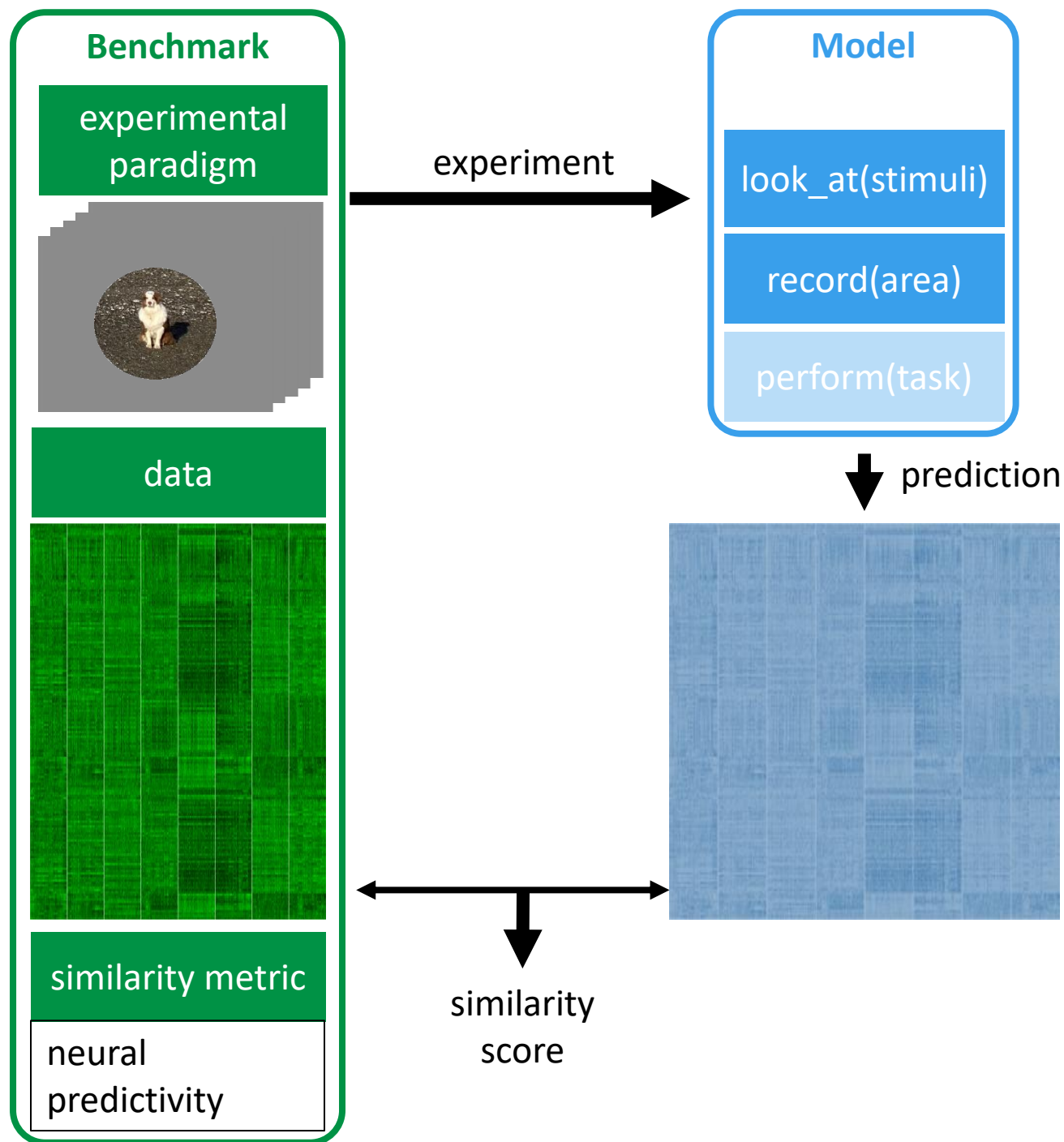


video courtesy of Kailyn Schmidt

# Neural data

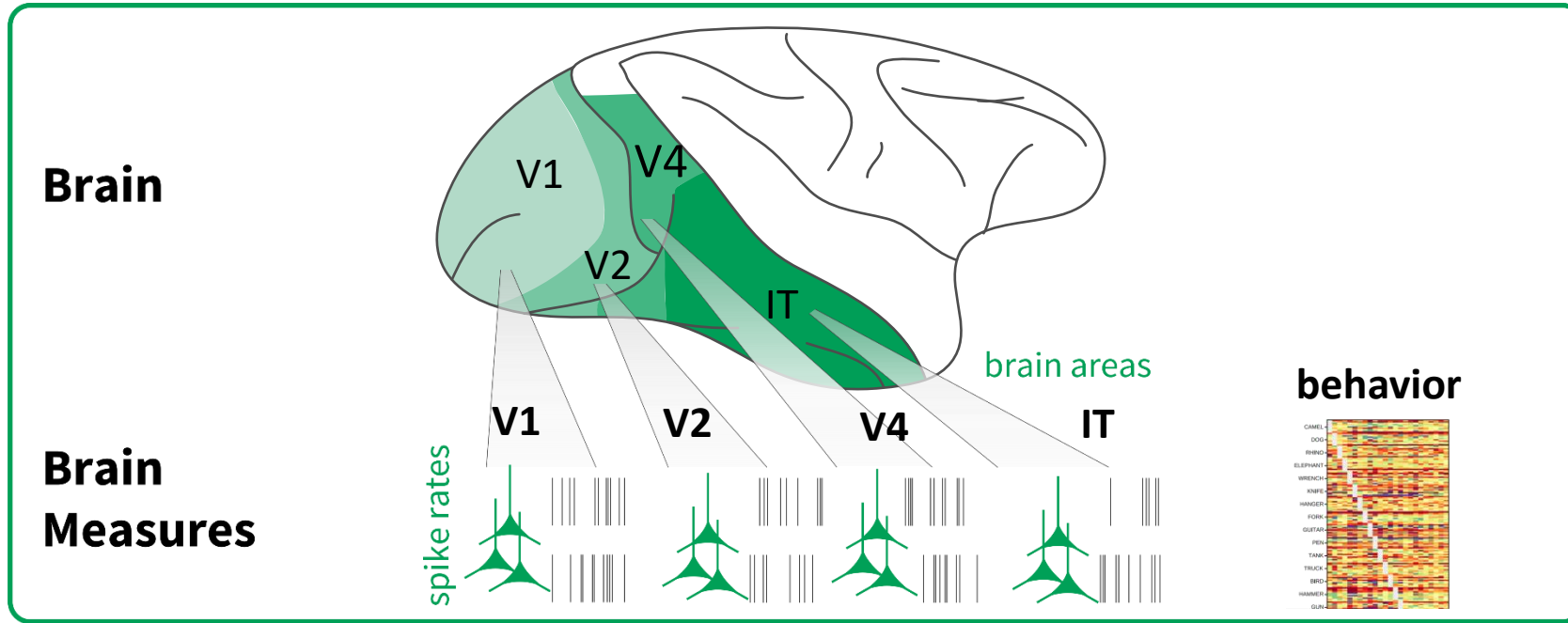


# Neural benchmark



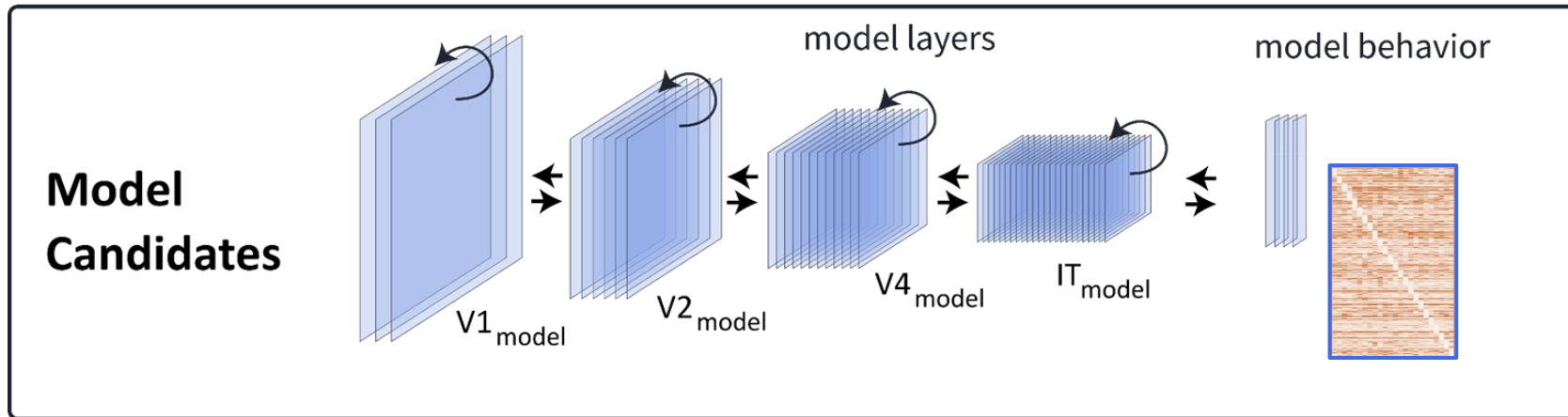


# Integrative testing of models on brain + behavioral data



**One model to  
predict *all* data  
(not piecewise efforts)**

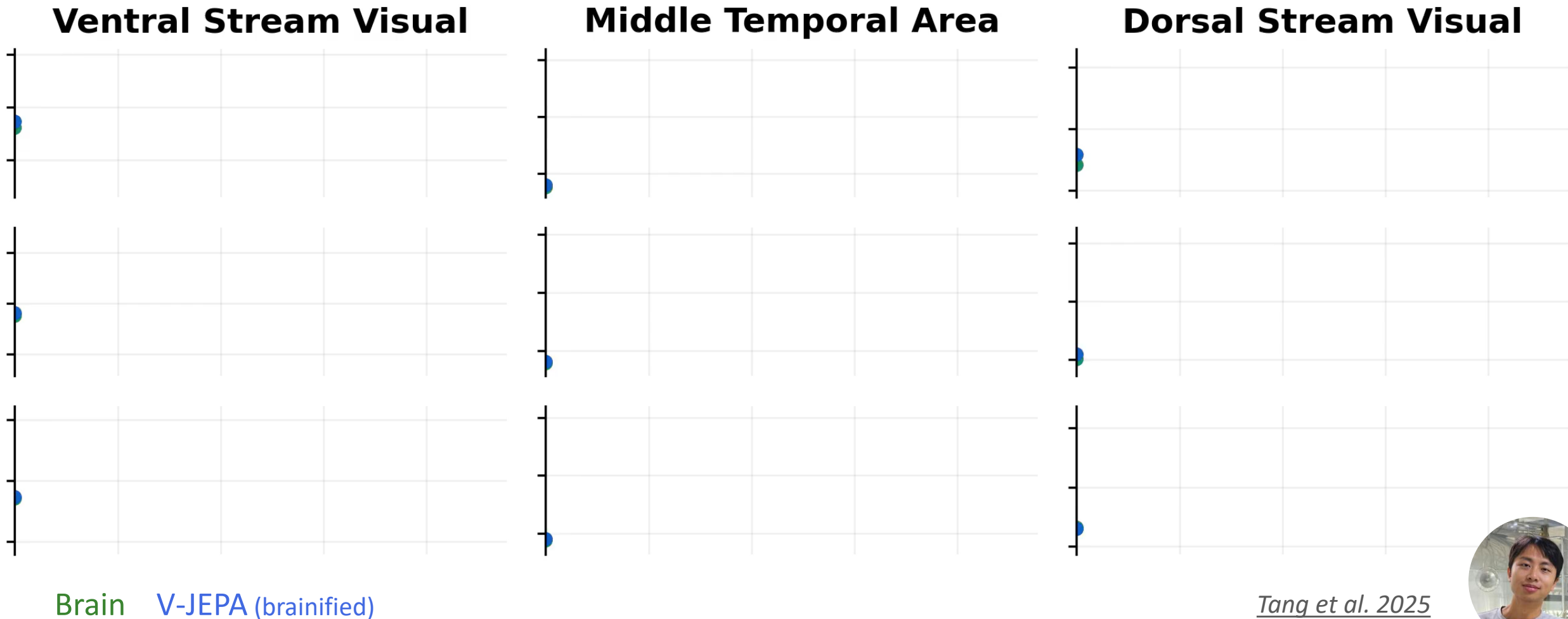
 **Brain-Score  
Benchmarks**



## Artificial neural network models

- Trained for computational task, weights optimized via backprop (*not trained on brain data*)
- Internal processing stages (hidden layers, “deep” learning)
- Accept any new input (pixels)

