Introduction to population receptive field (pRF) models

Serge O. Dumoulin

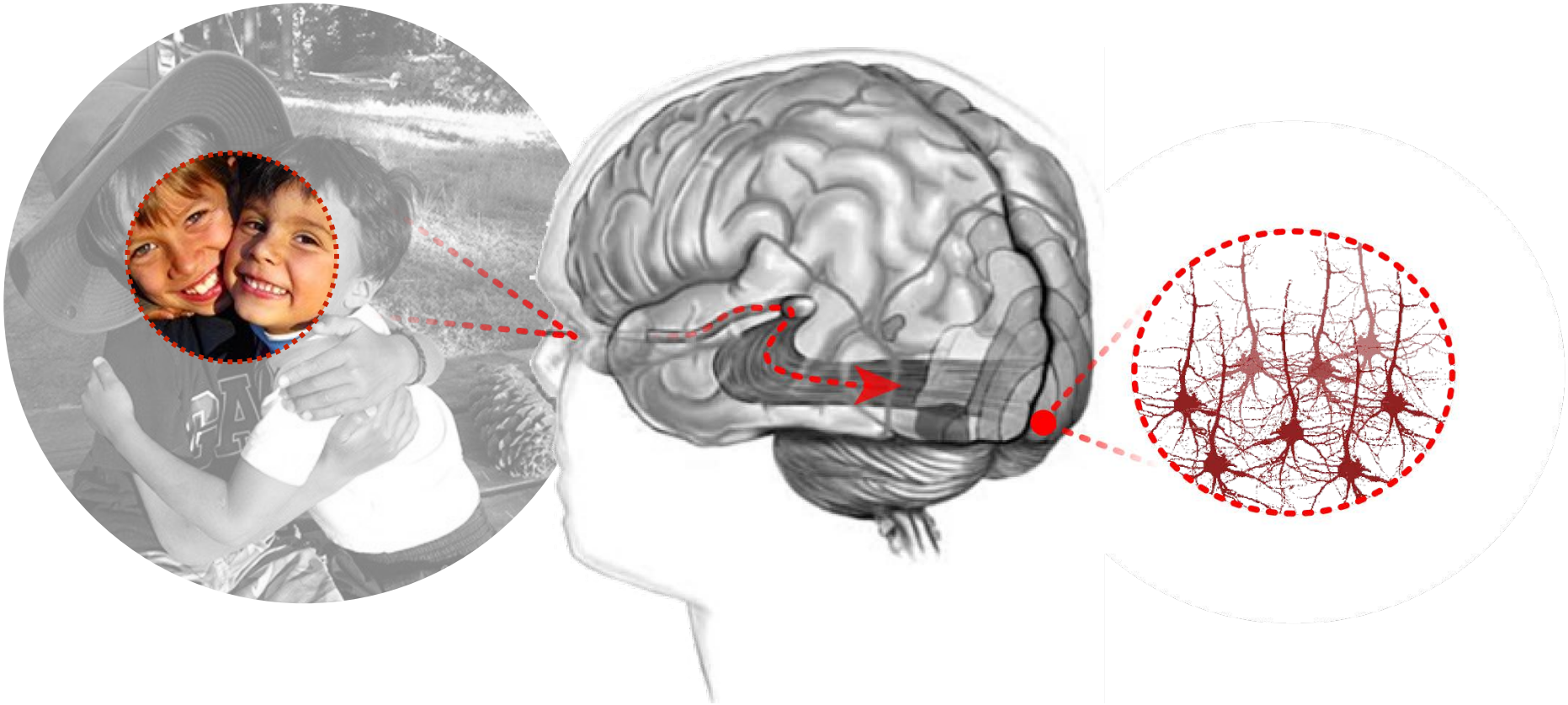
Spinoza Centre for Neuroimaging

Computational Cognitive Neuroscience and Neuroimaging, Netherlands Institute for Neuroscience

Experimental and Applied Psychology, Vrije University Amsterdam

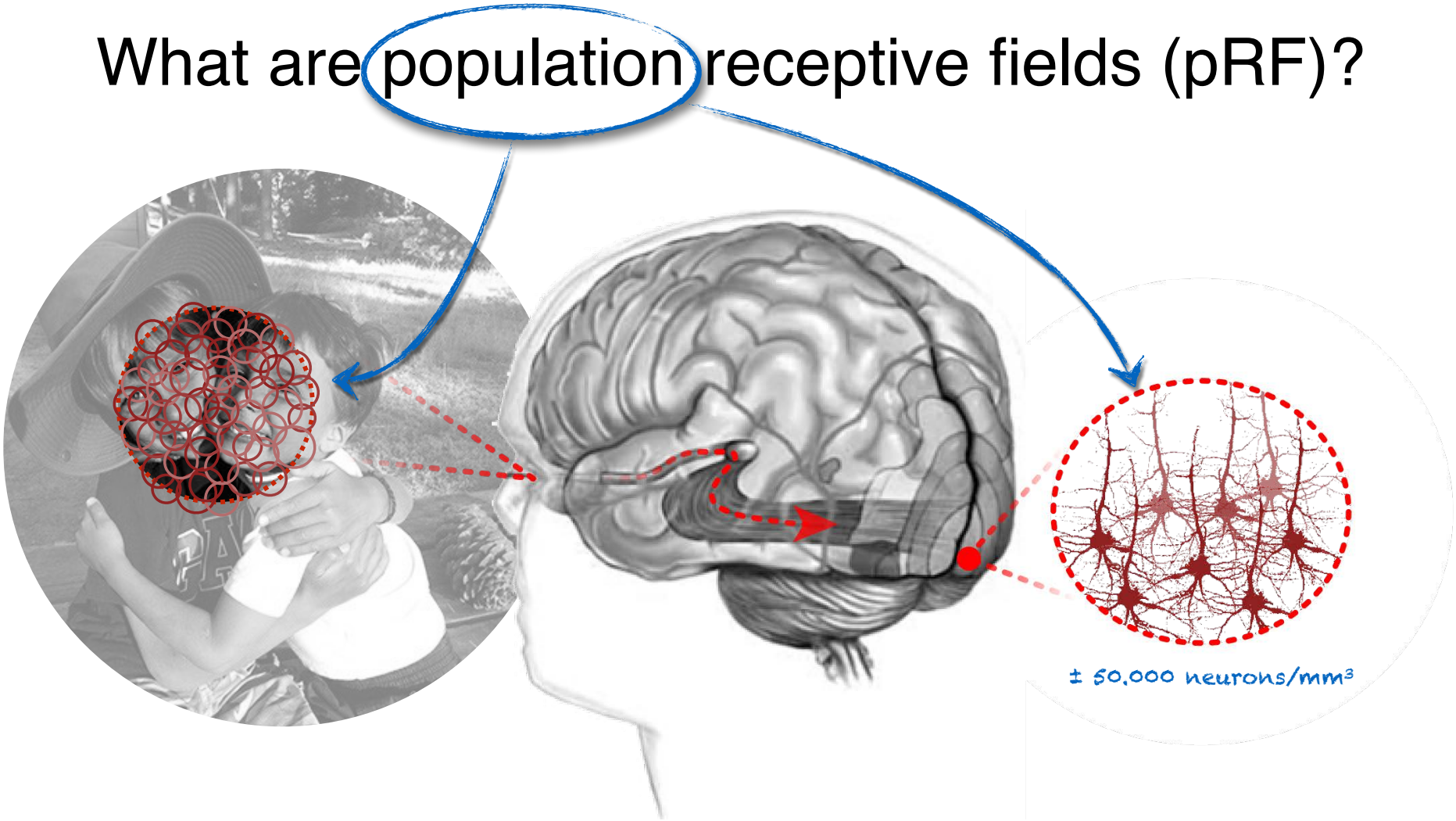


What are population receptive fields (pRF)?



Dumoulin, Wandell (2008)

What are population receptive fields (pRF)?



Dumoulin, Wandell (2008)

What contributes to population receptive fields (pRFs)?

