NOCH

Travis DeWolf
travis.dewolf@gmail.com

CNRG - UWaterloo

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Introduction

The NOCH
- The control theory
  - Hierarchical control
  - Optimal control
- The biology
- The NOCH

Implementation
- Videos!

High precision control

Conclusions

Introduction

Biology

In biology

- much work has been done on the individual neurobiological components of the motor control system, but
- little focusing on the structure and functioning of the system as a whole.

Control theory

In control theory

- focus has been on designing controllers under basic biological constraints, but
- little has been done investigating potential neural sites for the performed functions.

Mapping control theory to biology

The purpose of the NOCH framework is to further the understanding of the motor control system by bringing together the current neurobiological research and control theory in a biologically plausible fashion.

This will

- provide a system context for investigation of these neural areas, and
- further defined required functions and constraints of mathematical models.

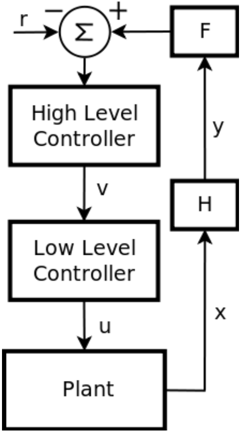
Mapping control theory to biology

Benefits:

- Provides insight into development of skillful movements and
- effective methods of treatment for malfulnctioning motor systems.
- Offers new techniques for control of robotic systems.
- Advances the development of neural prosthetics.
- Avatar.

The NOCH

Control system overview



u : low level control signal

v : high level control signal

x : low level feedback signal

H : low-to-high transform

y : high level feedback signal

F : high level feedback gain

r : reference signal

Hierarchical control

Goal is to reduce the dimensionality of the system, and then control the low dimensional high level optimally.

The low level is then responsible for matching the high level control signal as best as possible.

Two design methods for the high level,

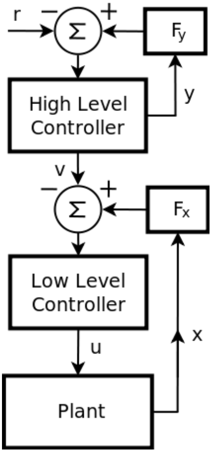
- explicit and
- implicit.

Explicit control

Simple low level model stored in the high level, which is used to generate the optimal control signal. No actual feedback from the plant reaches the high level.

Benefits:

- Autonomous system, and
- standard optimization techniques work.

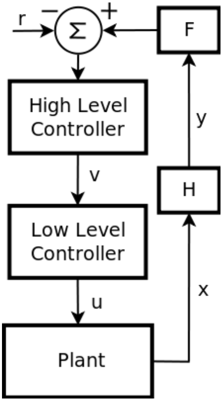


Implicit control

The actual state of the plant is used to update the high level.

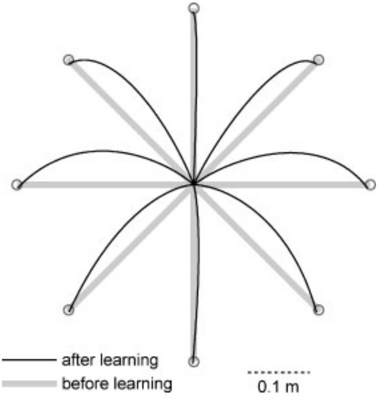
Benefits:

- Can explicitly account for and optimize low level costs,
- more robust to unexpected peturbations and inaccurate system models.



But standard optimization techniques aren't guaranteed to work.

Accounting for low level dynamics



Optimal control

Cost-to-go function: The cost of moving from a state to the target optimally.

Bellman equation:

$$\text{Cost-to-go} = \min(\text{cost of action} + \text{expected cost-to-go from resulting state})$$

iLQG - iterative Linear Quadratic Gaussian

The high level is optimized with a technique called iLQG.

Analagous to numerical optimization techniques.

An approximation of the system is made and used to seed the successive approximation until convergence upon a local minimum.

iLQG - iterative Linear Quadratic Gaussian

Downsides of iLQG:

- An iterative process.
- Can be highly computationally expensive.
- Must be seeded.
- Converges to local, not global, minimum.

Linear Bellman Controllers (LBCs)

Based on the observation that the optimal control problem is a dual of Bayesian inference.

Reduces the Bellman equation to a linear problem.

Allows all cost-to-go functions to be computed simultaneously from the eigenvector of a matrix encoding the passive dynamics and state desirabilities of the system.

One of the contributions of this thesis is providing a method for accounting for the low level dynamics with the LBC.