# SOTA ML models predict brain activity with high fidelity

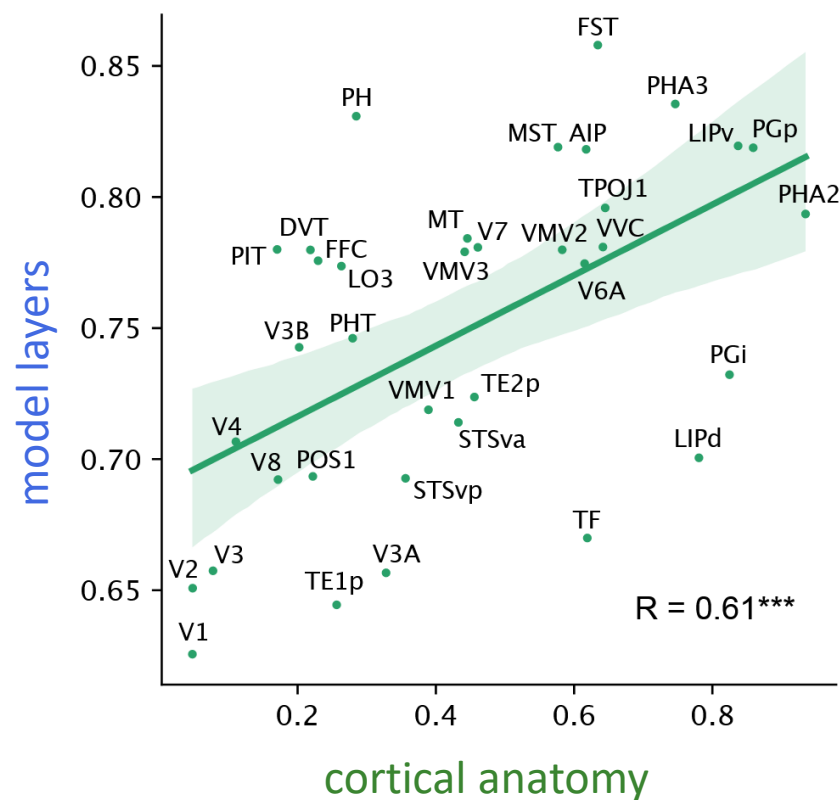


*Tang et al. 2025*

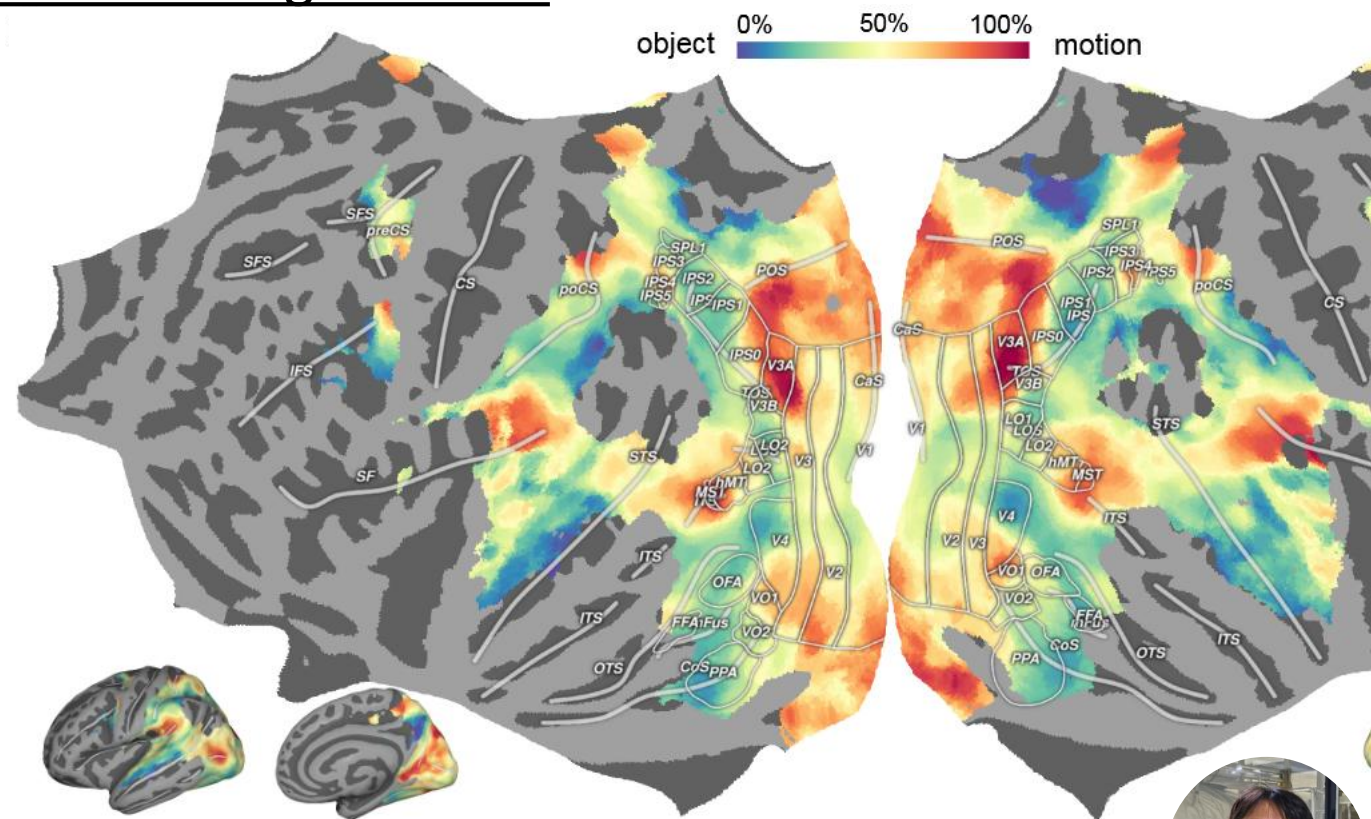


# SOTA ML models predict brain activity with high fidelity

## Anatomical hierarchy



## Functional organization



# Integrative Benchmarking on Brain-Score

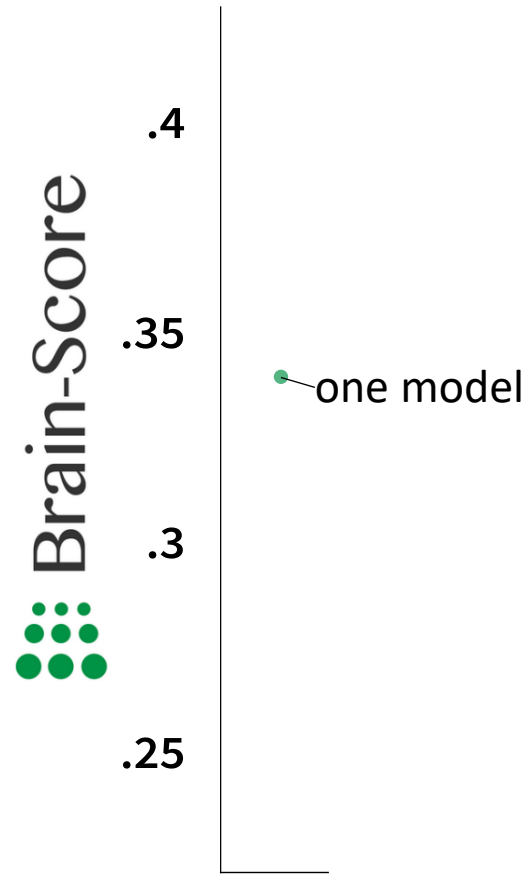
100+ brain & behavior benchmarks



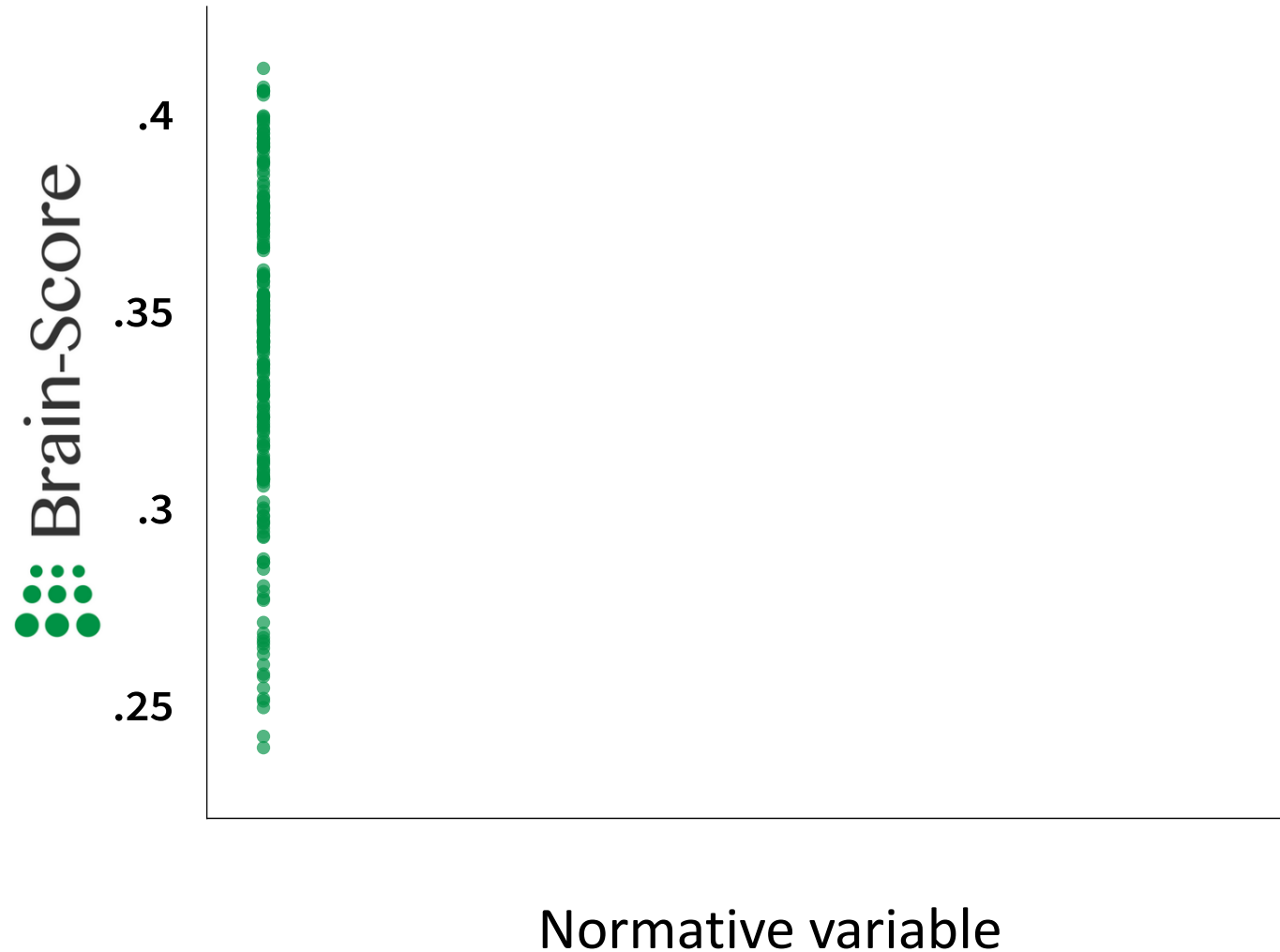
| Rank |   |                      | Model<br>submitted by | average | → V1_23 benchmark | → Freemanzlmba2013-V1-pls | → Marque2020-22 benchmark | → V1orientation 7 benchmark | → V1phi-alpha frequency 3 benchmark | → V1response_selectivity 4 benchmark | → V1receptive_field_size 2 benchmark | → V1curvature_modulation 1 benchmark | → V1response_magnitude 3 benchmarks | → Freemanzlmba2013-V2-pls | → MalayJong2015-V4-pls | → Sangheav2020-V4-pls | → Sangheav2020-V4-pls | → SangheavMung2020-V4-pls | → IT_5 benchmark | → MalayJong2015-IT-pls | → Ker2019-set | → Sangheav2020-IT-pls | → SangheavKowak2020-IT-pls | → SangheavMung2020-IT-pls | → behavior | → Rajalingham2018-dn | → GeInfo2021-error_consistency | → GeInfo2021-colour-error_cons | → GeInfo2021-format-error_cons | → GeInfo2021-trueconflict-error_c | → GeInfo2021-ledg-error_cons | → GeInfo2021-led-onl-lemp_cons | → GeInfo2021-led-onl-lemp_con | → GeInfo2021-false-al-outlet-error_co | → GeInfo2021-high-pass-error_cons | → GeInfo2021-low-pass-error_cons | → GeInfo2021-phase-amplitude | → GeInfo2021-power-equivalence | → GeInfo2021-rotation-error_cons | → GeInfo2021-houghette-error_co | → GeInfo2021-select-error_cons | → GeInfo2021-relayed-temp_L_cons | → GeInfo2021-uniform-noise-error | → engineering_23 benchmarks |      |      |     |
|------|---|----------------------|-----------------------|---------|-------------------|---------------------------|---------------------------|-----------------------------|-------------------------------------|--------------------------------------|--------------------------------------|--------------------------------------|-------------------------------------|---------------------------|------------------------|-----------------------|-----------------------|---------------------------|------------------|------------------------|---------------|-----------------------|----------------------------|---------------------------|------------|----------------------|--------------------------------|--------------------------------|--------------------------------|-----------------------------------|------------------------------|--------------------------------|-------------------------------|---------------------------------------|-----------------------------------|----------------------------------|------------------------------|--------------------------------|----------------------------------|---------------------------------|--------------------------------|----------------------------------|----------------------------------|-----------------------------|------|------|-----|
| 1    | effnetb1_outmixpatch_augmix_robust32_avgx4e7_manylayers_324x288 | Alexander Riedel     | 463                   | 568     | 379               | 757                       | 822                       | 822                         | 714                                 | 822                                  | 816                                  | 822                                  | 822                                 | 360                       | 360                    | 461                   | 603                   | 641                       | 481              | 198                    | 412           | 539                   | X                          | 580                       | 532        | 426                  | 495                            | 652                            | 338                            | -448                              | 218                          | -228                           | -112                          | 881                                   | 592                               | -482                             | 542                          | -122                           | 242                              | 349                             | 214                            | 351                              | 829                              | -129                        | 320  | -148 | 335 |
| 2    | resnext101_32x8d_vsl  | Martin Schrimpf      | 445                   | 476     | 271               | 632                       | 879                       | 822                         | 822                                 | 428                                  | 879                                  | 829                                  | 879                                 | 312                       | 312                    | 487                   | 536                   | 646                       | 502              | 212                    | 386           | 481                   | X                          | 516                       | 504        | 428                  | 563                            | 581                            | 376                            | 888                               | 821                          | 840                            | 816                           | 828                                   | 824                               | 387                              | 881                          | -178                           | 382                              | 382                             | -452                           | 321                              | 688                              | -423                        | 886  | 827  | 645 |
| 3    | resnet50_finetune_outmix_e3_robust_linf8255_e0_247x234          | Alexander Riedel     | 444                   | 584     | 384               | 774                       | 878                       | 822                         | 822                                 | 822                                  | 817                                  | 822                                  | 872                                 | 362                       | 362                    | 472                   | 567                   | 642                       | 477              | 201                    | 364           | 519                   | X                          | 484                       | 466        | 352                  | 441                            | 548                            | 332                            | -479                              | -112                         | 218                            | -187                          | 828                                   | 828                               | 874                              | -423                         | 382                            | 218                              | 219                             | -197                           | -422                             | 848                              | -142                        | 320  | -248 | 283 |
| 4    | effnetb1_272x240  | Alexander Riedel     | 439                   | 487     | 254               | 720                       | 788                       | 822                         | 724                                 | 822                                  | 448                                  | 821                                  | 821                                 | 334                       | 334                    | 494                   | 578                   | 643                       | 521              | 254                    | 381           | 530                   | X                          | 542                       | 500        | 336                  | 496                            | 548                            | 443                            | 782                               | 822                          | 387                            | -274                          | 814                                   | -428                              | -488                             | 887                          | -288                           | 487                              | 327                             | 328                            | 388                              | 814                              | 382                         | 852  | 388  | 551 |
| 5    | custom_model_ov_18_dagger_408                                   | William Bernos       | 436                   | 493     | 290               | 636                       | 774                       | 822                         | 822                                 | 481                                  | 777                                  | 819                                  | 828                                 | 342                       | 342                    | 514                   | 603                   | 669                       | 540              | 243                    | 425           | 561                   | X                          | 386                       | 553        | 453                  | 402                            | 582                            | 242                            | 348                               | -244                         | -228                           | -122                          | 812                                   | -421                              | -224                             | 388                          | 388                            | 188                              | -128                            | -148                           | -428                             | 322                              | -112                        | 219  | -287 | 407 |
| 6    | resnet-152_v2   | Brain-Score Team     | 432                   | 495     | 274               | 716                       | 828                       | 722                         | 828                                 | 872                                  | 812                                  | 828                                  | 812                                 | 328                       | 328                    | 485                   | 591                   | 635                       | 469              | 247                    | 382           | 532                   | X                          | 532                       | 478        | 370                  | 473                            | 528                            | 417                            | 721                               | 728                          | -428                           | -127                          | 822                                   | 822                               | -488                             | 824                          | -122                           | 388                              | 348                             | 328                            | 328                              | 847                              | 320                         | 888  | 388  | 538 |
| 7    | voneresnet50-non_stochastic                                     | Tiago Marques        | 430                   | 565     | 387               | 751                       | 822                       | 824                         | 788                                 | 818                                  | 377                                  | 824                                  | 828                                 | 328                       | 328                    | 484                   | 584                   | 632                       | 487              | 233                    | 398           | 543                   | X                          | 535                       | 517        | 394                  | 375                            | 530                            | 219                            | 381                               | -142                         | -284                           | -284                          | -417                                  | 288                               | 321                              | 321                          | -222                           | 328                              | 328                             | -128                           | -122                             | 822                              | 327                         | 321  | -122 | 471 |
| 8    | pnasnet_large   | Brain-Score Team     | 427                   | 511     | 284               | 758                       | 822                       | 770                         | 720                                 | 741                                  | 720                                  | 810                                  | 868                                 | 305                       | 305                    | 478                   | 578                   | 623                       | 500              | 212                    | 353           | 526                   | X                          | 503                       | 410        | 326                  | 487                            | 515                            | 480                            | 818                               | 817                          | 327                            | -128                          | 884                                   | 877                               | 828                              | 822                          | -128                           | 328                              | 381                             | 288                            | 387                              | 810                              | 322                         | 879  | -472 | 582 |
| 9    | resnet-152_v1   | Brain-Score Team     | 427                   | 524     | 282               | 766                       | 824                       | 782                         | 781                                 | 840                                  | 388                                  | 881                                  | 882                                 | 338                       | 338                    | 498                   | 598                   | 646                       | 502              | 247                    | 397           | 553                   | X                          | 549                       | 529        | 354                  | 378                            | 533                            | 219                            | 373                               | -122                         | -182                           | -288                          | -428                                  | -428                              | 384                              | -428                         | 218                            | -12                              | -122                            | 822                            | 327                              | 321                              | -122                        | 471  |      |     |
