NOCH: A framework for biologically plausible models of neural motor control

Travis DeWolf, Chris Eliasmith {tdewolf,celiasmith}@uwaterloo.ca

University of Waterloo

CNRG computational neuroscience research group compneuro.uwaterloo.ca

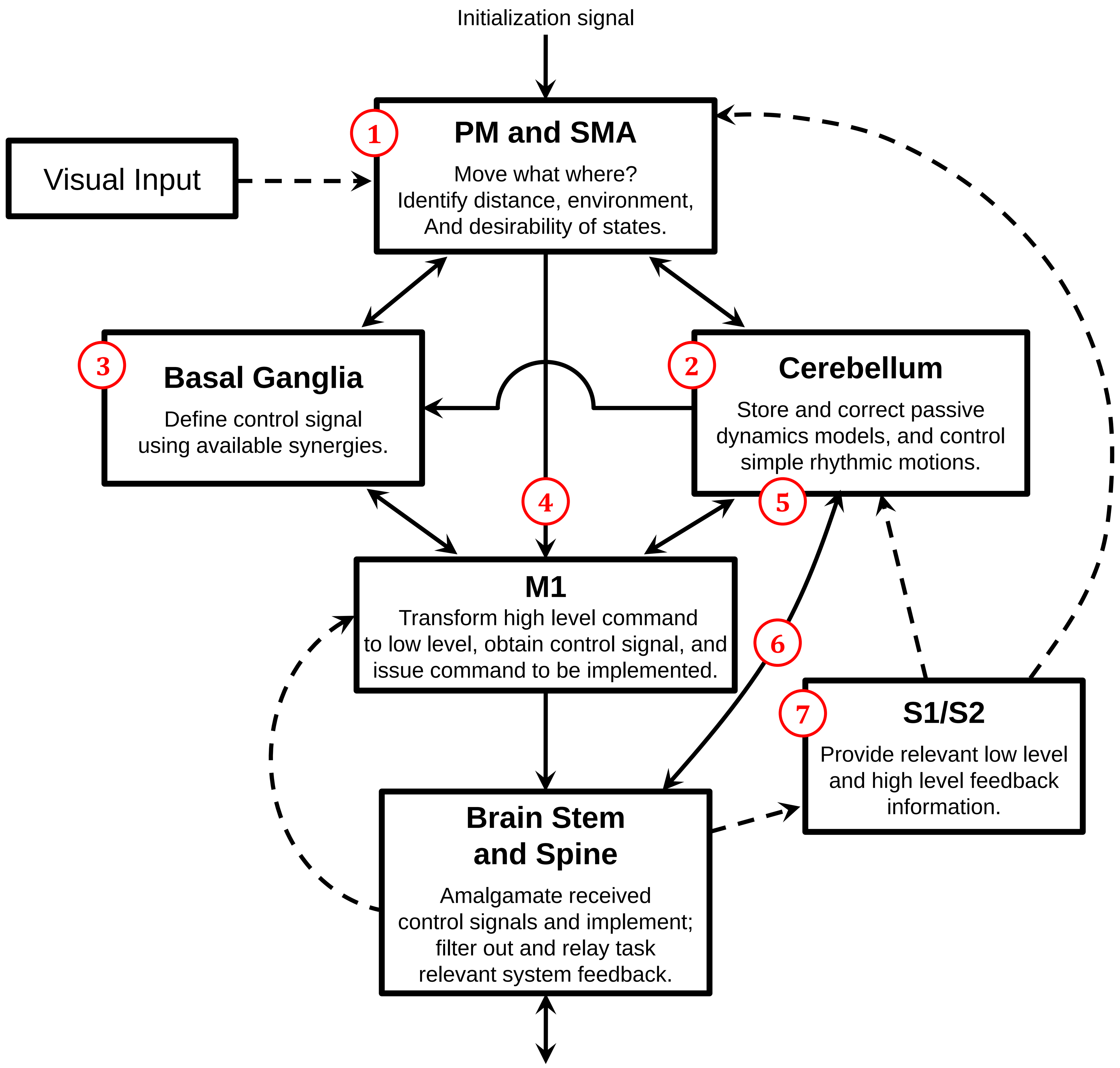
Motivation

- To bring together current neurobiological research and control theory into a framework for neural motor control
- Goals:
  - Further define the required functions and constraints on models of motor control
  - Provide a broad context for the investigation of neural components of motor control
  - Give insight into design of efficient and effective control systems

