Responses to Hermite function stimuli reveal intrinsically two-dimensional processing in cat V1

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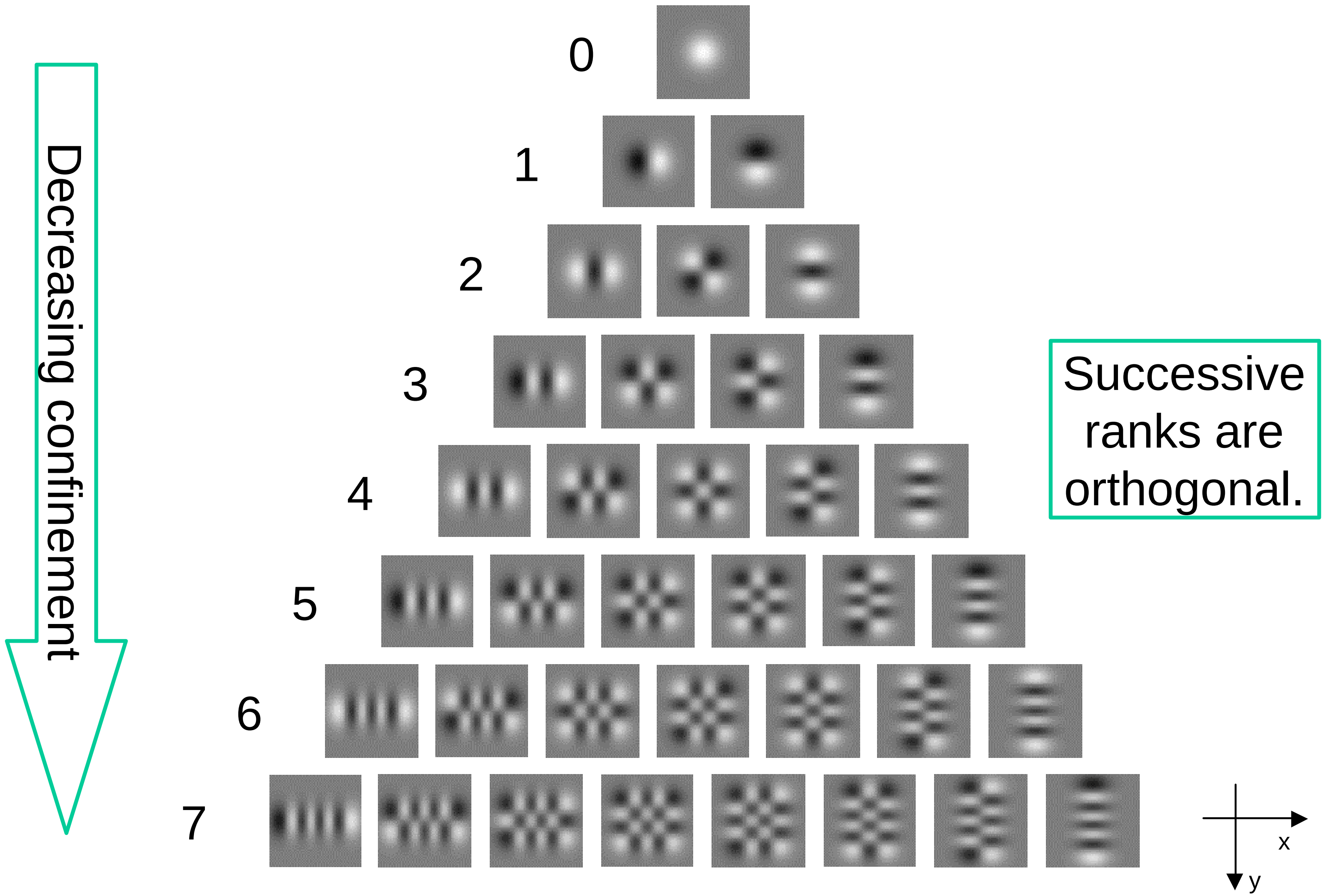
Motivation

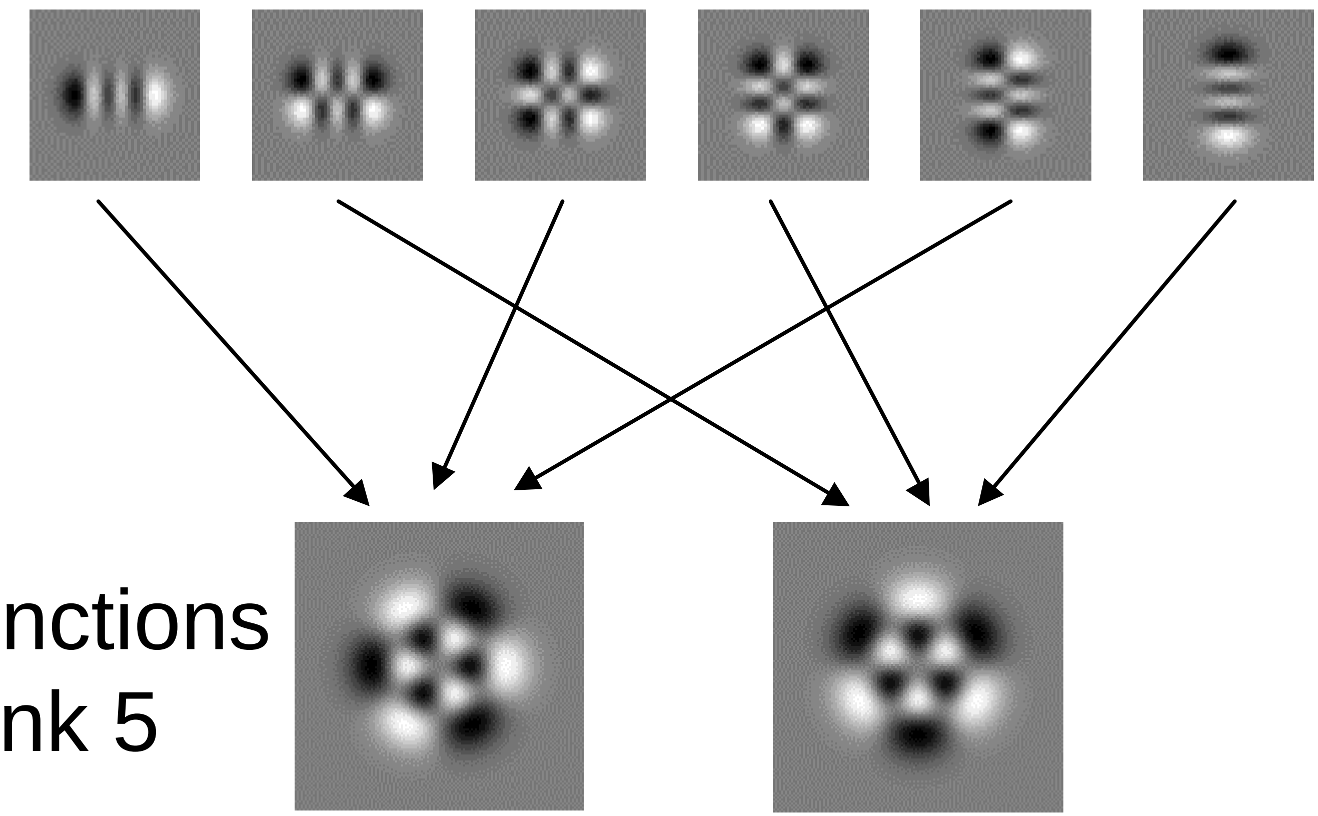
- Neurons are nonlinear: the apparent RF map depends on spatial context (basis set)
- Typical basis sets
  - Points and lines: one position, uniform in spatial frequency
  - Sine gratings: uniform in space, one spatial frequency
- But “real features” are typically local (neither pointlike nor uniform) in space and spatial frequency
- The “two-dimensional Hermite Functions”: basis functions local in space and spatial frequency

Two-Dimensional Hermite Functions



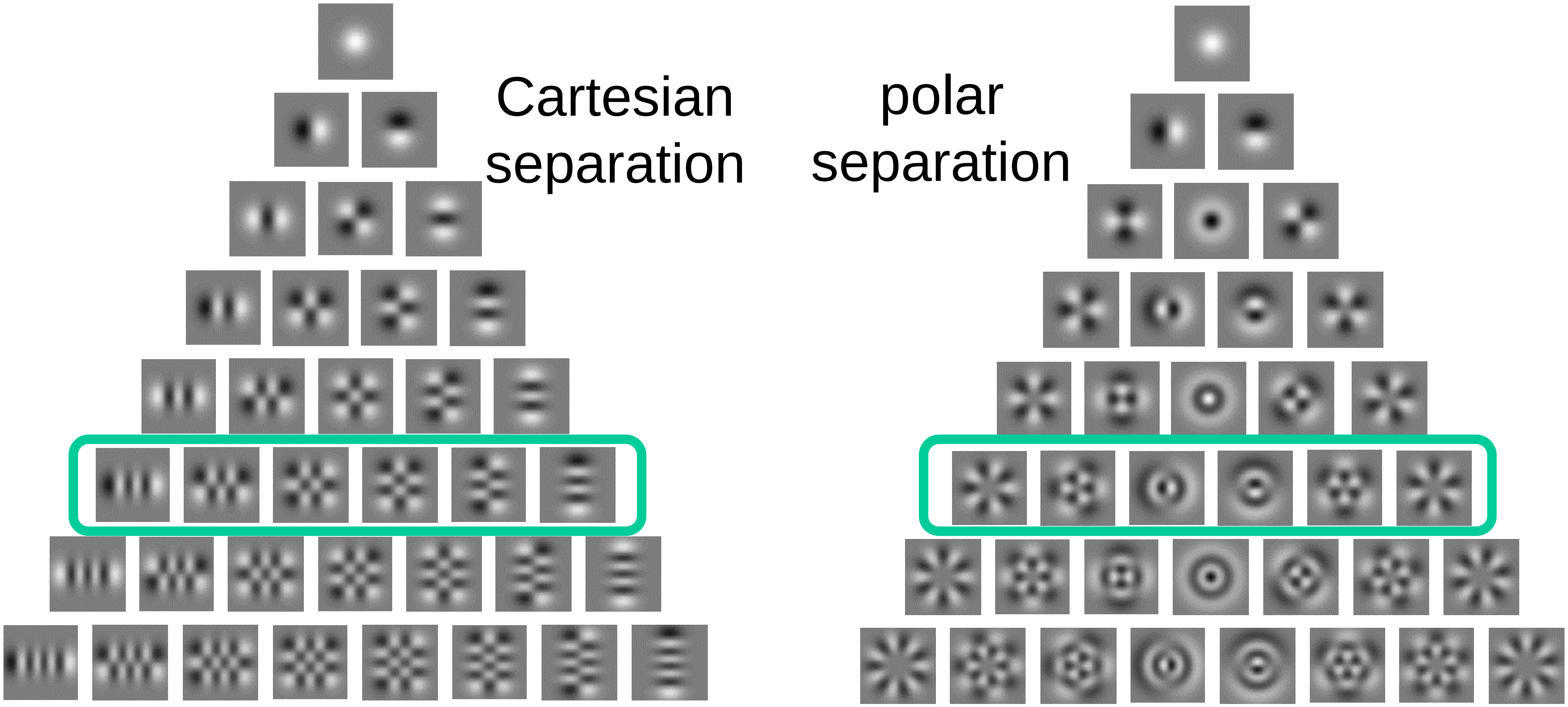
Polar Symmetry from Cartesian Components

