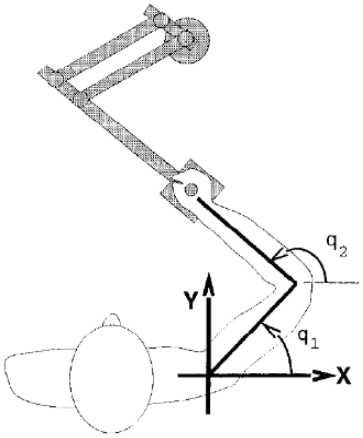
Estimating the sources of motor errors

with Max Berniker

www.koerding.com

Wide range of experiments
“Internal models”

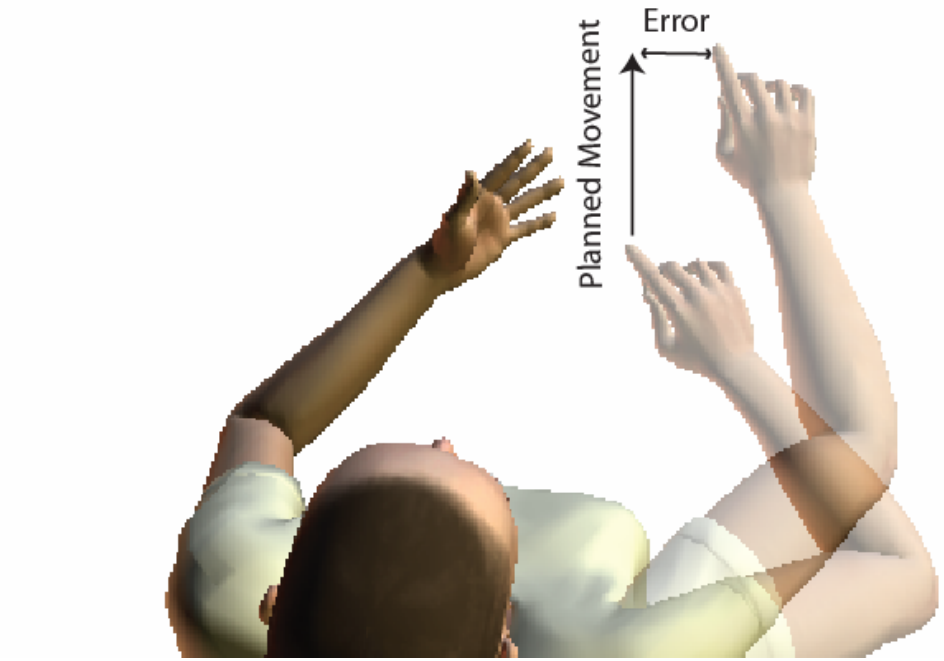


Perturb movement property

Measure movement

see Kording et al, Nature Neuroscience 2007

Ambiguity

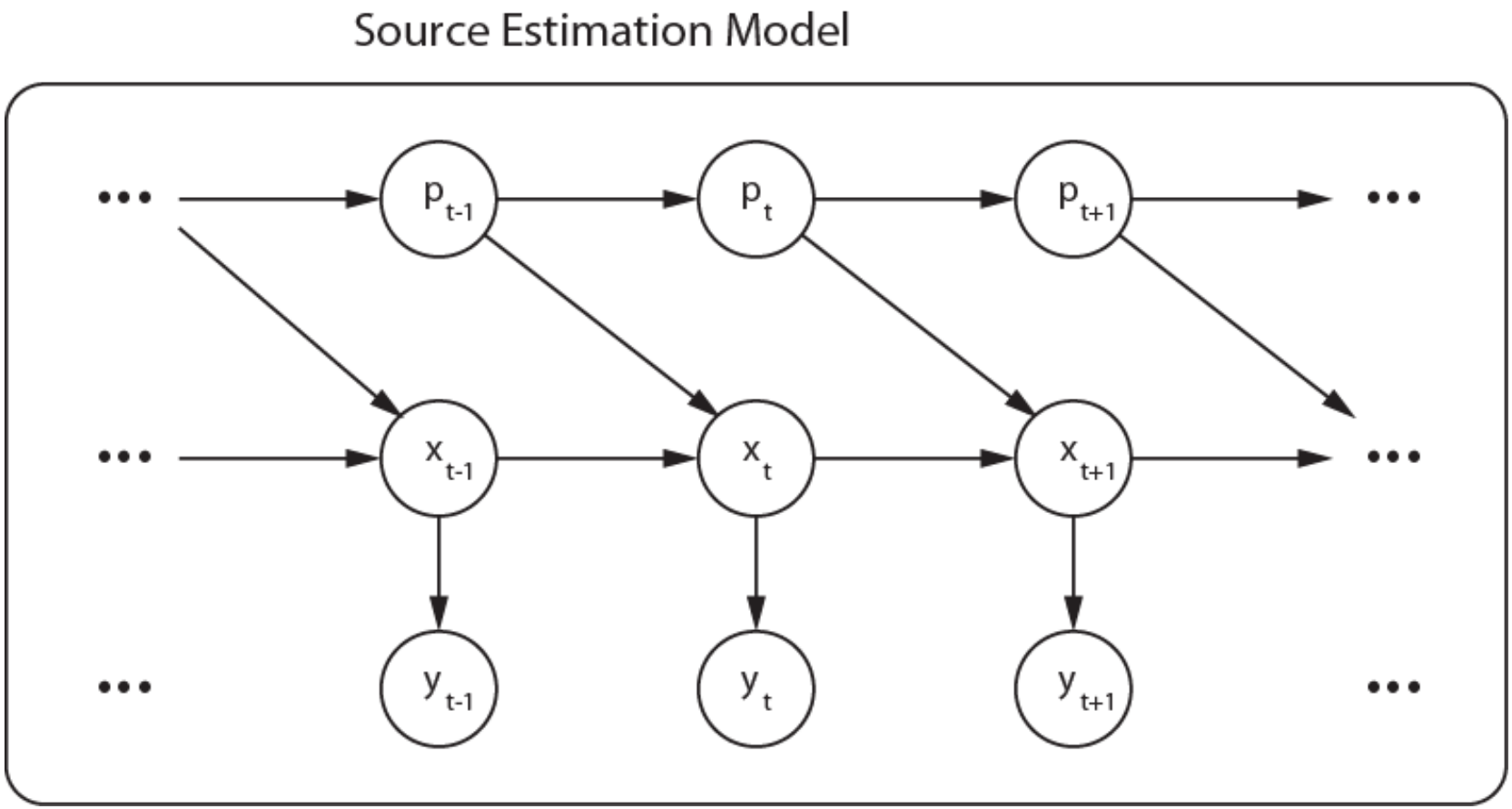


Limb impedance: Viscosity, stiffness, inertia, muscle strength
Environmental affordances: Object inertia, force fields

Different disturbances (vector d) may lead to the same error

see Kording et al, Nature Neuroscience 2007

Graphical model



Relevant variables

- Estimate of parameters
- Real parameters

- Estimate all variables using Extended Kalman Filter

Influence of perturbations on movement: linearization

$$Error = f(d, \hat{d}, movement)$$

$$Error \approx \sum_{i=1}^{N_d} I_i(movement)$$

$$I_i(movement) := \frac{\partial}{\partial d_i} Error$$

Numerical differentiation ☹

Simulating trajectories

$$
\begin{aligned}
\frac{\ddot{x}}{m} = & \quad EPcontroller \\
& + \quad \Delta F_{jointstiffness} + \Delta \hat{F}_{jointstiffness} \\
& + \quad \Delta F_{musclestrength} + \Delta \hat{F}_{musclestrength} \\
& + \quad \Delta F_{environment} + \Delta \hat{F}_{environment}
\end{aligned}
$$