| 10   | AdvProp_efficientnet-b6   | Joel Dapello         | 426                   | 504     | 281               | 728                       | 822                       | 722                         | 727                                 | 588                                  | 872                                  | 841                                  | 784                                 | 353                       | 353                    | 486                   | 587                   | 643                       | 482              | 220                    | 401           | 553                   | X                          | 555                       | 554        | 342                  | 386                            | 448                            | 324                            | 548                               | -178                         | -218                           | -128                          | 822                                   | 888                               | 888                              | 328                          | 214                            | 221                              | -122                            | -187                           | -182                             | 812                              | -142                        | -482 | -421 | 577 |
| 11   | nasnet_large  | Brain-Score Team     | 426                   | 536     | 282               | 791                       | 828                       | 888                         | 887                                 | 828                                  | 781                                  | 888                                  | 888                                 | 291                       | 291                    | 472                   | 585                   | 627                       | 480              | 198                    | 385           | 541                   | X                          | 532                       | 483        | 370                  | 443                            | 470                            | 415                            | 788                               | 888                          | 388                            | -118                          | -488                                  | 822                               | -442                             | 728                          | 271                            | 328                              | 329                             | 348                            | 328                              | 728                              | -182                        | 553  | -418 | 587 |
| 12   | resnet-50_v2  | Brain-Score Team     | 424                   | 505     | 270               | 740                       | 827                       | 824                         | 714                                 | 828                                  | 818                                  | 822                                  | 848                                 | 323                       | 323                    | 489                   | 596                   | 644                       | 482              | 233                    | 388           | 520                   | X                          | 536                       | 503        | 378                  | 418                            | 531                            | 304                            | 887                               | 881                          | 382                            | 388                           | 278                                   | -418                              | 342                              | -448                         | 327                            | 322                              | -188                            | -188                           | -188                             | 487                              | -148                        | -428 | -284 | 504 |
| 13   | resnet-101_v1   | Brain-Score Team     | 422                   | 492     | 266               | 719                       | 822                       | 770                         | 827                                 | 818                                  | 887                                  | -482                                 | 824                                 | 341                       | 341                    | 493                   | 590                   | 648                       | 506              | 229                    | 401           | 549                   | X                          | 548                       | 520        | 390                  | 383                            | 561                            | 205                            | 422                               | 218                          | -188                           | 382                           | 382                                   | 382                               | 382                              | 328                          | 284                            | 188                              | 384                             | 278                            | -148                             | -482                             | 284                         | -127 | -241 | 496 |
| 14   | resnet50-SIN_IN_IN  | Brain-Score Team     | 422                   | 516     | 275               | 758                       | 828                       | 828                         | 828                                 | 848                                  | 827                                  | 888                                  | 828                                 | 321                       | 321                    | 490                   | 596                   | 651                       | 510              | 202                    | 402           | 548                   | X                          | 539                       | 514        | 411                  | 379                            | 523                            | 235                            | -484                              | 228                          | 328                            | -288                          | -422                                  | 312                               | -312                             | 387                          | 380                            | -128                             | 879                             | -122                           | -182                             | -482                             | -114                        | 274  | -182 | 501 |
| 15   | resnet50-sup  | Nikhil Parthasarathy | 421                   | 527     | 278               | 775                       | 824                       | 822                         | 874                                 | 827                                  | 822                                  | 814                                  | 828                                 | 320                       | 320                    | 492                   | 602                   | 656                       | 510              | 200                    | 387           | 538                   | X                          | 536                       | 480        | 378                  | 381                            | 528                            | 235                            | -474                              | 221                          | 328                            | 388                           | -428                                  | 328                               | 321                              | 328                          | 322                            | 188                              | -118                            | -288                           | -184                             | 548                              | -122                        | 284  | -184 | 140 |
| 16   | densenet-201  | Brain-Score Team     | 421                   | 493     | 277               | 710                       | 822                       | 888                         | 881                                 | 821                                  | 741                                  | 822                                  | 788                                 | 325                       | 325                    | 488                   | 599                   | 655                       | 473              | 224                    | 397           | 545                   | X                          | 547                       | 494        | 390                  | 404                            | 537                            | 271                            | -479                              | 322                          | 322                            | -112                          | -448                                  | -422                              | 382                              | 382                          | 278                            | -187                             | -188                            | -112                           | -181                             | -428                             | -118                        | 388  | 272  | 526 |
| 17   | effnetb1_outmix_augmix_sam_e1_5avg_424x377                      | Alexander Riedel     | 421                   | 482     | 242               | 722                       | 822                       | 788                         | 824                                 | 784                                  | 810                                  | 888                                  | 778                                 | 291                       | 291                    | 499                   | 605                   | 650                       | 487              | 282                    | 381           | 558                   | X                          | 535                       | 448        | 364                  | 452                            | 564                            | 241                            | 370                               | -142                         | -122                           | -128                          | 388                                   | 378                               | -418                             | 822                          | -142                           | 128                              | -179                            | -118                           | 822                              | 382                              | -124                        | -181 | -242 | 298 |
| 18   | AdvProp_efficientnet-b7   | Joel Dapello         | 421                   | 504     | 275               | 733                       | 878                       | 788                         | 718                                 | 827                                  | 828                                  | 828                                  | 822                                 | 341                       | 341                    | 480                   | 581                   | 642                       | 482              | 218                    | 403           | 547                   | X                          | 582                       | 552        | 351                  | 375                            | 445                            | 305                            | 821                               | -128                         | 328                            | 382                           | 848                                   | 578                               | 828                              | -424                         | 322                            | 322                              | -188                            | -182                           | -122                             | -487                             | -118                        | -427 | 382  | 585 |
| 19   | resnet-50-robust  | Joel Dapello         | 418                   | 584     | 378               | 810                       | 888                       | 818                         | 788                                 | 781                                  | 840                                  | 727                                  | 874                                 | 365                       | 365                    | 437                   | 537                   | 552                       | 447              | 211                    | 386           | 486                   | X                          | 507                       | 560        | 379                  | 308                            | 515                            | -102                           | -184                              | -112                         | -121                           | 388                           | 342                                   | 328                               | -278                             | 284                          | 288                            | -122                             | -229                            | 282                            | 288                              | -148                             | 320                         | 284  | 288  | 361 |
| 20   | resnet_SIN_IN_FT_IN   | Simone Azeglio       | 417                   | 523     | 291               | 756                       | 822                       | 774                         | 728                                 | 824                                  | 877                                  | 888                                  | 884                                 | 321                       | 321                    | 490                   | 596                   | 651                       | 510              | 202                    | 383           | 532                   | X                          | 538                       | 472        | 376                  | 387                            | 499                            | 235                            | -484                              | 228                          | 328                            | -288                          | -422                                  | 312                               | -312                             | 387                          | 380                            | -128                             | 879                             | -122                           | -182                             | -482                             | -114                        | 274  | -182 | 492 |
| 21   | resnet-50_v1  |                      | 416                   | 511     | 274               | 718                       | 828                       | 722                         | 828                                 | 872                                  | 812                                  | 828                                  | 812                                 | 328                       | 328                    | 485                   | 591                   | 635                       | 469              | 247                    | 382           | 532                   | X                          | 536                       | 472        | 376                  | 387                            | 528                            | 415                            | 721                               | 728                          | -428                           | -127                          | 822                                   | 822                               | -488                             | 824                          | -122                           | 388                              | 348                             | 328                            | 328                              | 847                              | 320                         | 888  | 388  | 475 |