Cartesian functions of rank 5



polar functions of rank 5

Matched Basis Sets

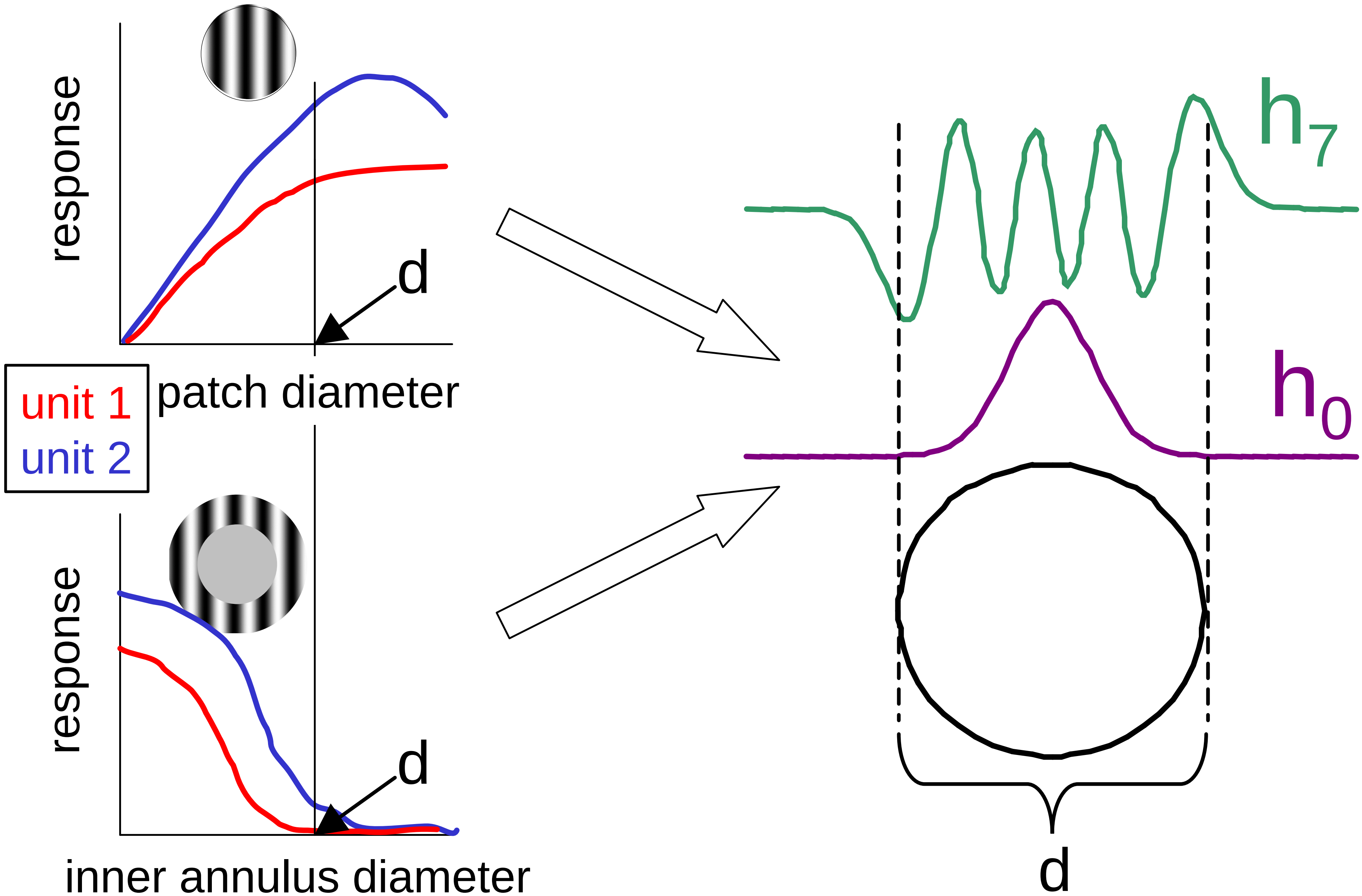


- Each basis set is complete.
- All elements have the same mean-squared contrast.
- Within each rank, the two sets have the same spatial extent and bandwidth.
- Within each rank, either set of functions is a linear combination of the other set.

Methods

- Cat V1, propofol and sufenta anesthesia
- Tetrode recording, on-line and then off-line spike sorting
- Quantitative characterization (orientation, SF, TF, CSF) with drifting sine gratings
- Determination of receptive field center size via responses to circular and annular patches of the optimal grating

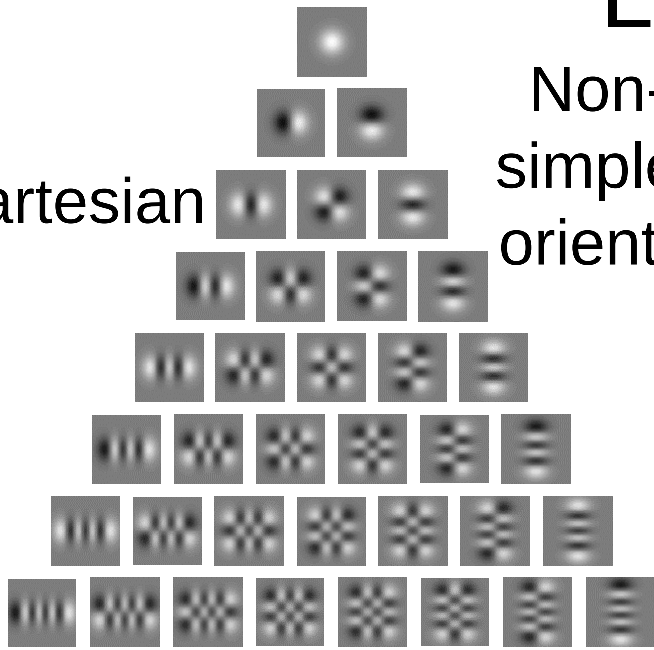
Stimulus Alignment

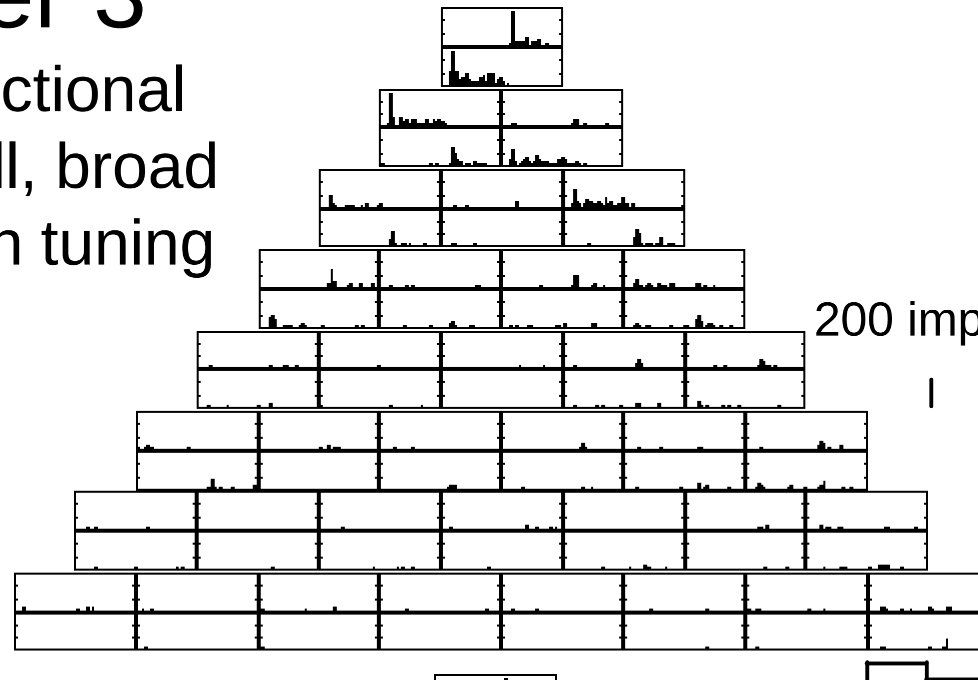


Layer 3

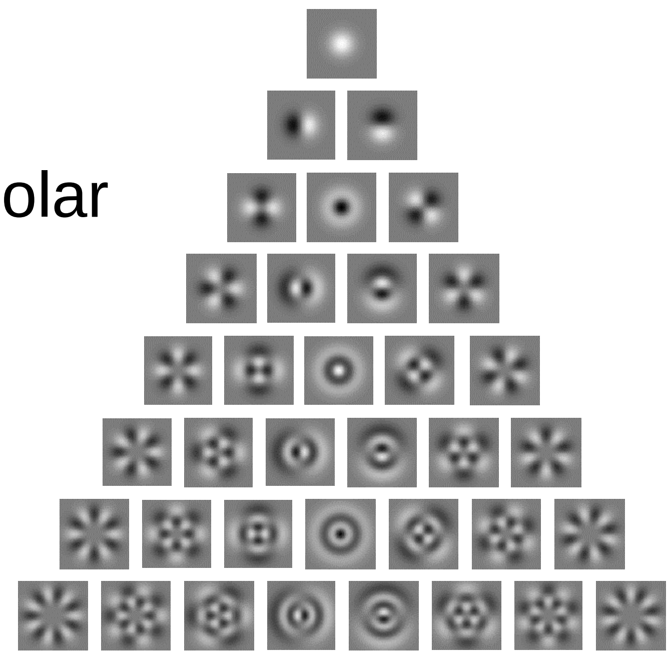
Non-directional
simple cell, broad
orientation tuning