Gaussian changes over time

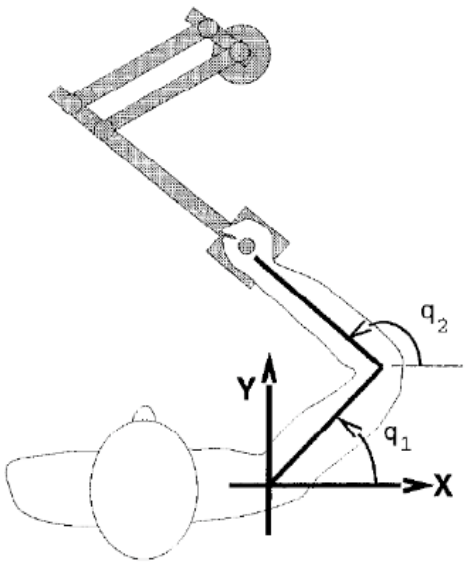
$$d_i(t + \Delta t) = d_i(t) + \eta_i(t)$$

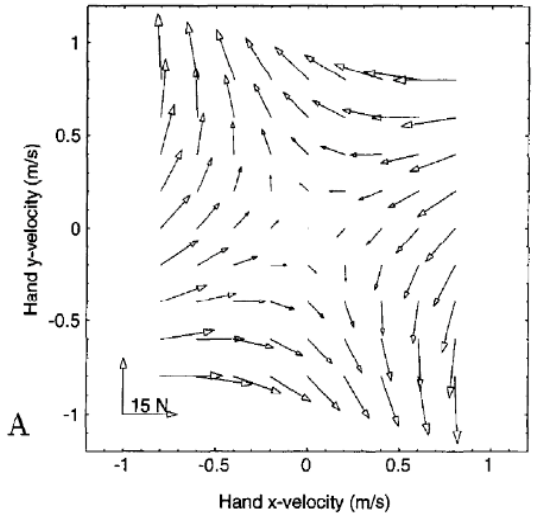
Where $\eta_i(t)$ is drawn from a Normal Distribution of width σ_i

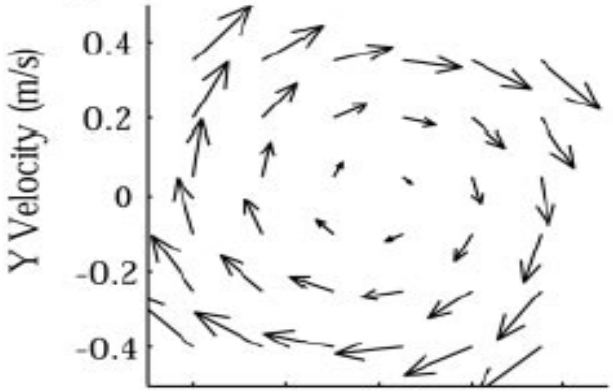
make σ_i proportional to nominal values

Extended Kalman filter for state estimation (converges well)