# What explains the model differences?

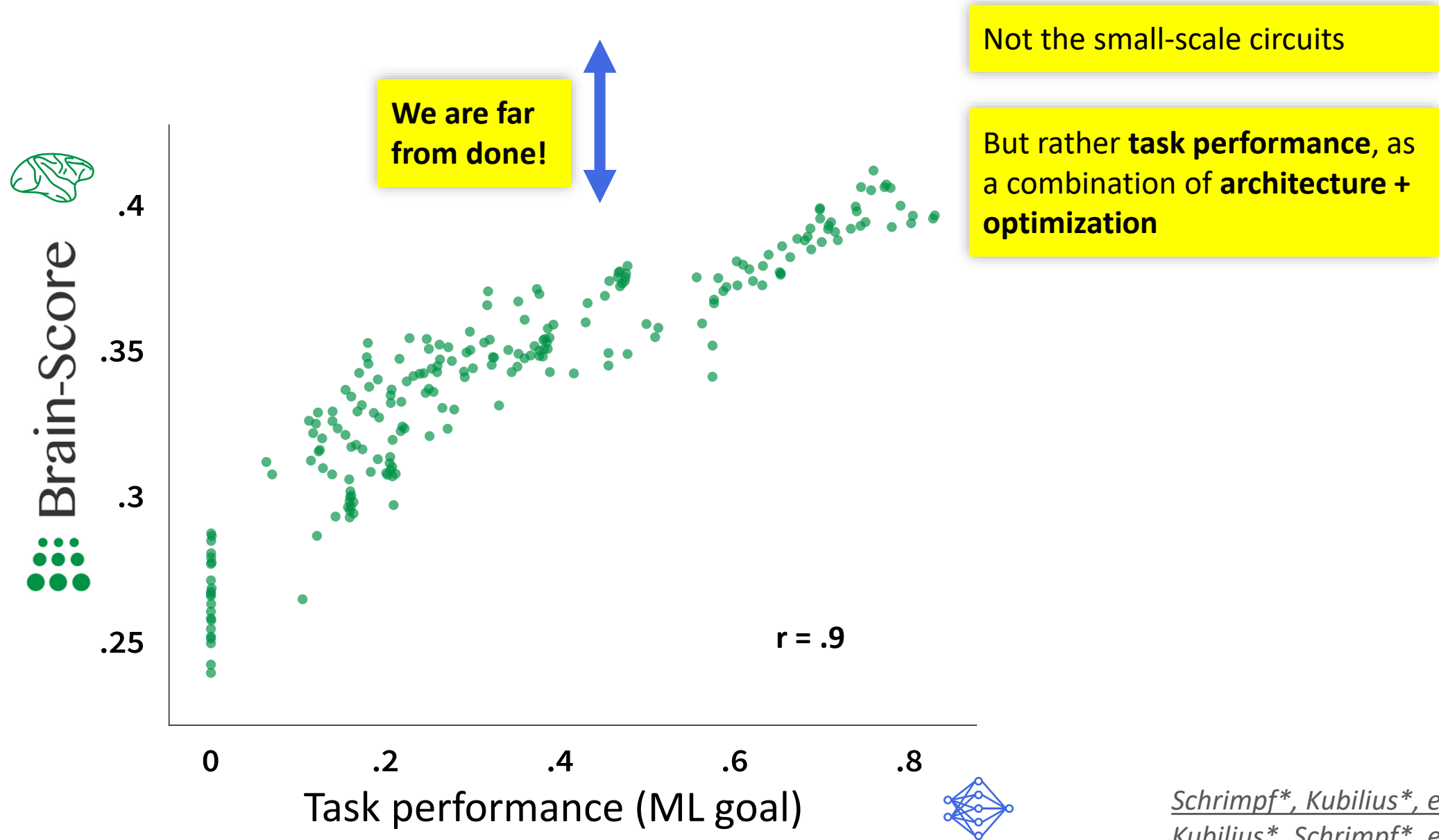


# What explains the model differences?

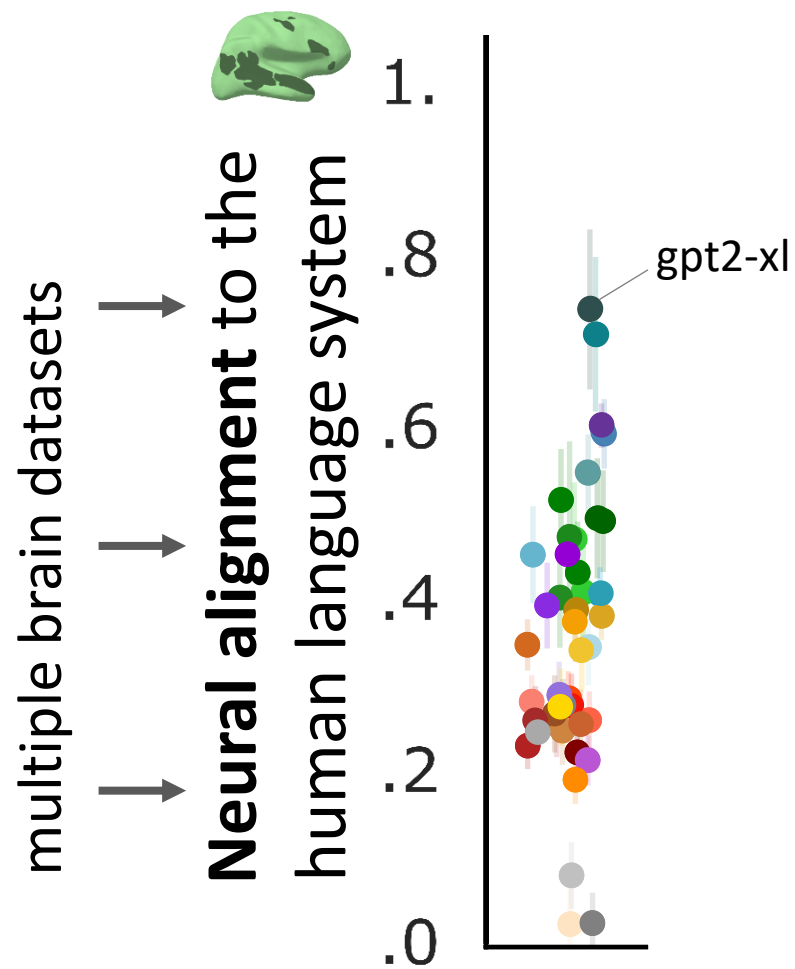


*cf. Yamins\*, Hong\*, et al. 2014*  
*Schrimpf\*, Kumbhani\*, et al. 2018*

# What explains the model differences?

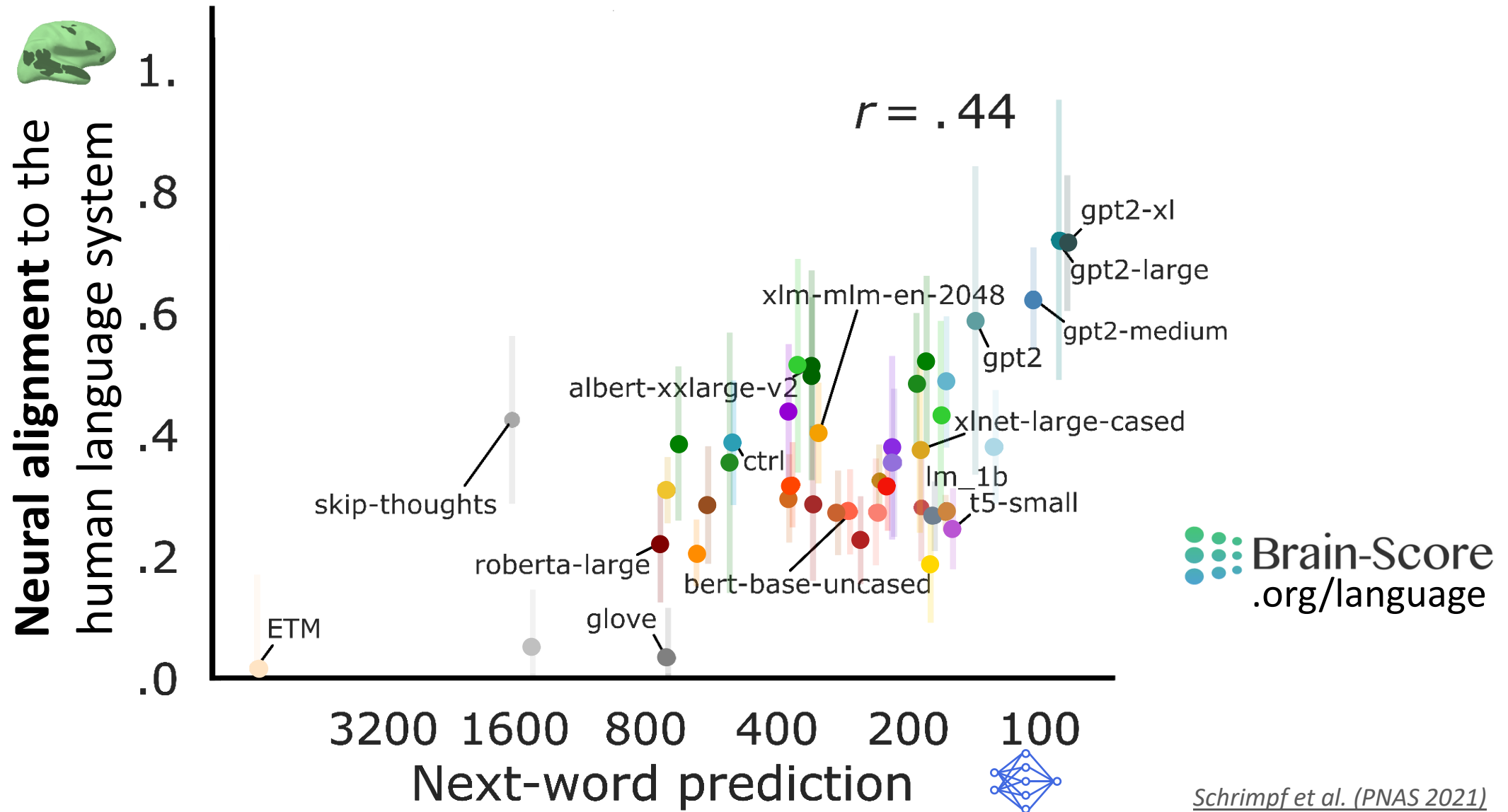