NOCH in action

1. Target(s) specified in high-level, low-dimensional space; visual input incorporated, identifying distances and object locations
2. Task-relevant internal model of system dynamics retrieved, and "automatic" motor commands issued
3. Optimal action is specified as a summation of weighted components (synergies)
4. High-level commands issued to M1; M1 transforms high- to low-level commands ; BG maps low-level command to synergies
5. Inertial information and motor plan corrections are added to the motor command by the CB
6. CB also sends motor commands regulating posture, locomotion, etc. directly to brain stem to be incorporated with descending commands
7. Task-relevant low-level feedback sent to M1 and CB from S1; in S2 feedback is transformed to a high-level signal and sent to the PM & SMA

The Neural Optimal Control Hierarchy (NOCH)

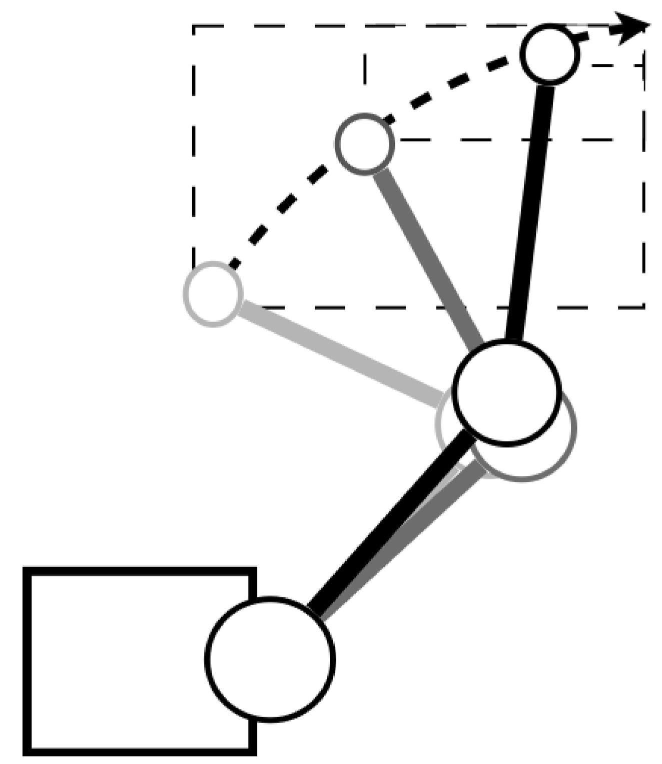


Empirical support

- Damage to PM and SMA impairs volitional complex movements[Schell1984]
- Damage to PMd impairs visual on-line error correction of movements[Lee2006]
- CB has a disynaptic pathway from dentate to striatum[Hoshi2005] for movement scaling (see results)
- CB is involved in control of posture, balance, and locomotion[Ghez1984] and has direct communication pathways to the brain stem
- Cerebro-CB is active during movement planning and mental rehearsal[Georgopoulos1982]

