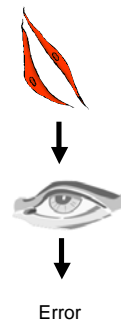


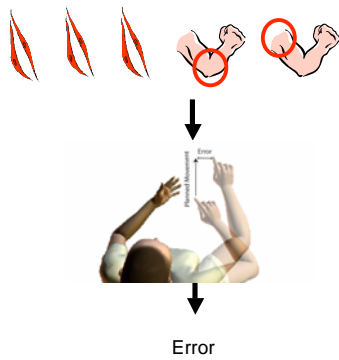
Causal inference in motor learning and adaptation

Konrad Körding,

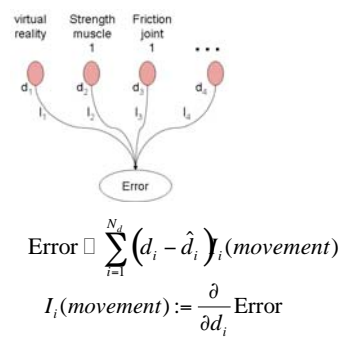
Last talk



More typical

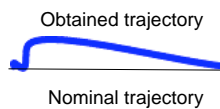


Influences

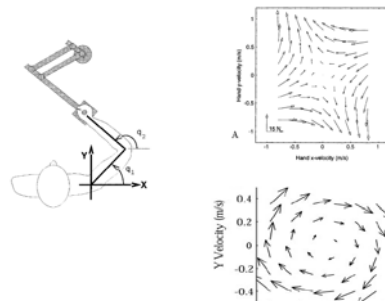


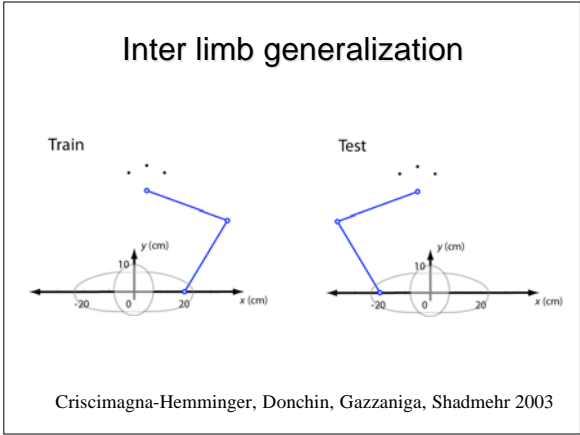