# Particular ML language models predict the human language system





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





"pan" ✓ "pan" ✓



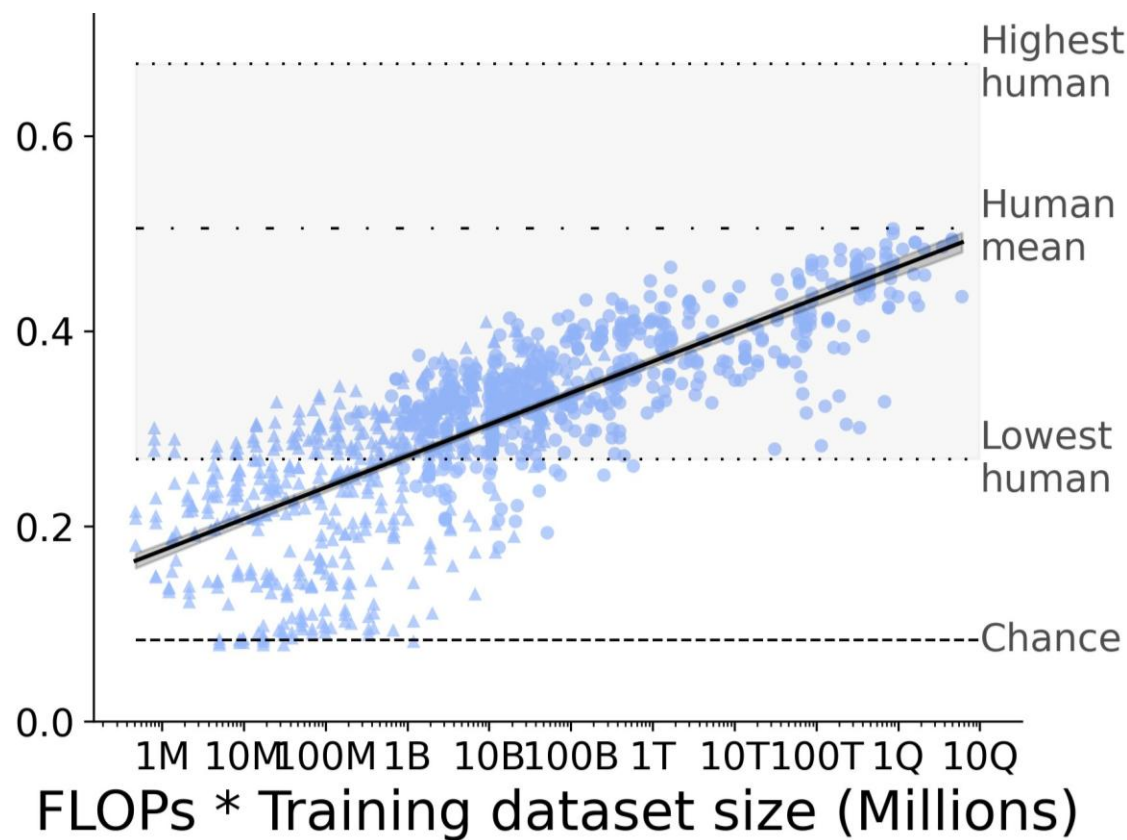
"pan" ✓ "pan" ✓



"pan" ✓ "lamp" ✗



Most models are unable to recognize fragmented images. But increased scale improves behavioral alignment

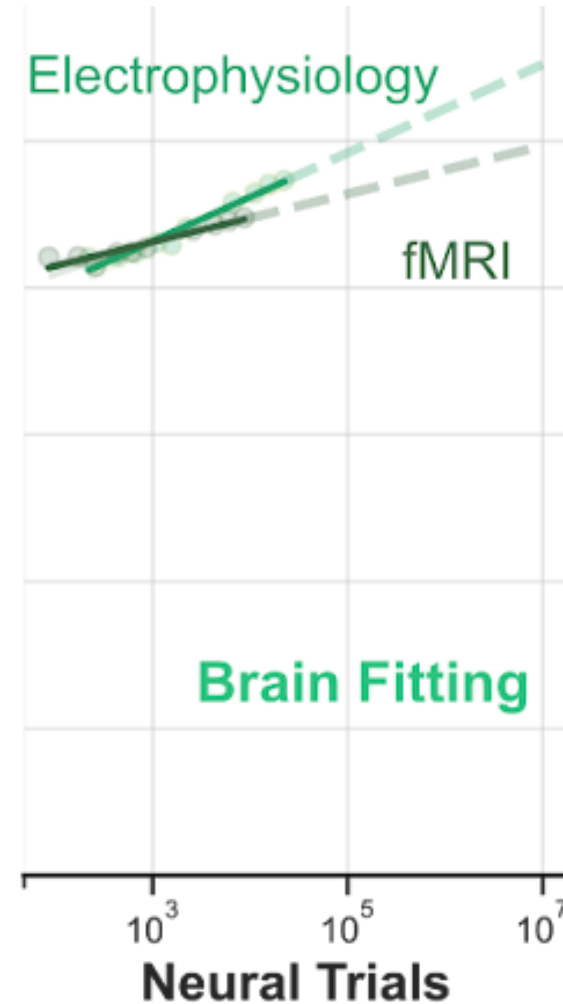
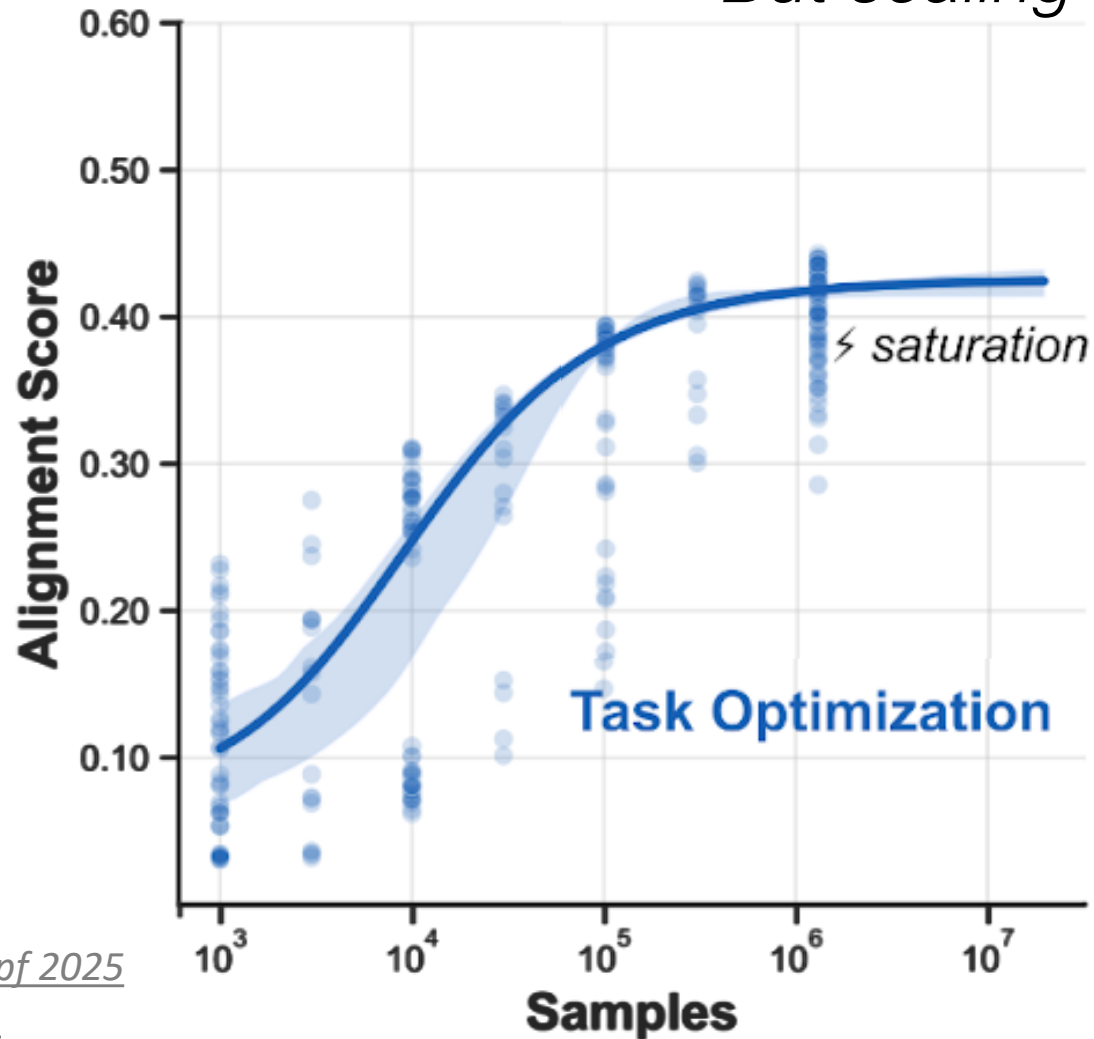


