SpinalDynamics

Study the organization of spinal cord neural networks responsible for locomotion

Florin Dzeladini

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Introduction

Goal

Using modelling tool to study the organization of spinal networks responsible for locomotion.

Target application

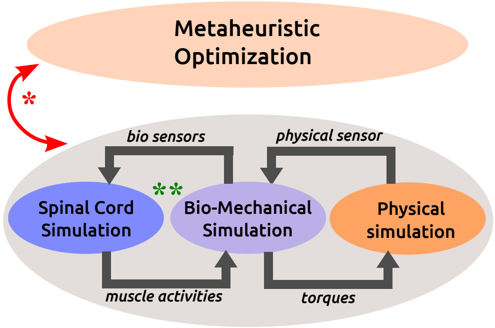
- Improve rehabilitation procedure
- Proof of concept for bio-inspired active prosthesis / orthosis controller

Scientific questions

Possible questions

1. Advantages of bio-inspired controller for orthoses and exoskeleton control
2. Spinal cord modular organization :
   - what are the roles of Central pattern generators and Motor primitives ? [Ivanenko 2014]
   - How does gait transition occur ?
3. Spinal cord input :
   - What are the role of afferent fibers in the generation of walking ? [Geyer&Herr 2010, Ting&al. 2009]
   - Descending fibers : How descending signals are incorporated into the spinal networks to modulate walking (change in speed/slope) [Ijspeert 2008]

Analysis and problem formulation: final goal



Todo* : API Extension to support :
- openSim
- Sim-mechanics

Todo** : Extend the controller structure to facilitate the link with existing bio-mechanical simulator

The library will be used on different simulators

Target physics simulators

1. Webots
2. Simbody - Gazebo
3. SimMechanics

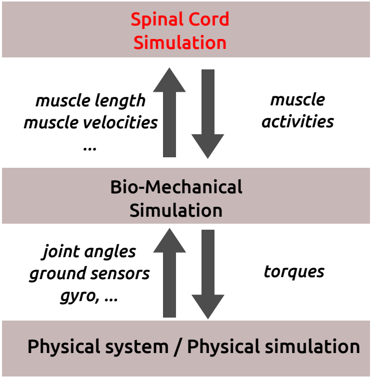
Bio-mechanical simulators

1. Libnmm (for Webots)
2. OpenSim (for Simbody)
3. *to be implemented*

Analysis and problem formulation

We separate the problem into :

- **Neural network : spinal cord simulation**
- Musculoskeletalsystem : bio-mechanical simulation
- Physics : physical simulation or physical system



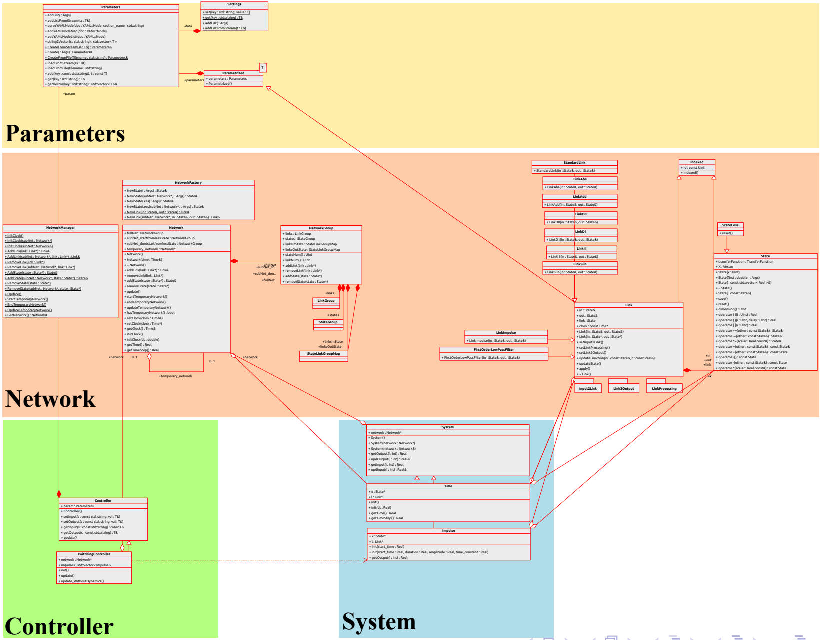
Conception : Spinal cord simulation library