Force field learning

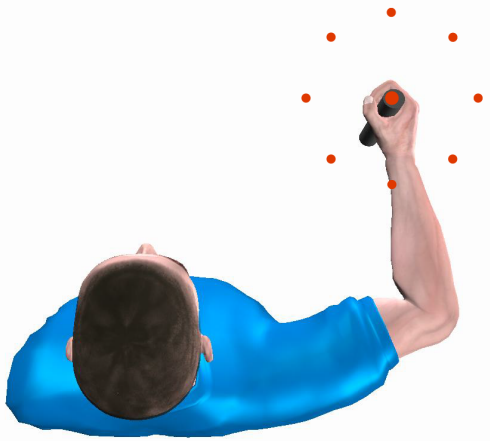






Shadmehr and Mussa Ivaldi 1994

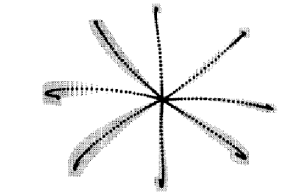
Learn

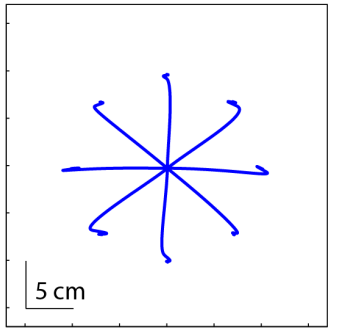


Generalize

Intrinsic disturbance

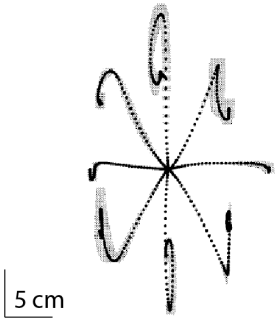
$\tau = W\dot{\theta}$