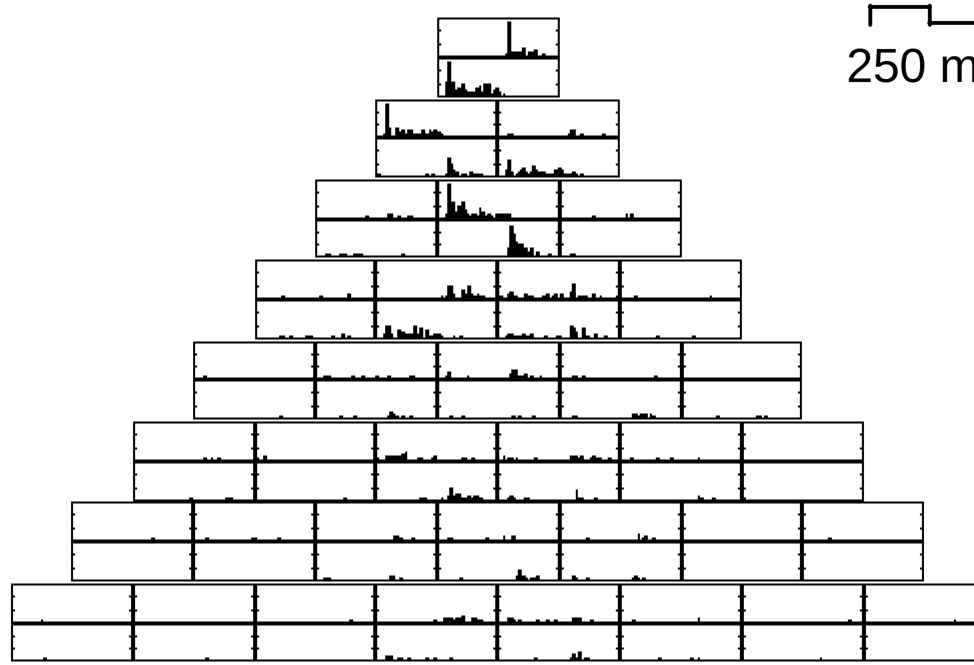
Cartesian





polar



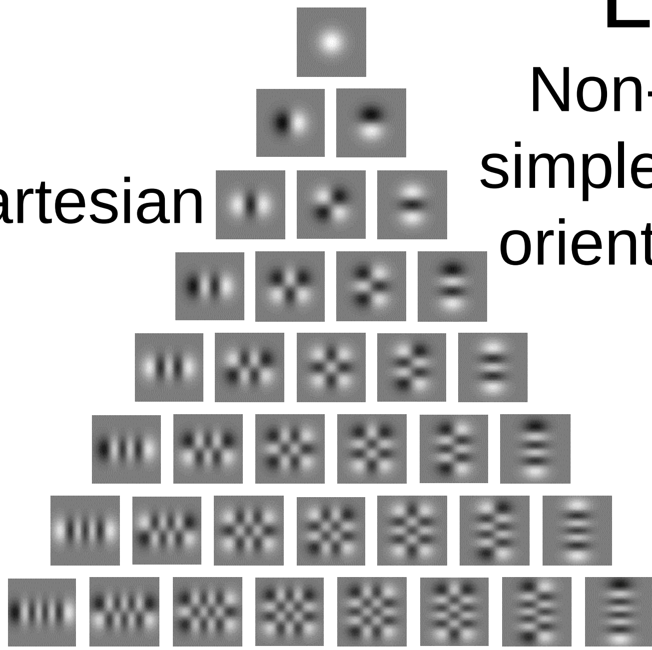


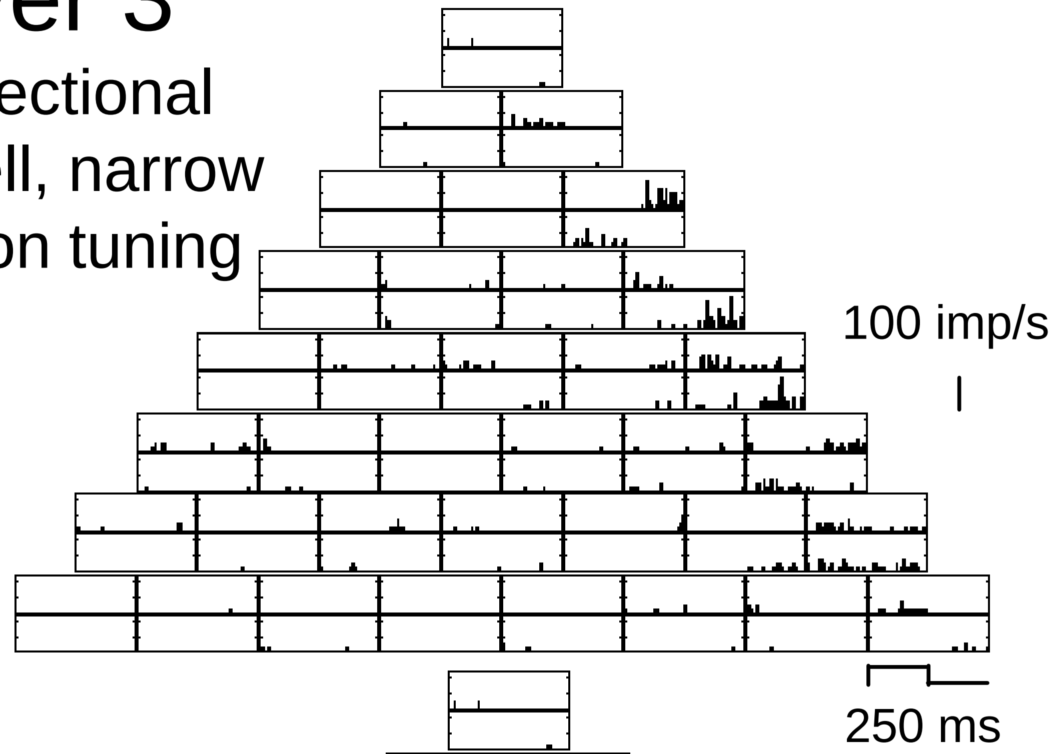
c3003s

Layer 3

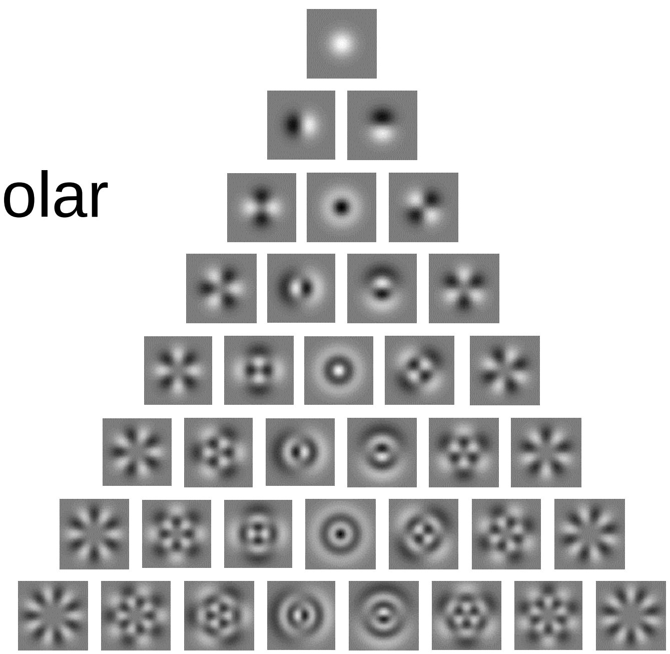
Non-directional simple cell, narrow orientation tuning