Neuronal RFs differ
(stimuli matter)

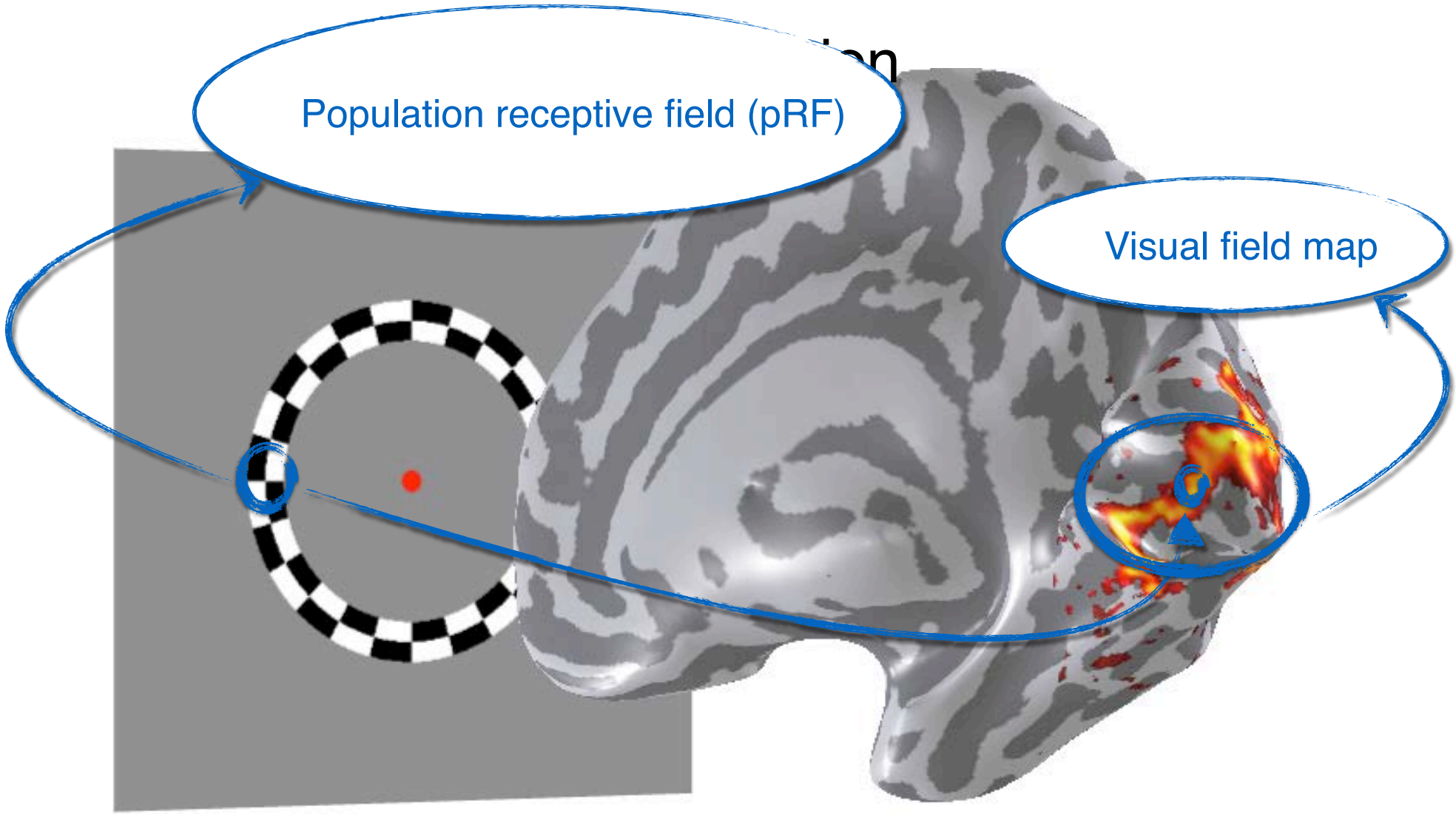
Neuronal population size
(measurement settings matter)

$$g_{pRF} = \sum_{p} \left(w(p) \cdot g_{nRF}(p) \right) \cdot g_{cognition} * g_{population} + k$$

E.g. attention field
(task matters)

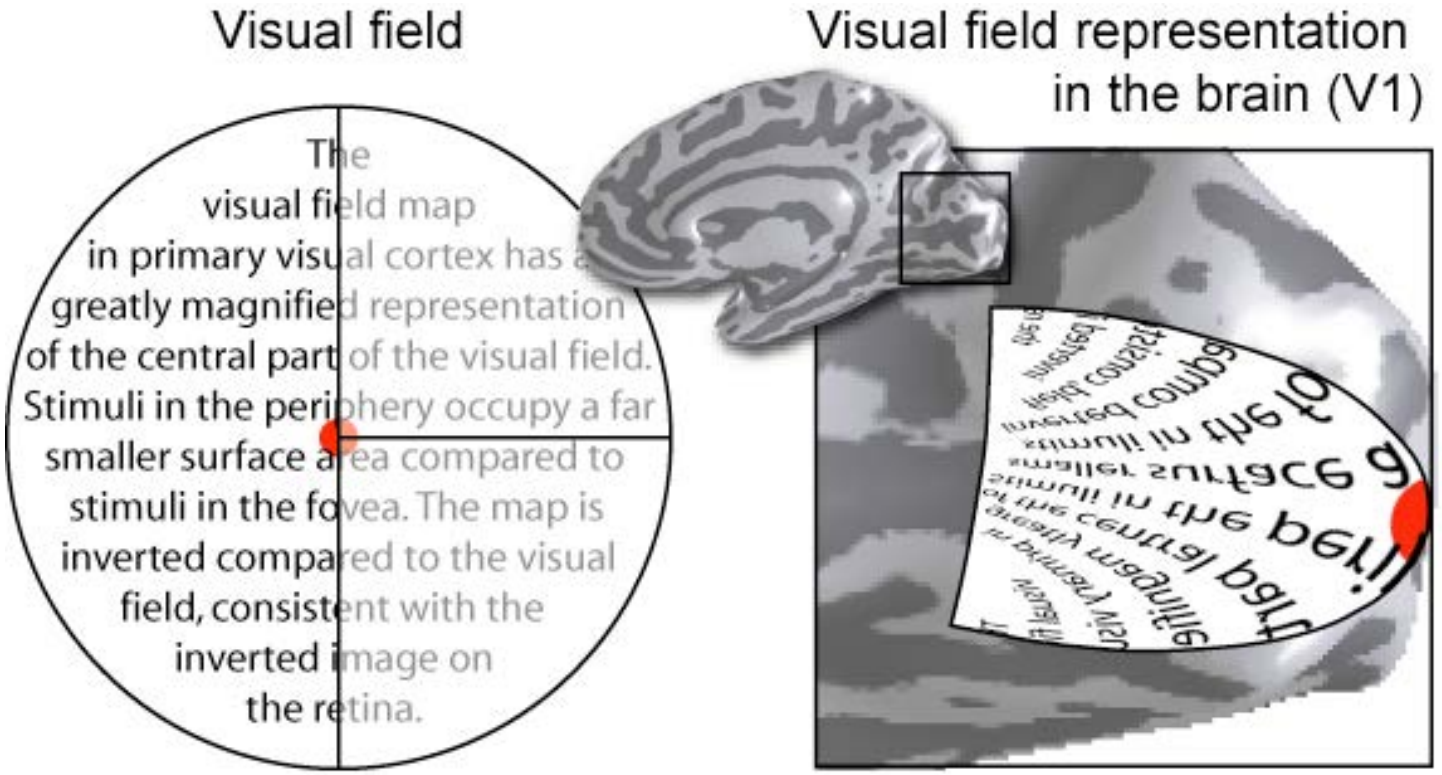
Nuisance factors
(HRF, eye-movements, head-movements, etc)

Dumoulin, Wandell, *Neuroimage* (2008); Dumoulin, Knapen, *Annual Reviews in Vision Science* (2018)



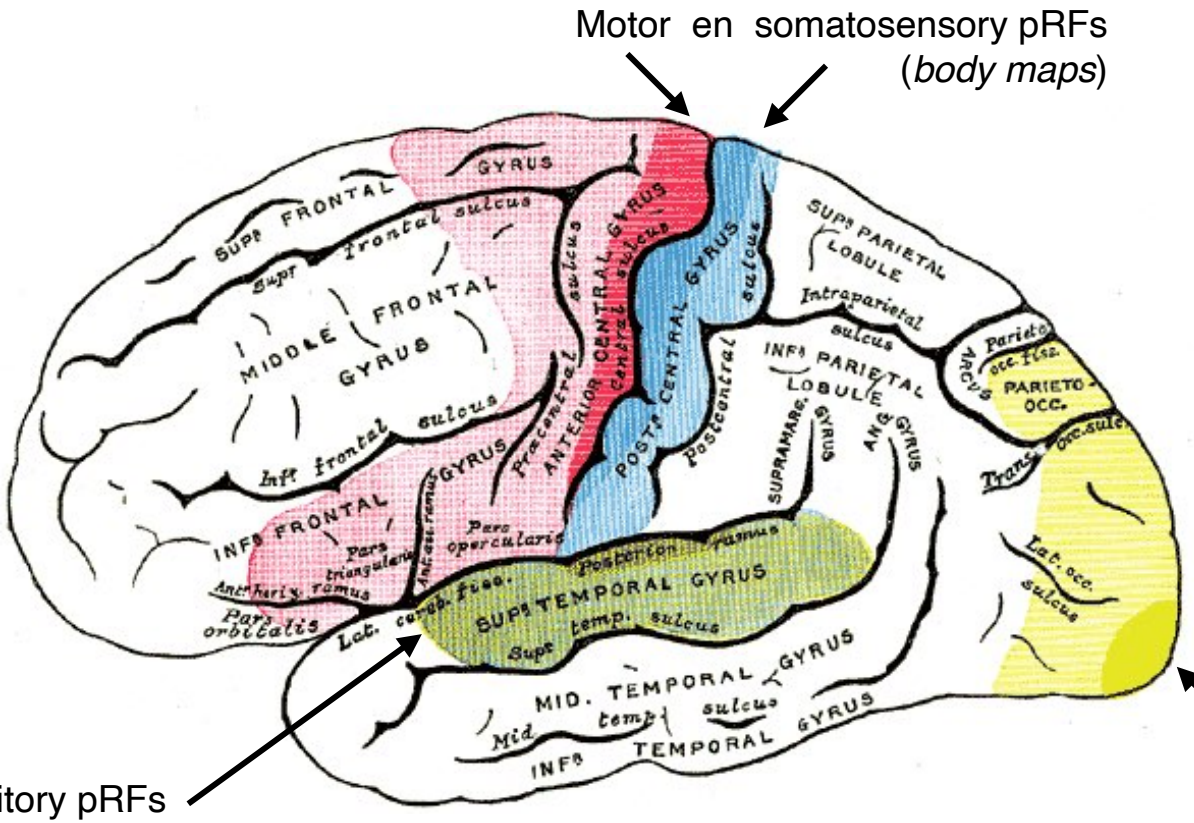
Engel et al *Nature* (1994), Sereno et al, *Science* (1995); and many others
Wandell, Dumoulin, Brewer *Encyclopedia of Neuroscience* (2009)