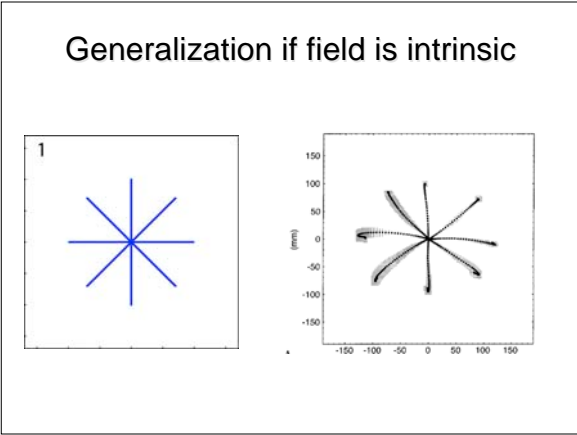
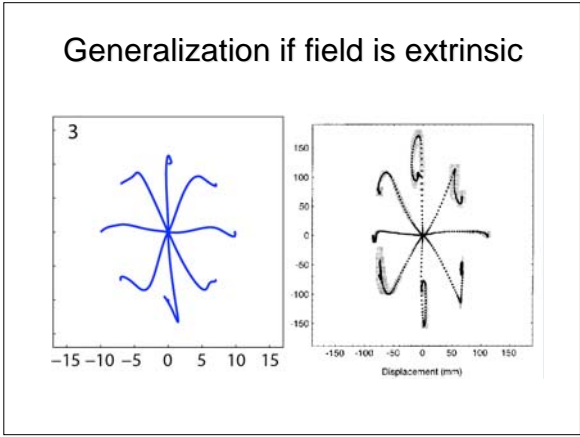
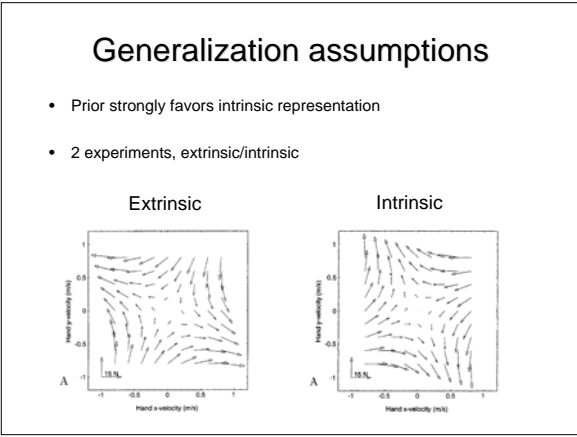
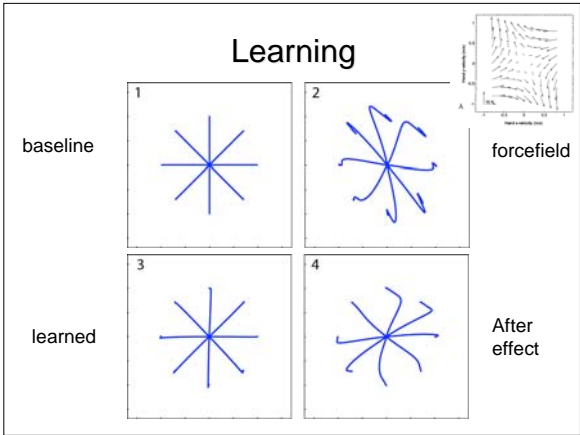
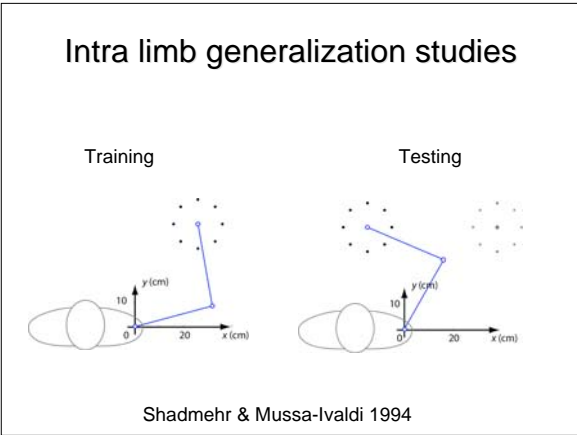
Integrating trajectories

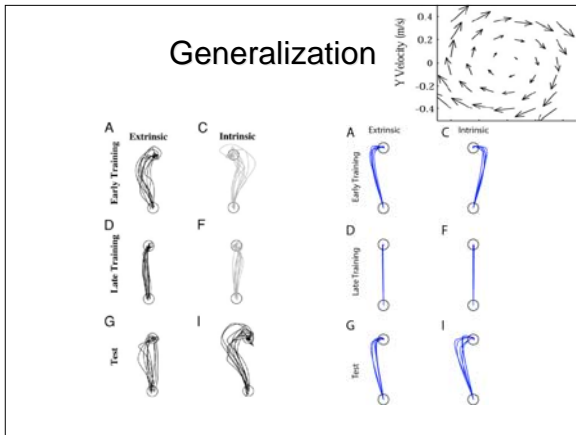
$$m\ddot{x} = F_{motor} + b_{ext}\dot{x} - \hat{b}_{ext}\dot{x} - \delta\hat{k}_m(x_o - x) + \delta\hat{b}_m\dot{x}$$