[Lonnqvist et al. 2025 \(ICML\)](#)  
see also [Muttenthaler et al. 2023](#)



# Is ML-like scaling the solution for brain models?

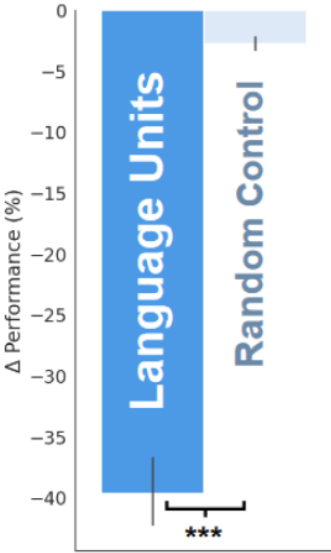
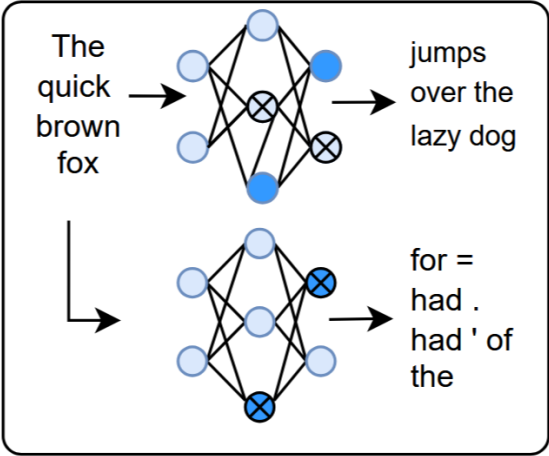
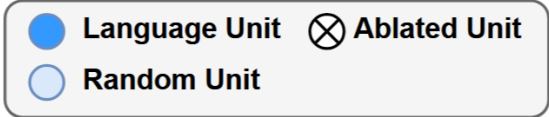
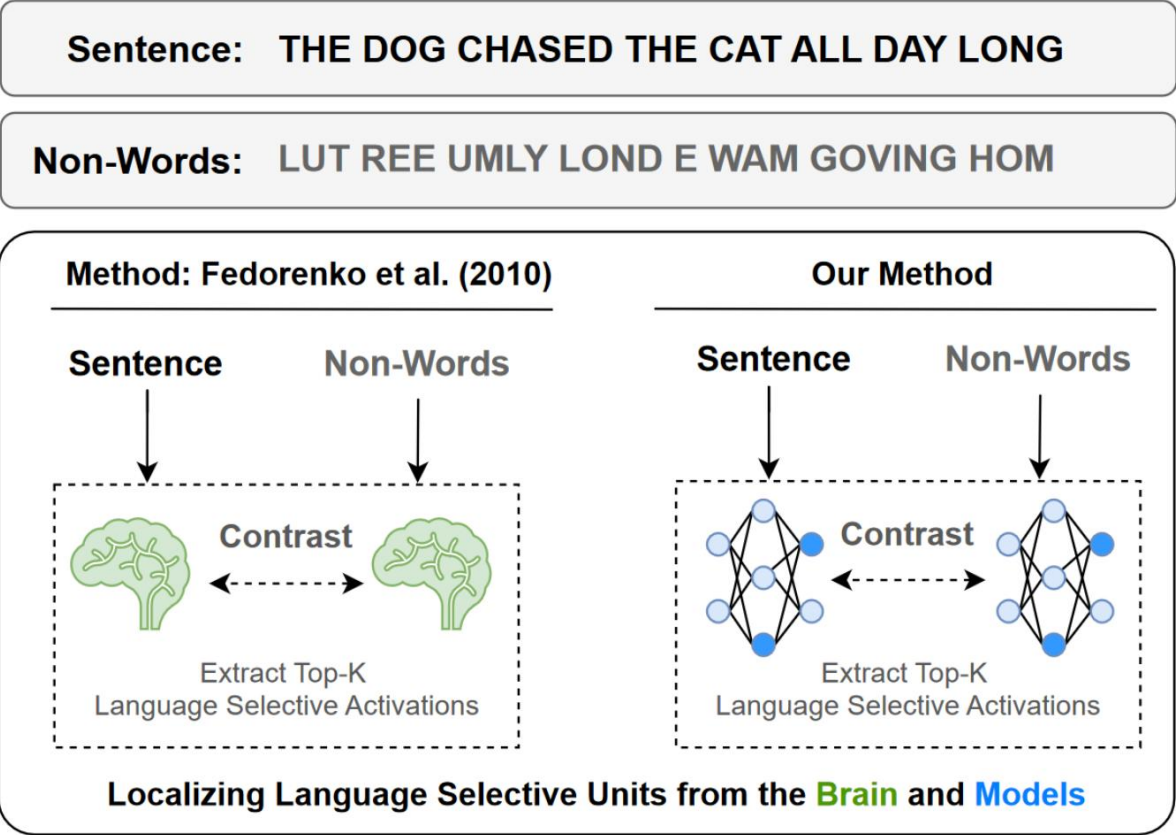
No. *But scaling brain data seems promising.*





1. AI → Neuro: Particular neural network models are state-of-the-art at predicting brain function and human behavior.
2. Neuro → AI: Neuroscience has found very effective ways of identifying network function which are applicable to AI.

# Neuroscience tools identify LLM mechanisms



“The quick brown fox...”

1% of units!

| Model                 | Ablate Language Units       | Ablate Random Units        |
|-----------------------|-----------------------------|----------------------------|
| Gemma-2B              | 11 liquido _ sota(.)uggoon3 | jumped over the lazy lamb. |
| Phi-3.5-Mini-Instruct | AME.AME and:ough.. MAR      | jumps over the lazy dog.   |
| Falcon-7b             | SomeSReadWhenISearchSome    | jumps over the lazy dog.   |
| Mistral-7B-v0.3       | foxfool foolfoolfoolfool    | jumps over the lazy dog.   |
| LLaMA-3.1-8B-Instruct | _ of_An_O_of_An_O_of        | jumps over the lazy dog.   |





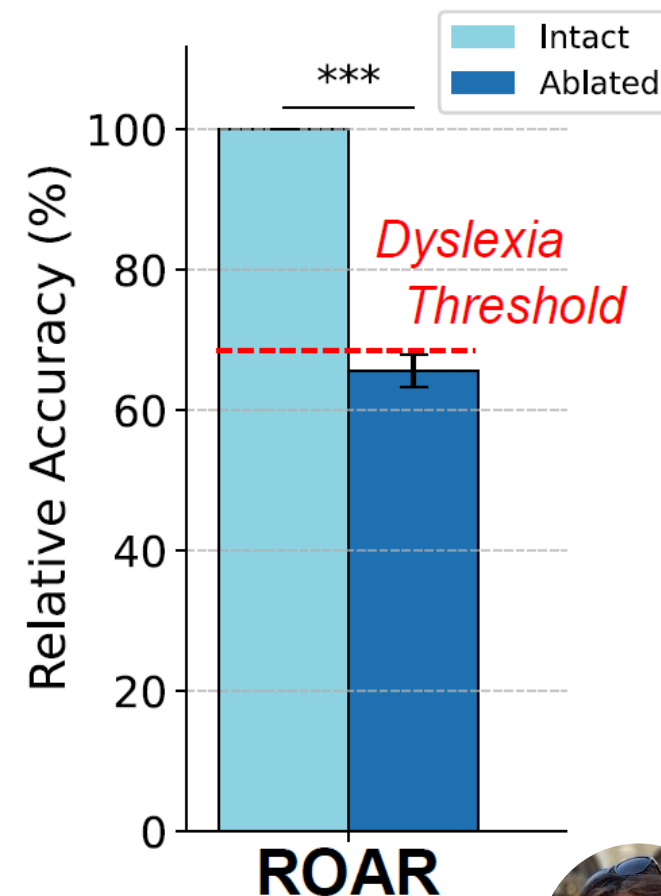
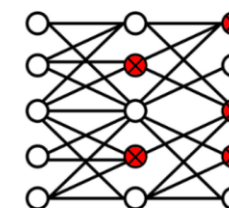
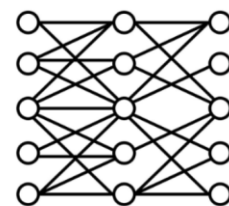
# Localize causal mechanisms of brain disorders (e.g., dyslexia)

Is this a real word?

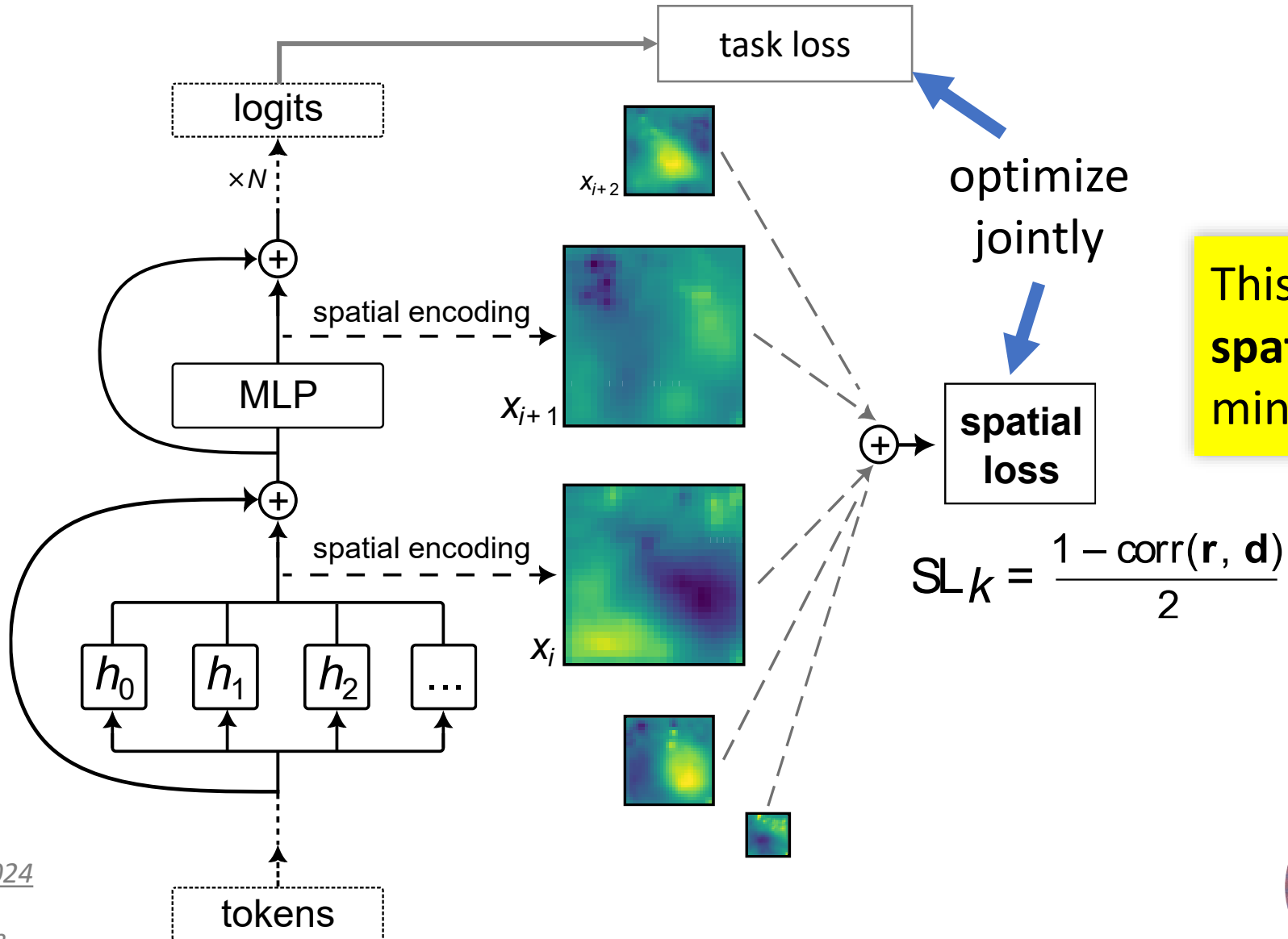
**Ablood**

The word in the image is a pseudo word. "Ablood" is not a real English word with a specific meaning.