Topographic maps



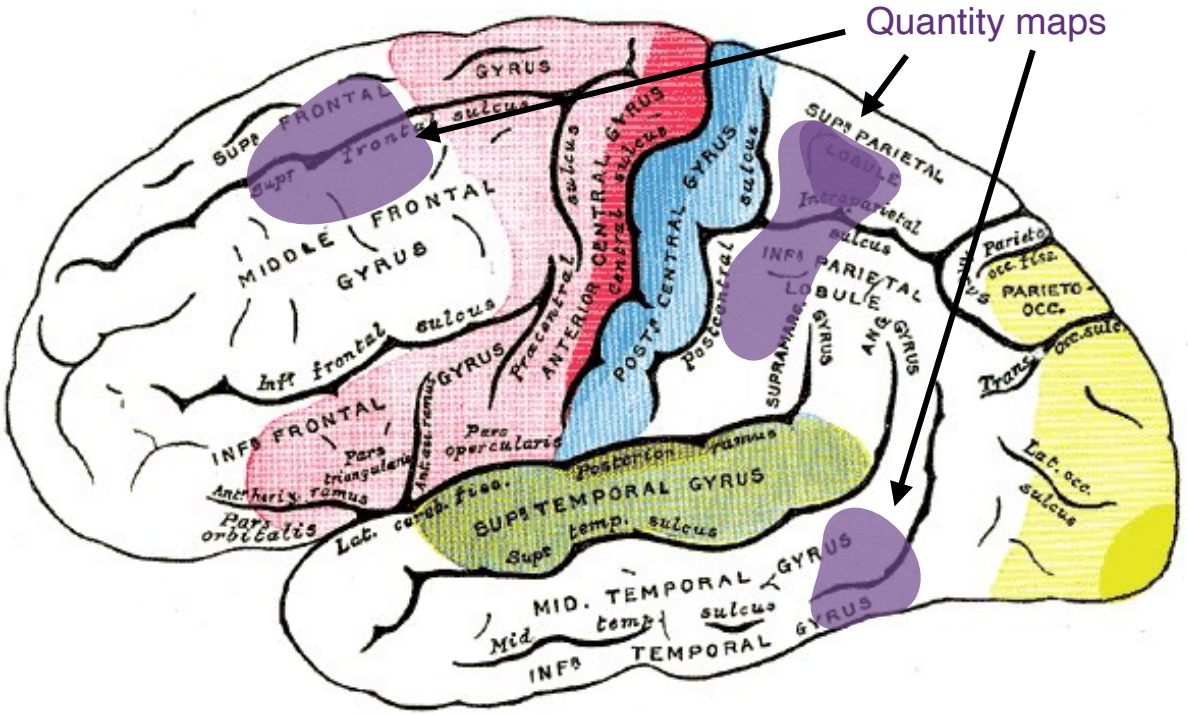
Wandell, Dumoulin, Brewer (2007)

pRFs (topography) in the brain



Gray (1918)

pRFs (topography) in the brain



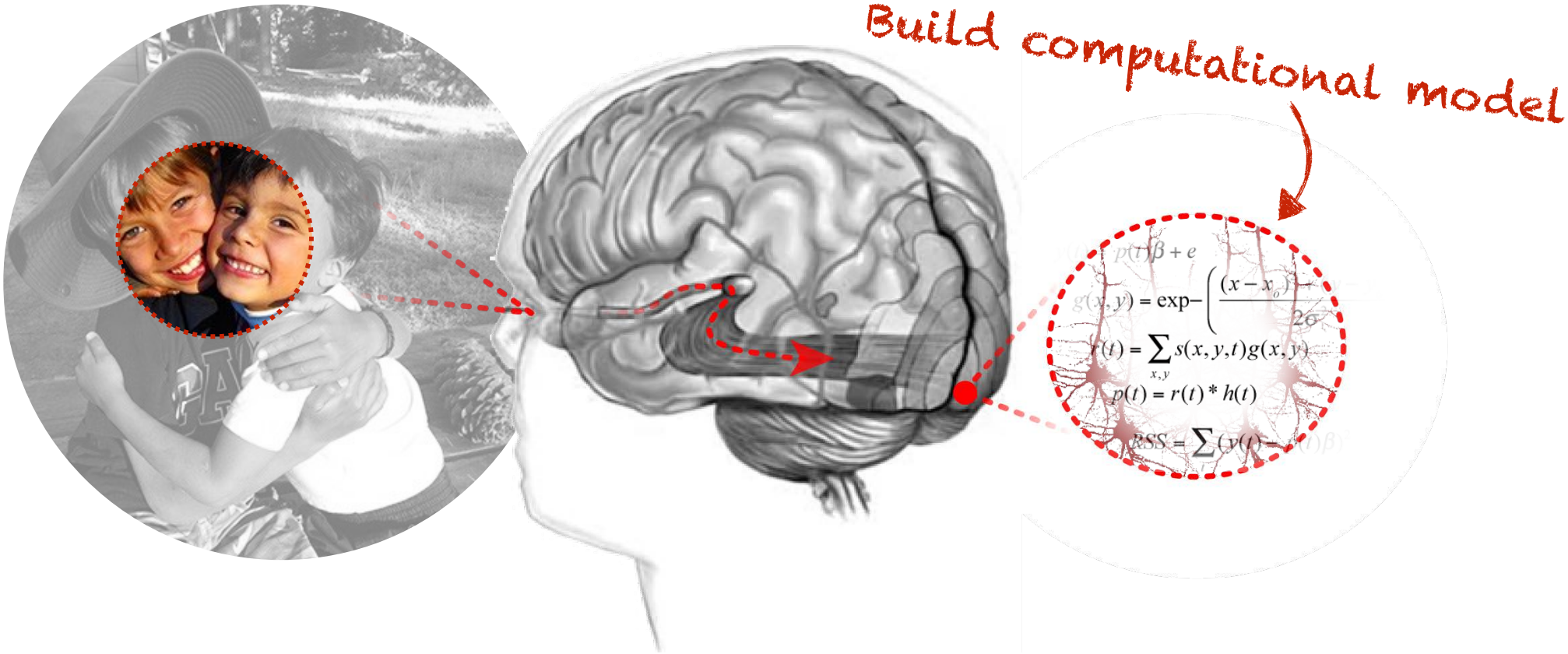
Harvey et al Dumoulin, *Science* (2013), *PNAS* (2015), *Nature Human Behaviour* (2017)

Conclusions

- population receptive fields (pRFs) are a fundamental feature of the brain

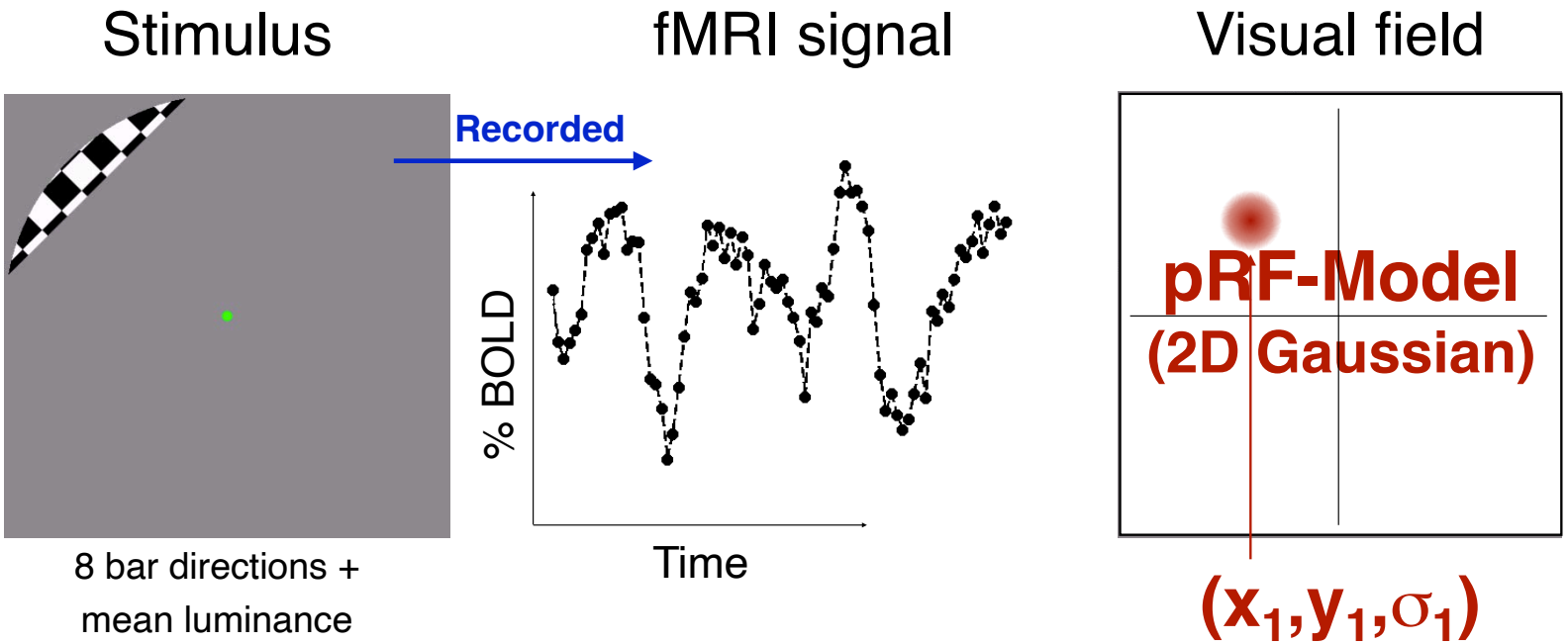


How do we measure population receptive fields (pRF)?