Arm reach implementation

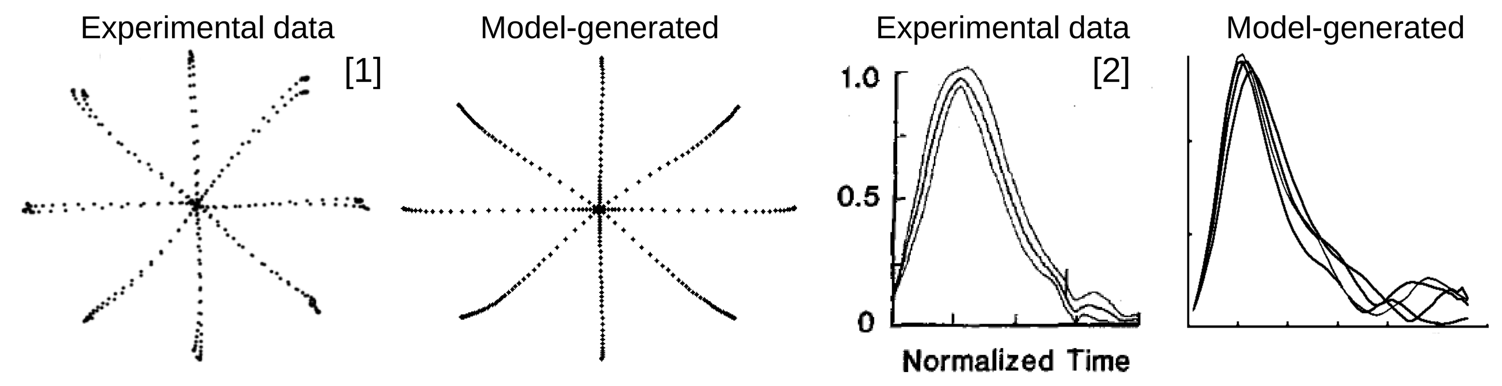
- High-level Linear Bellman Controller[Todorov2009]
- Quadratic programming converts high to low level signal
- CB damage: add noise to internal dynamics models
- HD: add unwanted components as noise into the signal



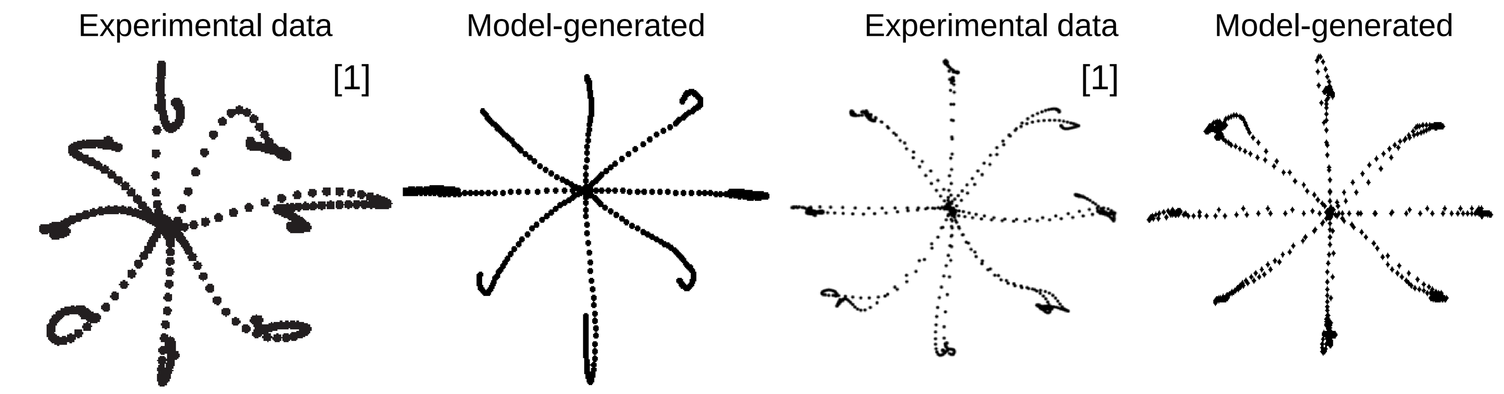
[1] Smith, 2000
[2] Soechting, 1984

Results

- Normal reach trajectories and velocity profiles



- Cerebellum damage
- Huntington's Disease



Predictions

- BG provides novel control signals and decomposes complex movements into component parts (see results)
- PM & SMA divide the operating space, and scale it to effect more precise commands as the target is approached (see results)
- CB is not sufficient for volitional adaptation of rhythmic movements
- S2 transforms system feedback to the high-level for PM & SMA to incorporate the low-level information