I cannot determine whether "Ablood" is a real word or a pseudo word without further context.



# Topographic language models (TopoLM)

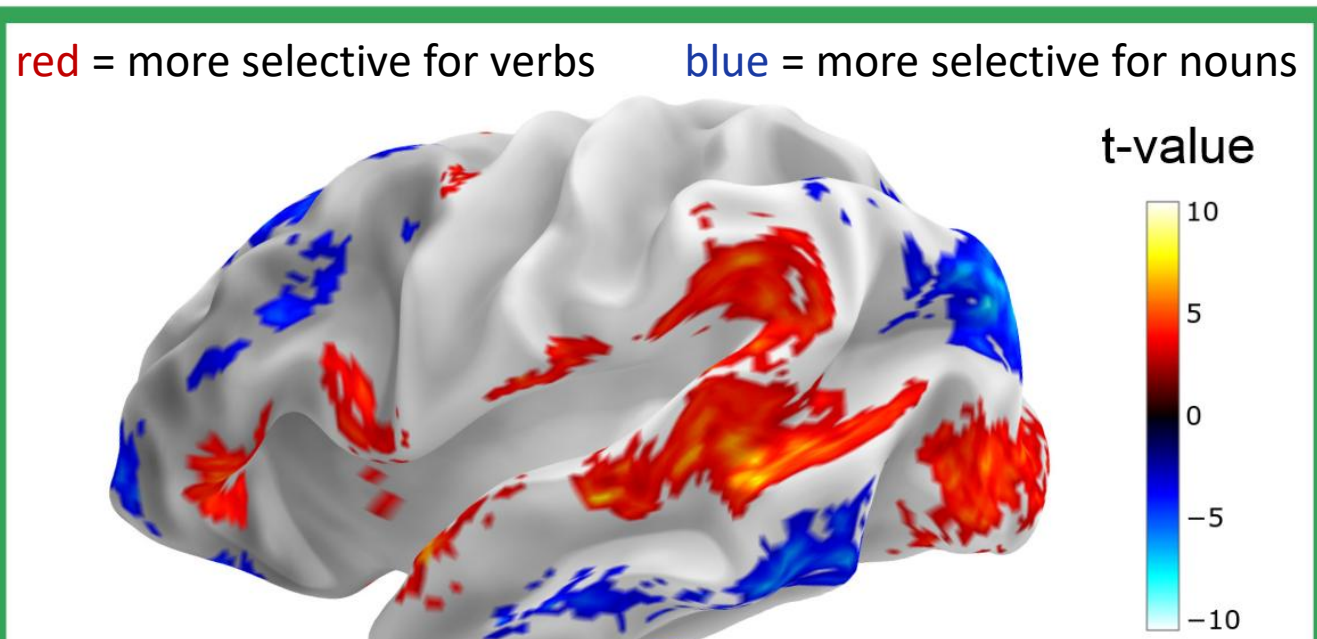


This loss encourages **spatial clustering** → minimizes wiring length

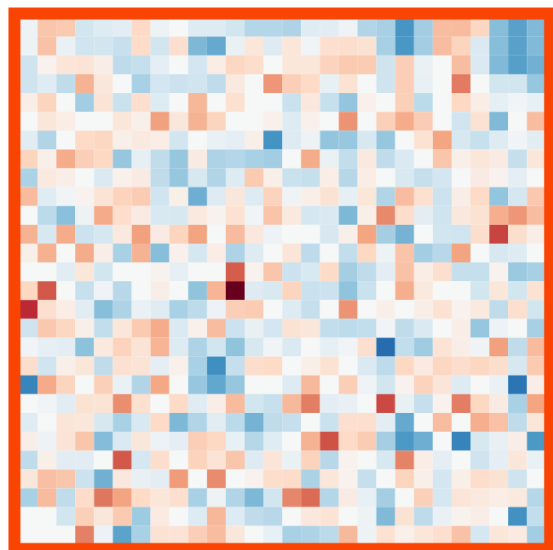


# TopoLM exhibits brain-like clustering of verbs and nouns

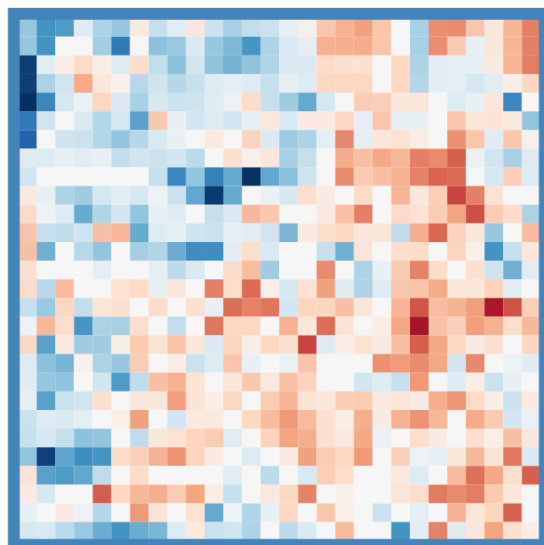
Neural Data — Hauptman et al. 2024



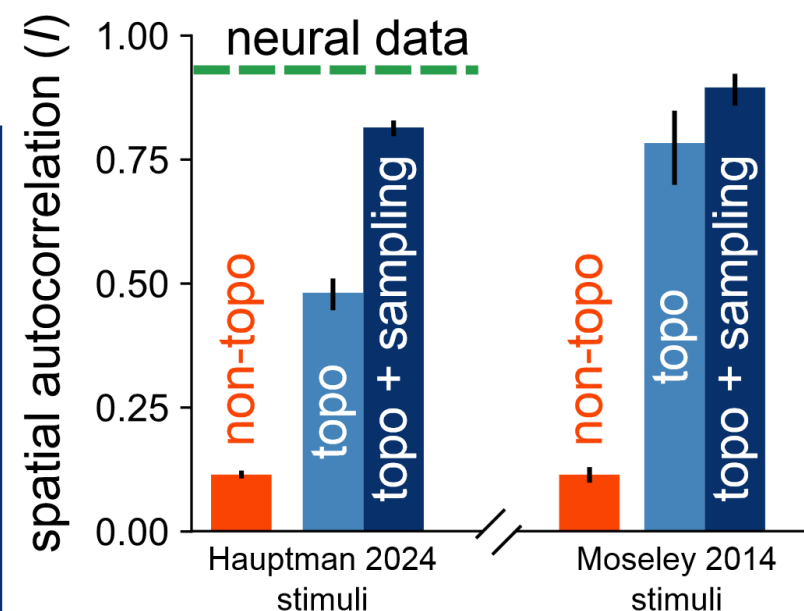
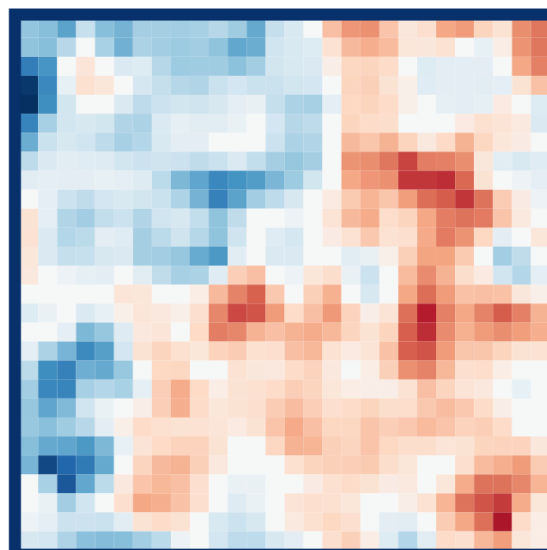
Non-topographic  
no fMRI readout sampling



Topographic  
no fMRI readout sampling

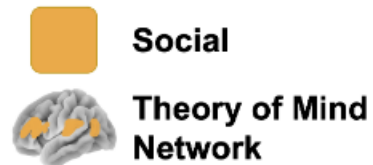
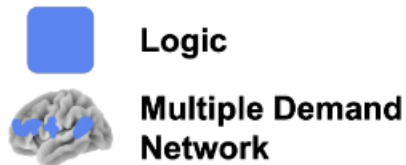
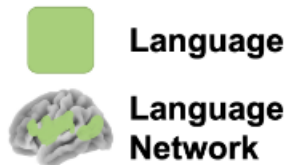
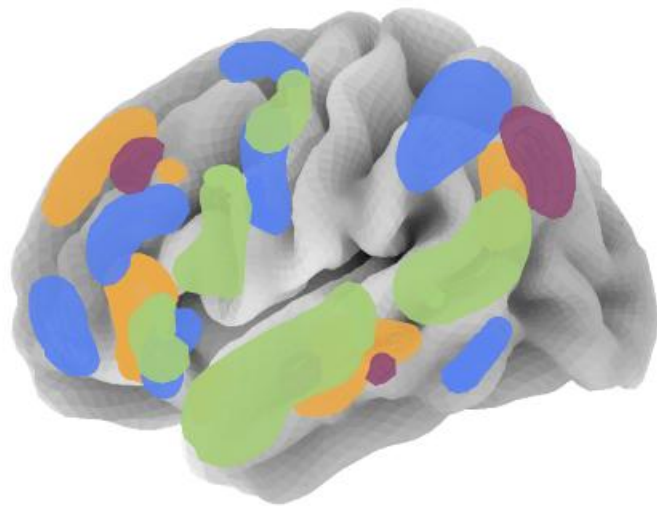


Topographic  
+ fMRI readout sampling

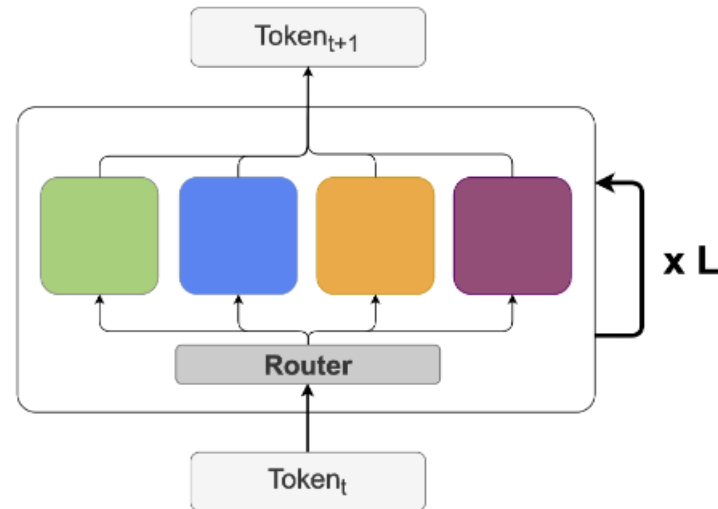


# Brain-Like Cognitive Reasoning

(a) Brain Cognitive Networks



(b) Model Architecture



(c) Steering Behavior

**Prompt**

Deniz invited 6 of her friends to her birthday party, but is worried that most of them will not come. What should she do?

**Social**

As a friend, you should be a good listener.

**Logic**

To find the answer, let's break it down into the following steps:  
....