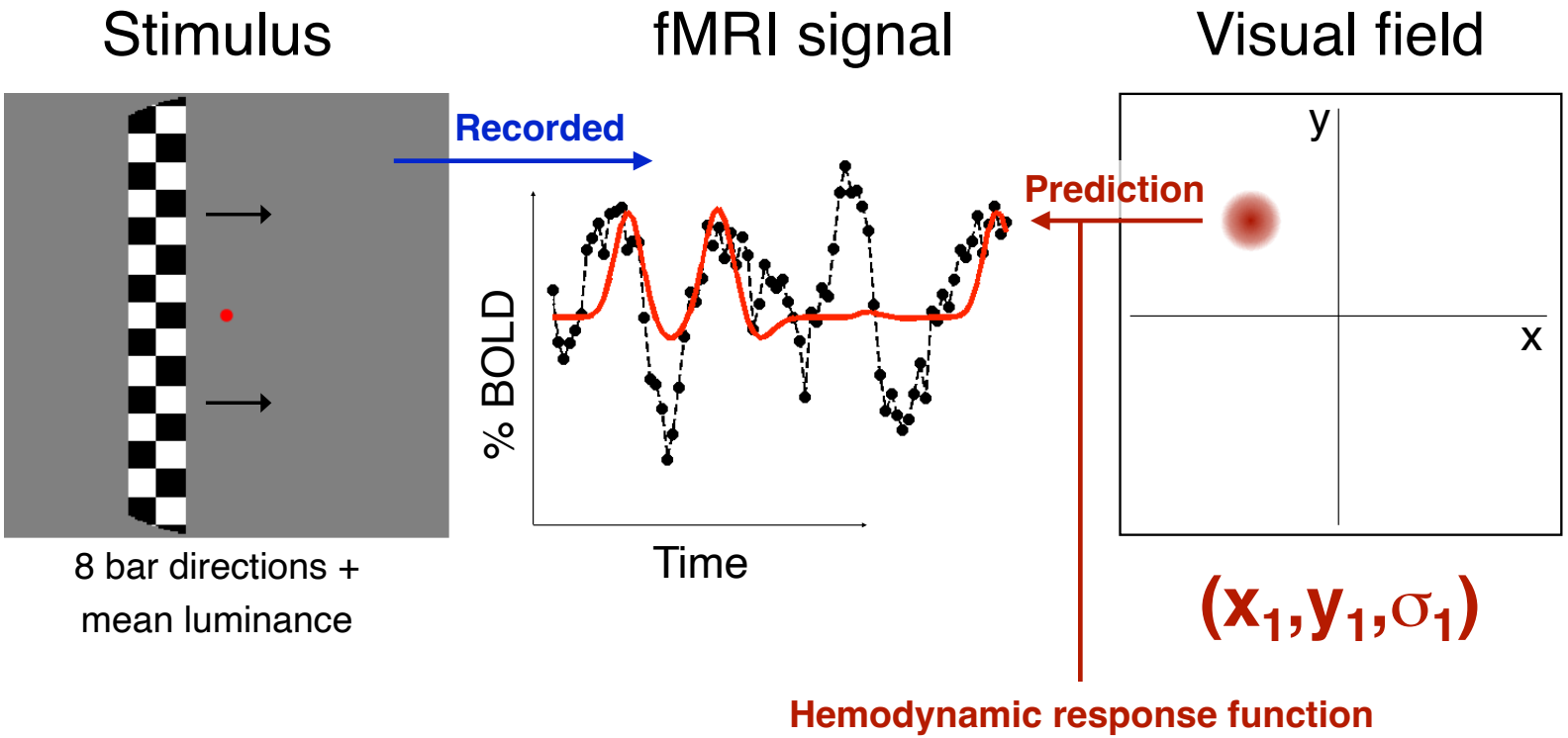
Dumoulin, Wandell (2008)

How do we build pRF models?



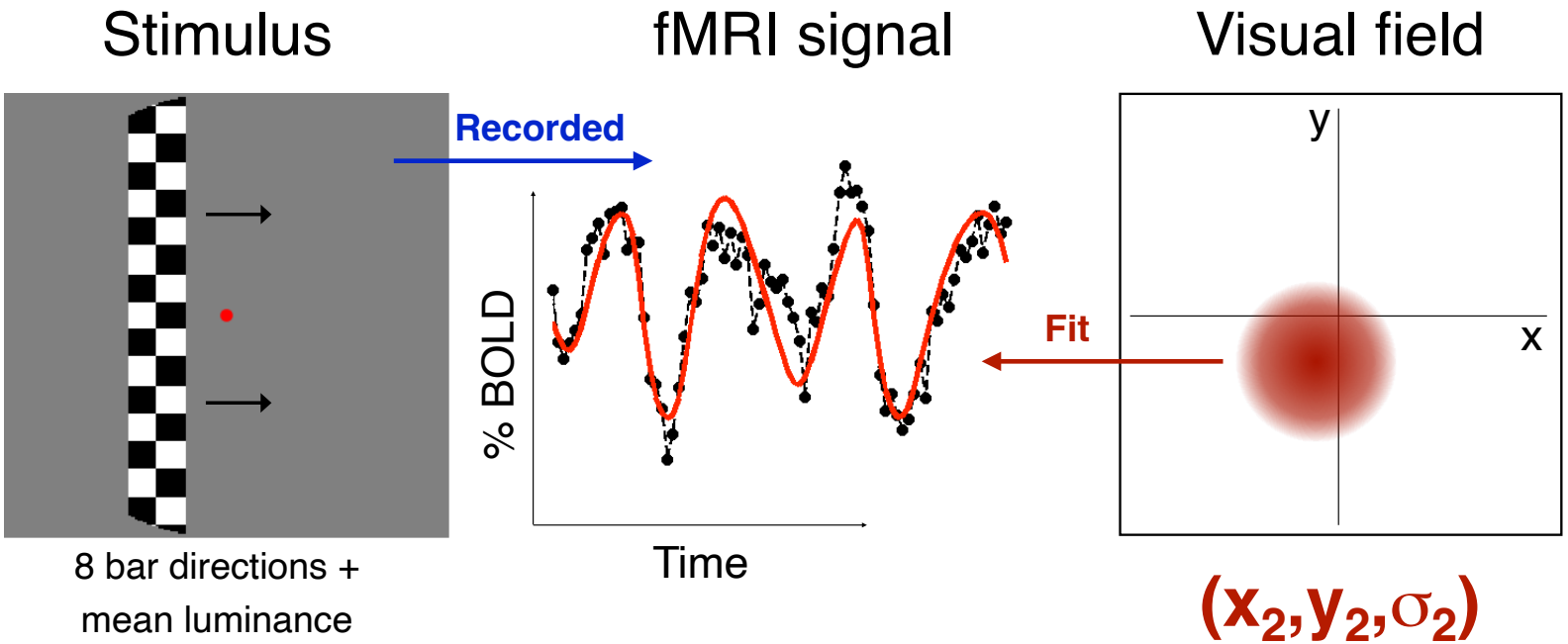
Dumoulin, Wandell (2008)

How do we build pRF models?



Dumoulin, Wandell (2008)

How do we build pRF models?

