The Natural Scenes Dataset (NSD): massive high-quality whole-brain 7T fMRI during visual perception and memory

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Outline

Why NSD?
What is in NSD?
Results thus far
Future outlook
Why NSD?

- Algonaughts... Benchmarks, models, code/data sharing, we’re on board!

- We need the best possible data. This is essential.

- **Goal 1:** To establish a massive benchmark dataset that can be used to answer a variety of scientific questions about vision

- **Goal 2:** To answer some scientific questions
Many recent ‘big data sharing’ efforts
- Algonauts
- Allen Brain Observatory
- BOLD5000
- Brain-Score
- DoctorWho
- HCP (Human Connectome Project)
- Individual Brain Charting
- Midnight Scan Club
- MyConnectome
- StudyForrest
- UK Biobank
- vim-1, vim-2
- (and others...)
How is NSD different?

- **Priority 1**: Big.
  - Large data per subject
  - Large number of subjects

- **Priority 2**: High SNR, high resolution.
  - 7T fMRI
  - Screen for the best subjects

- **Priority 3**: Push envelope on acquisition and analysis methods.

- **Priority 4**: Paranoid on details and documentation.
What is in NSD?

- **Type of data**
  - Functional data (7T)
    - NSD data (color natural scenes)
    - Resting-state data
    - Functional localizers (pRF mapping, category localizer)
    - Synthetic stimuli
  - Anatomical data (3T)
    - 6 T1s, 3 T2s
    - Diffusion
    - Angiogram, venogram
  - Behavioral data
  - Physiological data
- **Quantity of data**
  - 8 subjects
  - 40 hours of NSD data per subject
  - Whole-brain including cerebellum
  - 1.8-mm fMRI
- **Quality of data**
  - MRI image quality, imaging stability
  - Behavioral compliance (head motion, task performance)
  - Quality of BOLD response estimates
- **Value added by pre-processing**
  - Best possible spatial and temporal processing and denoising
  - Manually edited cortical surfaces and manually defined ROIs

fMRI acquisition details:
- 32-channel RF coil
- Caseforge headcases
- Whole-brain EPI (1.8 mm, 1.6 s, MB3, IPAT2)
- Multiple fieldmaps in each session

Adopt insights from sub-millimeter 0.8-mm fMRI
Kay, Jamison, Vizioli, Zhang, Margalit, Ugurbil
*NeuroImage*, 2019

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The NSD experiment

- Images taken from Microsoft COCO database
- Stimulus size: 8.4 deg
- Presented via a linearized high-quality LCD monitor (BOLDscreen 32)
- Trial design: 3-s ON, 1-s OFF
- Task: for each image, indicate if it is
  *new* (1) (I’ve never seen it before)
  *old* (2) (I’ve seen before, either today or in a past scan session)
Screen for the best subjects

- BOLD signal strength varies substantially across subjects
- Let’s not waste scan time!
Leaderboard

• Keep tabs on:
  – BOLD activity
  – Behavioral performance
  – Head motion
Nearly perfect response rates
Remarkable recall performance
fMRI pre-processing

- One temporal interpolation
  (slice time correction, upsampling)

- One spatial interpolation
  (time-varying fieldmaps, gradient nonlinearities, head motion, upsampling)

Upsampling improves fine-scale detail

1.8 mm

1 mm

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High measurement stability
High measurement stability
Robust and stable BOLD responses
Brain regions driven by NSD

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GLM analysis

- Single-trial beta estimates
- HRF estimation for each voxel
- Data-driven denoising (GLMdenoise)
- Ridge regression to stabilize single-trial estimates
High SNR in voxel responses

\[ \text{Noise Ceiling} = \frac{\sigma_{\text{signal}}^2}{\sigma_{\text{signal}}^2 + \sigma_{\text{noise}}^2} \]

David and Gallant, *J Neurophys*, 2005
Kay et al., *J Neurophys*, 2013
Lage-Castellanos et al., *PLOS Comp Bio*, 2019
High SNR in voxel responses
How can NSD data be used?

- Study representation of visual dimensions (orientation, spatial frequency, contrast, color, objects, scenes, etc.)
- Benchmark encoding models
- Train neural networks
- Characterize individual differences
- Topography and mapping
- Integration with other neuroimaging modalities
- Study short-term and long-term memory
- Investigate subcortical regions (LGN, cerebellum)
- Develop fMRI analysis methods
How can NSD data be used?

- Open questions for Algonauts and model benchmarking:
  - What types of models should we aim for?
  - RDMs? Individual units?
  - Group average or individual subjects?
  - What about spatial organization in the brain?
Take-home points

- NSD is a large 7T fMRI dataset with perception and memory of natural scenes
- Data are demonstrated to have high SNR, high resolution, and high stability
- NSD data can support a variety of uses including model benchmarking
- NSD data will be freely available: http://naturalscenesdataset.org