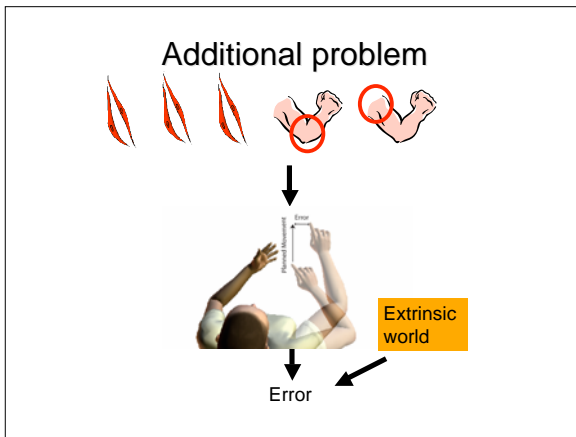
Force field learning



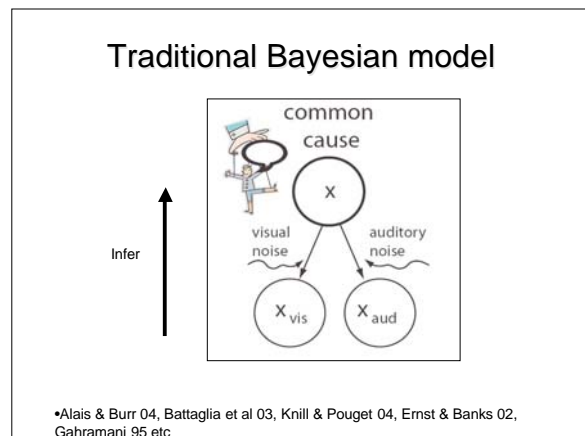
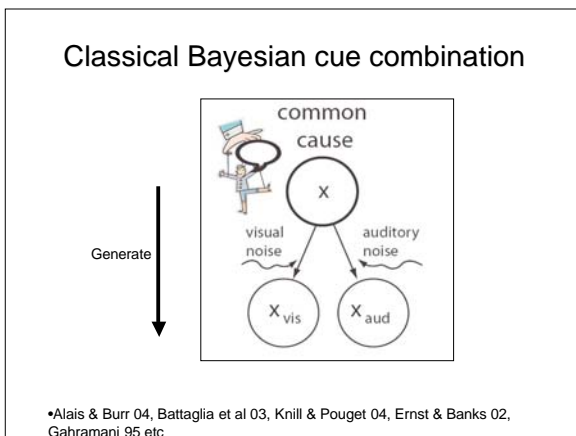




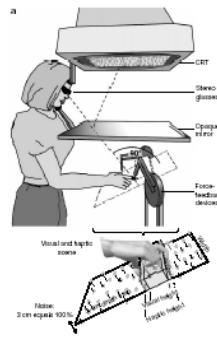
- ### Other effects
- Larger transfer from dominant to non-dominant hand
 - Lackner type coriolis room experiments
 - Movements of two joints



- ### Traditional assumption
- Adaptation is linearly proportional to error signal. (Thoroughman and Shadmehr 2000; Scheidt, Dingwell et al. 2001; Kawato 2002; Thoroughman 2005).
 - Large errors?

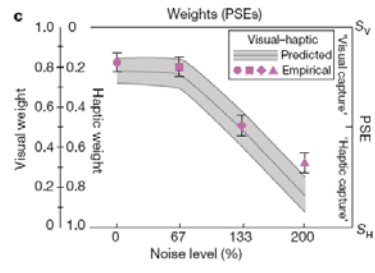


Experimental test




Ernst and Banks 2002

Results

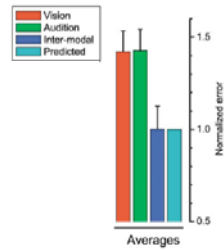


Ernst and Banks 2002

Visual Auditory combination (Ventriloquist effect)

Both cues  

Predicted gains

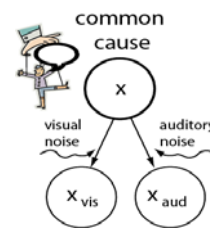


Alais and Burr 2004

What would happen now?