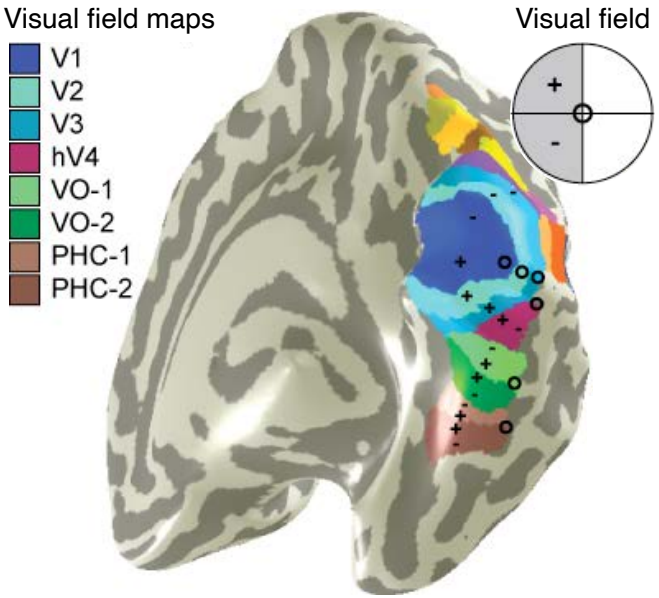


Dumoulin, Wandell (2008)

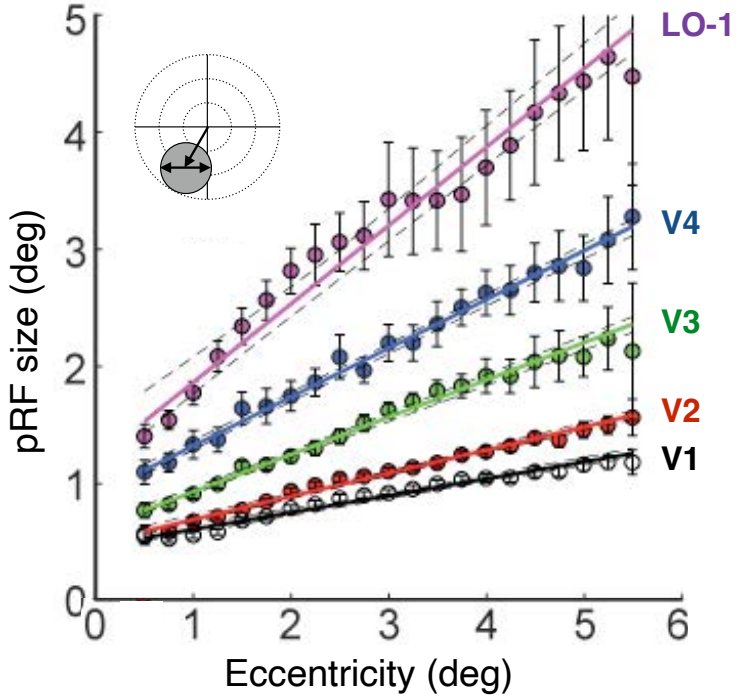
Basic pRF parameters

(Good sanity check)

pRF position (x,y): maps

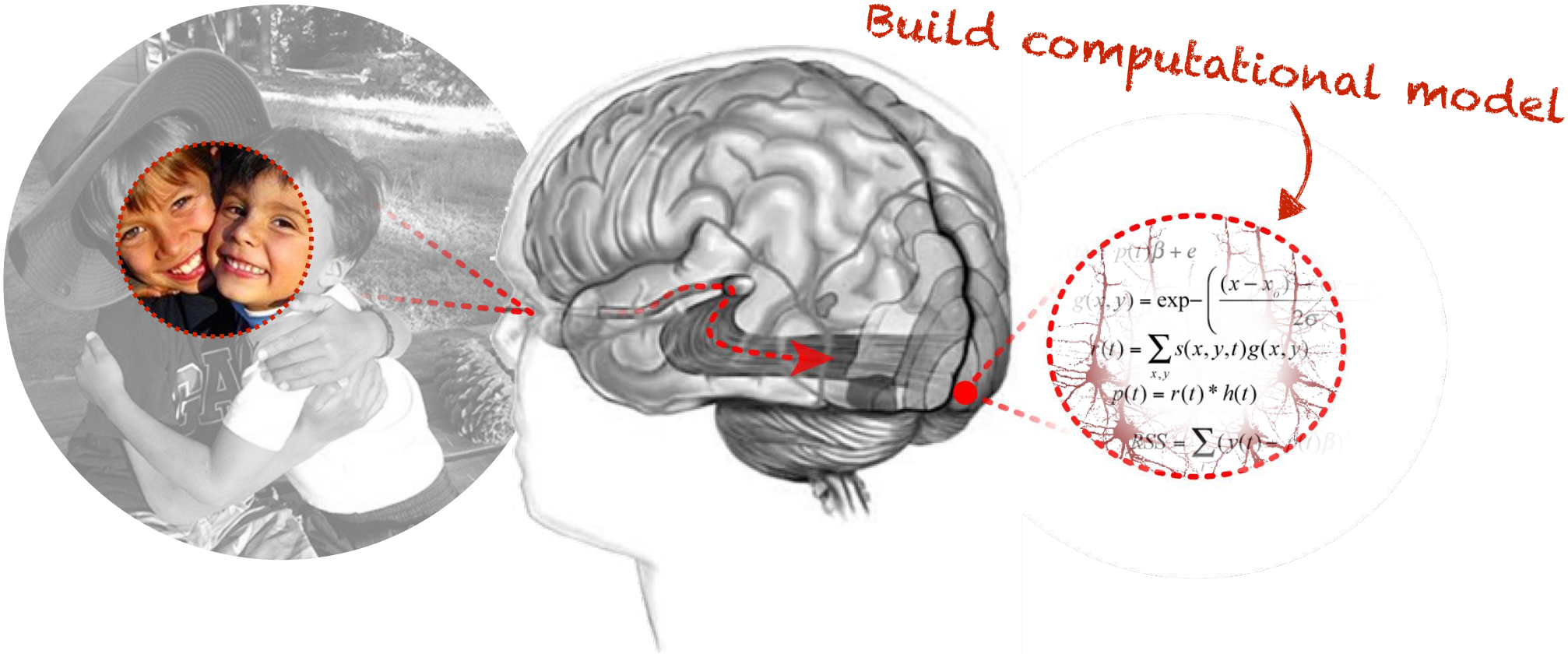


pRF size (σ)



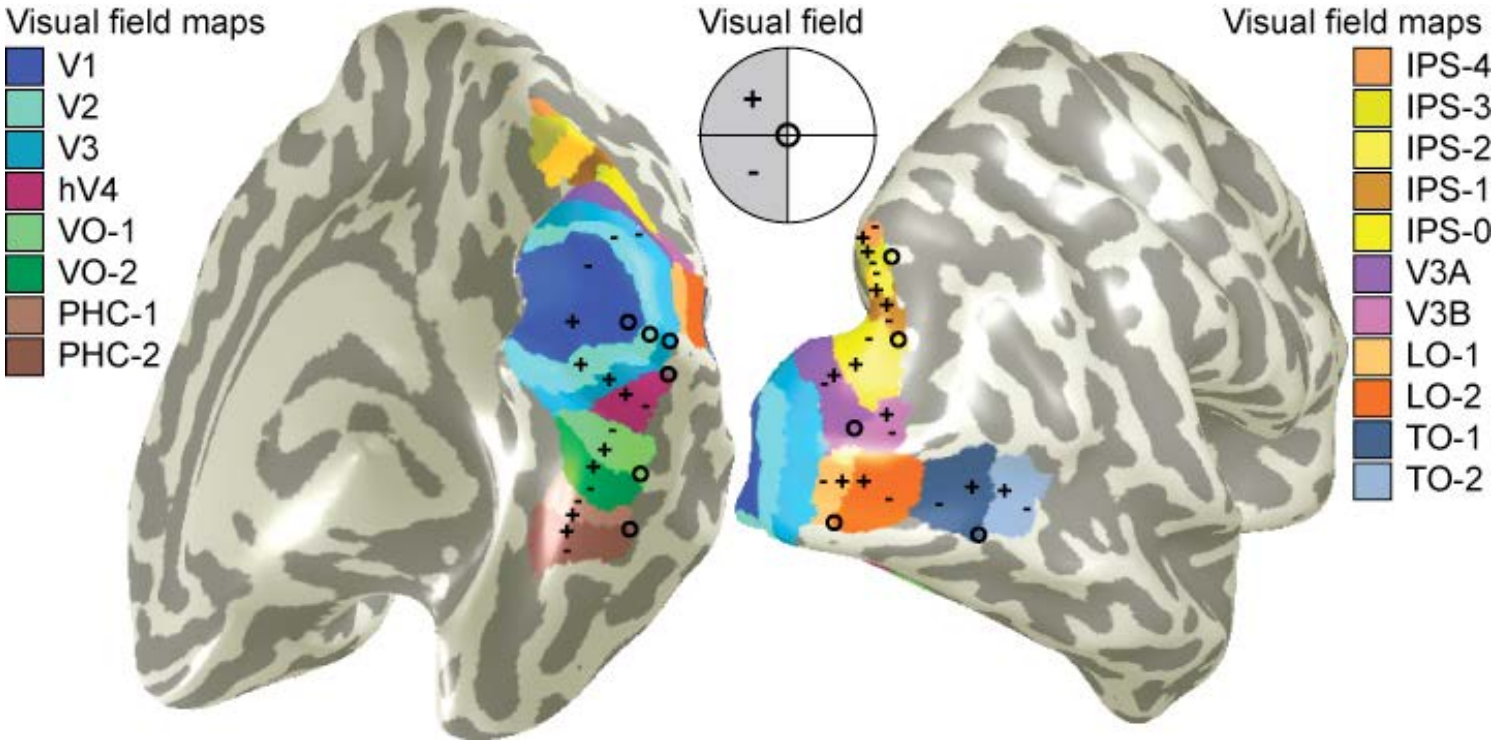
Dumoulin, Wandell (2008), Amano, Wandell, Dumoulin (2009), Levin et al (2010), Harvey, Dumoulin (2011), Zuiderbaan et al (2012), Hoffmann et al (2012), Dumoulin (2016)