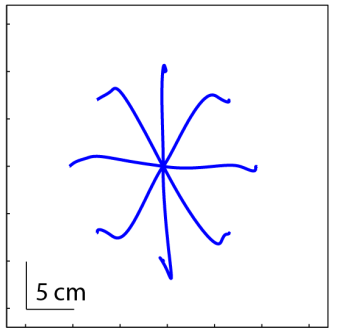




Extrinsic disturbance

$F = B\dot{x}$

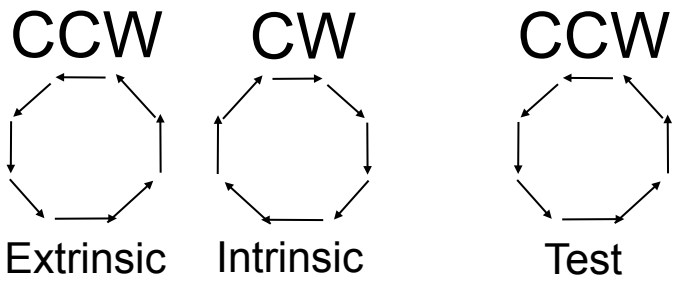


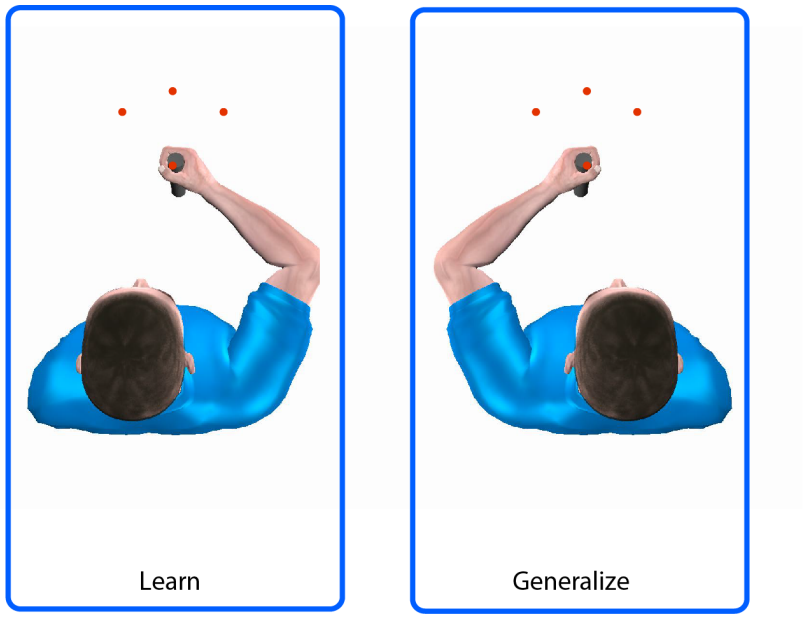


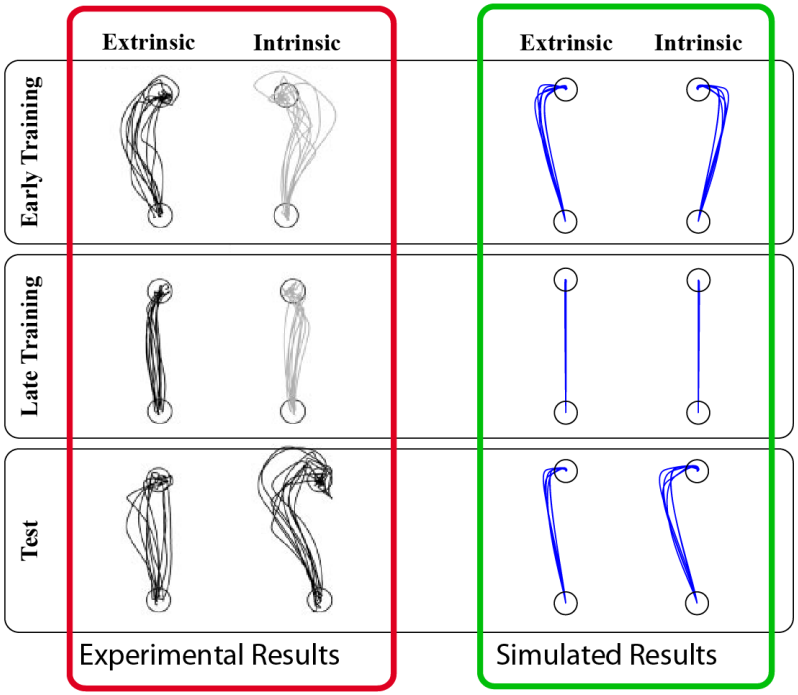
Experimental Data

Simulated Results

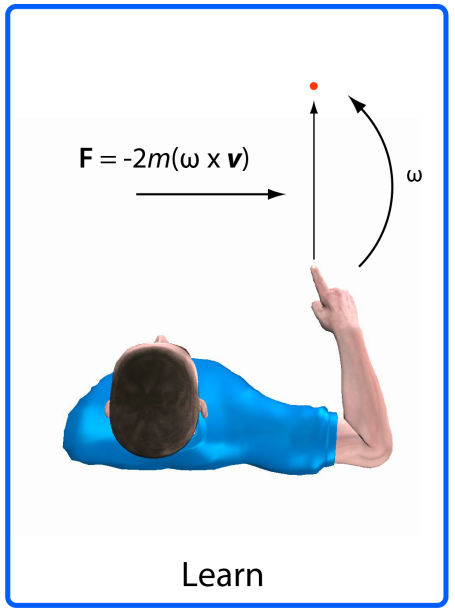