Motor system overview

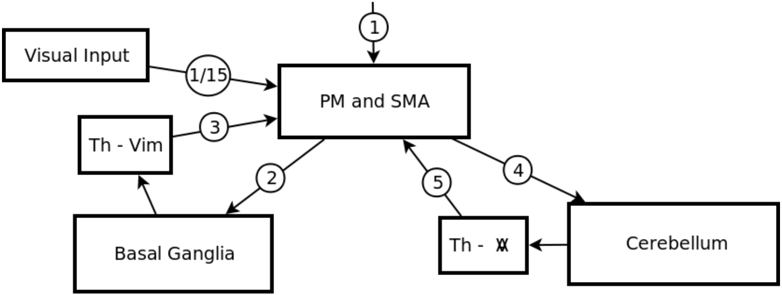
- M1: Primary motor cortex
- PM & SMA: Premotor cortex and supplementary motor areas
- BG: Basal ganglia
- CB: Cerebellum
- Th (VA & Vim): Thalamus (Ventral Anterior and Ventral InterMediate)
- BS: Brain stem
- S1: Primary sensory area

The NOCH

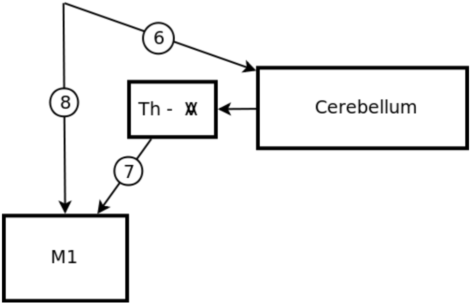
The NOCH

- High level controller
- Low level controller
- System feedback
- Whole system

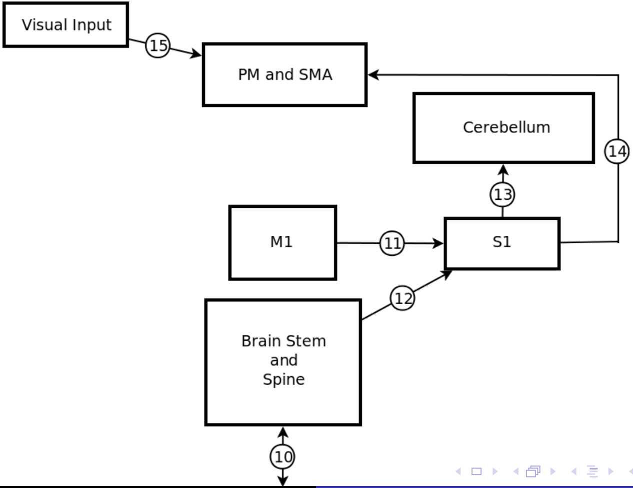
High level controller



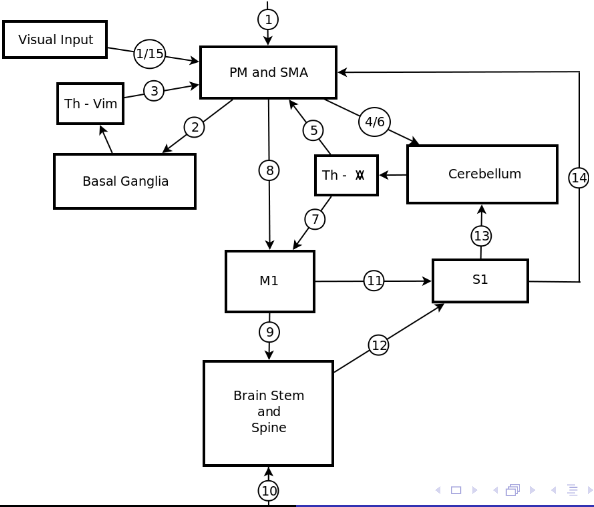
Low level controller



Sensory feedback



NOCH System diagram



Videos!

- Optimal linear controller, no hierarchy
- Optimal hierarchical controller
- LBC high level controller

High precision control

High precision control

Dynamic scaling

A problem with the LBC controller is that it can be both very computationally expensive and require massive storage space for precise movement in large environments.

The dynamic scaling technique presented here overcomes these restrictions and maintains approximately optimal control.

Dynamic scaling

This is based on the observation the passive dynamics at the high level are consistent throughout different sized environments.

The passive dynamics matrix, which describes the movement of the system without a control signal at every possible state, then only needs to be calculated once, at a relatively low resolution.

Video!

- Dynamic scaling

Conclusions

Conclusions!

Contributions

- NOCH framework
- LBC: Accounting for low level dynamics
- Dynamic scaling technique

Conclusions

Thank you!

Questions?

Extras