Looking back and moving forward: Dave Knill’s contributions to visual memory and motor control

Chris R. Sims
Knill Lab, ~2009–2013

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What I learned from Dave Knill

1. Think harder
2. Don’t be satisfied with inelegant solutions
3. Enjoy the journey
Outline (aka, this is an impossible task)

- Sensorimotor control and coordination
  
  
  
  
  
  

- Visual memory
  
  
  
  
  
  
Sensorimotor control

\[
\hat{x} = f(x_{obs}) \quad \text{State estimation}
\]
\[
u = g(\hat{x}) \quad \text{Feedback control law}
\]
\[
\mathcal{L} = h(x, u) \quad \text{Cost function}
\]

Goal: Minimize $\mathcal{L}$ w.r.t. $f$, $g$
Stochastic optimal feedback control
Stochastic optimal feedback control
“The results of the current experiment provide the first direct evidence for continuous, on-line visual control of the moving hand that extends throughout the course of reaching movements. We hope that these results will help to settle the long-running debate concerning the role of visual feedback in the control of reaching movements. The technique of perturbing a virtual hand during reaching movements provides a promising tool for further exploring the nature of the visual feedback that the brain uses to control reaching movements.”

(Saunders & Knill, 2003)*

* Research also presented at first VSS meeting in 2001
Sensorimotor coordination

- Uncertainty
- Estimated
- Actual
Sensorimotor coordination

- Observed
- Unobserved
- Estimated
- Actual
Sensorimotor coordination

- Observed
- Unobserved
- Estimated
- Actual
Experiment

• Task: Sort a bunch of objects into two piles

• Demands on vision:
  — Motor guidance
  — Information acquisition/planning

• Manipulate:
  — Difficulty of motor task
  — Difficulty of perceptual discrimination

• Examine adaptive timing of eye movements

(Sims, Jacobs, & Knill, 2011)
Saccade timing as utility maximization

(Sims, Jacobs, & Knill, 2011)
Motor control is decision-making
Daniel M Wolpert\textsuperscript{1} and Michael S Landy\textsuperscript{2}

Motor behavior may be viewed as a problem of maximizing the utility of movement outcome in the face of sensory, motor, and task uncertainty. Viewed in this way, and allowing for the availability of prior knowledge in the form of a probability distribution over possible states of the world, the choice of a movement plan and strategy for motor control becomes an application of statistical decision theory. This point of view has proven successful in recent years in accounting for movement under risk, inferring the loss function used in motor tasks, and explaining motor behavior in a wide variety of circumstances.

(Wolpert & Landy, 2012)
II. Perceptual memory

Memory as Bayesian inference?
Memory as Bayesian inference?

![Diagram showing probability density and memory as a Bayesian inference](image-url)
Memory as Bayesian inference?

![Diagram](image)

- **Stimulus** $x$
- **Posterior** $p(y | x)$
- **Prior** $p(x)$
- **Memory** $y$
Memory as Bayesian inference?

$$x \sim \text{Normal} \left( \mu, \sigma_x^2 \right)$$

$$y \mid x \sim \text{Normal} \left( x, \sigma_y^2 \right)$$

**Memory** = \( p(x \mid y) \) ?
Memory as Bayesian inference?

(Ma, Husain, & Bays, 2014)
Memory as Bayesian inference

Efficient communication

\[ p(x) : \text{Visual statistics} \]
\[ \mathcal{L}(x, y) : \text{Cost function} \]
\[ C : \text{Channel capacity} \]

Goal: Minimize \( \mathcal{L}(x, y) \) w.r.t. \( p(y \mid x) \)
subject to \( I(x, y) \leq C \)
Memory as efficient communication

\[ p(x) = \text{Normal}(\mu, \sigma) \]
\[ \mathcal{L} = (y - x)^2 \]
\[ C = \frac{C_{tot}}{n} \]
What is the cost of misremembering?

- Different cost functions imply different optimal distributions of memory error, given the same channel capacity.
What is the cost of misremembering?

Measured, inverse decision theory

Predicted, natural task

(Sims, 2015; JOV)
Looking back and moving forward

(Trommershaüser, Maloney, & Landy, 2008)