Criscimagna Hemminger et al 2003

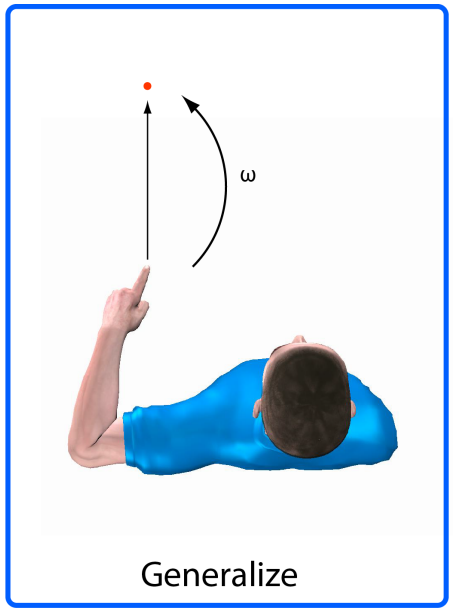


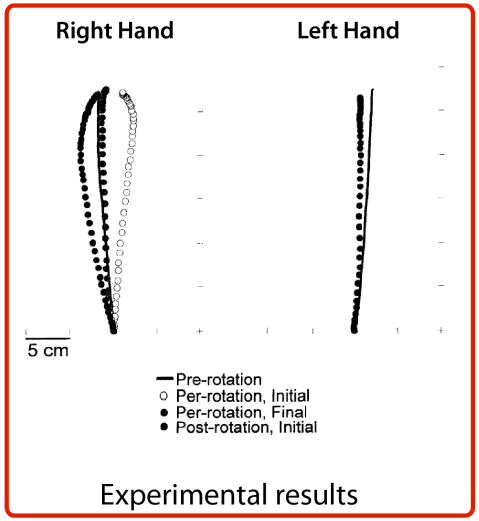


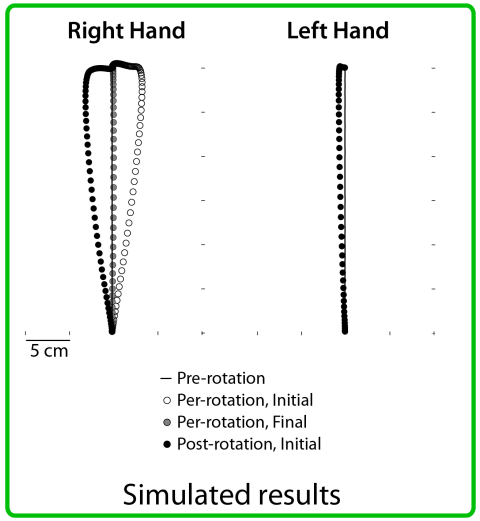


Dizio and Lackner 1995

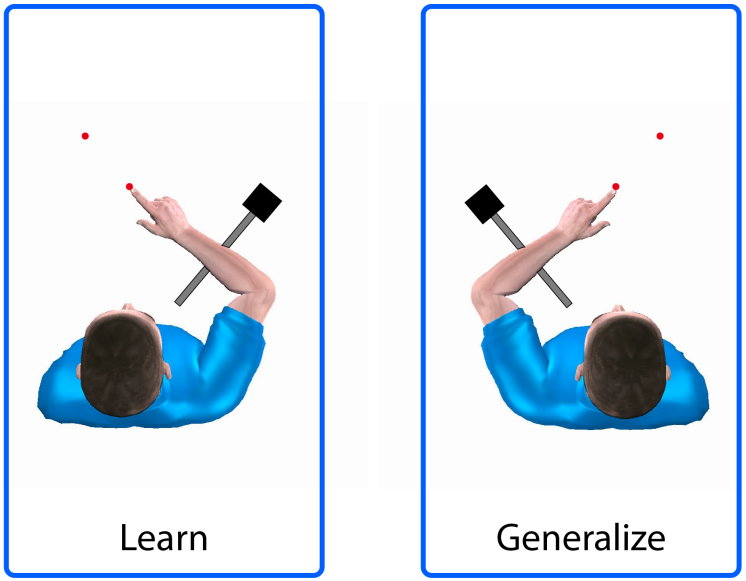






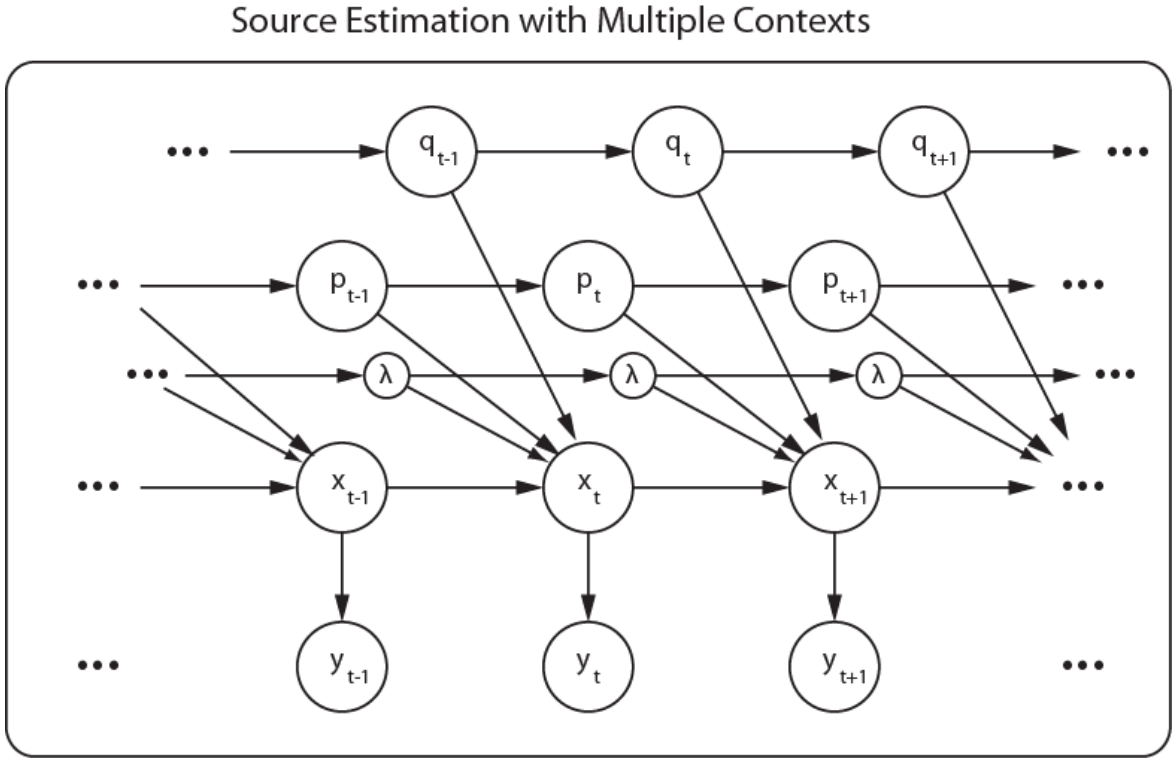