Why did we develop pRF modelling? *(in 2005)*



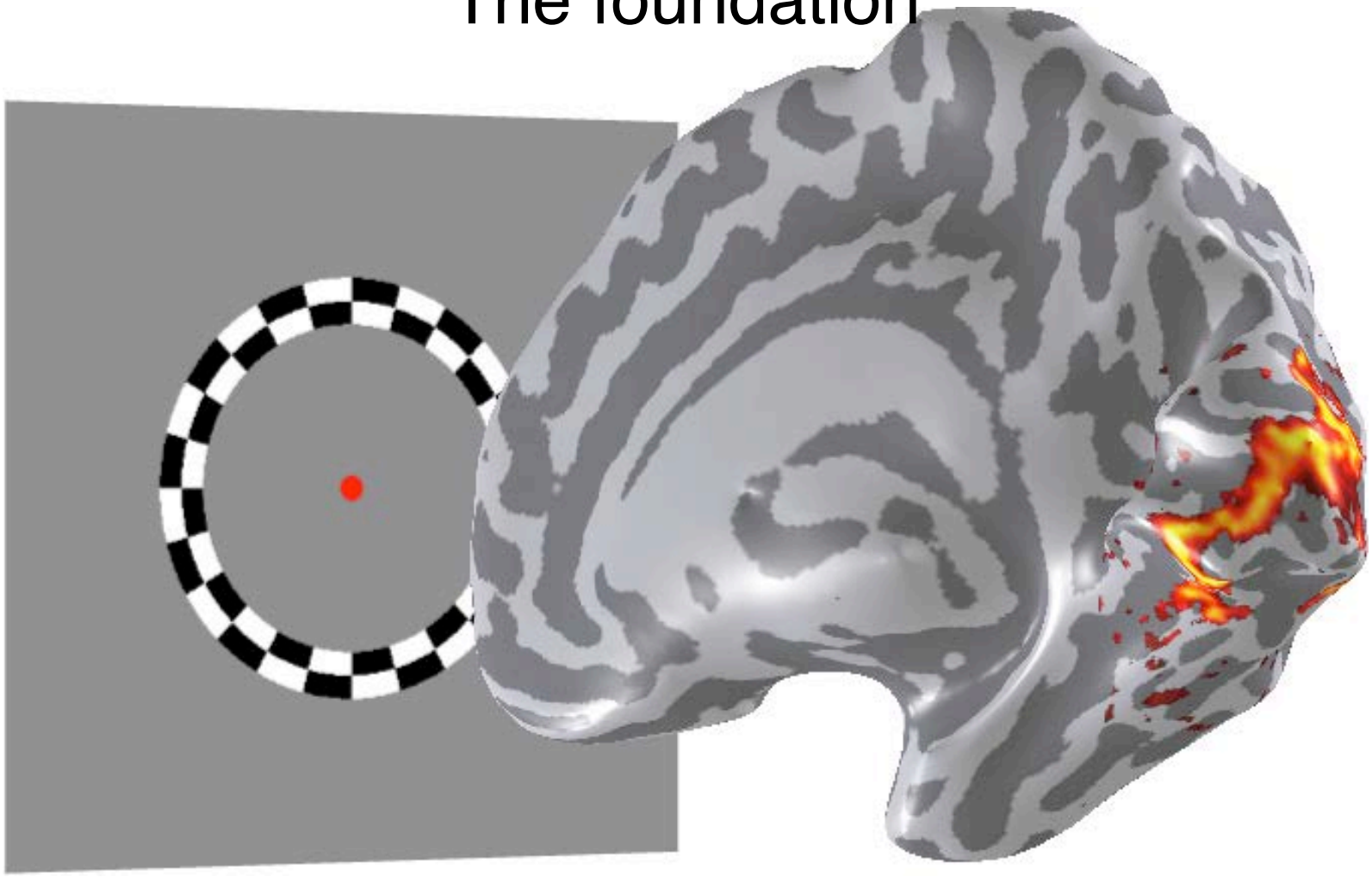
Dumoulin, Wandell (2008)

Visual field map discoveries



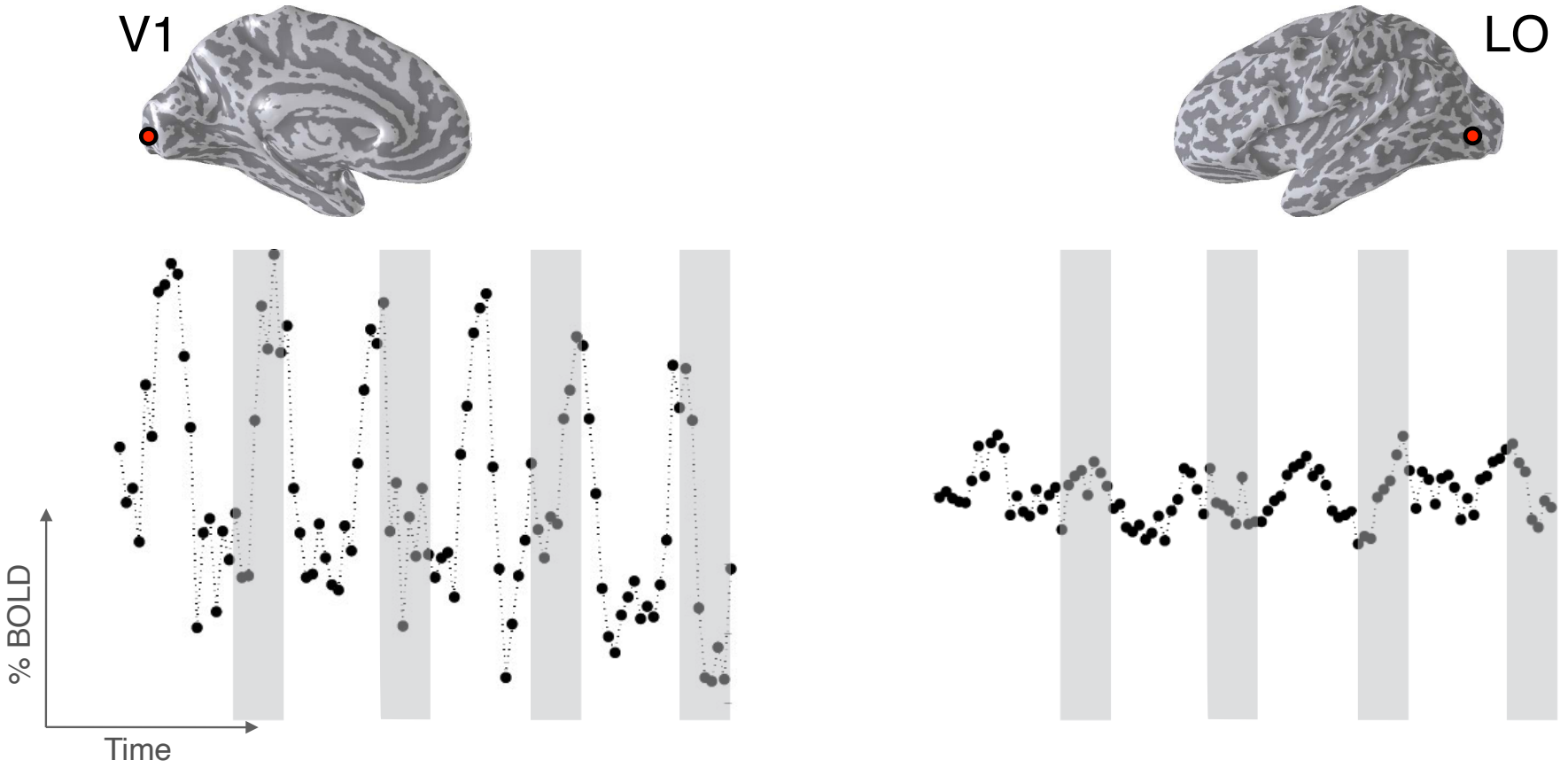
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The foundation