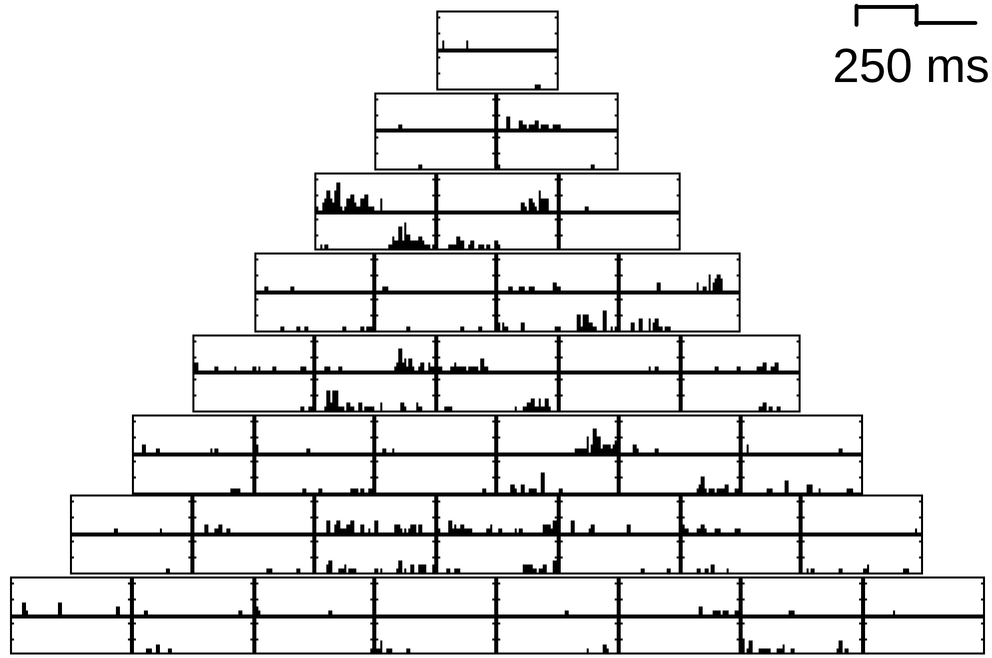
Cartesian





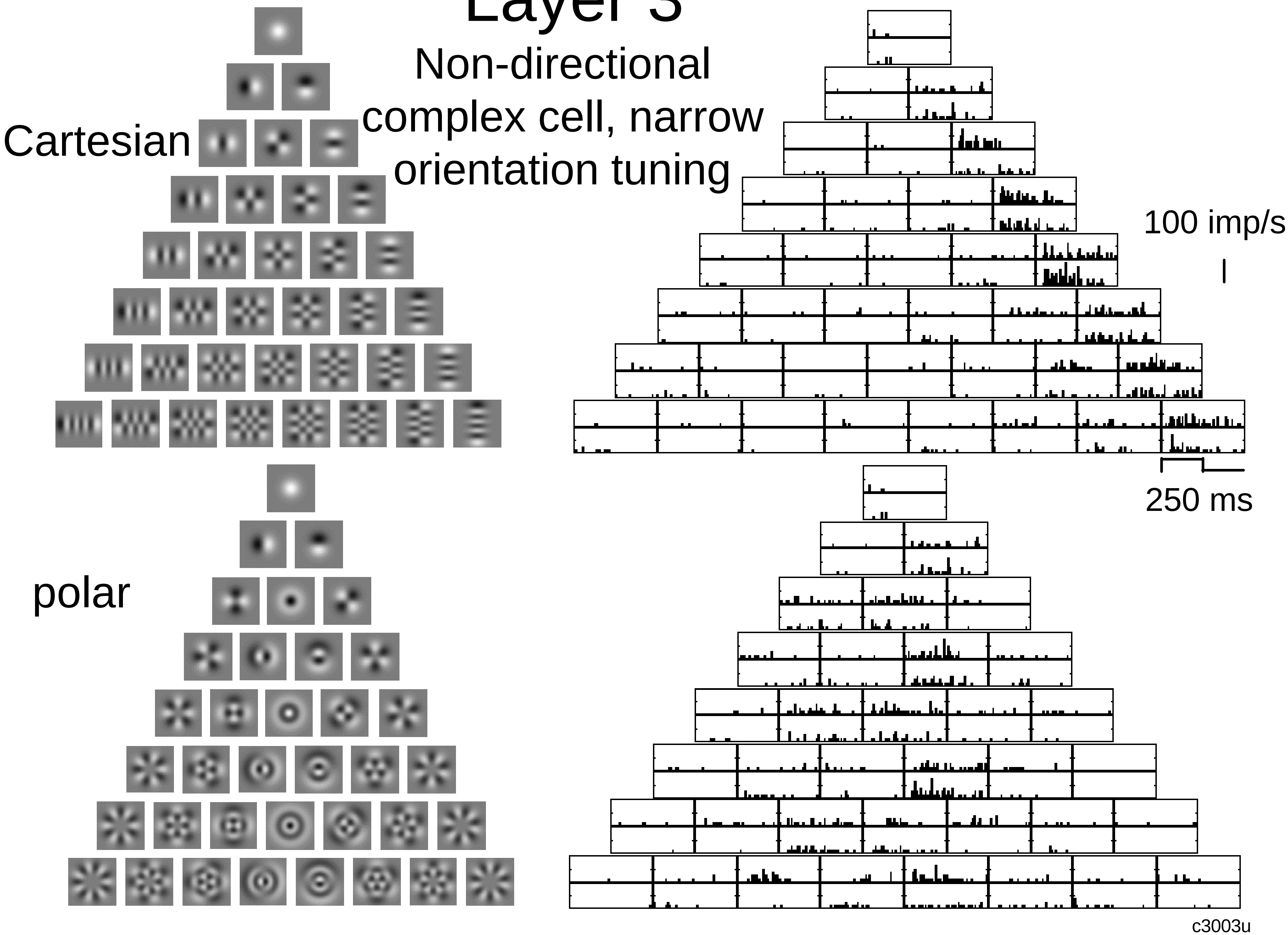
polar





c3003t

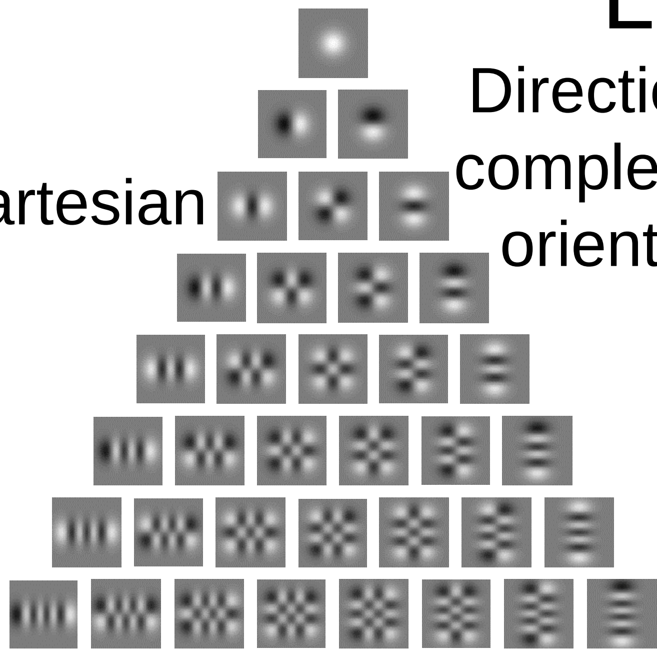
Layer 3

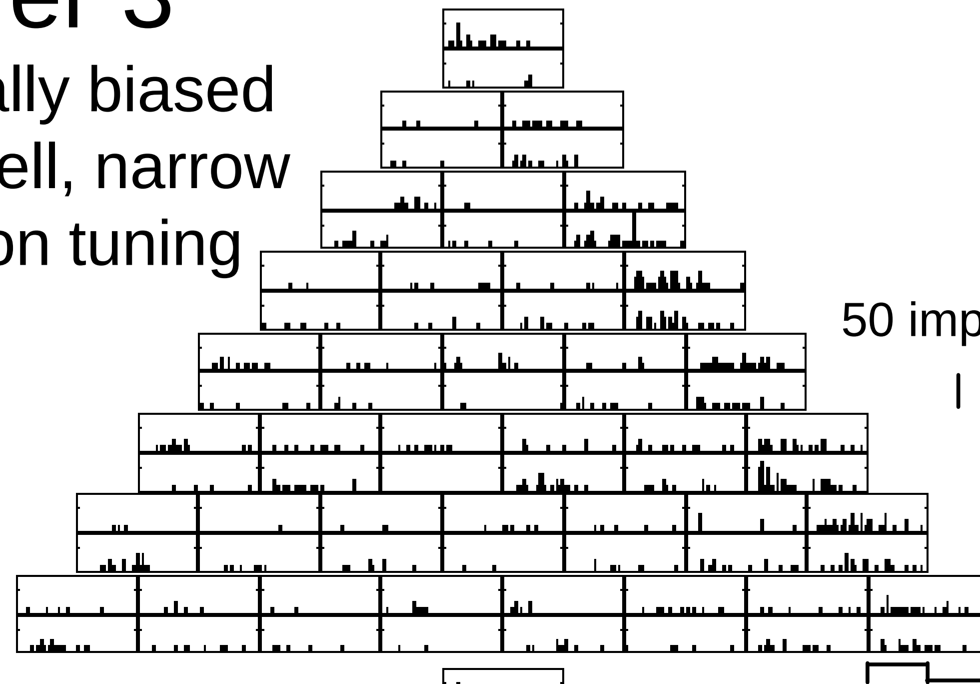

Non-directional
complex cell, narrow
orientation tuning
Cartesian
polar
100 imp/s
250 ms
c3003u

