How do we computationally model sensory integration? A Learner-Based View of Cue Combinations and Approaches to Optimal Predictions

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In our systems there is redundancy of sensory information that can lead to improper redintegration of our percept into a holistic scene. This is important when considering particularly visual information- motion, binocular disparity, and texture gradients are all important when taking into account how visual scenes are discerned. In order to understand the cue combination we can integrate linear cues simply by sensory integration rules. We can understand this somewhat through basic cues like motion and texture cues at different distances. As described by this equation- $d(m,t)= w_d (m) + w_d (t)$. The question is how we decide the weights for motion and texture in our visual perception- cue weights should be based on cue reliabilities. Cue reliability may be hard to measure since there are certain physical factors: atmospheric or optical blurring and biological factors: neural noise that lead to confusion. The optimal linear cue combination- maximum likelihood (or Kalman filter) theory of cue reliability. A cue is relatively reliable if the distribution of inferences based on that cue has a relatively small variance. Motion and texture cues are conditionally independent given scene parameter(s) of interest. Conditional independence and independence are different- motion and texture cues are not independent. If motion cue indicates a small depth, then texture cue probably also indicates a small depth nut these cues- motion and texture cues are conditionally independent The noise in the motion cue is independent from the noise in the texture cue. In other words, the trial-by-trial variabilities (i.e., noise) in the motion and texture measurements are uncorrelated. Integration of senses is represented the brain through a series of pathways and mechanisms for representation. For example the necker cube, can be represented in infinite ways as it it transform from a 2D to 3D shape but given a another cue (a block through it) we can limit the possible orientations of the cube. The idea 'visual capture' was repeated in this articles, as subjects increasingly weigh visual cues in discerning shape. The MLE approach was appended with other models to shown a top-down and bottom-up approach to sensory feedback. These articles explore how we can computationally model sensory cue integration.

Articles I'm thinking of using:

1. Humans integrate visual and haptic information in a statistically optimal fashion.

Ernst, Banks

As a person combines visual and haptic feedback, their innenwelt changes as they perceive the world weighted by each sensory input. Vision predominates touch but to varying levels- perhaps based off of a MLE integrator. This weighting of the visual system is proportional to the variance associated with visual estimation relative to that of haptic estimation. By feeling raised ridges, participants judged the height with each sense separately then with both, varying the noise of the stimuli across trials.

2. Bayesian Integration in Sensorimotor Learning
Konrad P. Ko¨rding & Daniel M. Wolpert

Learning a new motor skill can be modeling through a Bayesian function that takes in multiple sensory modalities to change it's posterior. Increased levels of uncertainty in senses can lead to more reliance on our priors and also in new sensorimotor tasks we can optimize our probability of success through this Bayesian model. In a virtual reality task, subjects were trained to reach a visual target with varying conditions of blurriness to increase visual uncertainty. The results of these trials were compared to three models of visual-motor interaction with predicts uncertainty.

3. Merging the senses into a robust percept
Marc O. Ernst and Heinrich H. Bu¨ lthoff

Integration of senses is represented the brain through a series of pathways and mechanisms for representation. For example the necker cube, can be represented in infinite ways as it it transform from a 2D to 3D shape but given a another cue (a block through it) we can limit the possible orientations of the cube. The idea 'visual capture' was repeated in this articles, as subjects increasingly weigh visual cues in discerning shape. The MLE approach was appended with other models to shown a top-down and bottom-up approach to sensory feedback.

4. Battaglia, P.W., Jacobs, R.A, and Aslin, R.N. (2003). Bayesian integration of visual and auditory signals for spatial localization. Journal of the Optical Society of America A, 20, 1391-1397.
Cue-consistent versus cue-conflict environments
Two models for cue-conflict situations: Winner-take-all (Visual Capture) and Maximum Likelihood Estimation (MLE).
Procedure has, Auditory-only trials – Estimate auditory mean and variance
Visual-only trials– Estimate visual mean and variance Compute predictions of two models on visual-auditory trials: – Compute Visual Capture predictions (Compute MLE predictions)

Broadband noise filtered to mimic the spectral characteristics of a sound source external to the listener

Random-dot stereogram of a bump protruding from a background surface
Noise could be added to visual stimulus
– Low noise: easy to detect and localize bump
– High noise: difficult to detect and localize bump

5. Sensory integration for reaching: models of optimality in the context of behavior and the underlying neural circuits
PN Sabes - Progress in brain research, 2011 - Elsevier
Although multisensory integration has been well modeled at the behavioral level, the link between these behavioral models and the underlying neural circuits is still not clear. This gap is even greater for the problem of sensory integration during movement planning and execution. The difficulty lies in applying simple models of sensory integration to the complex computations that are required for movement control and to the large networks of brain areas that perform these computations. Here I review psychophysical, computational, and physiological work on multisensory integration during movement planning, with an emphasis on goal-directed reaching. I argue that sensory transformations must play a central role in any modeling effort. In particular, the statistical properties of these transformations factor heavily

into the way in which downstream signals are combined. As a result, our models of optimal integration are only expected to apply "locally," that is, independently for each brain area. I suggest that local optimality can be reconciled with globally optimal behavior if one views the collection of parietal sensorimotor areas not as a set of task-specific domains, but rather as a palette of complex, sensorimotor representations that are flexibly combined to drive downstream activity and behavior.

6. Decoding Seen and Attended Motion Directions from Activity in the Human Visual Cortex

fMRI showed significant results in image contrast as subjects displayed greater responses to visual motion and adapted responses to repeated motion directions. Directional selectivity in individual motional stimuli could not be discerned however activity in areas V1–V4 and MT+/V5 suggested eight directions that were could be involved in perception of the direction of movements. Ensemble activity could also predict which of two overlapping motion directions was the focus of the subject's attention, as the perceptual attentional systems activated. Thus the theory that feature-based attention can bias direction-selective population activity in multiple visual areas is partially explained by the MT+/V5 and early visual areas (V1–V4). This theory is know takes root in the gain-modulation models of feature-based attention and theories of early attentional selection.

These processes interpolate our attentional selection, conscious perception, and direction-selective responses.

7. Coordinate transformations and sensory integration in the detection of spatial orientation and self-motion: from models to experiments

AM Green, DE Angelaki - Progress in brain research, 2007 - Elsevier

An accurate internal representation of our current motion and orientation in space is critical to navigate in the world and execute appropriate action. The force of gravity provides an allocentric frame of reference that defines one's motion relative to inertial

8. Audiovisual sensory integration using hidden markov models

PL Silsbee, Q Su - Speechreading by Humans and Machines, 1996 - Springer

An improved method of integrating audio and visual information in an audiovisual hidden Markov model based ASR system is investigated. The method uses an adaptive integration formula, which incorporates the integration into the HMM at a pre-categorical stage.

9.Using animal models of enriched environments to inform research on sensory integration intervention for the rehabilitation of neurodevelopmental disorders

S Reynolds, SJ Lane… - Journal of …, 2010 - jneurodevdisorders.biomedcentral …

The field of behavioral neuroscience has been successful in using an animal model of enriched environments for over five decades to measure the rehabilitative and preventative effects of sensory, cognitive and motor stimulation in animal models.

10. A Bayesian view on multimodal cue integration

MO Ernst - Human body perception from the inside out, 2006 - books.google.com

A Bayesian View on Multimodal Cue Integration, inference provides a formal way to model uncertainty about the world by combining. In general, the Bayesian framework can be used to construct "ideal observer" models.