Wang and Sainburg 2004

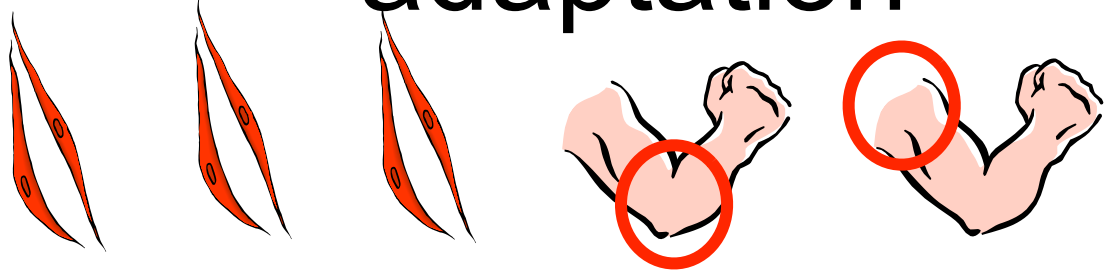


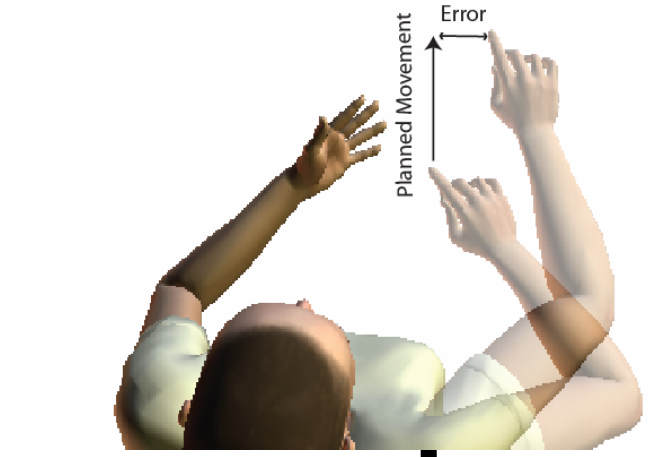
Current work: Generalize to contexts

- Variables not always relevant
- Coffee cup only relevant when in my hand



A normative view on human motor adaptation





Extrinsic world

Error