Layer 3

Directionally biased complex cell, narrow orientation tuning

Cartesian

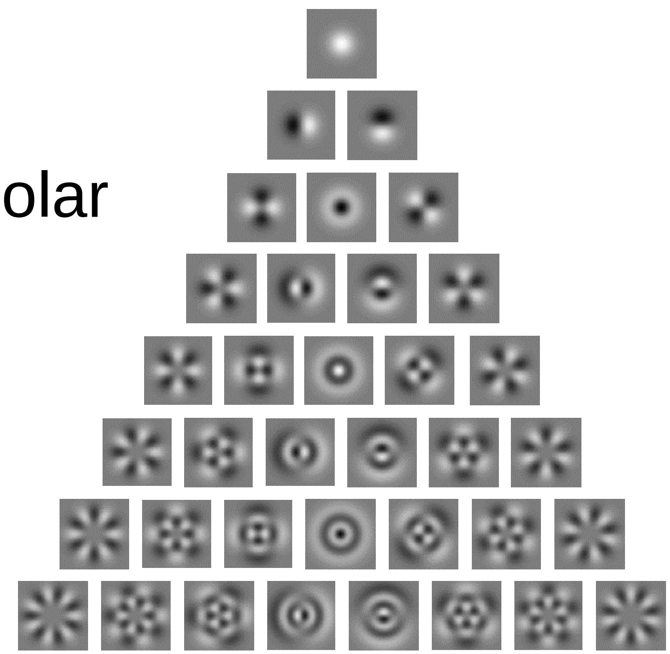


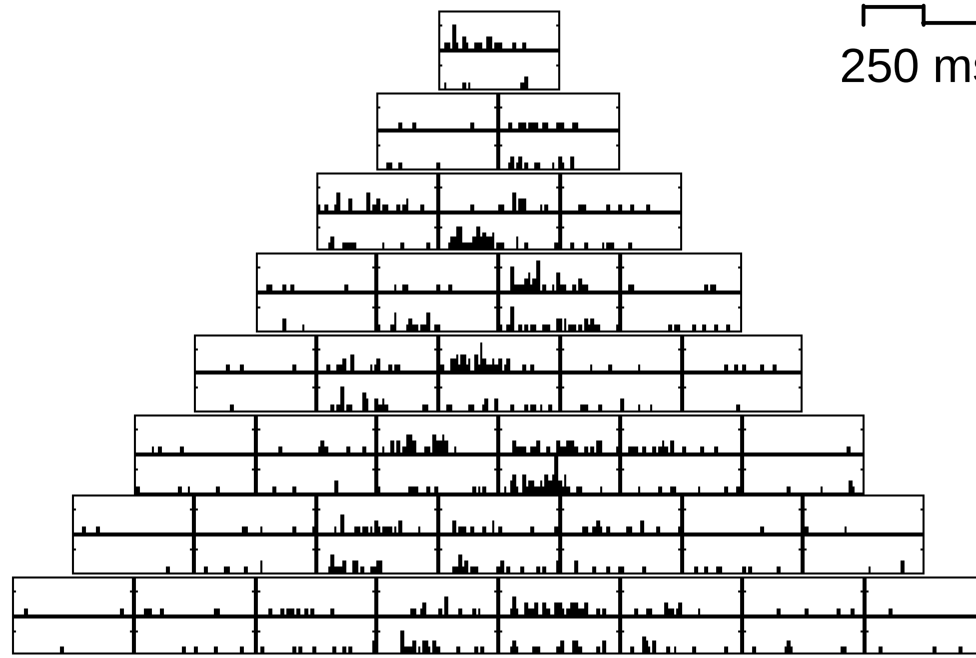


50 imp/s

250 ms

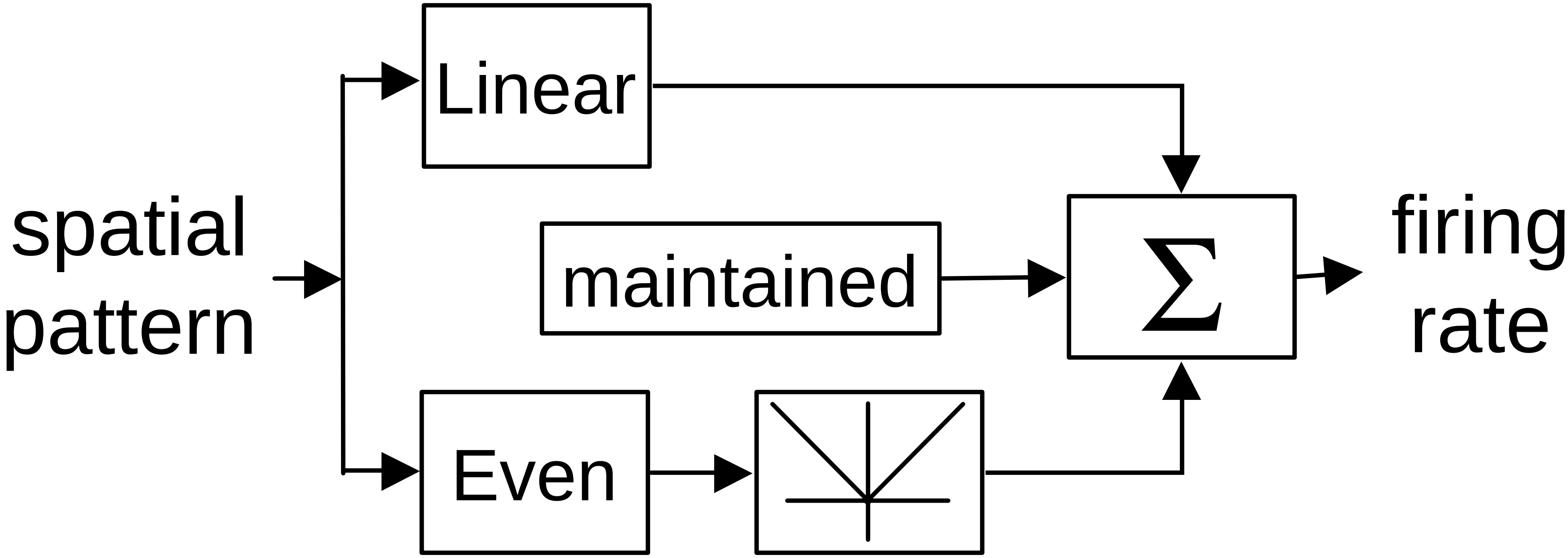
polar

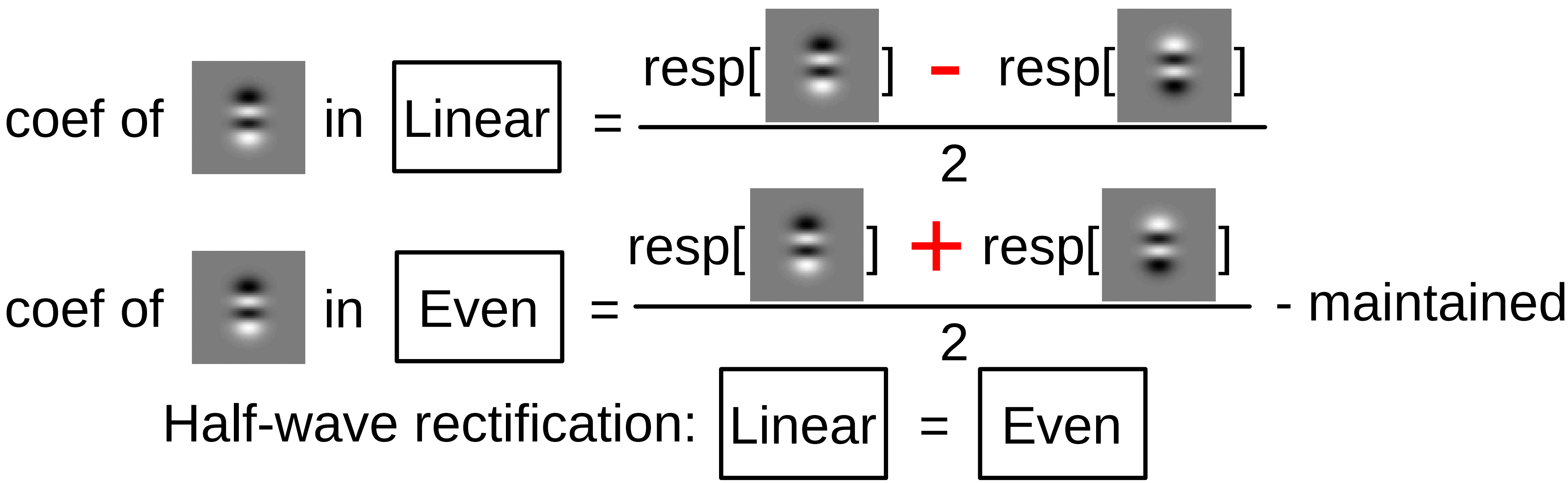




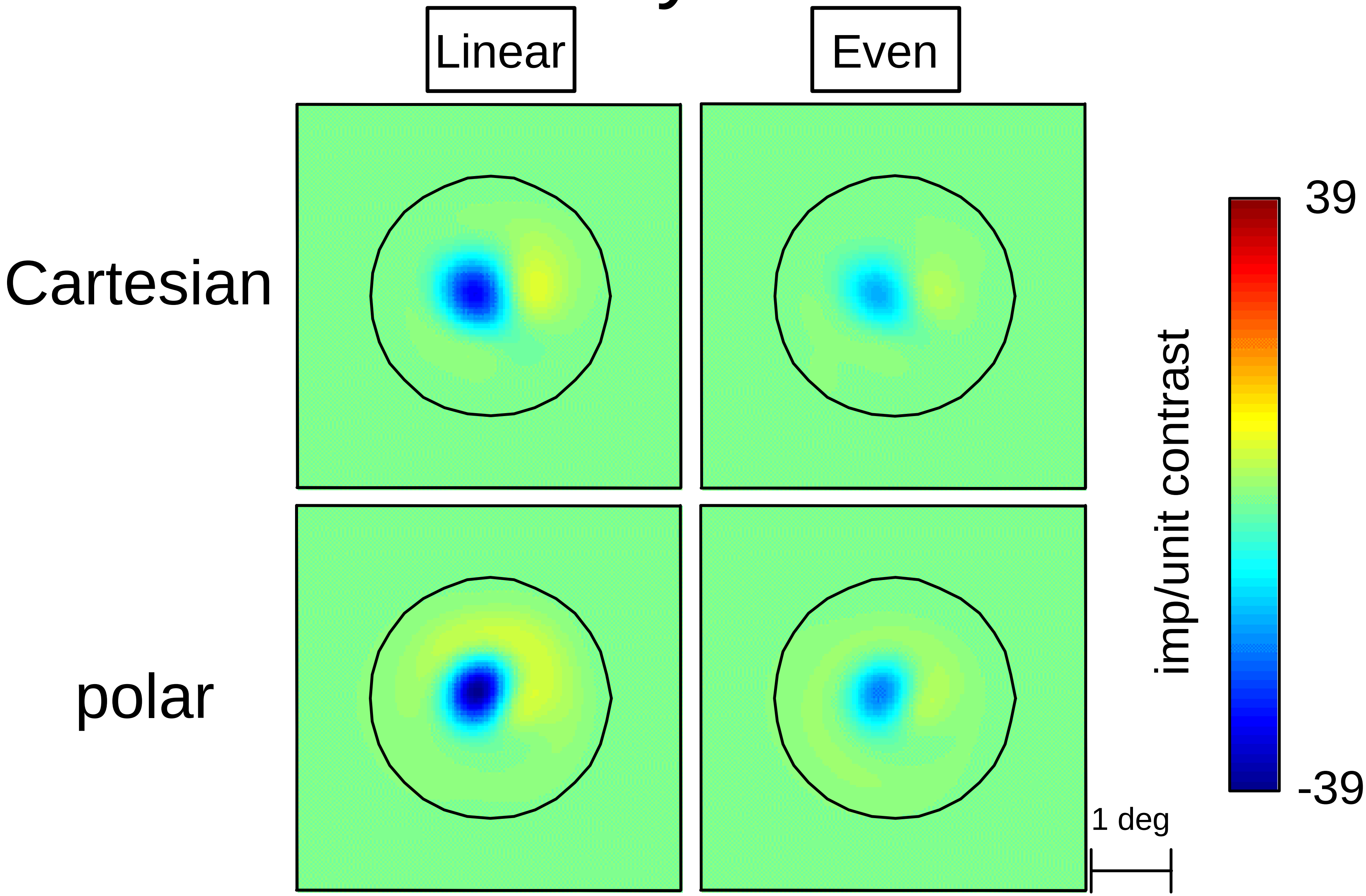
c3003x

Quantitative (“Model”) Framework





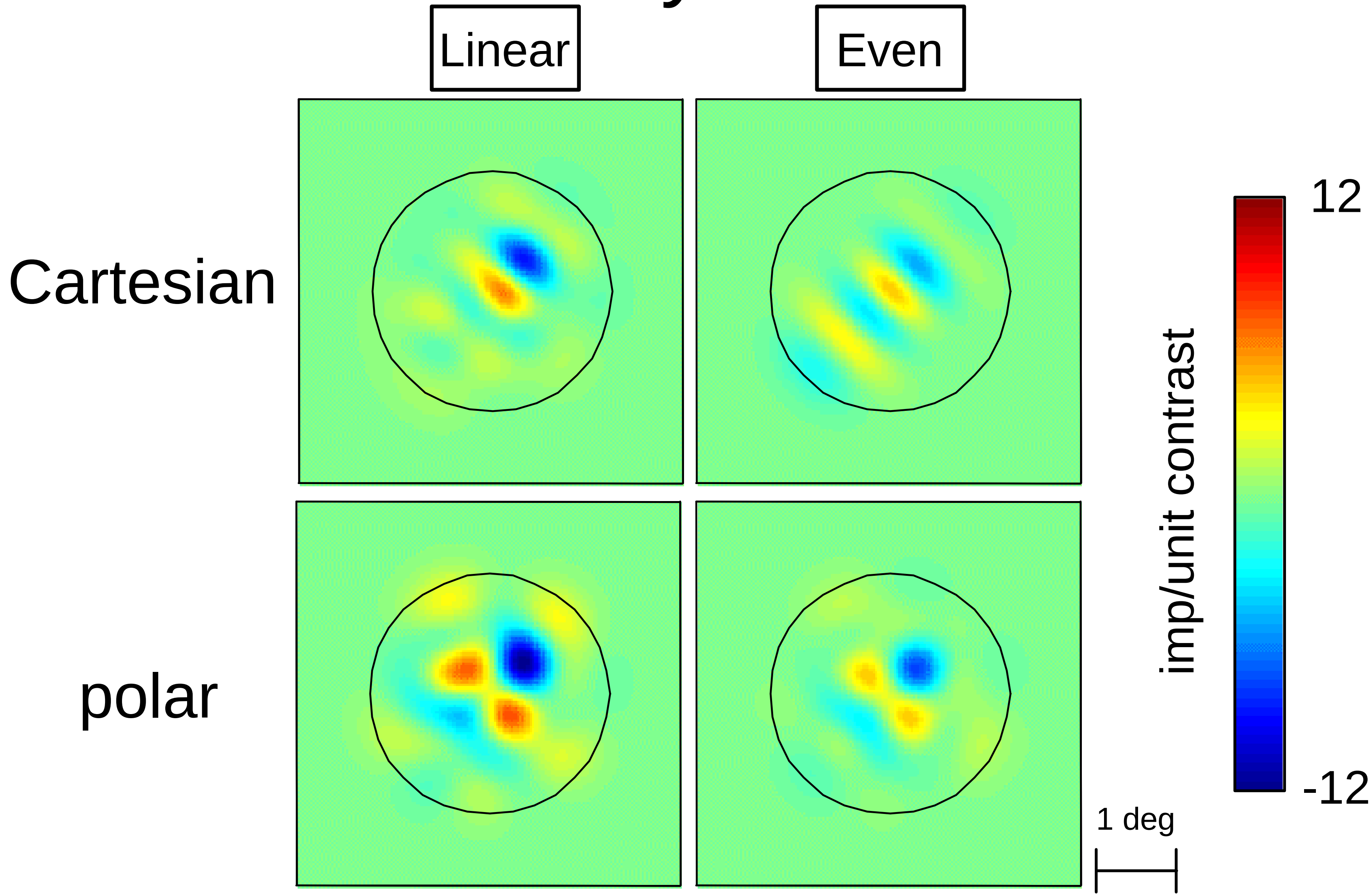
Layer 3



Non-directional simple cell, broad orientation tuning

c3003s

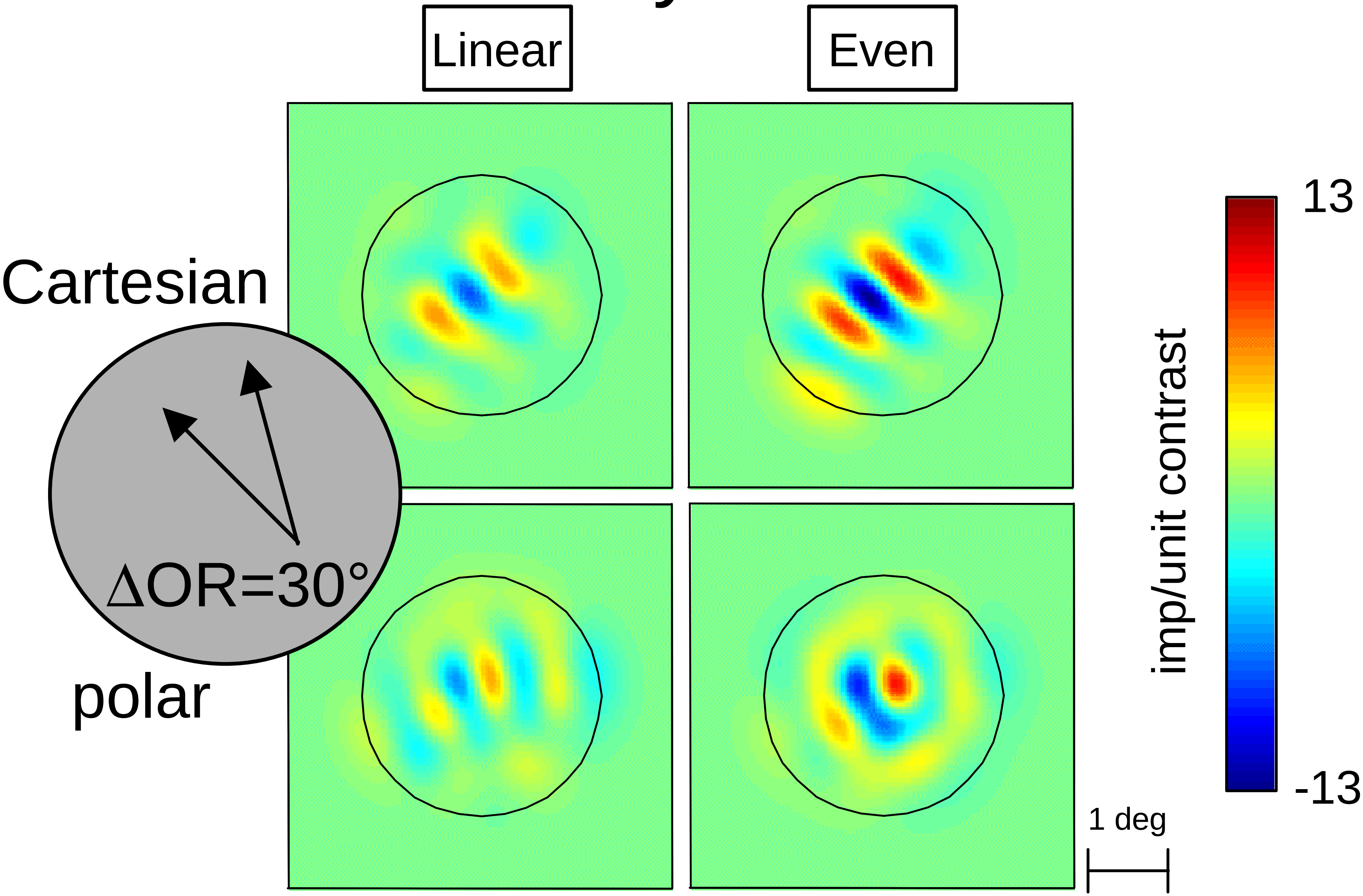
Layer 3



Non-directional simple cell, narrow orientation tuning