General principle

The simulation of the spinal cord is abstracted as the simulation of a multidimensional dynamical stystem.
The basic components of the library are :

- **Parameters** : class used as a generic multi-purpose container
- **Network** : made of links and states
- **System** : abstract a functional part of a network
- **Controller** : abstract a controller as a set of:
  - inputs
  - outputs
  - internal variables

Conception : Class diagram



Conception : Spinal cord simulation library

General principle : Network

A network is a multidimensional dynamical system

- A network is made of links and states
  - Links describe how states are updated when the network is updated
  - States store the different states of the network
- Any network has a time object : the clock of the network
  - All links have access to the time object
- All states have a memory

Conception : Spinal cord simulation library

General principle : System

A **System** abstracts the encapsulation of a functional part of a network. It is made of :

- States and Links
- a getOutput and a getInput method

Example : the **Time** system.

The **Time** is a **System** used as the basic clock of any network.
It's a one state one link system.
The update is defined as : $x(t+1) = x(t) + dt$

Conception : Spinal cord simulation library

General principle : Controller

A **Controller** is a class with one update method and 3 **Parameters** containers storing

- inputs : const pointer of type T
- outputs : pointer of type T
- internal states : any type T

A typical implementation of a controller will have a **Network** pointer and a container to store **Systems**.

Implementation

General information

- Programming language : c++
- Hosted : bitbuckets (will most probably move to GitHub)
- Documenation : Doxygen
- Coding style : Google C++ Style Guide

Implementation

Coding principle : Test Driven Development

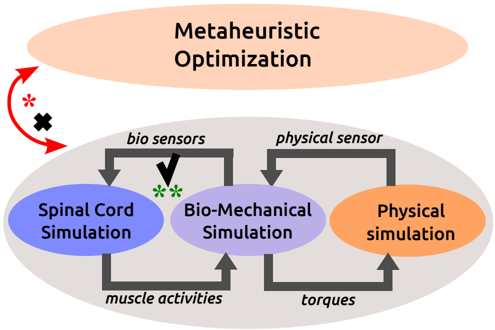
- First write how you will use your program (i.e. write tests)
- Then code to make your program pass the tests

Unit test library : Catch

Advantages

- When writing complex library it is easy to forget that some features have been implemented.
  With TDD we already have a **How-to** *: the* **Unit tests**
- When trying to implement deep changes in a library, it is hard/impossible to know all the different part of the software that will be affected.
  With TDD we know: all tests that don't pass after the changes reflect the affected parts

Achievement



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Next steps

Implement bio-inspired walking controller

- *Implement an algorithm for self organization of spinal reflexive pathways [Marques, H.G. 2013]*
- *Implement a reflexive walking controller [Geyer&Herr, 2010]*
- *Implement a central pattern generator based controller [Taga, 1996]*

Twitching controller

Twitch definition : spontaneous motor activity (SMA)

Controller design process

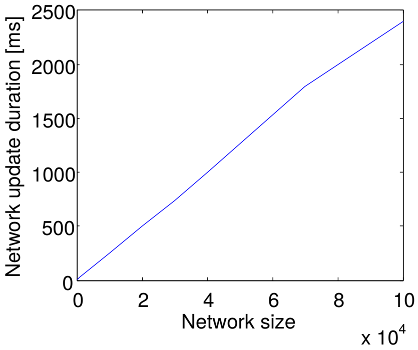
- Design the network architecture : (create Systems and Links child (if needed)
- Implement the controller : choose input / output and parameters

Applied to the twitching controller

- **LinkImpulse** class : child of **Link**
  first order differential equation generating an impulse at a given time
- **Impulse** class : child of **System**
  encapsulation of a LinkImpulse and a State. The output is an impulse.
- **TwitchingController** class : child of **Controller**
  implementation of a network of impulses.

Twitching controller: performance

Network creation time



Network update time