**World**

Deniz invited 6 of her friends to her birthday party ...

**Language**

Deniz should invite more friends to her birthday party ...

*Fedorenko et al. 2024*

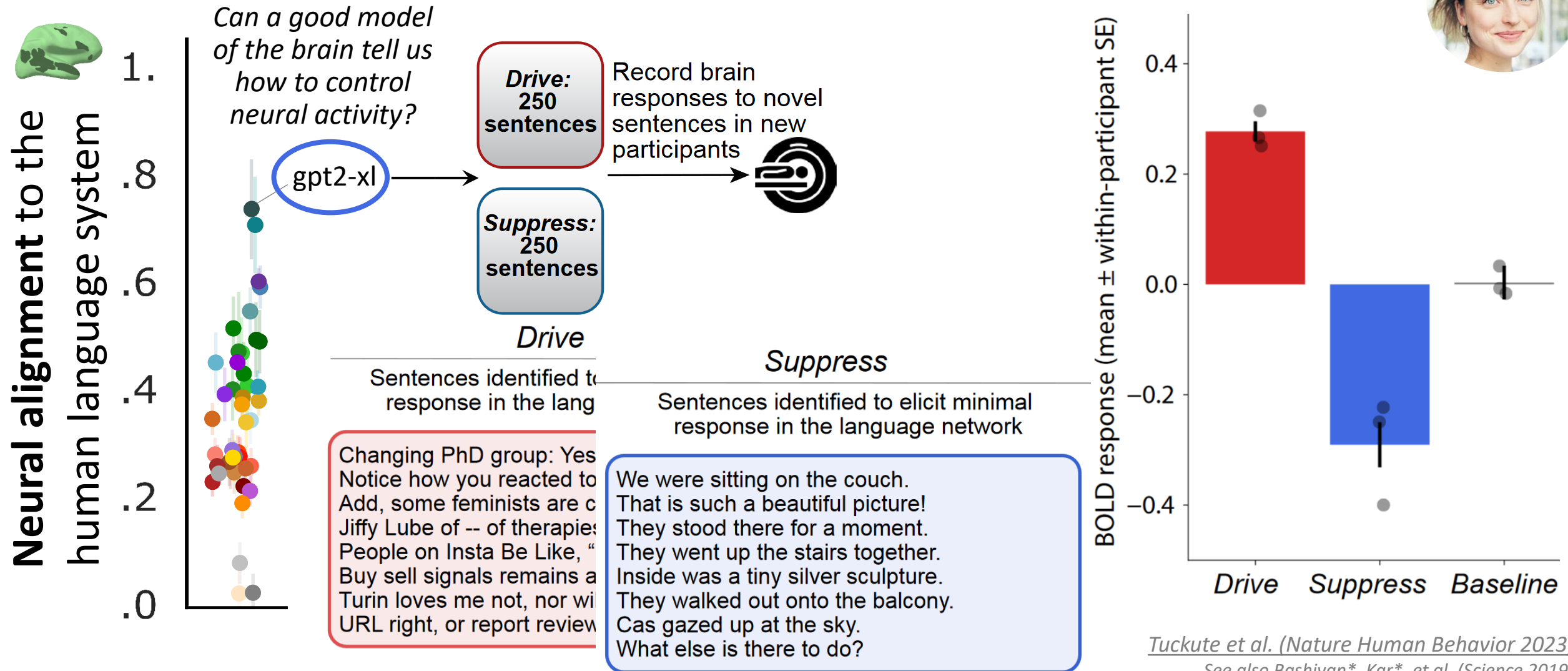
*AlKhamissi et al. 2025*



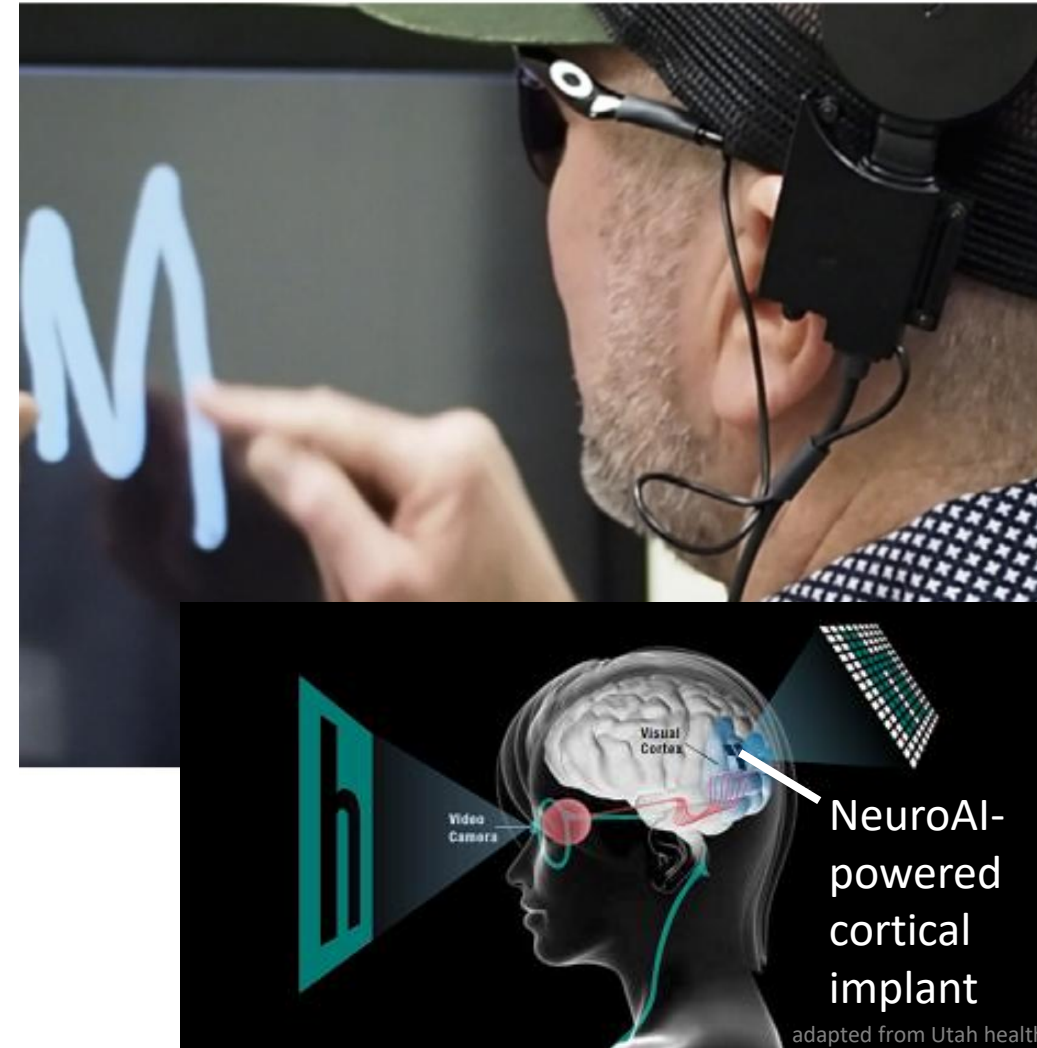
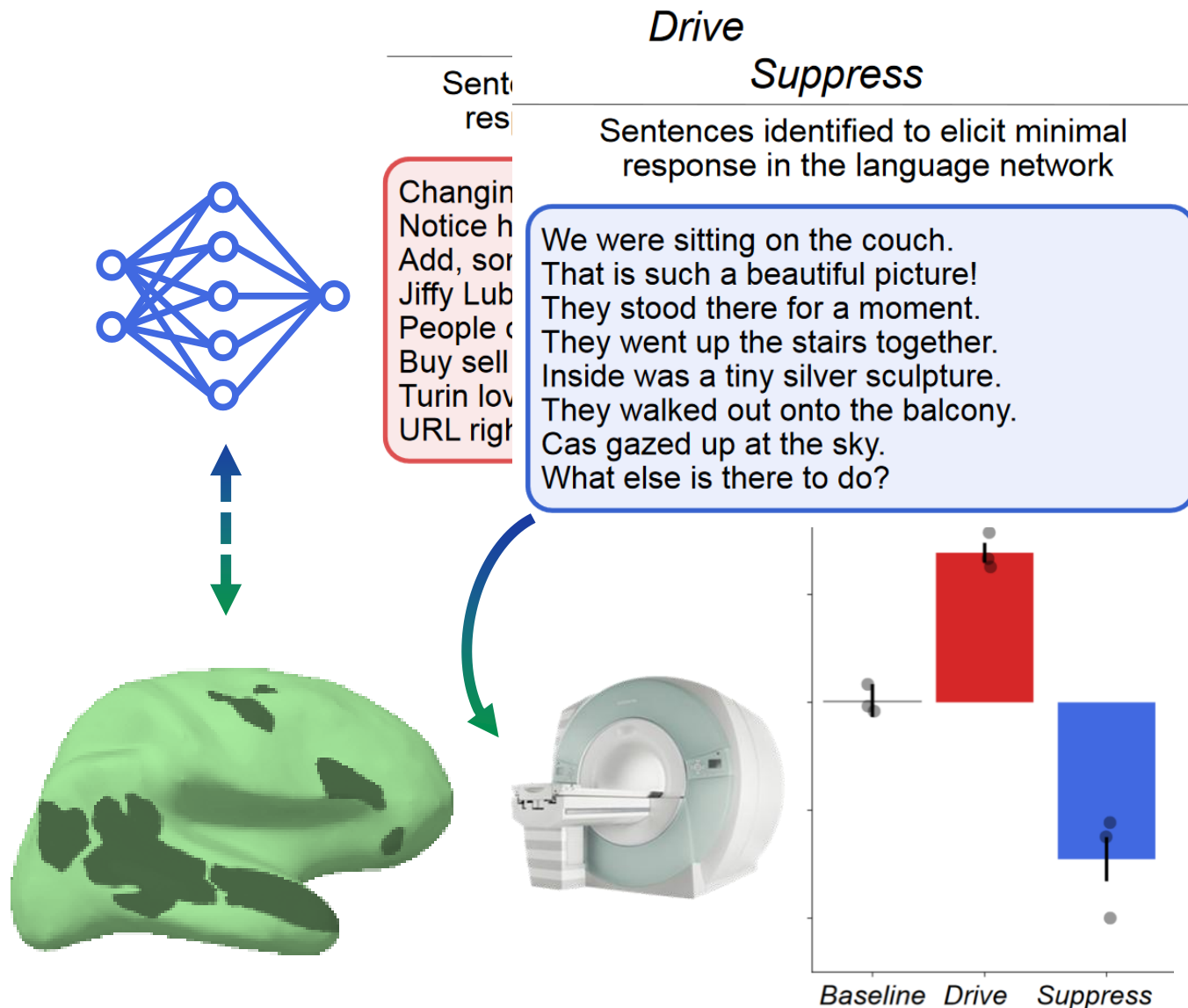
1. AI → Neuro: Particular neural network models are state-of-the-art at predicting brain function and human behavior.
2. Neuro → AI: Neuroscience has found very effective ways of identifying network function which are applicable to AI.
3. NeuroAI → Clinic: Digital twins to help treat brain disorders.



# We can use brain-aligned LLMs to noninvasively control neural activity



# NeuroAI models can control brain activity



*Tuckute et al. (2023)*  
*Beauchamp et al. (2020)* *Chen et al. (2021)* *Schrimpf et al. (2024)*



# NeuroAI Lab

1. AI → Neuro: Particular neural network models are state-of-the-art at predicting brain function and human behavior.



2. Neuro → AI: Neuroscience has found very effective ways of identifying network function which are applicable to AI.

3. NeuroAI → Clinic: Digital twins to help treat brain disorders.