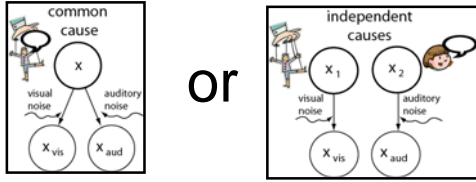


Do we believe this kind of model?



Assumes there is one and only one cause!

Alternative model



or

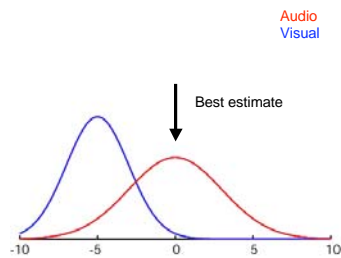
Kording and Tenenbaum, NIPS 2006
Kording, Beierholm, Ma, Quartz, Tenenbaum, Shams, submitted

Calculate probability of model

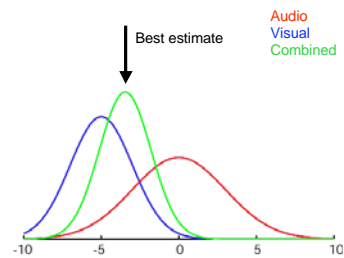
- Using Bayes rule:

$$p(\text{common}|x_{\text{vis}}, x_{\text{aud}}) = \frac{p_{\text{common}}p(x_{\text{vis}}, x_{\text{aud}}|\text{common})}{p_{\text{common}}p(x_{\text{vis}}, x_{\text{aud}}|\text{common}) + (1 - p_{\text{common}})p(x_{\text{vis}}, x_{\text{aud}}|\sim\text{common})}$$

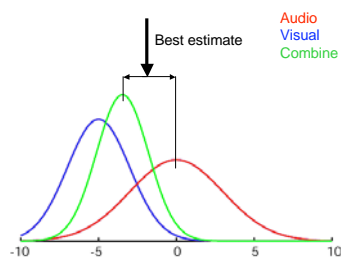
Independent causes: where is the auditory stimulus



Common cause: where is the auditory stimulus

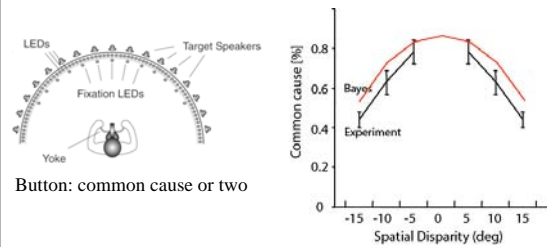


Mean squared error estimate



$$\hat{X} = P(C|X_{\text{vis}}, X_{\text{aud}})\hat{X}_c + P(\sim C|X_{\text{vis}}, X_{\text{aud}})\hat{X}_{\sim c}$$

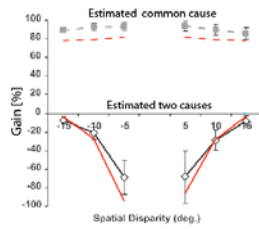
Experimental test



Button: common cause or two

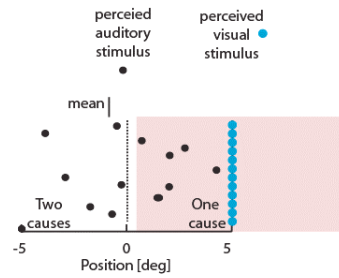
Wallace et al 2005 Hairston et al 2004

Measured gain

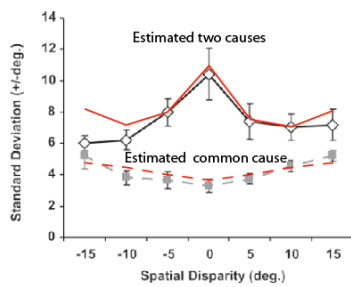


Wallace et al 2005 Hairston et al 2004

How can the gain be negative?

