Bidirectional and hierarchical learning models of cognitive representation and computation in the visual cortex

— Project outline —

Nov, 2016

Haruo Hosoya
Senior researcher, ATR
Background: Visual cortex

- Major neural basis of our visual system
- A wealth of experimental facts from neuroscience
  - Anatomy: multiple pathways/stages, feedforward/feedback, ...
  - Physiology: tuning/selectivity to various visual features, ...
- Theoretical questions:
  - What are underlying computational principles?
  - How do they lead to our highly sophisticated visual system?
- Potential applications: brain information decoding, artificial intelligence, ...

![Diagram of the visual cortex showing pathways and areas such as V1, V2, V4, IT, and C+.]
Background: Efficient coding theory

- Hypothesis: the visual cortex might employ a coding strategy optimized to the statistics of natural inputs
- Sparse coding theory [Olshausen & Field 1996] and related theories explained a number of receptive field properties in V1
  - edge detection, color coding, binocular disparity, motion, etc.
- Our recent hierarchical model exhibited a good match with V2 properties [Hosoya & Hyvärinen 2015]
- But most of these results focused on early visual stages
Background: Bidirectional computation (background)

- Bidirectional (feedforward and feedback) circuitry is ubiquitous in the visual cortex, but its precise roles are not well understood.
- Modern approaches to study bidirectionality is Bayesian inference.
  - Seminal hierarchical Bayesian vision model [Rao & Ballard 1999]
  - Our project touched on this direction.
    - blind-spot filling-in [Hosoya NeCo 2012]
- But prior studies concentrated on rather low-level phenomena.

\[
P(x | y) = \frac{P(y | x) P(x)}{P(y)}
\]

Bayes’ theorem
Project goal

- Bidirectionality in visual cortex has been considered to play roles in visual imagery, contextual inference, and attention.
- But we consider that bidirectional computation may be far more essential for the visual system than previously thought.
- Questions:
  - What are other kinds of bidirectional visual computation?
  - What are the underlying theoretical principles?
  - How can they explain related to neural properties?
  - How do they lead to our sophisticated visual functionalities?
Recent result: a mixture of sparse coding models

- A hierarchical model with a mixture of sparse coding models can
  - reconcile parts-based and holistic processing of faces and objects
  - explain selectivities and certain tuning properties of face neurons in the monkey IT cortex
- A top-down “explain-away effect” is crucial for these properties
- Preprint available [Hosoya & Hyvärinen 2016]
Future plan

• We will pursue other roles of bidirectionality in visual functions, e.g.,
  – High-level representations of objects, scenes, faces, etc.
  – Visual attention
  – Invariant visual recognition
  – Visual perception, imagery, and illusion
• Larger-scale bidirectional vision model integrating individual models
• Applicability to realistic problems
References


[Hosoya & Hyvärinen 2016] Hosoya H, Hyvärinen A. A mixture of sparse coding models explaining properties of face neurons related to holistic and parts-based processing. bioRxiv: http://dx.doi.org/10.1101/086637