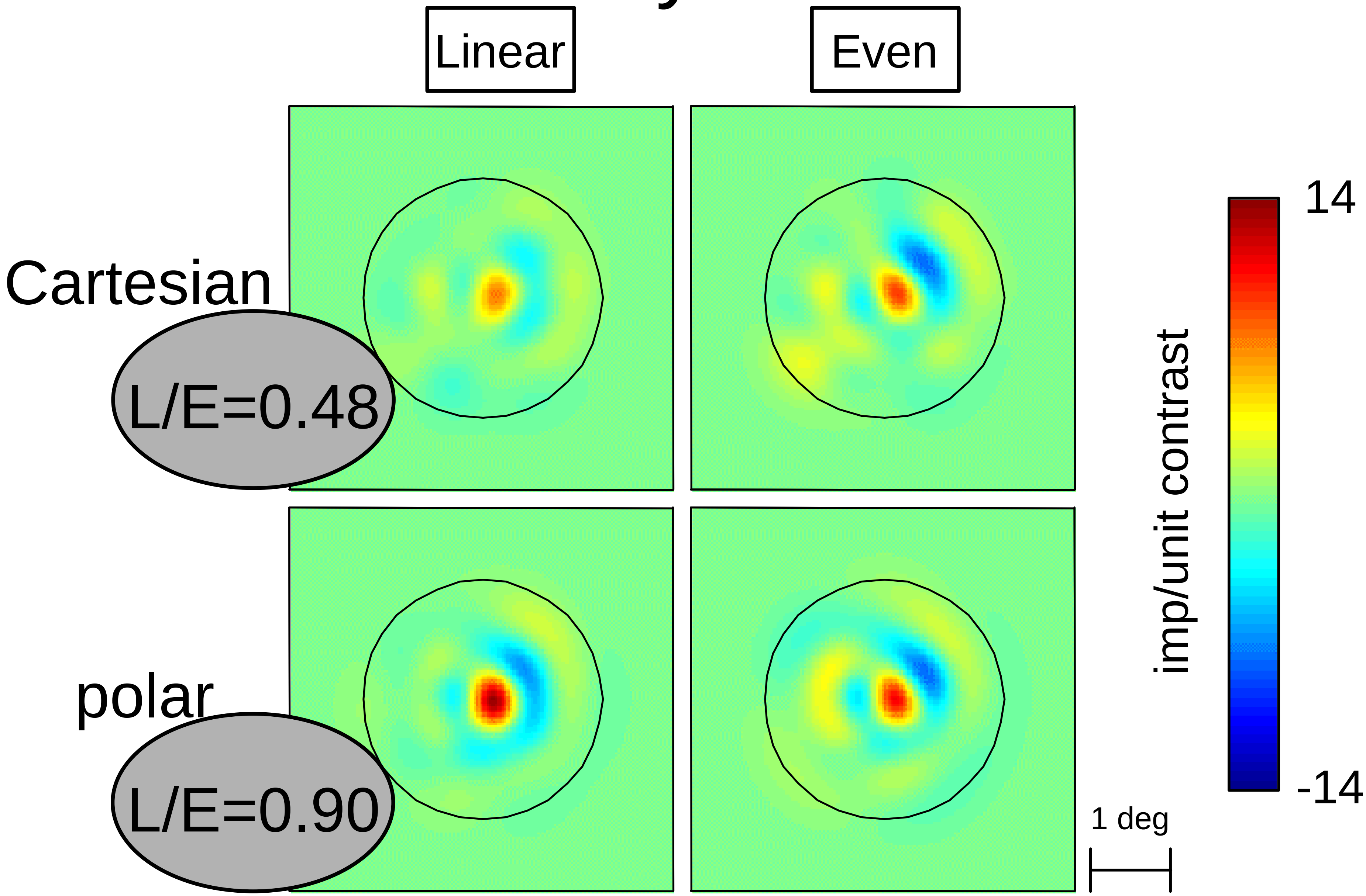
c3003t

Layer 3



Non-directional complex cell, narrow orientation tuning c3003u

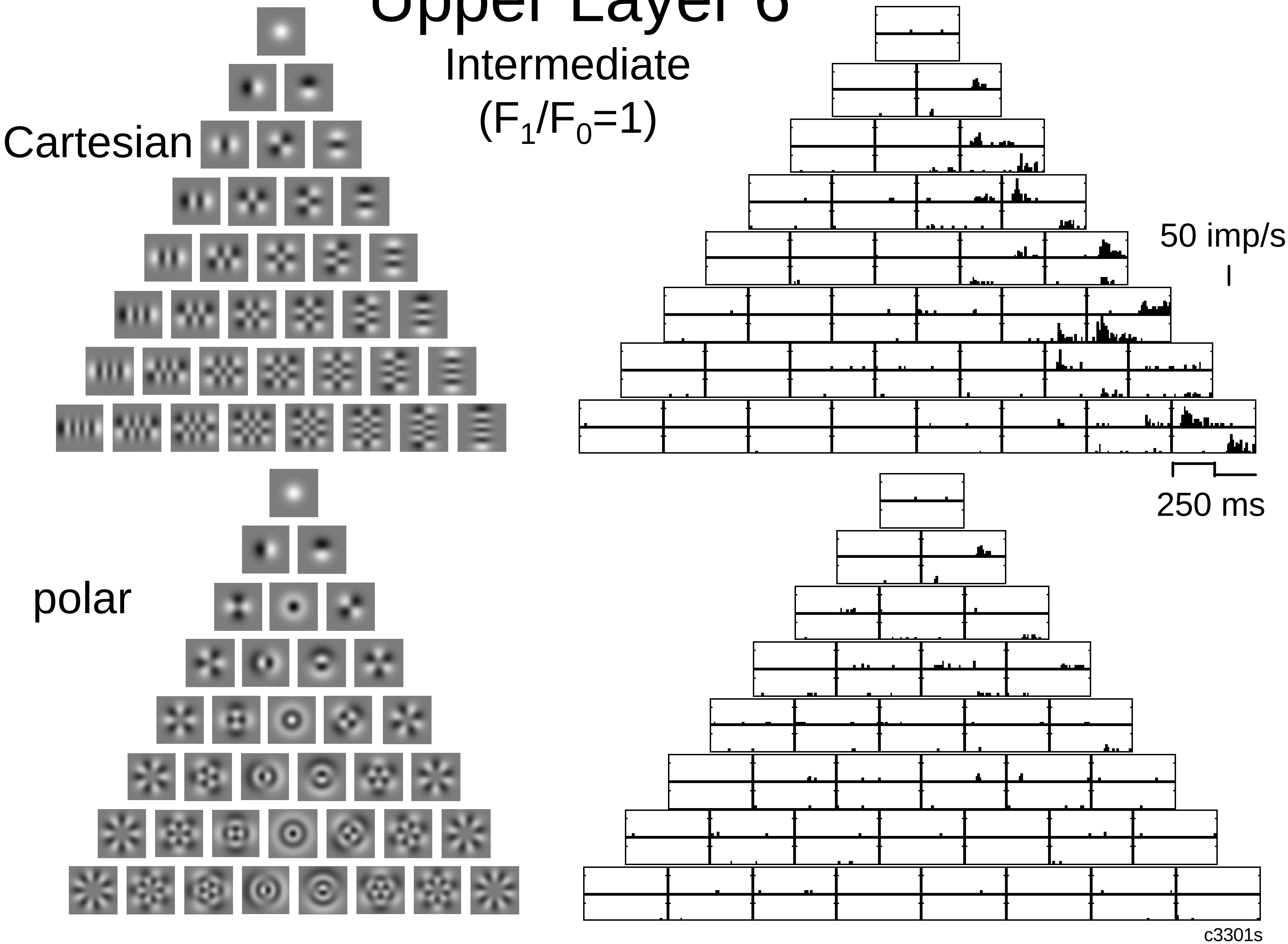
Layer 3



Directionally biased complex simple cell, narrow orientation tuning

c3003x

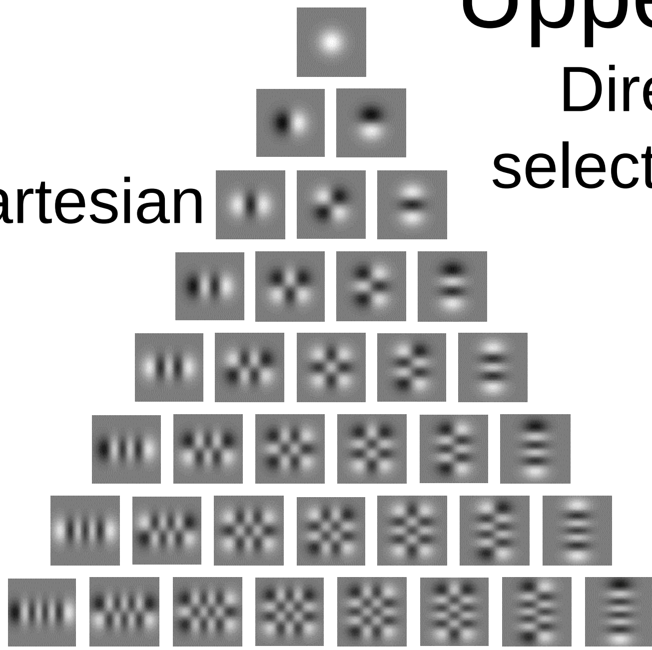
Upper Layer 6

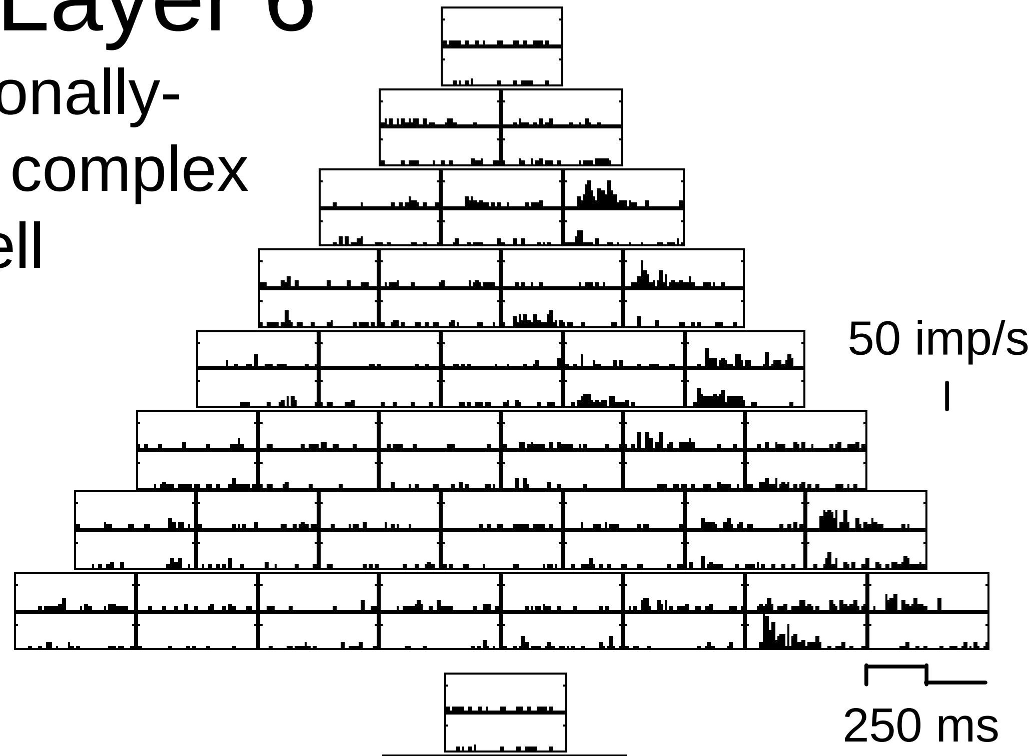


Upper Layer 6

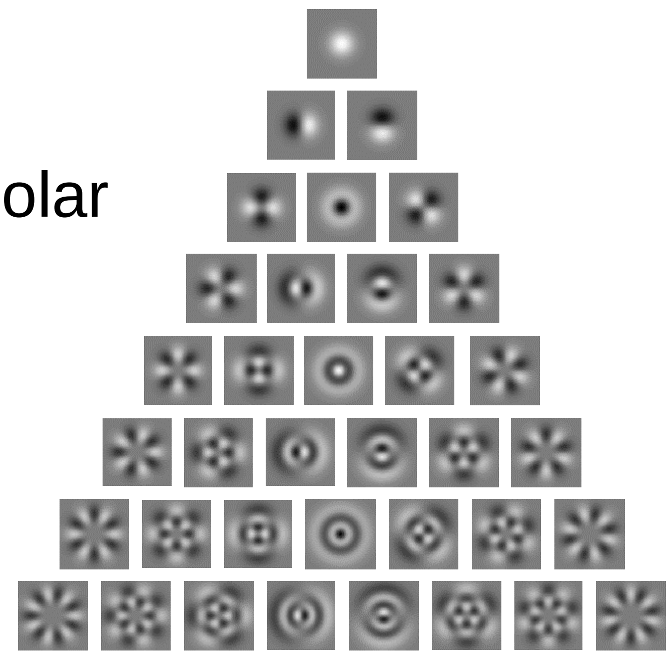
Directionally-selective complex cell

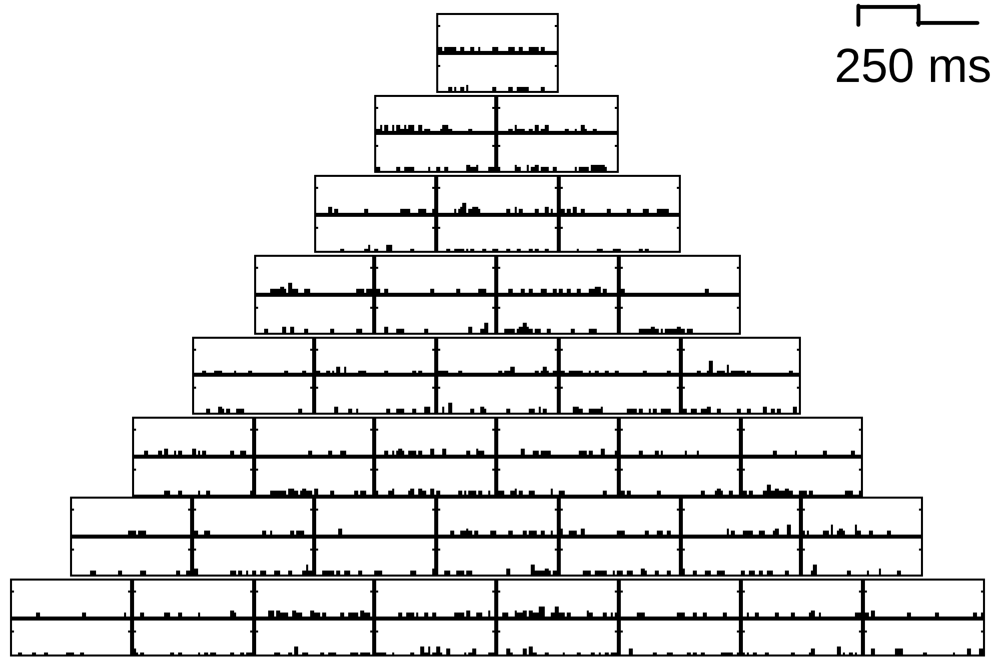
Cartesian





polar

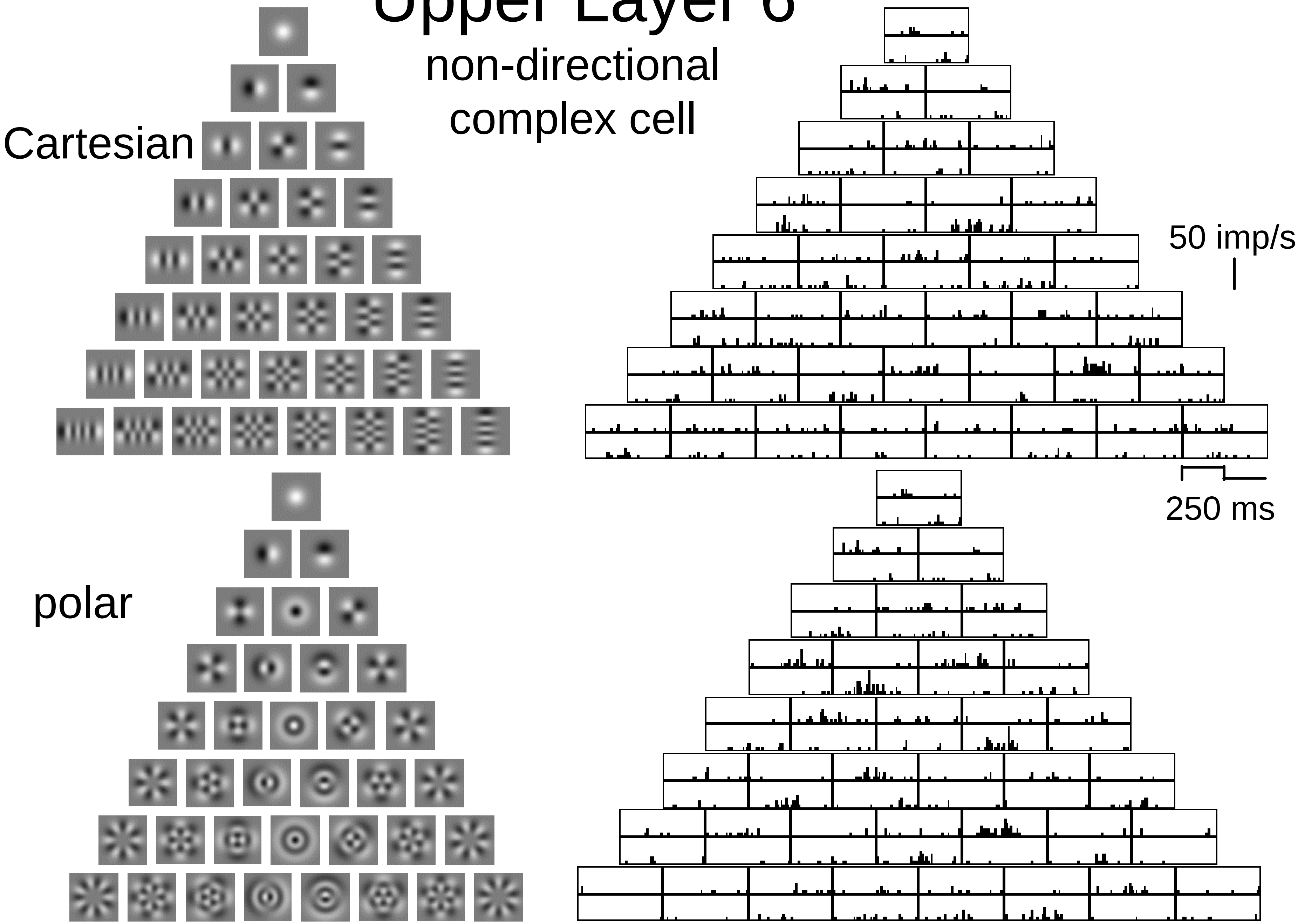




c3301t

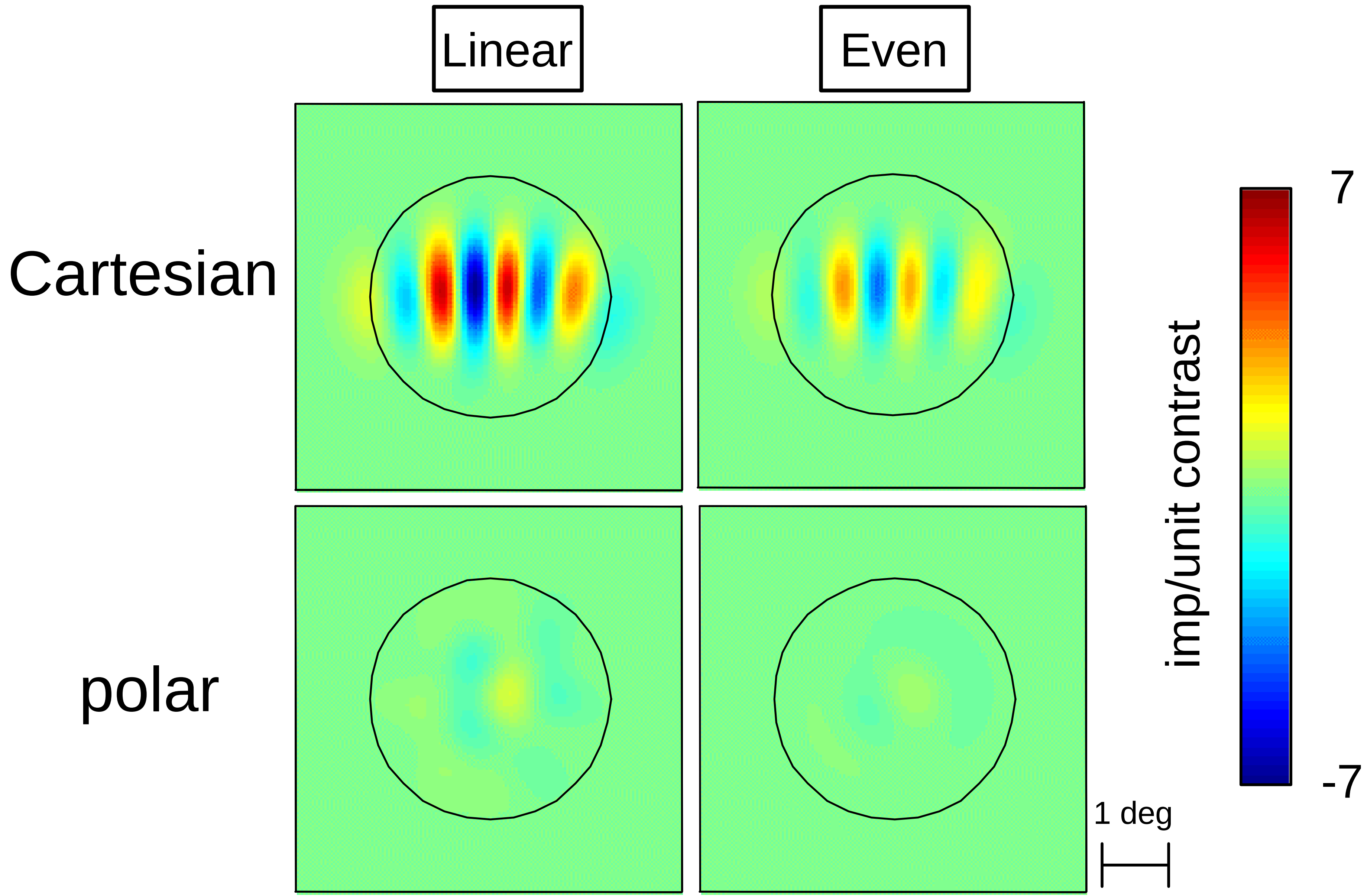
Upper Layer 6

non-directional