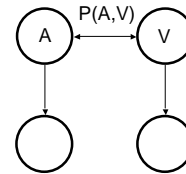


Predicting the variance



No good prediction if we assume model selection

Alternative Models

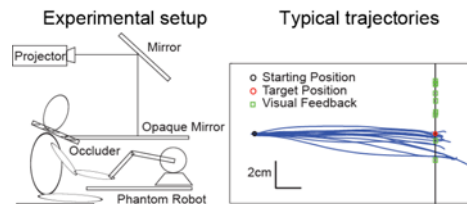


Shams and coworkers, Roach et al, Bresciani et al, Ernst, ...

Problem: No counterfactual reasoning possible, which $P(A,V)$ to choose?

Back to motor adaptation

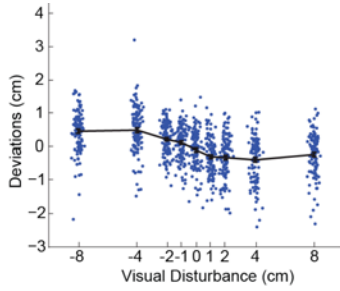
Method



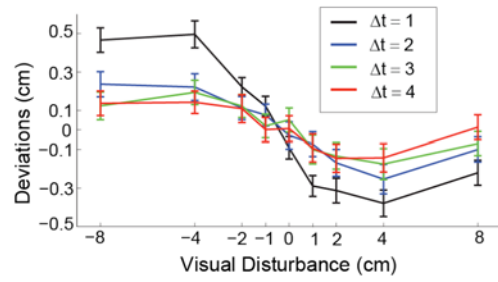
Conditions:

- > 9 types of visual errors: 0, ±1, ±2, ±4, ±8 cm
- > 100 repetitions for each type, randomly presented.
- > 7 subjects

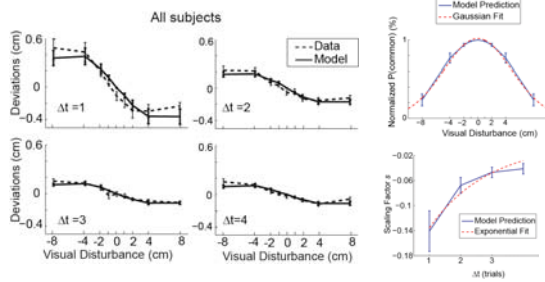
Typical behavior



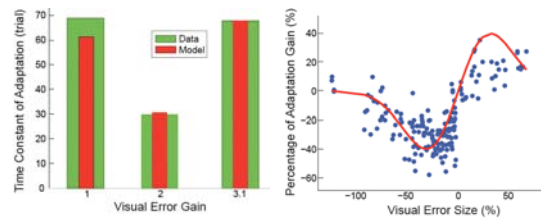
Typical data



Model: Causal inference, also linear over time



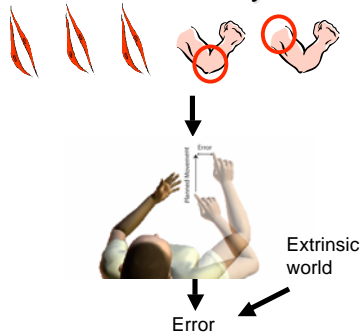
Model fitting with two other studies



Error augmentation,
Jim Patton

Saccadic gain adaptation,
Ric Robinson

Summary



Acknowledgements

Max Berniker
Kunlin Wei

Josh Tenenbaum
Reza Shadmehr

Ulrik Beierholm
Wei Ji Ma
Steven Quartz
Ladan Shams