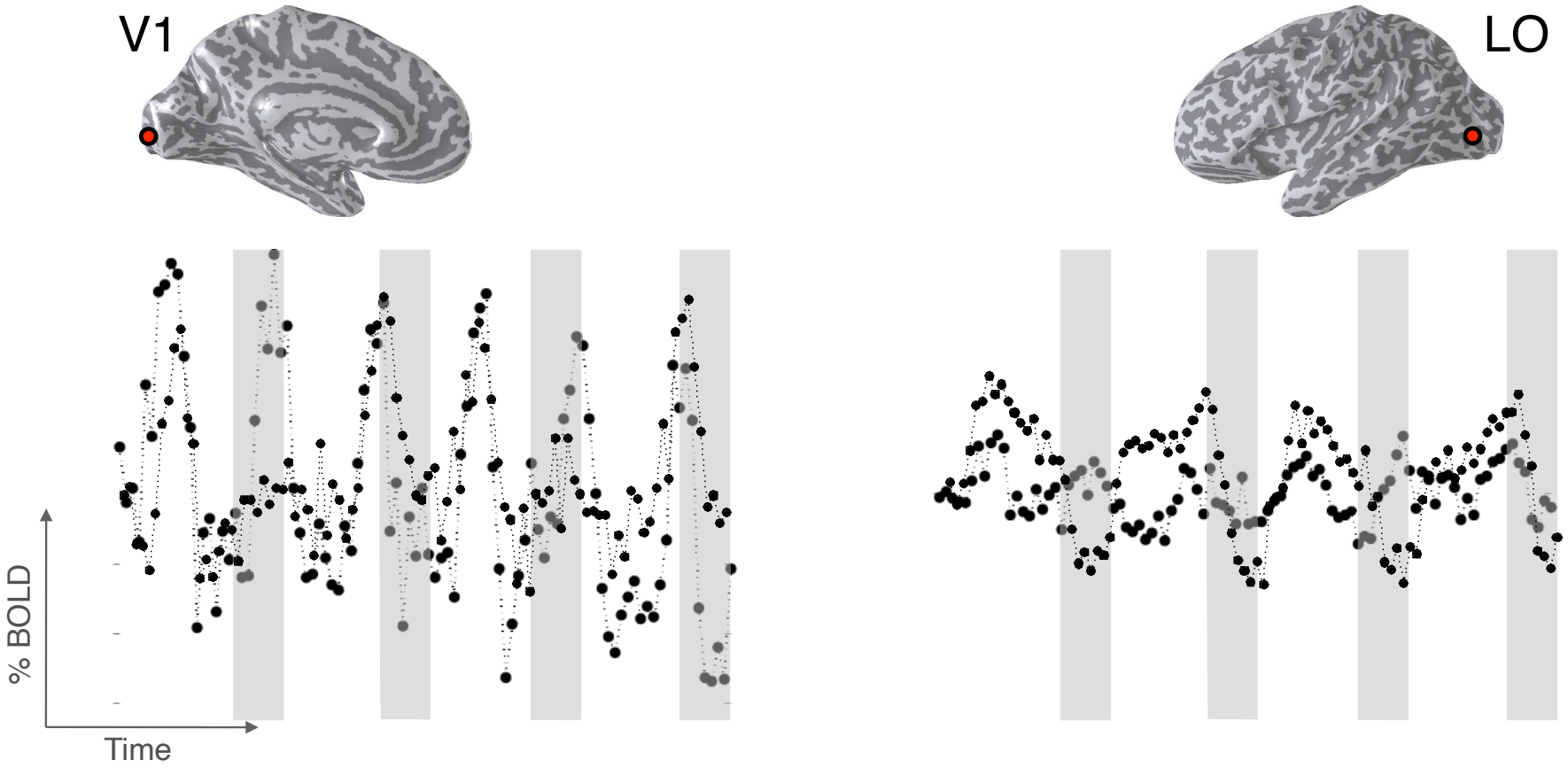
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Wandell, Dumoulin, Brewer *Encyclopedia of Neuroscience* (2009)

Signal differences in visual cortex



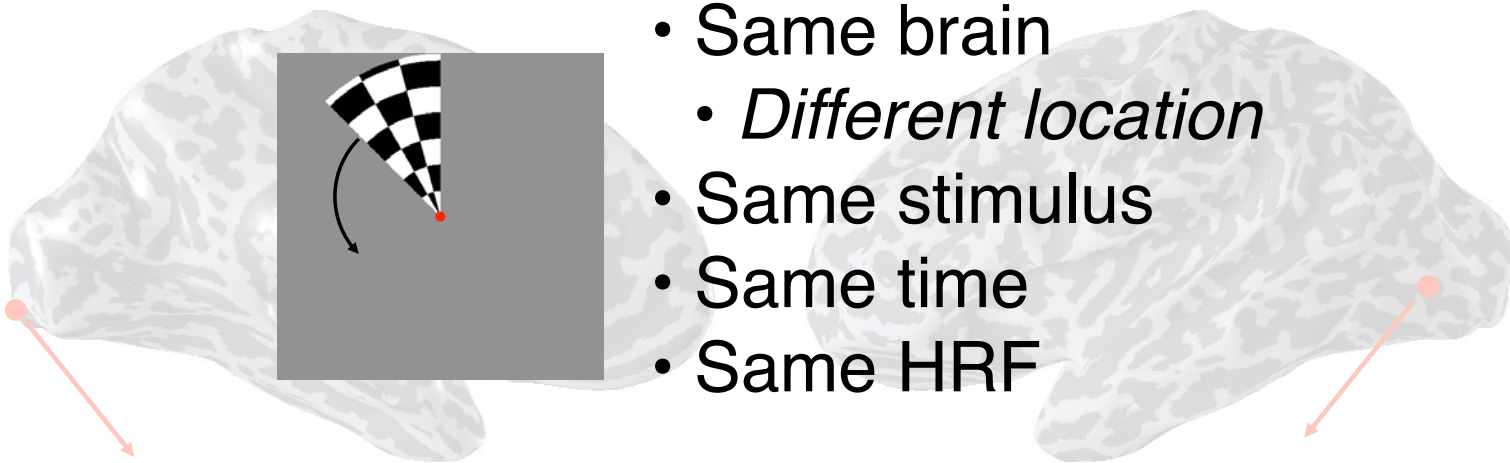
Dumoulin, Wandell *Neuroimage* (2008)

Signal differences in visual cortex

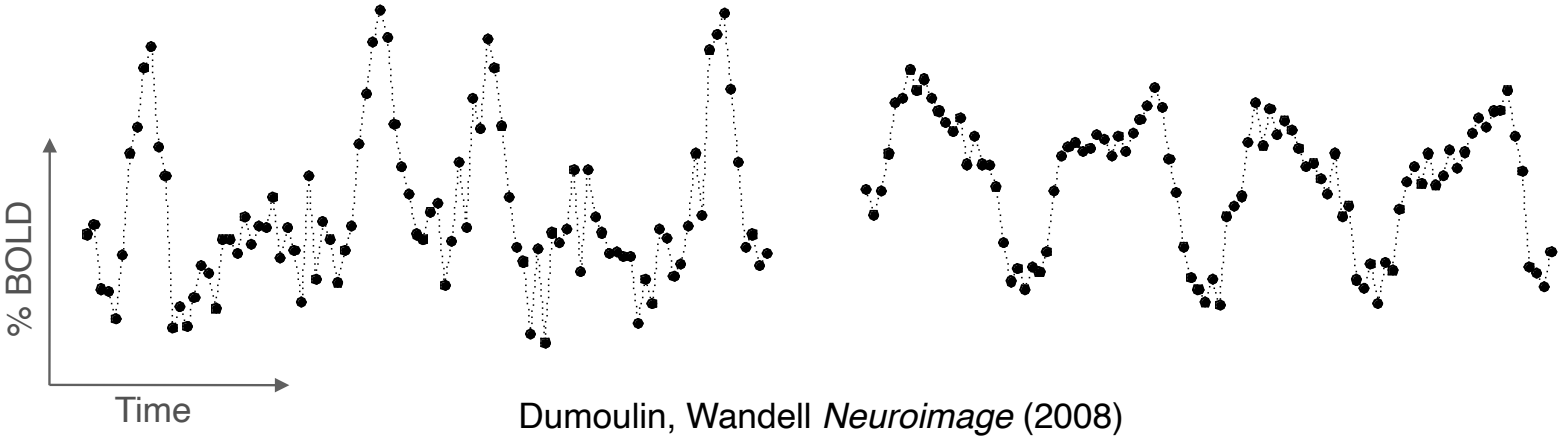


Dumoulin, Wandell *Neuroimage* (2008)