complex cell



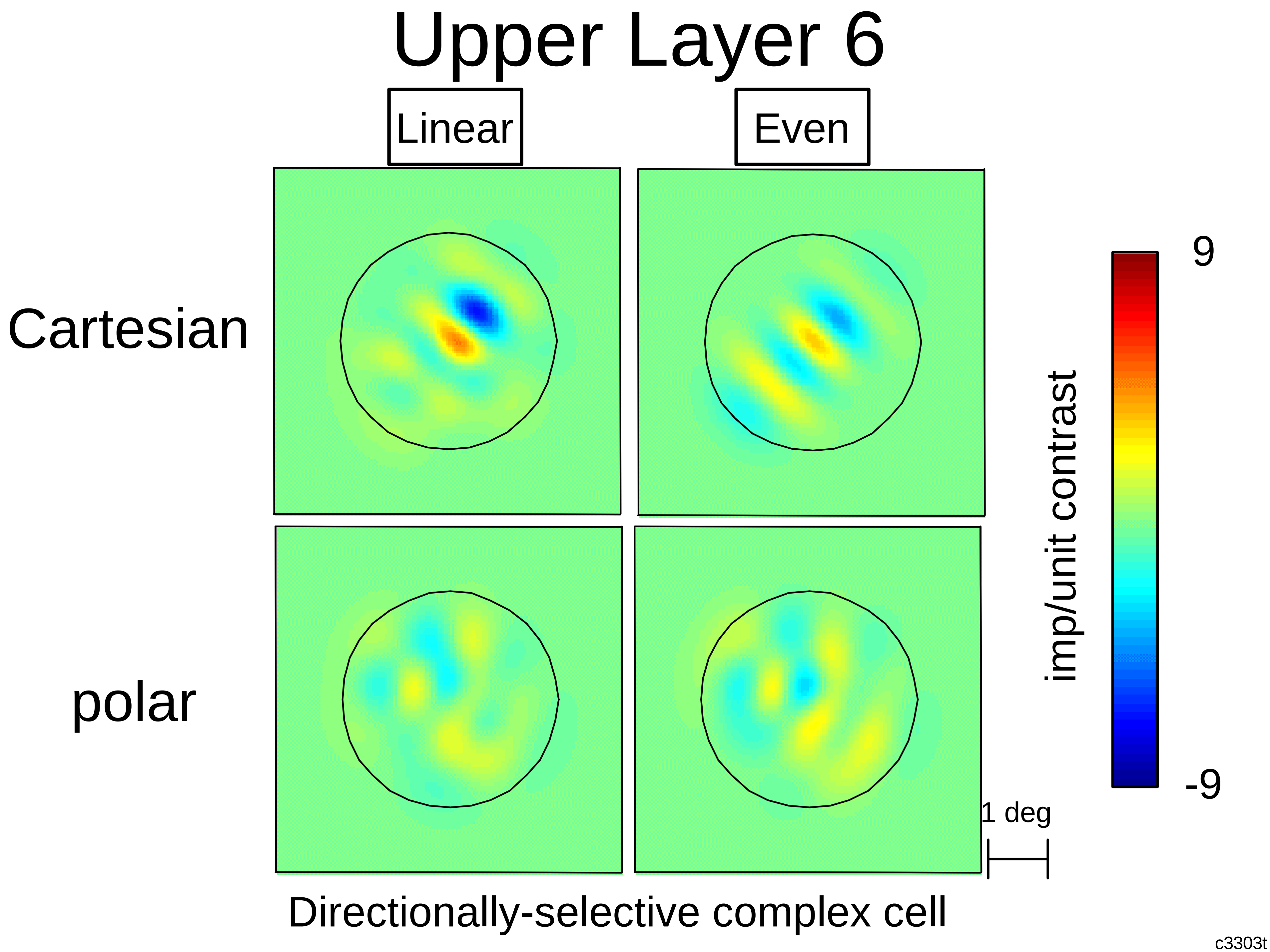
c3301u

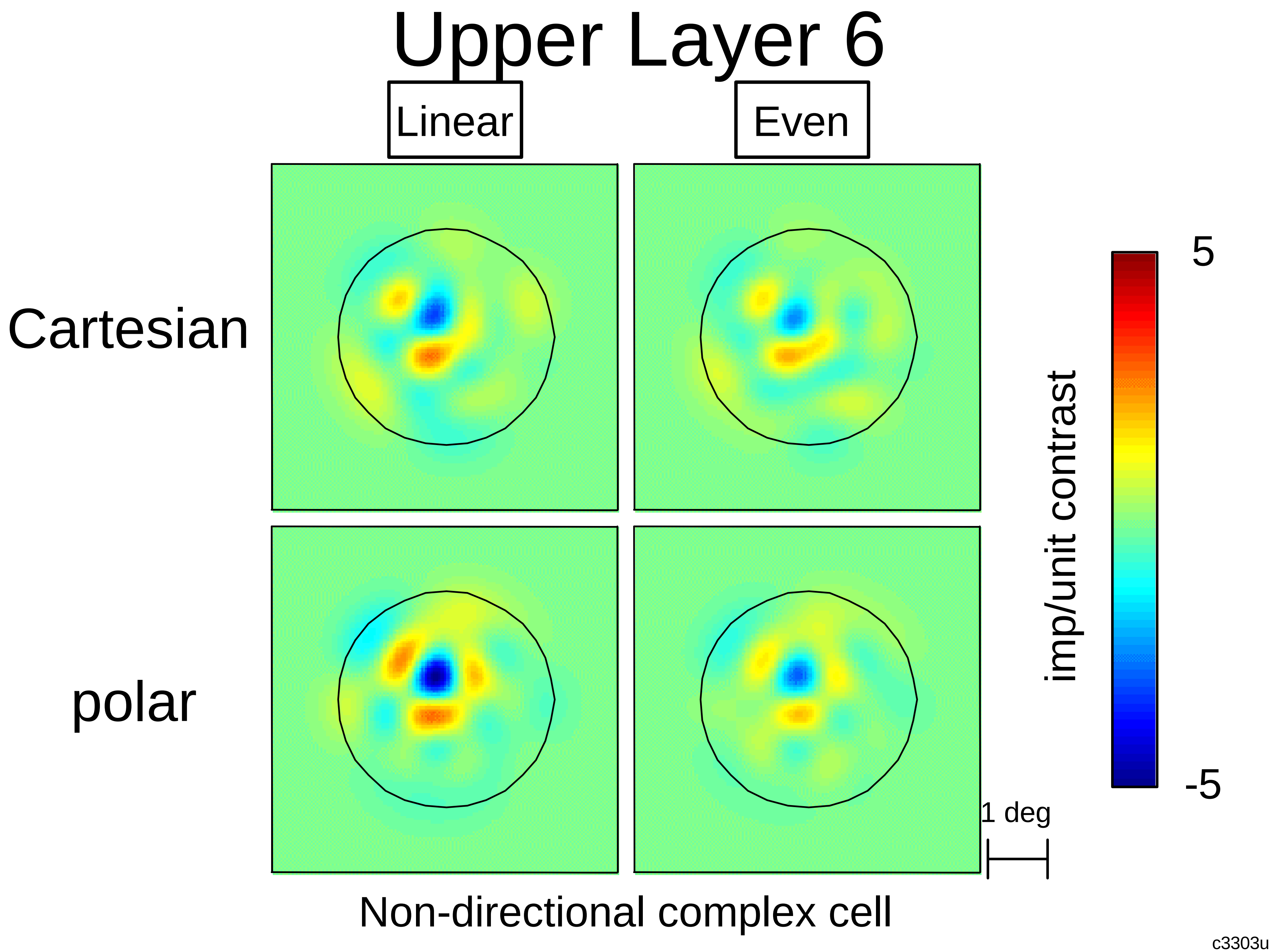
Upper Layer 6



Intermediate (F_1/F_0=1)

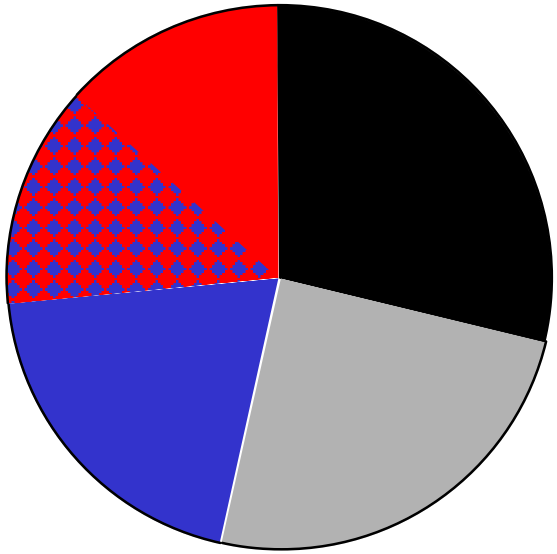
c3303s


Upper Layer 6
Linear
Even
Cartesian
polar
imp/unit contrast
9
-9
1 deg
Directionally-selective complex cell
c3303t


Upper Layer 6
Linear
Even
Cartesian
polar
imp/unit contrast
5
-5
1 deg
Non-directional complex cell
c3303u

Summary

- 34/45 well-isolated neurons (12 sites) responded well to TDH stimuli
- 12/34 differed in overall sensitivity for Cartesian and polar TDH stimuli
  – 7: Cartesian > polar, 5: Cartesian < polar
  – 3/7 showed an increased “linear”/”even” response ratio for polar stimuli
- 15/34 differed in RF shape
  – Cartesian maps are better match to grating tunings
- 13/34 showed neither difference



Conclusions

- Cartesian and polar TDH basis sets have the same spatial extent, spatial frequency content, and contrast, but nevertheless reveal distinct linear and nonlinear filtering properties in typical V1 neurons.
- Speculations
  - The presence of elongated domains underlies this behavior.
  - These bottom-up influences are relevant to understanding V1 responses to natural scenes.