Signal differences in visual cortex

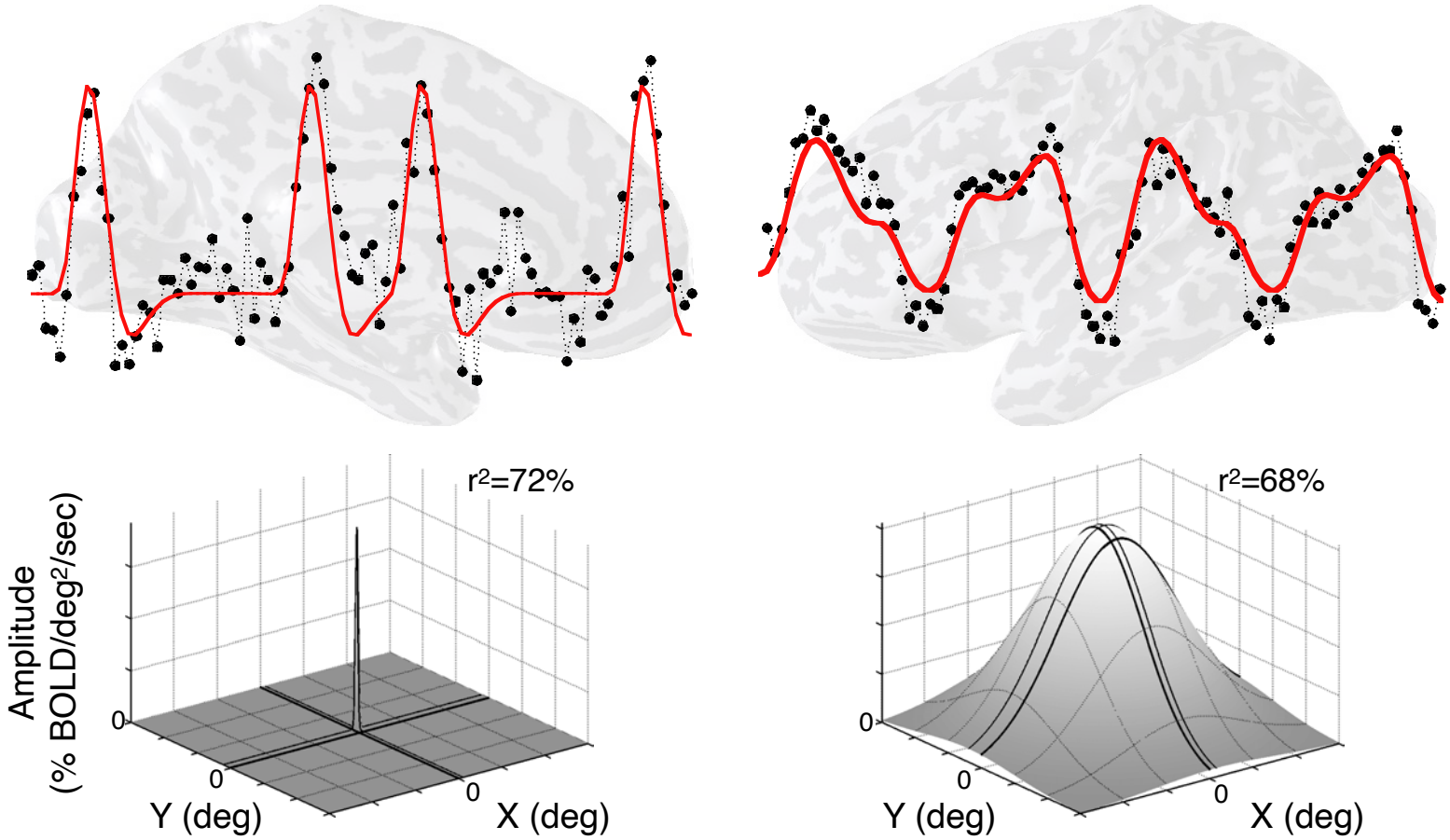


- Same brain
  - *Different location*
- Same stimulus
- Same time
- Same HRF



Dumoulin, Wandell *Neuroimage* (2008)

Signal differences explained



Conclusions

- population receptive fields (pRFs) are a fundamental feature of the brain
- pRF method quantitatively connects neuroimaging signals to neural properties
- Opens avenues for modelling more complex neuronal properties

Some example applications

Model extensions

- **Center-surround**
  e.g. Zuiderbaan et al, *J Vision* (2012)
- **Compressive spatial summation**
  e.g. Kay et al, *J Neurophys* (2013)
- **Divisive normalisation**
  e.g. Aqil et al, *PNAS* (2021)
- **Bilateral pRFs**
  e.g. Hoffmann et al, *Neuron* (2012)
- **1D logarithmic pRFs**
  e.g. Harvey et al, *Science* (2013)
- **Connectivity (connective fields)**
  e.g. Haak et al, *Neuroimage* (2013)
- **Temporal pRFs**
  e.g. Zhou, *J Neurosci* (2018)

Beyond fMRI

- **Intracranial electrodes (ECoG)**
  e.g. Harvey et al, *Neuroimage* (2013)
- **Causal links to perception**
  e.g. Winawer et al *Neuron* (2016)
- **Psychophysics**
  e.g. Klein et al *J Vision* (2016)
- **MEG**
  e.g. Kupers et al *Neuroimage* (2021)
- **(mouse) two-photon imaging**
  e.g. Self et al *Nat. Comm.* (2021)
- **(macaque) neurophysiology**
  e.g. Klink et al *Elife* (2021)

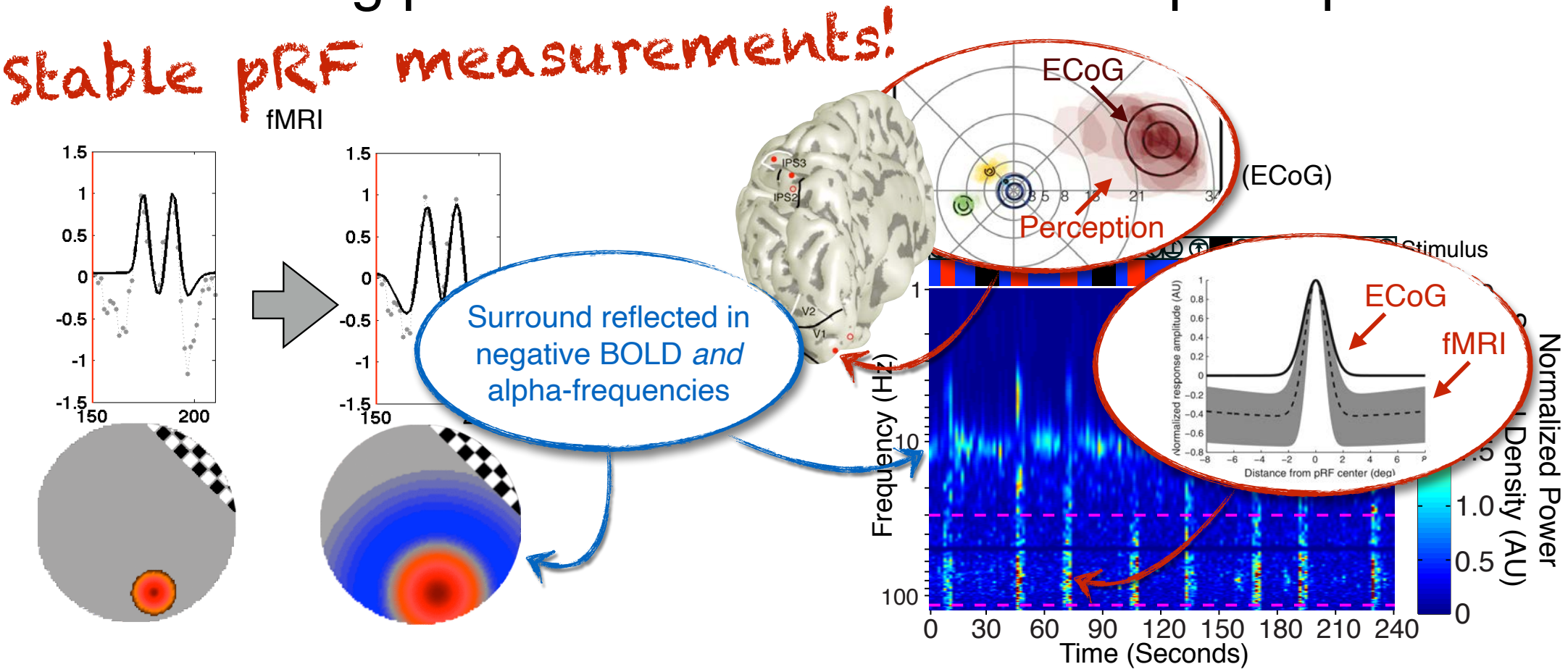
Beyond vision

- **Subcortex**
  e.g. DeSimone et al, *J Neurosci* (2015)
- **Hippocampus**
  e.g. Silson et al *J Neurosci* (2021)
- **Cerebellum**
  e.g. van Es et al, *Curr Biol* (2019)
- **Auditory cortex**
  e.g. Thomas et al, *Neuroimage* (2015)
- **Motor and somatosensory cortex**
  e.g. Schellekens et al, *Neuroimage* (2018)
- **Default mode network**
  e.g. Szinte et al *Cer Cortex* (2020)
- **Attention**
  e.g. Klein et al, *Neuron* (2015)
- **Numerical cognition**
  e.g. Harvey et al, *Science* (2013)
- **Time perception**
  e.g. Harvey et al *Curr Biol* (2020)

Clinical neuroscience

- **Macular degeneration**
  e.g. Baseler et al, Nat *Neurosci* (2011)
- **Amblyopia**
  e.g. Clavagnier et al, *J Neurosci* (2015)
- **Achiasma**
  e.g. Hoffmann et al, *Neuron* (2011)
- **Hemihydranencephaly**
  e.g. Fracasso et al, *Opthal Phys Opt* (2016)
- **Brain lesions**
  e.g. Papanikolaou et al, PNAS (2014)
- **Alzheimer's disease**
  e.g. Brewer et al, *Front Psychol* (2014)
- **Autism spectrum disorders**
  e.g. Schwarzkopf et al, *J Neurosci* (2014)
- **Schizophrenia**
  e.g. Anderson et al, *J Neurosci* (2017)
- **Dementia (PCA)**
  e.g. de Best et al, *JAMA Neurology* (2020)

Extending pRFs from fMRI to ECoG to perception



Zuiderbaan, Harvey, Dumoulin, *J Vision* (2012); Harvey et al, *Neuroimage* (2013); Winawer, Parvizi, *Neuron* (2016); Aqil et al, *PNAS* (2021)

Conclusions

- population receptive fields (pRFs) are a fundamental feature of the brain
- pRF method quantitatively connects neuroimaging signals to neural properties
- Opens avenues for modelling more complex neuronal properties
- Has broad applications in visual, cognitive and clinical neuroscience

